Fellow	Geetartha Dutta
Host Organisation	NTNU, Norway
Scientific coordinator	Jo Eidsvik

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

During my fellowship, I worked on evaluating geophysical data in the context of monitoring CO_2 storage in subsurface reservoirs, which helps in determining the optimal times for collection of such data. Geophysical data could be highly valuable in predicting potential leakage of CO_2 from subsurface reservoirs, and thus preventing its adverse effects. But since geophysical data is usually quite costly, it is advisable to do a value of information (VOI) analysis before collecting such data to find the optimal times for collecting data.

We built a VOI analysis framework for CO_2 storage monitoring by considering a simple stratigraphic model of 'm' layers with uncertain petrophysical and topographic properties. Inspired by invasion percolation theory, when the volumetric pressure of a layer exceeds the capillary threshold pressure of its sealing layer, the residual volumes leak to the layer above. Assuming that the rate of volumetric pressure increase and the capillary threshold pressure for a layer are random, the time of leakage for that layer is simulated. This is then used to simulate the geophysical data as well as the prospect values for different decision alternatives. We assume that the geophysical data informs about the heights of the CO_2 columns in different layers with some uncertainty, which is modelled by adding some random noise to the CO_2 heights. The prospect values are functions of the leakage time from the topmost layer. Then, the VOI of the geophysical data is computed by regressing the prospect values on the simulated data.

We did VOI analyses for CO_2 storage in a synthetic 3-layer case, as well as for a case inspired by the Sleipner CO_2 storage project. We used an ellipsoidal cap model to approximate the geometry of the top layers in each case. We carried out the VOI analysis for varying times of survey to find the optimal times of data collection. The results indicated that there is high value in collecting data at intermediate times (i.e. after the probability of migration has increased above an initially low value). On the other hand, if data collection is done too late there may be less opportunity to take remedial measures.

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

1. ***Title:*** *Value of Seismic Monitoring of CO_2 Storage in a Multi-Layer Stratigraphic System*
   Authors: *Geetartha Dutta, Jo Eidsvik, Philip Ringrose*
   Status: *Published*
   Publisher: *European Association of Geoscientists & Engineers*
   Source: *Fifth EAGE Conference on Petroleum Geostatistics, Nov 2023, Volume 2023, p.1 - 5*
   References:
   Anyosa, S., Bunting, S., Eidsvik, J., Romdhane, A., & Bergmo, P. (2021). Assessing the value of seismic monitoring of CO_2 storage using simulations and statistical analysis. International Journal of Greenhouse Gas Control, 105, 103219.

   Callioli Santi, A., Ringrose, P., Eidsvik, J., & Haugdahl, T. A. (2022). Assessing CO_2 storage containment risks using an invasion percolation markov chain concept. Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16), http://dx.doi.org/10.2139/ssrn.4282992.

   Dutta, G., Mukerji, T., & Eidsvik, J. (2019). Value of information analysis for subsurface energy resources applications. Applied Energy, 252, 113436.

Abstract:

Based on the invasion-percolation concept, we present a stochastic model to simulate the height of the CO_2 column and hence the pore pressure in continuous time in each layer of a multi-layer stratigraphic system. Assuming the capillary threshold pressure of the sealing layer as the limiting factor, we extract the time of CO_2 migration from a layer to the layer above. By modelling the heights in different layers explicitly, we facilitate the linkage to monitoring, assuming that seismic data can be used to estimate the heights of the CO_2 columns that build up in various layers over time. We conduct value of information (VOI) analysis to understand when it is optimal to gather seismic data about the CO_2 plume in the stratigraphic layer model.

2. ***Title:*** *Targeted CO_2 storage monitoring in a multi-layer stratigraphic system*
   Authors: *Geetartha Dutta, Ricardo Martinez, Philip Ringrose, Jo Eidsvik*
   Status: *Published*
   Publisher: *Swiss Federal Office of Topography (swisstopo), Mont Terri Underground Rock Laboratory, St-Ursanne, Switzerland*
   Source: *1st Caprock Integrity & Gas Storage Symposium 2024 – Extended abstracts, p. 169 – 172*
   References:
   Anyosa, S, Bunting, S, Eidsvik, J, Romdhane, A, Bergmo, P. 2021. Assessing the value of seismic monitoring of CO_2 storage using simulations and statistical analysis. Int. J. Greenh. Gas Control. 105, 103219, https://doi.org/10.1016/j.ijggc.2020.103219
   Callioli Santi, A, Ringrose, P, Eidsvik, J, Haugdahl, TA. 2022. Assessing CO_2 Storage Containment Risks Using an Invasion Percolation Markov Chain Concept. Proceedings of the 16th Greenhouse Gas Control Technologies Conference (GHGT-16), 23-24 Oct 2022, http://dx.doi.org/10.2139/ssrn.4282992
   Dutta, G, Mukerji, T, Eidsvik, J. 2019. Value of information analysis for subsurface energy resources applications. Appl. Energy 252, 113436, https://doi.org/10.1016/j.apenergy.2019.113436
   Furre, AK, Eiken, O. 2014. Dual sensor streamer technology used in Sleipner CO_2 injection monitoring. Geophys. Prospect. 62, 1075-1088, https://doi.org/10.1111/1365-2478.12120
   White, JC, Williams, G, Chadwick, A, Furre, AK, Kiær, A. 2018. Sleipner: The ongoing challenge to determine the thickness of a thin CO_2 layer. Int. J. Greenh. Gas Control. 69, 81–95, https://doi.org/10.1016/j.ijggc.2017.10.006
   Abstract:
   An important question for long-term geological storage of CO_2 in subsurface formations is understanding the potential for migration and leakage out of the store over periods of hundreds to thousands of years. To assess these risks and to help optimize monitoring systems, we have developed a framework for assessing migration probability in a multi-layer stratigraphic system using invasion-percolation concepts. Previous work (Callioli et al. 2022) has suggested embedding an invasion-percolation model in a Markovian structure to model the migration probability from one layer to another in a stratigraphic model of m layers. For each layer we estimate the height of the CO_2 column and hence the pore pressure function, assuming the capillary threshold pressure as the limiting factor. When the capillary threshold pressure is exceeded, migration to the next layer occurs, and so on to the subsequent layers. However, residual trapping and CO_2 dissolution mean that a limited volume fraction migrates to the next layer, leading to an overall decrease in migration

probability upwards through the system. By modelling the heights in different layers explicitly, we facilitate the linkage to monitoring, assuming that seismic data can be used to estimate the heights of the CO_2 columns that build up in various layers over time. We conduct Value of Information (VOI) analyses to understand when it is optimal to gather seismic data when monitoring the CO_2 plume in the stratigraphic layer model. The VOI analysis seems to indicate that there is high value in collecting data at intermediate times (i.e. after the probability of migration has increased above an initially low value). On the other hand, if data collection is done too late there may be less opportunity to take remedial measures. By using optimal seismic acquisition designs (i.e., both short and long-offset data), we also show how thin CO_2 layers can be detected using a combination of reflected and refracted waves. This then allows detection thresholds for the more probable migration events to be quantified. We demonstrate this VOI framework for monitoring designs using a case study inspired by the Sleipner CO_2 storage project.

3. **Title:** *Targeted CO_2 storage monitoring in a multi-layer stratigraphic system*
   Authors: *Geetartha Dutta, Jo Eidsvik, Philip Ringrose, Ricardo Martinez*
   Status: *In preparation*
   Publisher: *International Journal of Greenhouse Gas Control*

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

1. *Oral presentation at the Geophysics and Applied Mathematics in Exploration and Safe production (GAMES) meeting, May 8-9, 2023, Trondheim, Norway.*
2. *Oral presentation at the 22nd Annual Conference of the International Association for Mathematical Geosciences (IAMG), August 5-12, 2023, Trondheim, Norway.*
3. *Attended the 15th Trondheim Symposium in Statistics, October 27, 2023, Trondheim, Norway.*
4. *Oral presentation at the Fifth EAGE Conference on Petroleum Geostatistics, November 27-30, 2023, Porto, Portugal.*
5. *Poster presentation at the First Caprock Integrity & Gas Storage Symposium, January 24-25, 2024, St-Ursanne, Switzerland.*

IV – RESEARCH EXCHANGE PROGRAMME (REP)

I visited CWI, Netherlands for my REP during Feb 12 – 19, 2024, under the supervision of Jannis Teunissen. It was nice to meet researchers in the Multiscale Dynamics group and exchange research ideas. I gave a presentation on my research work, particularly on the use of value of information (VOI) to determine the optimal times for monitoring CO_2 storage in subsurface reservoirs. The researchers in the Multiscale Dynamics group showed a lot of interest in the concept of VOI, and its applicability in their research domain. I also attended a machine learning seminar during my stay there.