Continuous Seismic Time Lapse Trail in Saudi Arabia Using a Seismic ACROSS Source EOR and CCS Applications*

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Abstract

For the exploration of unconventional resources, the time lapse is one of essential technologies. For developing the time lapse technology for EOR (enhanced oil recovery) and CCS (Carbon Capture and Storage) we have used a very stable and continuous seismic source called ACROSS (Accurately Controlled Routinely Operated Signal System) with multi-geophones. Since 2011, we have tested this technology in the context of carbonate rocks in Saudi Arabia. The Al Wasee water pumping site approximately 120 km east of Riyadh city has been selected as a trail-site. The intention is to observe the changes in aquifers induced by pumping operations. One ACROSS source unit was installed at the Al Wasee site in December 2011 and continuing the field test. The instrument has been operated from 10 to 50 Hz with 40 tons-f at 50 Hz. Using alternatively clockwise and counter-clockwise rotations we can synthesize vertical and horizontal forces, respectively. 31 3C-geophones in 2 km × 3 km area and four nearby 3C-geophones have been used to monitor the seismic changes from pumping the water. The one and half month data between December 2012 and February 2013 show continuous and clear change of observed waveforms for all 31 stations while the source signature did not change. The change is closest and fastest at the station #42. The cause of continuous change with time is interpreted as pumping of water by 64 wells located in this field.

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Objectives

The goal of the project is to develop a time lapse technique for EOR and CCS, that utilizes the use short period seismic stations and a very stable and continuous seismic source called ACROSS (Accurately Controlled and Routinely Operated Signal System). The Al Wasee water pumping site approximately 120 km east of Riyadh has been selected as a trial-site. The intention is to observe the changes in aquifers during water production. One ACROSS source unit was installed at the Al Wasee site in December 2011. The instrument has been operated from 10 to 50 Hz with 40 ton-f at 50 Hz.

Monitoring the change of characteristics of seismic waves travelling in the ground can provide the change of physical state in the subsurface caused by migration of water, oil and gas from one place to another place by production and/or natural causes.
The seismic ACROSS (Accurately Controlled and Routinely Operated Signal System) source is a very accurate and repeatable seismic source developed in Japan. The use of this seismic source and geophone receiver arrays enables us to continuously monitor the physical state of the CO2 storage zone by every 2 hours if the size of storage zone is 3 km wide x 3 km long x 3 km in depth (Fig. 1). The processing of every two hours monitoring data can image the change of storage zone.

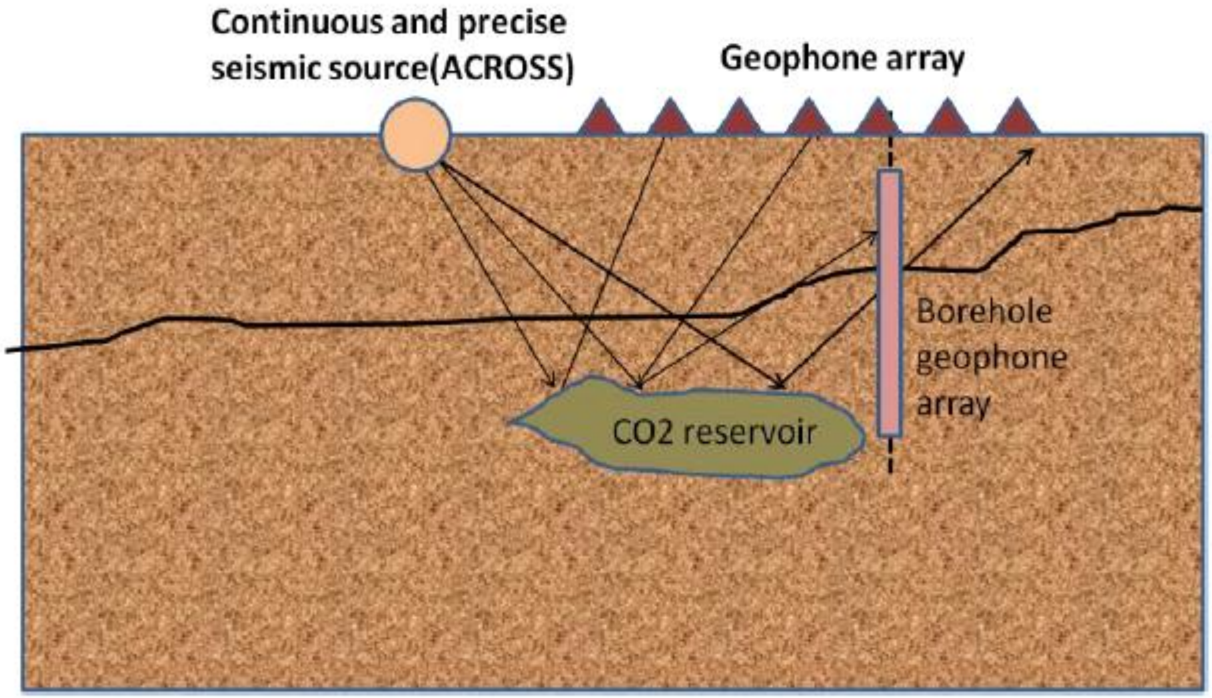
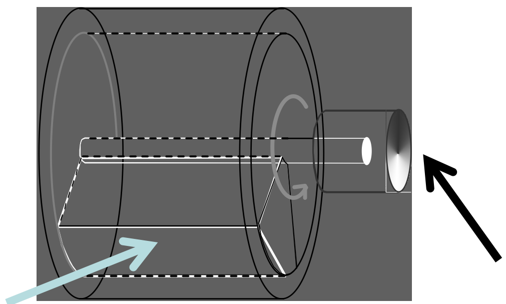


Figure 1: Schematic diagram to show the time-lapse monitoring using single seismic ACROSS source and geophone array

Very stable seismic source (ACROSS)

- Seismic ACROSS. This innovative instrument can be operated during *several years continuously*.
- It can generate **vertical and/or horizontal vibrations** of 10-50Hz frequency with 40ton-f power.

ACROSS



AC servo motor

Eccentric mass

Figure 2: Seismic ACROSS source unit showing the servo-motor. The system uses a frequency band ranging from 10 to 50 Hz. It can generate a 40 tons-f centrifugal force at 50 Hz.

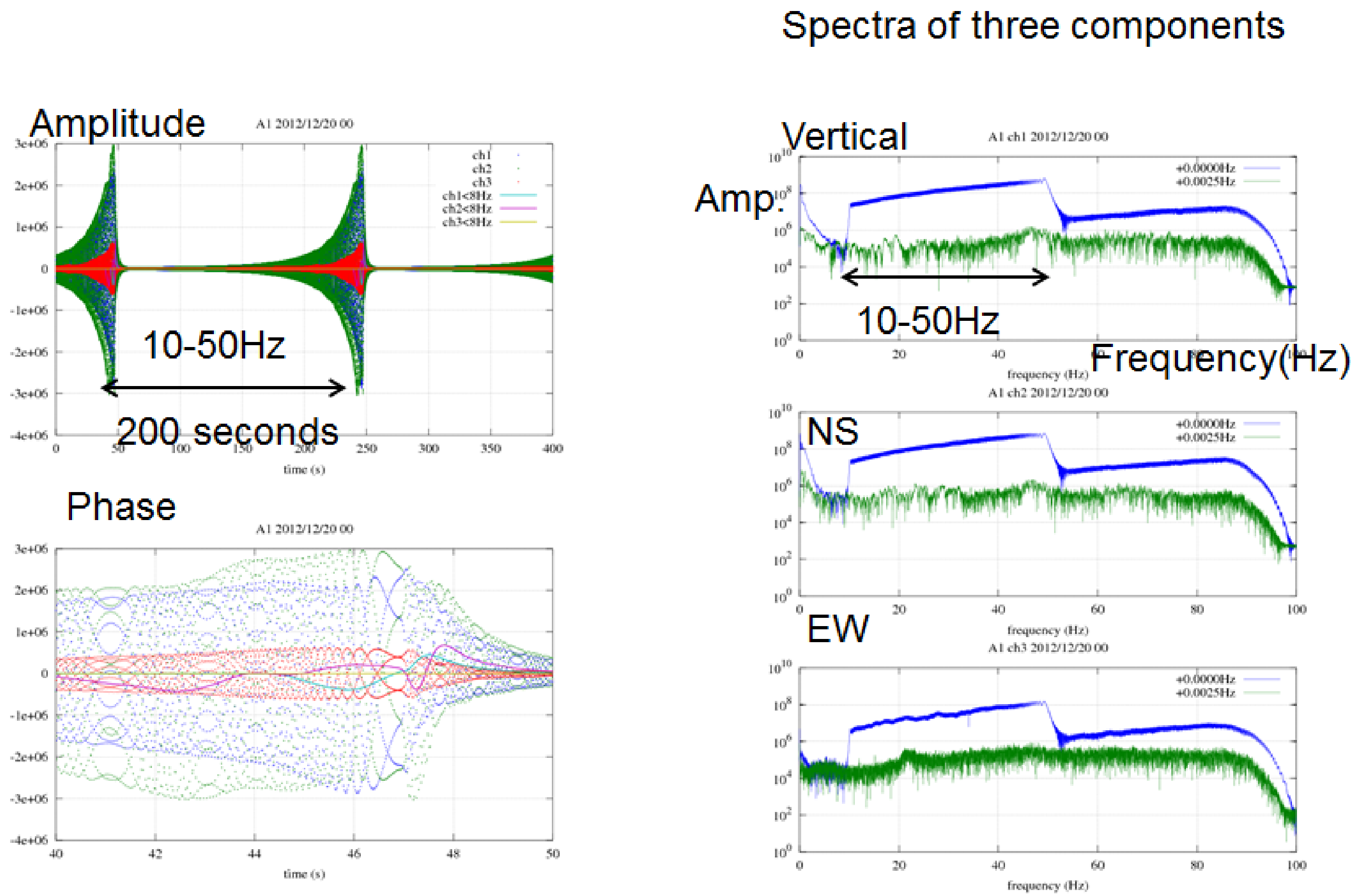


Figure 3: Example of sweep signal by ACROSS in Saudi Arabia.

Figure 4: The center is the coupling unit of ACROSS to the ground at the depth of 5 m from the surface.

Figure 5: Constructing wall of basement.

Figure 6: Basement room.

Figure 7: The top of the ACROSS room.

Location

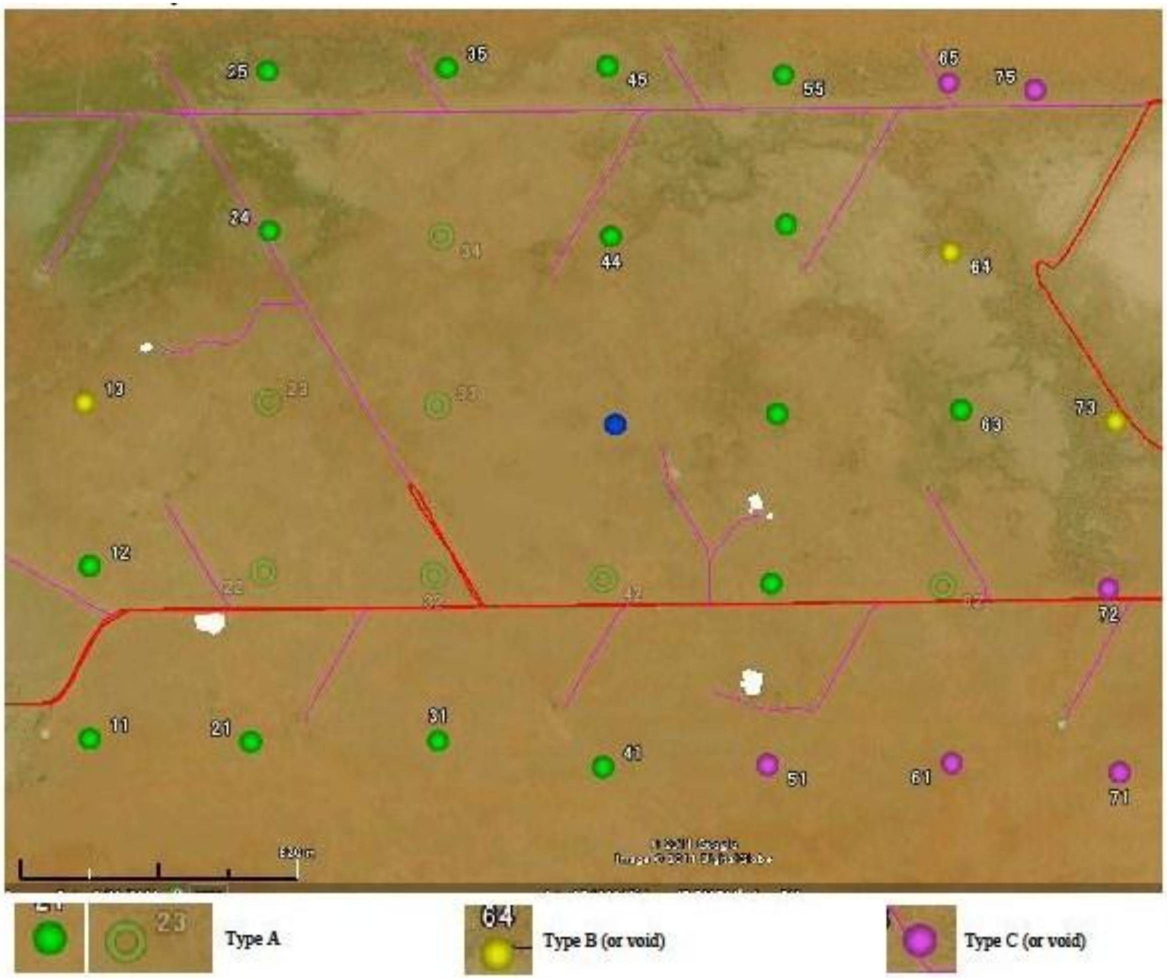


Figure 8: Seismic stations and source locations

The ACROSS source is placed at the center of an array of geophones and 31three-components surface seismic stations were deployed in 3 km x 2 km area with 500 m distance grids (Fig. 9). The basement of the Al Wasee field is composed of limestone-dolomite locally covered with sand-dunes.

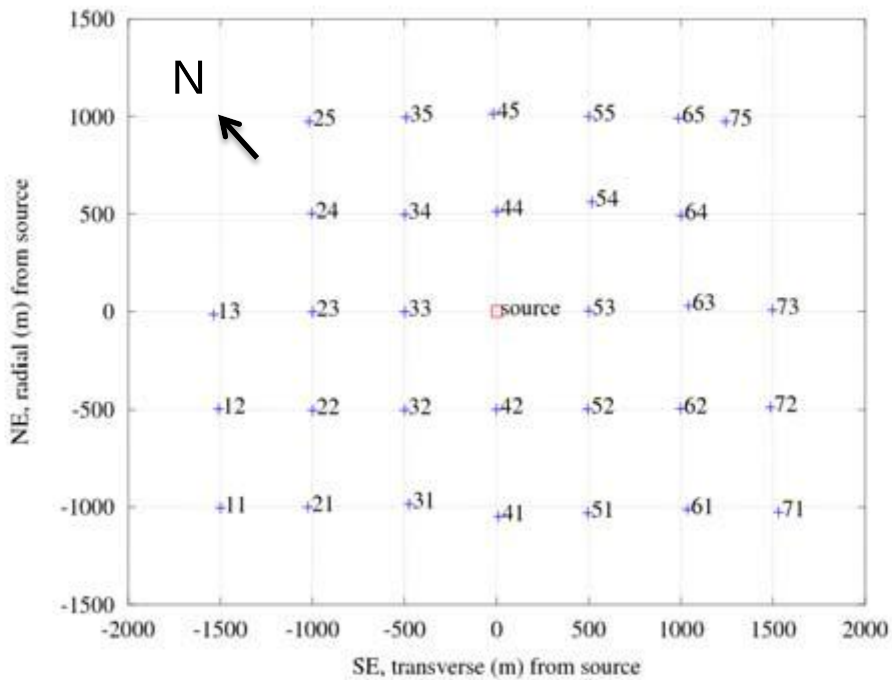


Figure 9: Location map of seismic ACROSS source at (0, 0) and 31 3C-1Hz geophones. The scale is m. The heading is N45°E. The rotation axis of the motor is NE-SW. We refer to NW-SE and NE-SW as radial and transverse direction, respectively.

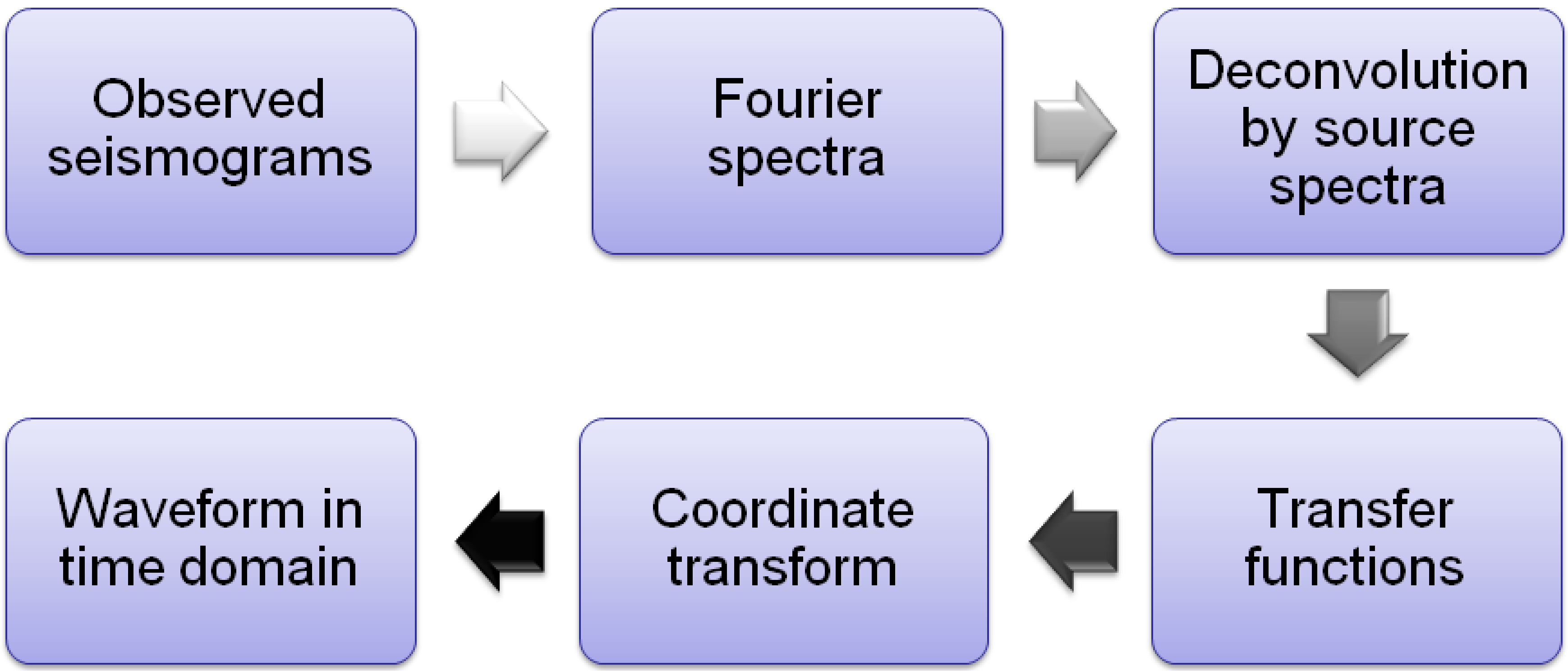


Figure 10: Sequence of the data processing.

Results by operation in September and November, 2012

We operated the system in September and November. There is more than one month absence of data due to the adjustment of equipment. We obtained the first results shown in Figs. 11-13. The distances between the ACROSS source and each station is approximately 500m. The rotational axis of the ACROSS source is parallel to # 42-source-# 44 line and perpendicular to # 33-source-# 53. There is some noise due to not enough S/N because 2 hours stacking is not enough for some stations.

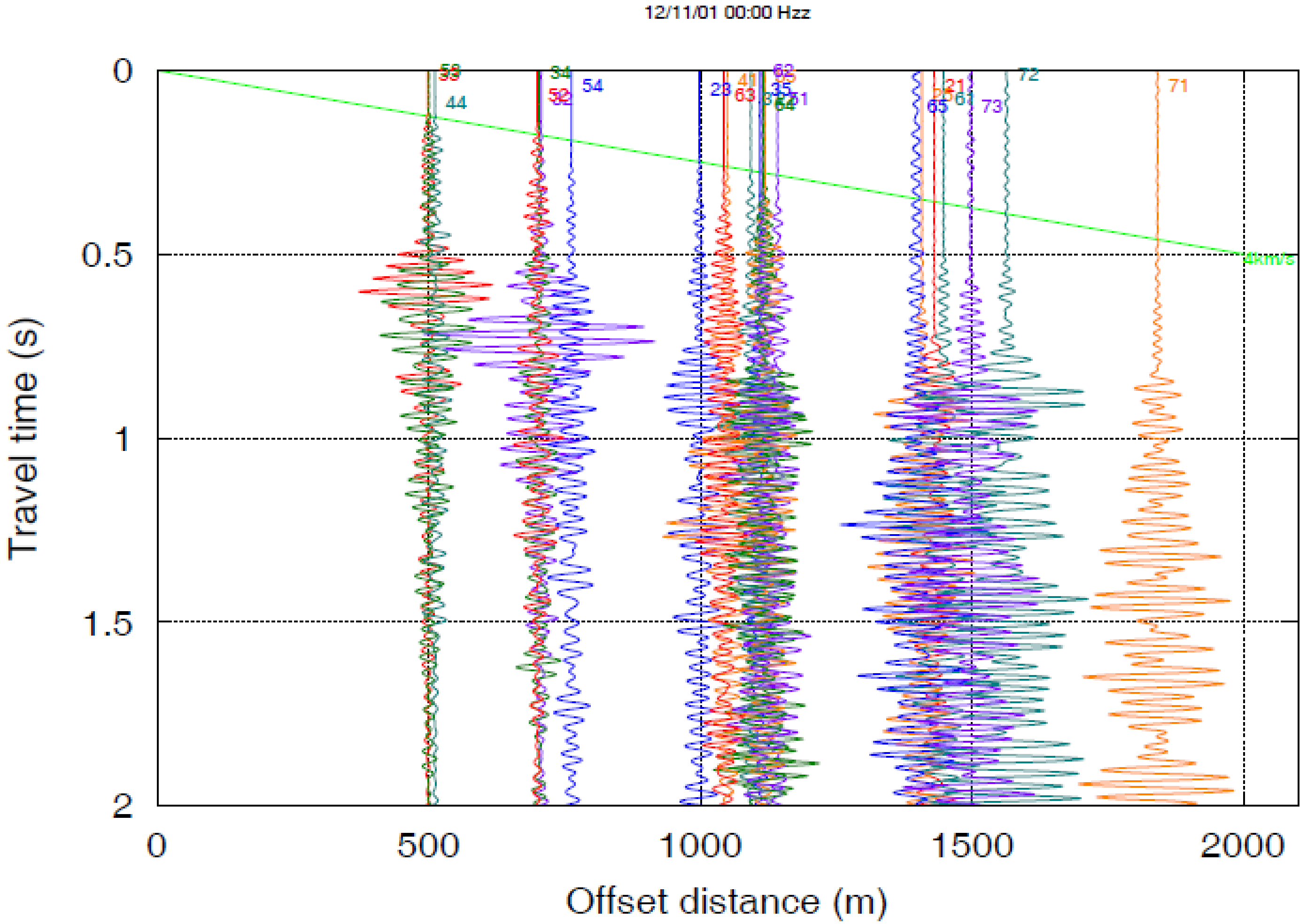


Figure 11: Example of transfer functions for the vertical single force at 24 sites obtained by six hours data. Vzz: Vertical geophone records exited by the vertical single force.

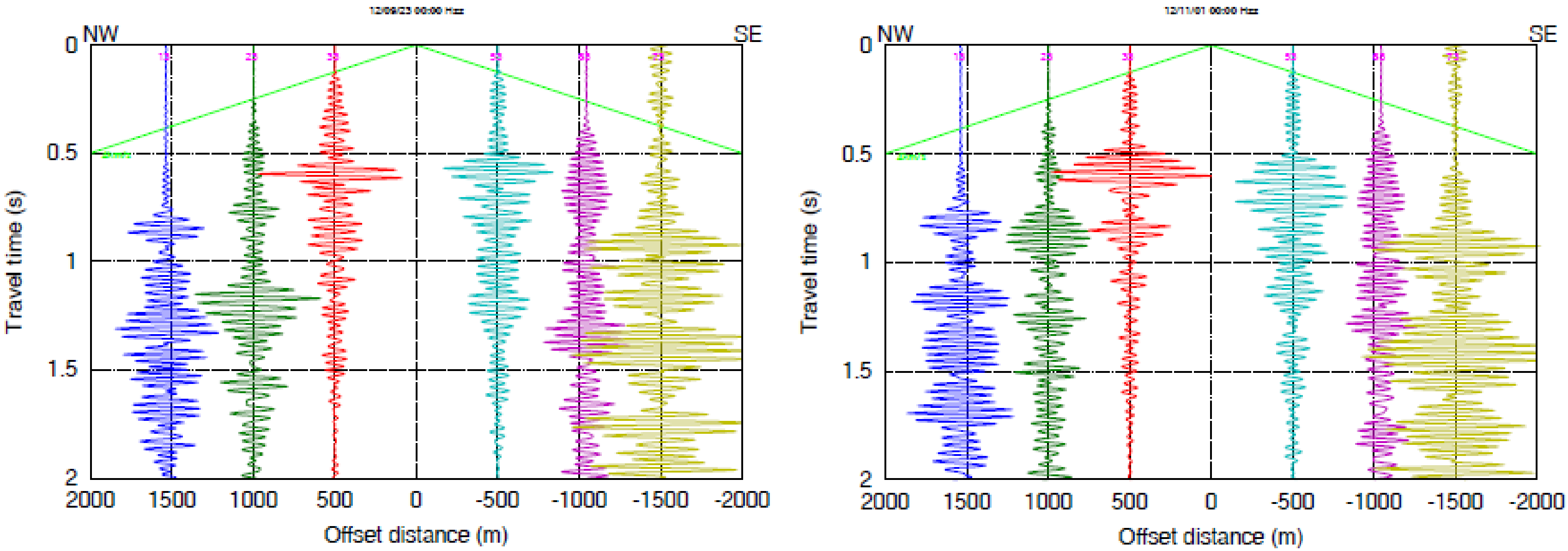


Figure 12: Time lapse of transfer functions at six stations observed by vertical geophones exited by vertical vibration using 2 hours data between 0-2Hr in September 23 (left) and 0-2Hr in November 1(right), 2012 although the source spectra are the same for both data. The 10-40 Hz Hanning window was used.

The comparison of two sets of transfer functions shows very large waveform changes between data in September 23 and November 1 (see Fig. 12). Because source spectra of two sets are the same, the difference of two sets might be caused by propagation path characteristics and/or nearby structural change. Fig. 13 shows the waveform change during September 22 and 23 and November 1 and November 13. During two weeks in November, the waveform changes are not large, but there is a very large gap between September and November. It is important to note the clear daily variation. Similar drastic change is also identified by horizontal geophone records by horizontal vibration, although there are no illustrations in this presentation.

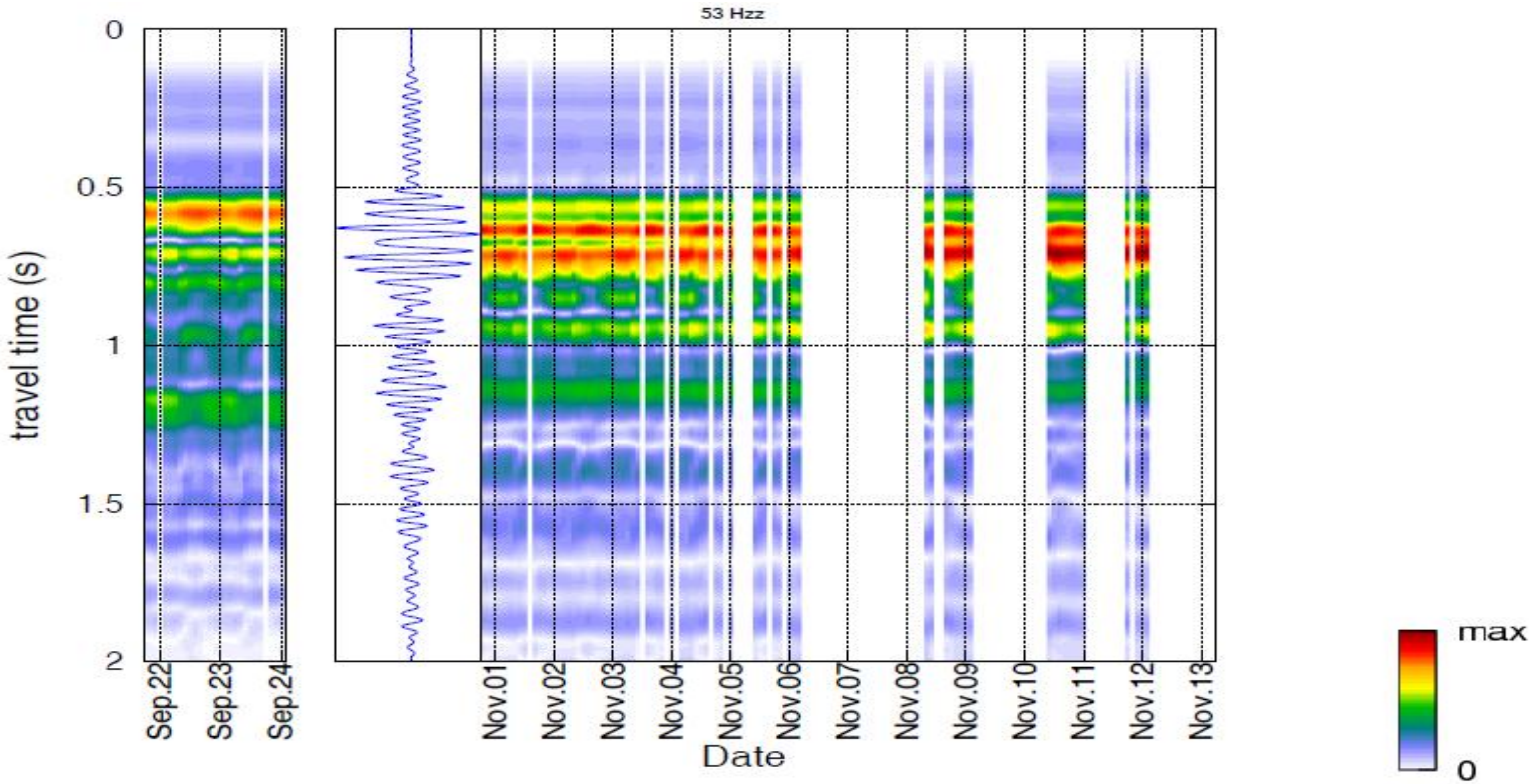


Figure 13: Time lapse of envelope of transfer functions of the station # 53 (-500 m distance) from September 22 to 24 and from Nov. 1 to 13, 2012 observed by vertical geophone exited by vertical vibration. Amplitudes are shown by color. The daily variation is clearly identified.

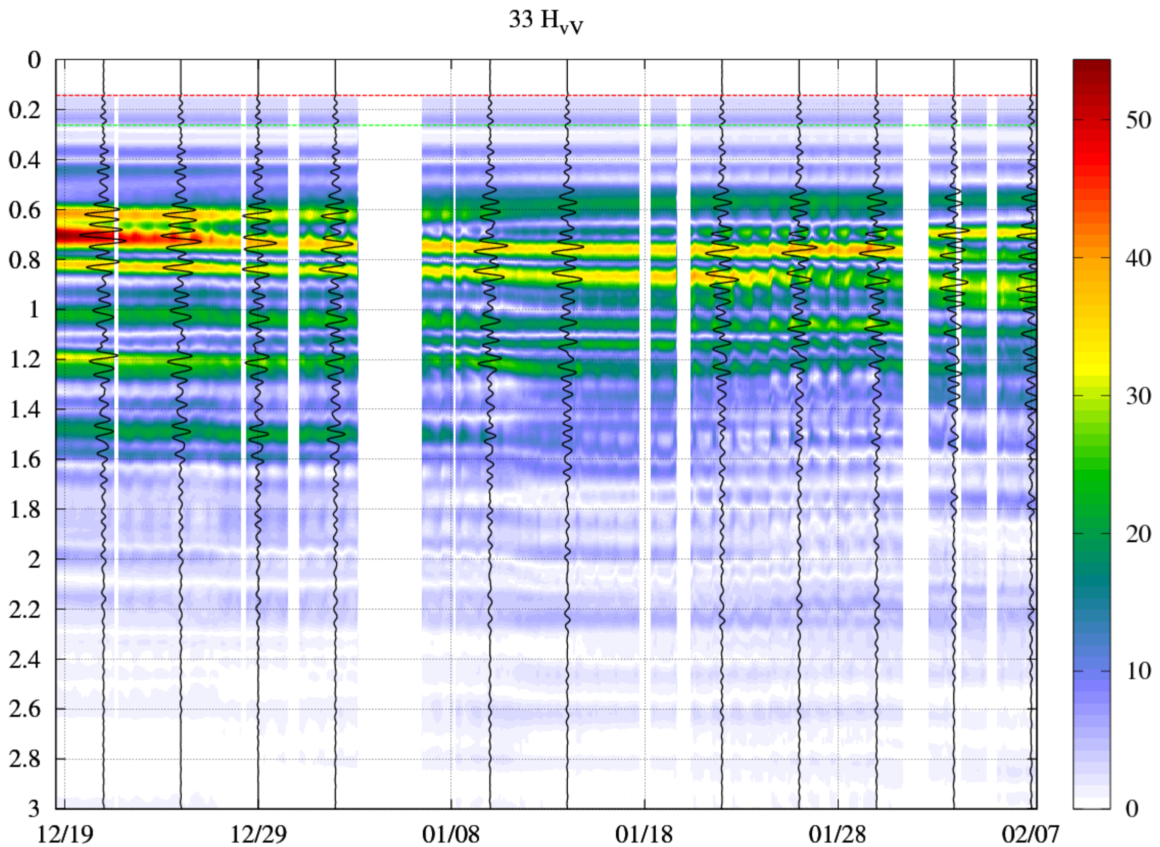


Figure 14: Time lapse of envelope of transfer functions of the station # 33 from December 18 and January 19.

Conclusions

The first time-lapse field experiment has been carried out in September and November, 2012. The very drastic change is seen in transfer functions for the vertical vibration. Because there is no change of source spectra between in September and November, the change of waveforms of transfer function might caused by change of water tables in this period, although we should carefully re-examine the possibility of source characteristic changes. The change in two weeks in November is rather small, but we may notice clear daily variations on waveforms. The daily variation may cause stacking over several days. There are 64 pumping wells in the Al Wasee filed and they might drastically change the distribution of water tables. Further studies are needed. The results show promising data to discuss the time lapse problem. We are confident that the field test in Al Wasee will have a great impact in the time-lapse studies in the world.

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THANK YOU FOR YOUR ATTENTION!