Soil CO₂ Flux and Temperature Measurements in Kızıldere Geothermal Field

Serhat Kucuk[1], Ali Baser[1], Onder Saracoglu[1], Taylan Akın[2], Erdinc Senturk[3], Mahmut Kaan Tuzen[3] and Serhat Akın[1]

1-Middle East Technical University, Petroleum and Natural Gas Engineering Department, Ankara, Turkey

2-Pamukkale University, Geological Engineering Department, Denizli, Turkey

3-Zorlu Energy Group, Zorlu Plaza, Avcılar, Istanbul, Turkey

kserhat@metu.edu.tr, alibaser@metu.edu.tr, ondersar@metu.edu.tr, takin@pau.edu.tr, erdinc.senturk@zorlu.com, mahmut.tuzen@zorlu.com, serhat@metu.edu.tr

ABSTRACT

Geothermal fields in Turkey have substantially higher carbon dioxide content compared to a typical geothermal field in the world. Geothermal Emission Control (GECO) project aims to reduce carbon emissions by reinjecting produced carbon dioxide from a pilot reinjection well. A high-resolution CO_2 flux meter is used to measure the surface carbon dioxide flux and temperature parameters in Kızıldere field, which is one of the demonstration fields in this project. The aim of these measurements is to map the natural variation of the soil CO_2 flux in the Kızıldere Geothermal Field and to construct a baseline data to find out whether the injected CO_2 leaks to the surface via faults and natural fractures during/after the prospective injection operations. The measurement grid is constructed in a way that the soil CO_2 flux and temperature data will be as comprehensive as possible to include all the potential leakage sites. Monthly measurements are conducted to monitor the seasonal changes.

1. INTRODUCTION

Global increase in the atmospheric CO_2 level and related climate effects are of a great concern. Researchers and scientist are working on solutions to mitigate the anthropogenic CO_2 emissions. One of the noteworthy methods is the storage or sequestration of the captured CO_2 in deep geological formations. Injecting the carbon dioxide into deep formations may be an important part of Carbon Capture, Utilisation and Storage (CCUS) applications. Furthermore, incorporating the CCUS technologies with the geothermal power production may increase the total efficiency of the system in terms of environment and economic point of views.

One of the Horizon2020 projects, Geothermal Emission Control (GECO), aims to prove the utilisation of geothermal fields as CO_2 sinks, by re-injecting the greenhouse gases produced at the geothermal plants back into the deep formations and to provide cleaner, and cost-effective non-carbon emitting geothermal energy across the Europe and the World. For that reason, a CO_2 reinjection operation will be hosted by one of the demonstrations sites of the project - Kızıldere Geothermal Field, Turkey.

Kızıldere Geothermal Field is one of the largest geothermal power sources of the world with a total installed capacity of 260 MW as of June 2019 (Kucuk et al., 2020). Kızıldere geothermal field is located at the eastern part of the Büyük Menderes Graben, between Aydın and Denizli provinces, Turkey (Şimşek et al., 2009). The field is bounded by the Buldan Horst at the north and the Babadag Horst at the south. Currently, more than 70 wells are operational (both production and injection) to feed the geothermal power plants in the field and to reinject the geothermal fluid into the reservoir after its heat is harvested.

The geothermal fluid of Kızıldere field can be characterized by its high CO_2 content. As an average, geothermal fluid from the shallower reservoir sections has 1.5wt% of dissolved CO_2, and that value increases to 3wt% at deeper metamorphic sections (Haizlip et al., 2012). Considering that most of the production is coming from the metamorphics, CO_2 emission rates can be very significant when Kızıldere geothermal power plants operate at full capacity. To address this issue, a pilot CO_2 reinjection plan is under preparation, which will be operational in 2020 as part of the GECO project.

One of the most important issue that arises in reinjection of the emitted CO_2 is to monitor the movement of the injected CO_2 plume in the reservoir. It is critical to assure the environment and public safety by proving no-leakage occurs throughout the lifespan of the operation. For that reason, a baseline of the natural variation in soil CO_2 flux must be obtained at the project site before starting any re-injection operation (Madsen et al., 2009; Szizybalski et al., 2017). By that way, any changes during or after the CO_2 injection can be detected by comparing the recent and background flux data. The aim of this study is to form a well-organized surface soil CO_2 flux baseline data before starting CO_2 reinjection in the Kızıldere Geothermal Field, Turkey, as part of the GECO project.

2. MEASUREMENT DEVICE AND METHODOLOGY

The CO_2 flux measurements were taken using LI-8100A Soil Gas Flux System (LI-COR Biosciences, 2015), which measures the diffusion of CO_2 from the soil to the atmosphere (Madsen et al., 2009). The closed-chamber method is applied using a 20 cm diameter survey chamber. The method consists of setting a 20 cm collar into the measurement point (preferably 24 hours before the measurement to assure undisturbed soil conditions), taking the measurement at the point, and interpretation of the data to obtain CO_2 fluxes.

A schematic diagram of the Analyzer Control Unit of the device is shown in Figure 1 (LI-COR Biosciences, 2015). A unique pneumatic system moves the bellows which lowers and raises the survey chamber on the collar, placed on the soil. When the chamber is closed, some portion of air within the chamber is circulated through the infrared gas analyzer (IRGA) where CO_2 and H_2O concentrations are measured simultaneously, which are then used to calculate soil CO_2 efflux, F_c. An exponential function

proposed by Madsen et al. (2009) is used to fit the time series of CO_2 concentration (µmol/mol) values to obtain the rate of CO_2 concentration increase in the chamber ($\frac{dC_c}{d_t}$, µmol/mol/s). Then, the CO_2 efflux rate, F_c (µmol/m²/s), is estimated with the following equation.

$$F_c = \frac{10\,V\,P_0\,(1-W_0)}{R\,S\,(T_0+273.15)}\,\frac{\partial C'}{\partial t} \tag{1}$$

Where F_c is soil CO_2 efflux rate (µmol/m²/s), V is the volume of the system including the survey chamber, the pump, and the tubing in the measurement loop (cm³), P_0 is the initial atmospheric pressure (kPa), W_0 is the initial water vapor mole fraction in the air (µmol/mol), S is the soil surface area (cm²), T_0 is the initial air temperature (°C), R is the gas constant (8.314 Pa.m³/°K/mol) and $\frac{dC'}{d_t}$ is the initial rate of change in water-corrected CO_2 mole fraction (C', µmol/mol).

The CO_2 concentration gradient between the upper soil layer and the atmosphere just above the soil is the primary driving force for the CO_2 diffusion from soil to the atmosphere. There are some key factors affecting the quality of soil CO_2 flux measurements. The followings are the most fundamental considerations.

- Pressure equilibrium must be maintained between inside the survey chamber and the ambient air in order to accurately obtain the naturally occurring CO_2 flux in the measurement site.
- A good mixing of air inside the chamber must be ensured since only a small portion of air inside the chamber is sent to the infrared gas analyzer (IRGA). While ensuring a good mixing, causing pressure disturbances must be avoided.
- Effects of altered CO_2 diffusion gradients must be minimized.
- Disturbance to the environmental conditions must be avoided in the measurement site.

For detailed information about the measurement instrument and the method, the reader is referred to Madsen et al., (2009) and LI-COR Biosciences (2015).
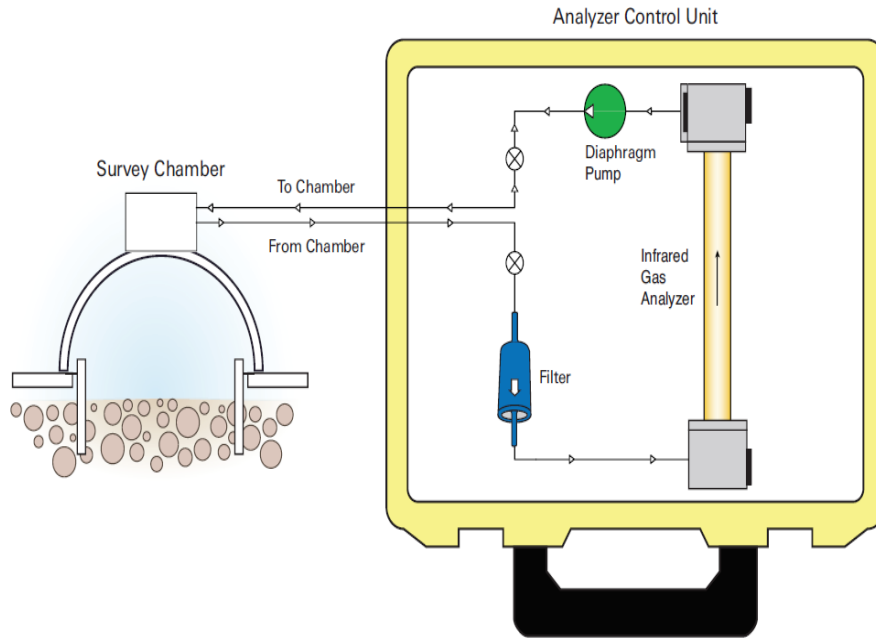

Figure 1. Schematic of the CO_2 measurement in LICOR 8100A Survey Chamber *(LI-COR Biosciences, 2015)*

3. GRIDDING THE AREA

As part of the Horizon 2020 project Geothermal Emission Control (GECO), some portion of the emitted CO_2 will be reinjected into the deep Menderes metamorphic sections. The goal is to mitigate the CO_2 emission rates of the Kızıldere geothermal power plants as well as maintaining the reservoir pressure for a better management of the Kızıldere geothermal field. One of the most critical part of this operation is to monitor the injected CO_2 so that any leakage will be detected, if occurs. For that reason, a baseline data of the natural CO_2 soil flux distribution in the vicinity of the injection site has to be obtained.

The measurement grid has been constructed in a way that enables tracking the natural variation of the soil CO_2 flux data as comprehensive as possible to include all the potential leakage sites. There are approximately 70 measurement points in the injection region (Figure 2). The measurement points are divided into three main areas as, (1) the very vicinity of the injection well, (2) between injection well and nearby production wells, and (3) the horst section to the north of the injection well along the faults.
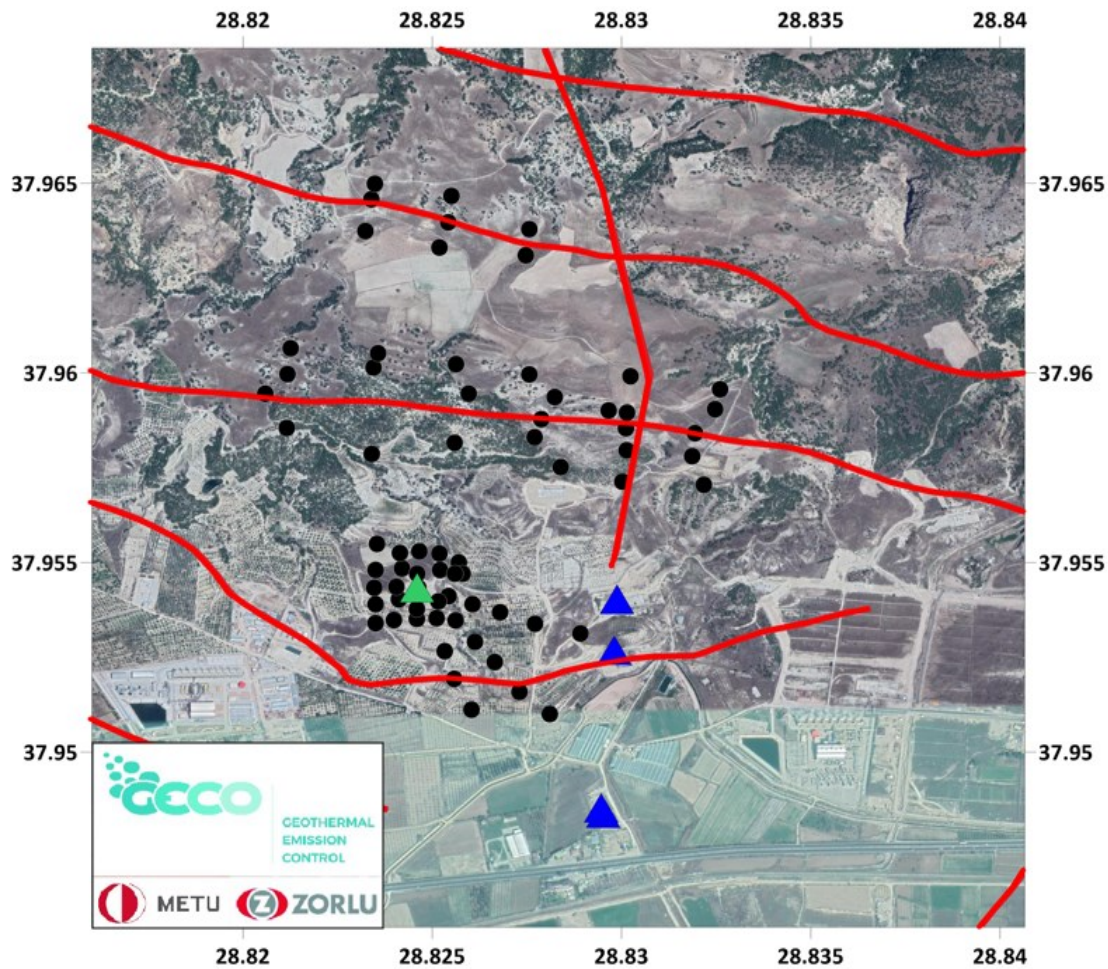
Figure 2. Green triangle: Potential injection well, Blue triangles: Nearby production wells,

Black circles: Measurement points, Red lines: Projections of the faults to the surface

Twenty-five of these measurement points are located at the vicinity of the injection well to detect a leakage in case of casing or cement failure. Since it is highly probable that the injected CO_2 will move towards the nearby production wells, because of the siphon effect, some measurement points have been located between the injection well and the nearby production wells. Lastly, in order to map the natural soil CO_2 flux variation at the horst section, where fault structures are observed, several measurement points have been located to the north of the injection well. The latter measurement points are required to track any potential CO_2 movement to the surface through the faults from the injection depth.

RESULTS OF THE MEASUREMENTS

Starting in February 2019, four measurements were conducted in February, March, April, and in June. Initially, measurement at the very vicinity of the potential injection well was carried out with 20 measurement locations. Then, the measurement mesh was increased to include the northern region where the fault structures can be observed at the surface. Some measurement points were placed on the path from the injection well towards the nearby production wells. Because of the weather conditions and some other factors such as damage to the collars by the local residents and animals, measurements at each point at each month were not possible. So, there are slight differences between each measurement trips in terms of the number of measured points and locations.

In order to calculate the CO_2 fluxes, an exponential function is used to fit the time series of CO_2 concentrations, considering the effects of water vapor dilution (Madsen et al., 2009). An example match of one of the measured data is shown in Figure 3. At each location, two measurements with a length of 90 seconds each, and with a dead band of 20 seconds were conducted. The dead band is required to reach a steady mixing inside the survey chamber. That's why the initial data was discarded from analysis (green line). After fitting all the data exponentially, the averages of the two observations at each point were obtained, and assigned as the soil CO_2 flux at the corresponding points and time.
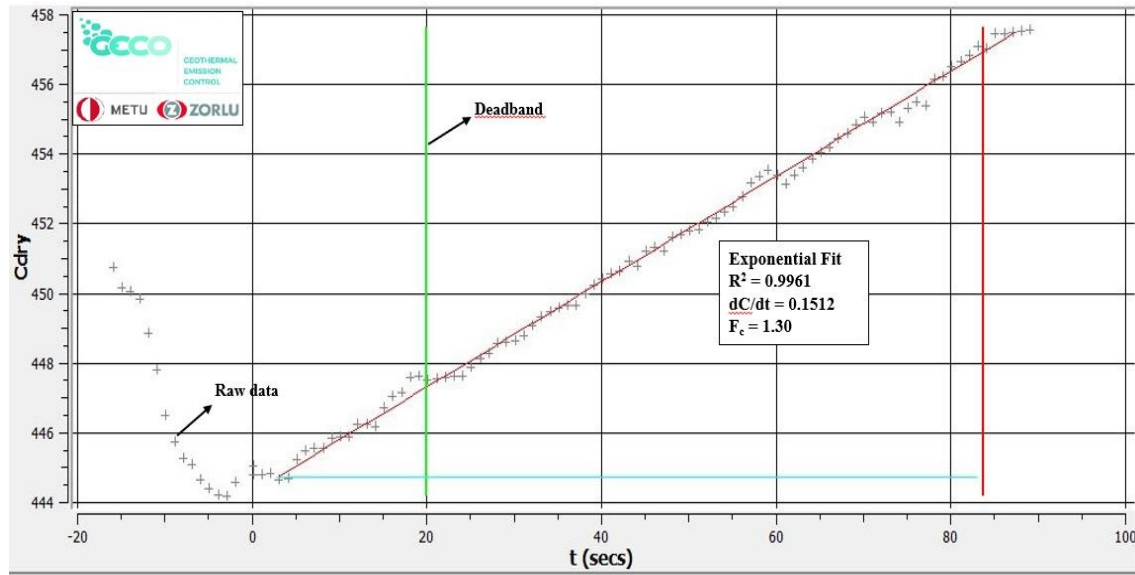
Figure 3. Illustration of an exponential fit to measured dry CO_2 concentrations in time

Measured concentrations show a good agreement between each other and with the global atmospheric CO_2 levels. The measured CO_2 concentration values ranged from 400 to 450 µmol/mol, or ppm, excluding some outliers. The average concentration of all measurements was approximately 420 µmol/mol. In Figure 4, the measured fluxes at each month are mapped where the white crosses represent the measurement locations. Note that, there is only a limited data in February since the points were located at the very vicinity of the potential injection well. It can be seen that, after the grid is enlarged, two points along the faults at the northern section yields high soil CO_2 flux consistent in each measurement at March, April, and June. The results of the measurements so far can be better observed in Figure 5, where the natural variation of the soil CO_2 flux (µmol/m^2/s) in the injection region is mapped by taking the averages of the four measurements (February, March, April, and June) at each point.
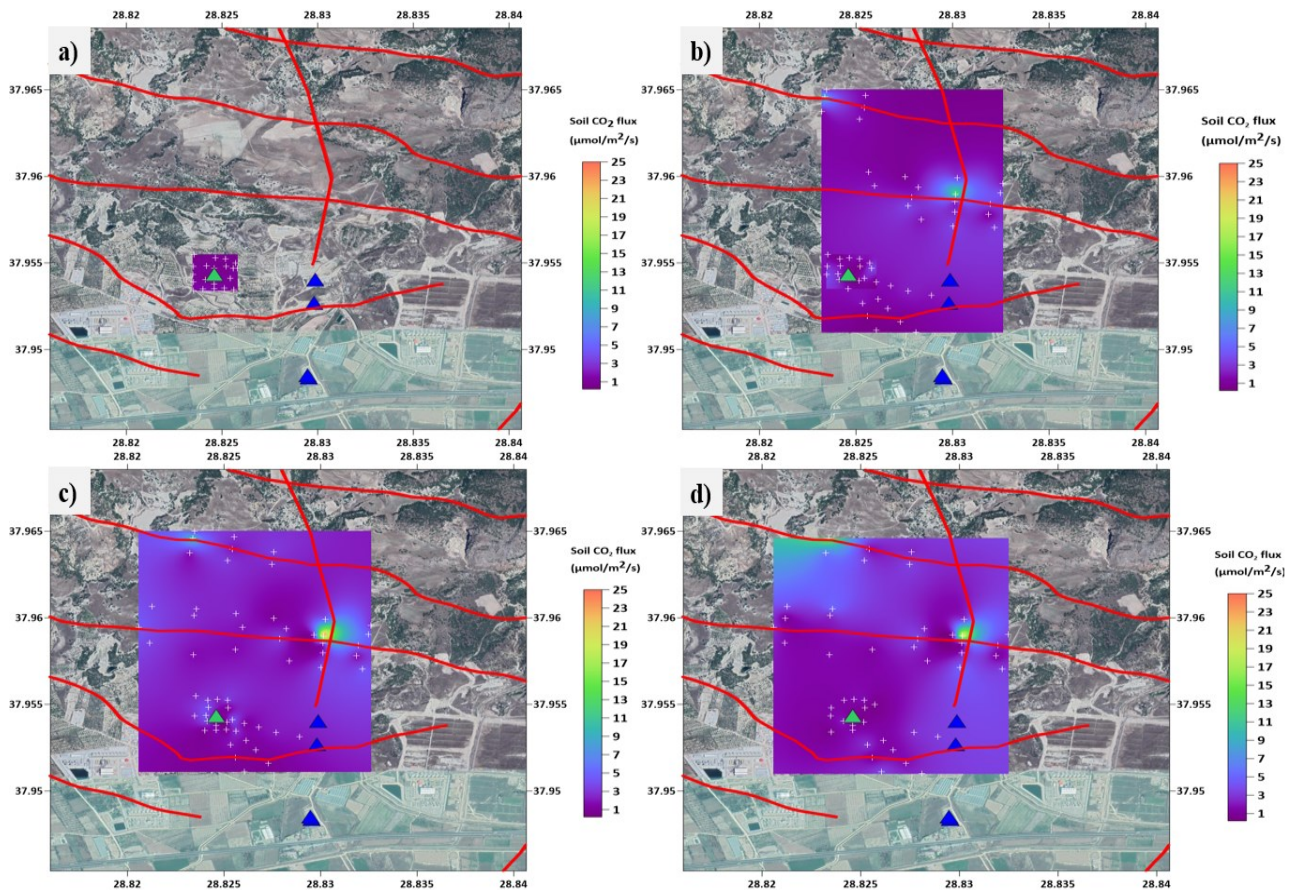
**Figure 4. Soil CO_2 fluxes (a) February (b) March (c) April (d) June**
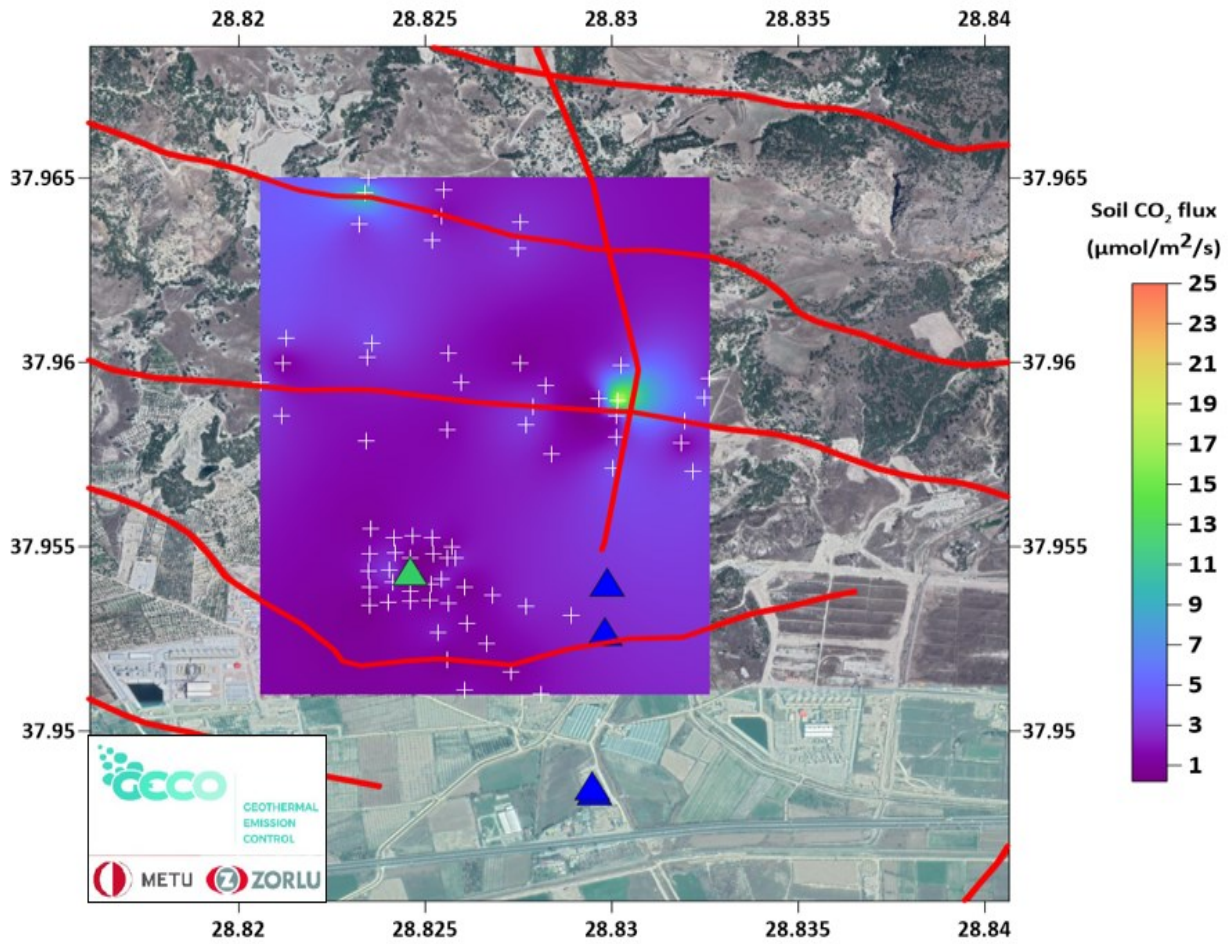
Figure 5. Natural variation of the soil CO_2 flux in the potential CO_2 injection area in Kızıldere Geothermal Field – average of the four measurements

High soil CO_2 flux values were observed at two locations with a rate of 13.5 $\mu mol/m^2/s$ and 20 $\mu mol/m^2/s$. Those locations are very close to the fault-surface intersection region, which acts like a geothermal CO_2 vent at the surface. The fractured rocks (Figure 6) and the topography of the region strengthens that assessment. If the injected CO_2 moves to the north along the faults, it is highly probable that a sharp increase in the measured soil CO_2 fluxes will be observed at those locations. The rest of the measured fluxes were equal to or less than 4 $\mu mol/m^2/s$.


Figure 6. Fractured rocks in the measurements site where high soil CO_2 fluxes were observed

The effects of soil temperature at the measurement site should also be considered. Since microbial respiration depends on the ambient temperature, any changes in the soil CO_2 fluxes can be related to the changes in the soil temperatures. In order to support the baseline data of soil CO_2 fluxes, the soil temperature was measured using an 6000-09TC Omega probe (LI-COR Biosciences, 2015), at a soil depth of 5 to 10 cm. The effect of soil temperature on the soil CO_2 fluxes is differentiable in the measurements. The plot of measured soil CO_2 fluxes and diurnal changes in the soil temperature in each month is shown in Figure 7. Additionally, it has been observed that the spatial distribution of the measurement points was also an important factor. Any correlation between the flux and soil temperature becomes relatively unclear after the measurement area is enlarged by adding many points to the north in March, and the spatial variation of the measurement points becomes the main consideration. On the other hand, it should be noted that only four measurement trips have been realized so far, and it is highly probable that the effects of soil temperature will be pronounced more clearly once a dataset of the whole year has been collected.
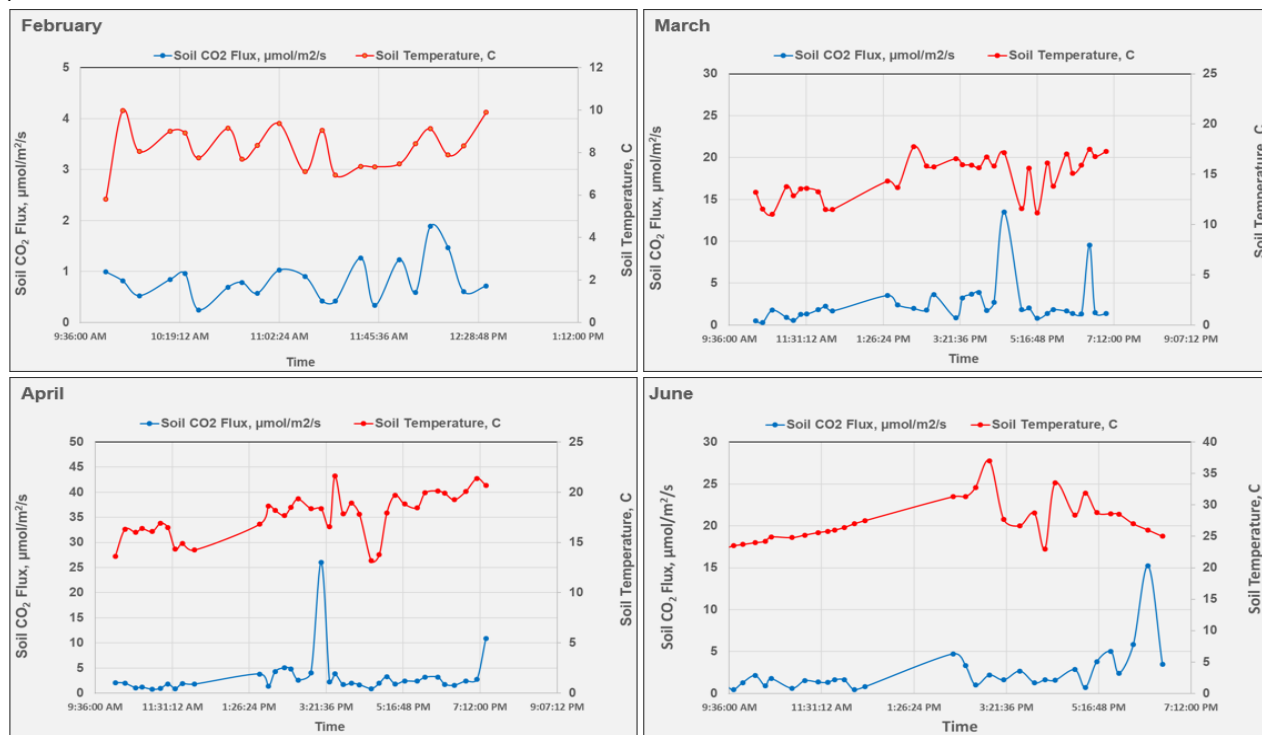
Figure 7. Soil CO_2 flux and soil temperature measurements during the day time in all measurements – each point represent a different measurement location

The correlation between the soil CO_2 flux and soil temperature can also be seen by plotting the average values of the four measurements at each point (Figure 8). Although there are only four measurements so far (in February, March, April, and June), the correlation is quite visible and expected to be clearer with the future measurements. The average soil CO_2 flux ranged from 0.8 to 2.8 $\mu mol/m^2/s$, while the range of the all measurements was from 0.15 to 26 $\mu mol/m^2/s$. But it should be noted that the two points with high fluxes (approximately 13.5 $\mu mol/m^2/s$ and 26 $\mu mol/m^2/s$) increase the average values significantly. The average soil temperature was in range of 8 to 10 °C, while the range of all measurements was from 5 to 37 °C.
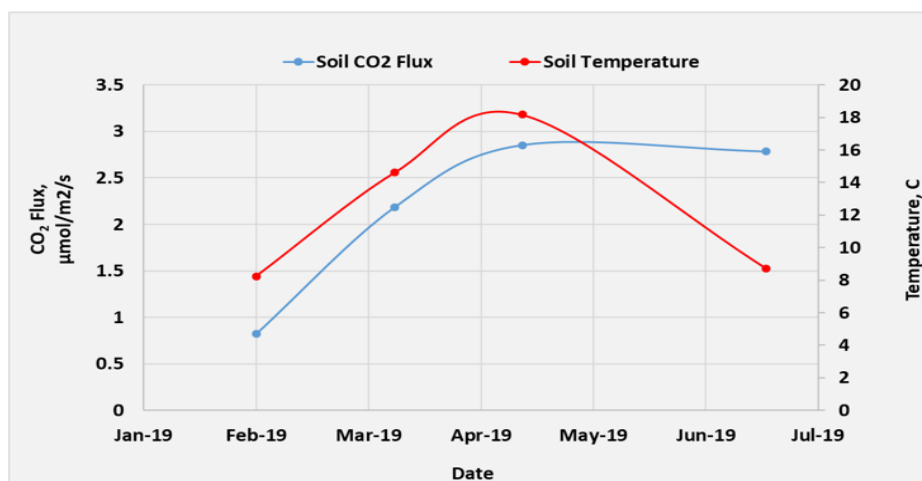
Figure 8. The average of soil CO_2 flux and soil temperature measurements

6

Effects of vegetation is another important parameter that should be considered throughout the monitoring. This issue was not a significant consideration so far since vegetation was only limited inside and around the collar compared to the close terrain (Figure 9). This situation could be explained by the perturbations that are created during the preparation of the area for setting the collars. But these perturbations probably did not affect the CO_2 flux and soil temperature measurements since stabilized soil conditions have been assured by waiting at least 24 hours prior to measurements. But in order to assure that vegetation will not be an important issue during the measurements, forthcoming measurements will be compared.

Figure 9. Collars for setting the survey chamber during measurement

CONCLUSION

A high-resolution CO_2 flux meter was used to measure the surface carbon dioxide flux and temperature in Kızıldere field. The aim of these measurements was to map the natural variation of the soil CO_2 flux in the Kızıldere Geothermal Field and to construct a baseline data to find out whether the injected CO_2 leaks to the surface via faults and natural fractures during and after the prospective CO_2 injection operations. The soil CO_2 flux measurement grid was constructed in such a way to include all potential leakage sites. Starting from February 2019, four soil CO_2 flux measurements with approximately 70 measurement locations at each time were conducted to monitor the seasonal changes. It has been concluded that two locations where high CO_2 fluxes were obtained are natural CO_2 vents on the surface. In case of any movement of injected CO_2 to the surface along the faults, these locations may show increased CO_2 flux values. The effects of vegetation and seasonal changes at the measurement site were mapped. In order to better understand the natural variation of soil CO_2 flux near the planned reinjection site, as well as to visualize the effects of diurnal changes on the measured values, further measurements will be conducted. Obtaining the baseline data of natural soil CO_2 flux distribution in the injection site prior to planned injection in 2020 will play a key role in monitoring the path of injected CO_2 together with other monitoring techniques such as sampling wells and tracer testing.

ACKNOWLEDGEMENT

REFERENCES

Haizlip, J.R., Guney, A., Tut-Haklidir, F., Garg, S. (2012): The impact of High Noncondensible Gas Concentrations on Well Performance Kizildere Geothermal Reservoir, Turkey, *Proceedings*, Thirty-Seventh Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California.

Kucuk, S., Baser, A., Saracoglu, O., Senturk, E., Tuzen, M.K., and Akin, S., (2020). Reinjection Optimization of Kızıldere Geothermal Field for Sustainable Reservoir Pressure Management. Proceedings World Geothermal Congress 2020 Reykjavik, Iceland, April 26 – May 2, 2020.

LI-COR Biosciences. (2015). *Using the LI-8100A Soil Gas Flux System*. 1–220. Retrieved from https://www.licor.com/env/support/LI-8100A/manuals.html

Madsen, R., Xu, L., Claassen, B., & McDermitt, D. (2009). Surface Monitoring Method for Carbon Capture and Storage Projects. *Energy Procedia*, *1*(1), 2161–2168. https://doi.org/10.1016/j.egypro.2009.01.281

Simsek, S., Parlaktuna, M., and Akin, S.: Data Gathering and Evaluation of Kızıldere Geothermal Field, Report prepared for Zorlu Energy, (2009).

Szizybalski, A., Zimmer, M., Pilz, P., & Liebscher, A. (2017). Results from twelve years of continuous monitoring of the soil CO2 flux at the Ketzin CO_2 storage pilot site, Germany. *Energy Procedia*, *125*, 543–548. https://doi.org/10.1016/j.egypro.2017.08.186