Rn and CO2 in Depth, as a Proxy for Pre-Seismic Activity

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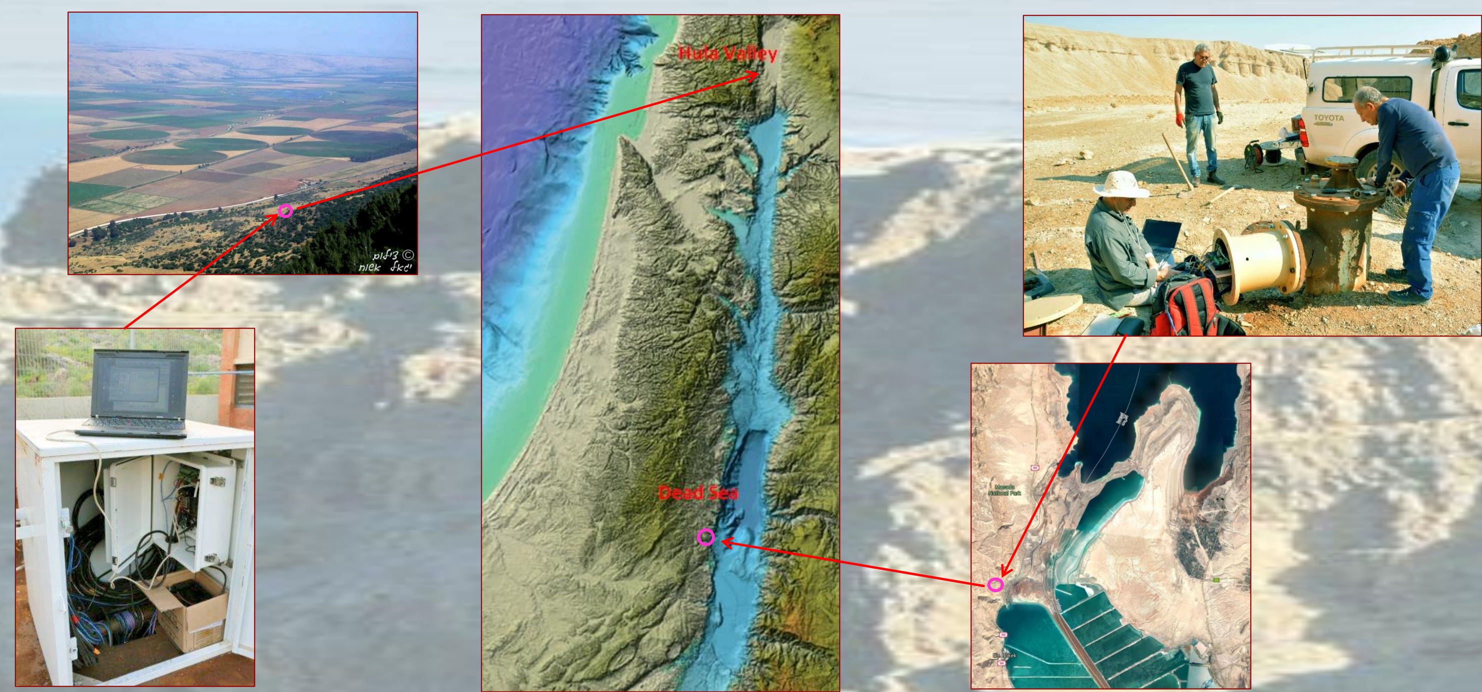
Abstract

Rn and CO2 in-depth, as a proxy for pre-seismic activity Hovav Zafrir1,4, Uri Malik1, Elad Levintal2, Noam Weisbrod2, Yochai Ben Horin3, Zeev Zalevsky4, Nimrod Inbar5 1Geological Survey of Israel, 32 Yesha'ayahu Leibowitz, Jerusalem 9371234, Israel, 2The Zuckerberg Institute for Water Research, Ben-Gurion University, 8499000 Sede Boqer, Israel, 3Soreq Nuclear Research Center, Yavne 81800, Israel, 4Faculty of Engineering, Bar Ilan University, Ramat-Gan 52900, Israel, 5Ariel University, Ariel 40700, Israel. (First author e-mail: hzafrir@gmail.com; zafrir@gsi.gov.il). Abstract The method of long-term monitoring of subsurface gases in shallow to deep boreholes assumes that the climatic influence on geo-physicochemical parameters is limited since its energy decreases with the increase in the thickness of the geological cover. Hence, the monitoring of radon (Rn), CO2 and other constituents above and below the water table in deep boreholes enables to eliminate the climatic-induced periodic contributions, from the residual portion of the signals that are associated with the regional geodynamic processes, as have been proved by us recently for radon(*). Monitoring of radon and CO2 at a depth of several tens of meters along the Dead Sea Fault Zone, between the Dead Sea and the Hula Valley has led to a clear discovery of the phenomenon that both gases are affected by an underground tectonic activity related to the pre-seismic processes of producing earthquakes, even if they are weak. The pre-seismic processes even if not all end with earthquakes, cause the movement of gases in the subsurface geologic media and creating non-periodic signals that are wider than 20 to 24 hours. Hence, monitoring of any other natural gas at depth may show a similar expansion signal and may serve as a precursor for earthquakes. The necessary conditions needed to explore anomalous signals of gases that induced by pre-seismic processes at the depth, as accumulation and relaxation of lithospheric stress and strain, are: a) setup of a monitoring system within boreholes airspace, drilled to active faults, b) verify that there is at least one gas with concentration level few times above the conventional background level of the regional subsurface content, c) utilizing high sensitive detectors to recover changes in the gas content, with detection limit of few percents of the local average (As an example: for radon, the required content is at least 1kBq/m3 and the required sensitivity is better than 5%). (*) Zafrir, H., Ben Horin Y., Malik, U., Chemo, C., and Zalevsky, Z., 2016, Novel determination of radon-222 velocity in deep subsurface rocks and the feasibility to using radon as an earthquake precursor, J. Geophys. Res. Solid Earth, 121, 6346–6364, doi: 10.1002/2016JB013033.

Radon and CO_2 monitoring technique in deep subsurface, as a proxy for investigating tectonic pre-seismic processes that occur before earthquakes

Rn and CO2 long-term monitoring sites located within the Dead Sea Fault Zone, at Hula Valley and Near the Dead Sea



The Borehole's Cross Sections

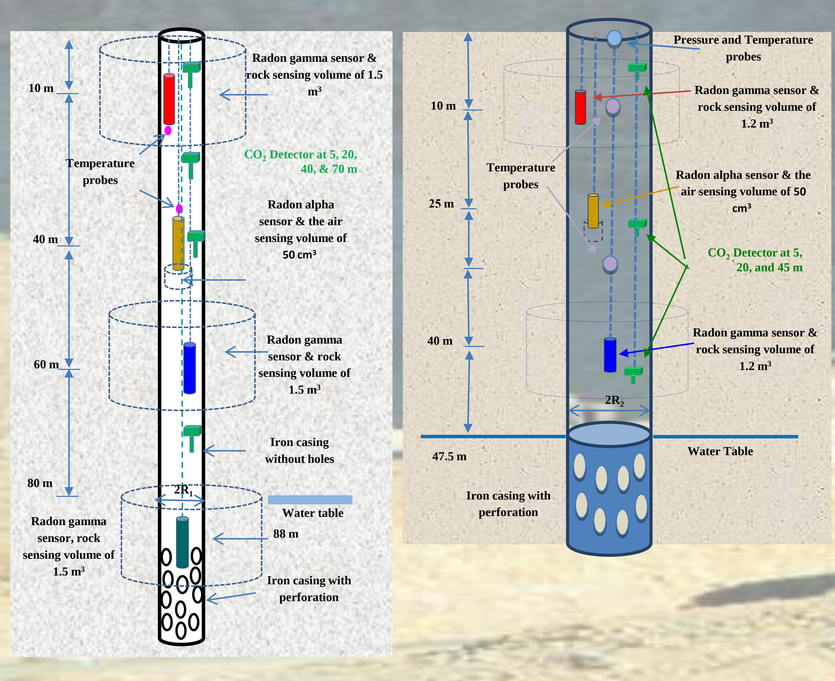


Figure 1: The radon and CO_2 monitoring layout at the Sde-Eliezer (left) and Nahal Mor (right) sites.

Sde-Eliezer Long Time Series 1/2/2015 to 1/5/2017

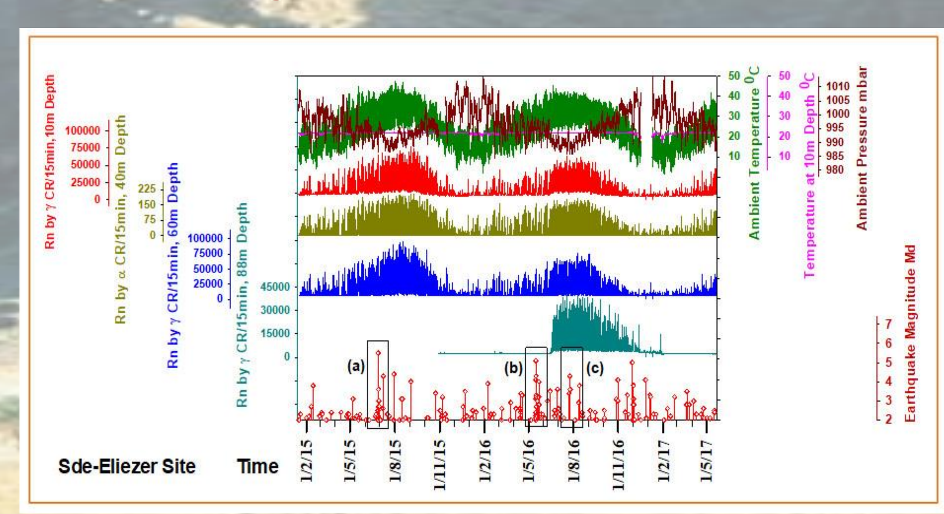


Figure 2: Continuous time series of the measured parameters at the Sde-Eliezer site (15-min temporal resolution) collected during the first course of two and a half years (844 days) since February 2015. An interesting feature is the change in the signature of the radon detector at 88m depth, caused by the drop of the water table to below 88m, as a result of over pumping in the Hula Valley (as also happened the year after in the same month).

I - The Periodical Effect of the Climatic Variables on the Radon Temporal Variation

Monitoring the temporal variability shows that the **radon signals measured by gamma detectors** at **10m** and **60m** have very sharp, clear, and accurate peaks as a result of a high counting rate and low error (better than 0.6%). The **radon peaks that were measured by alpha detector** at **40m** are spread out since its count rate certainty is lower (lower than 10%).

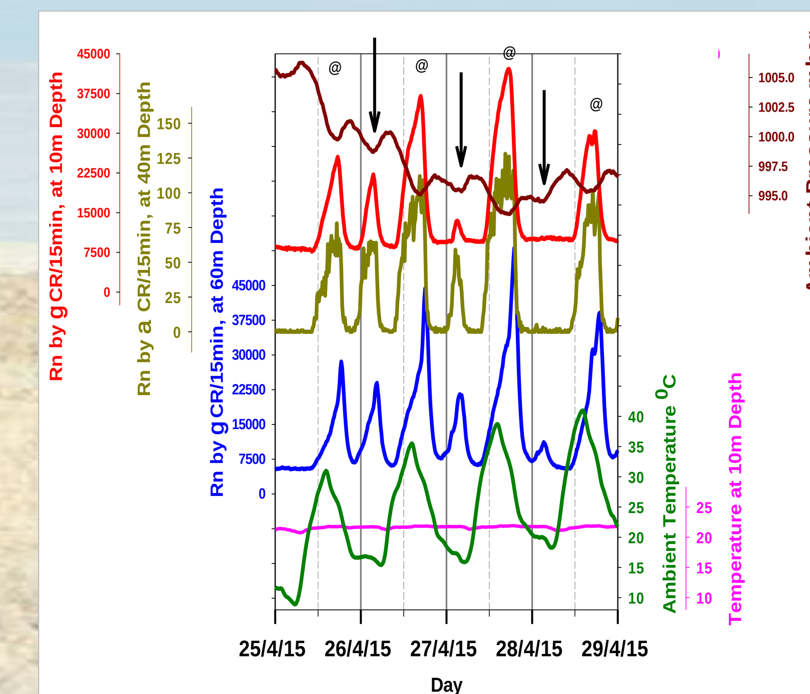
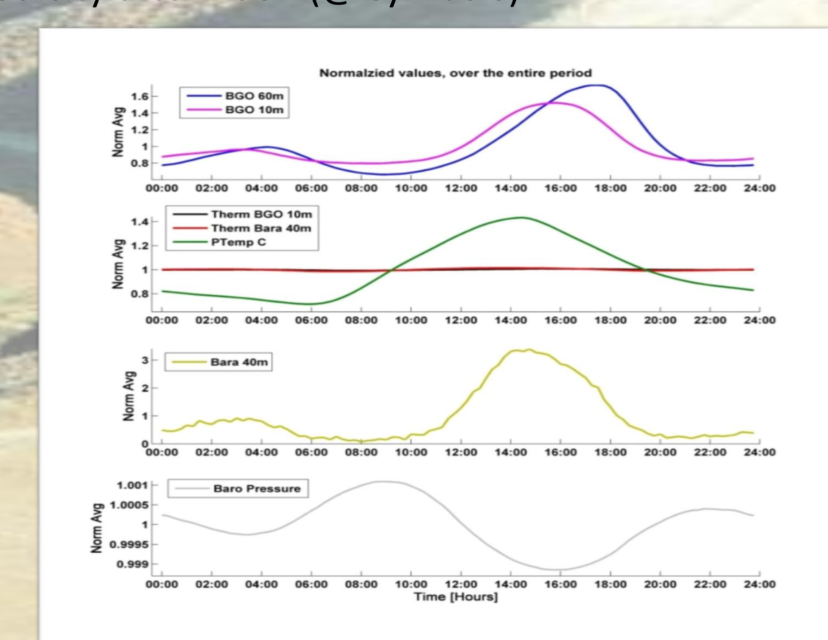


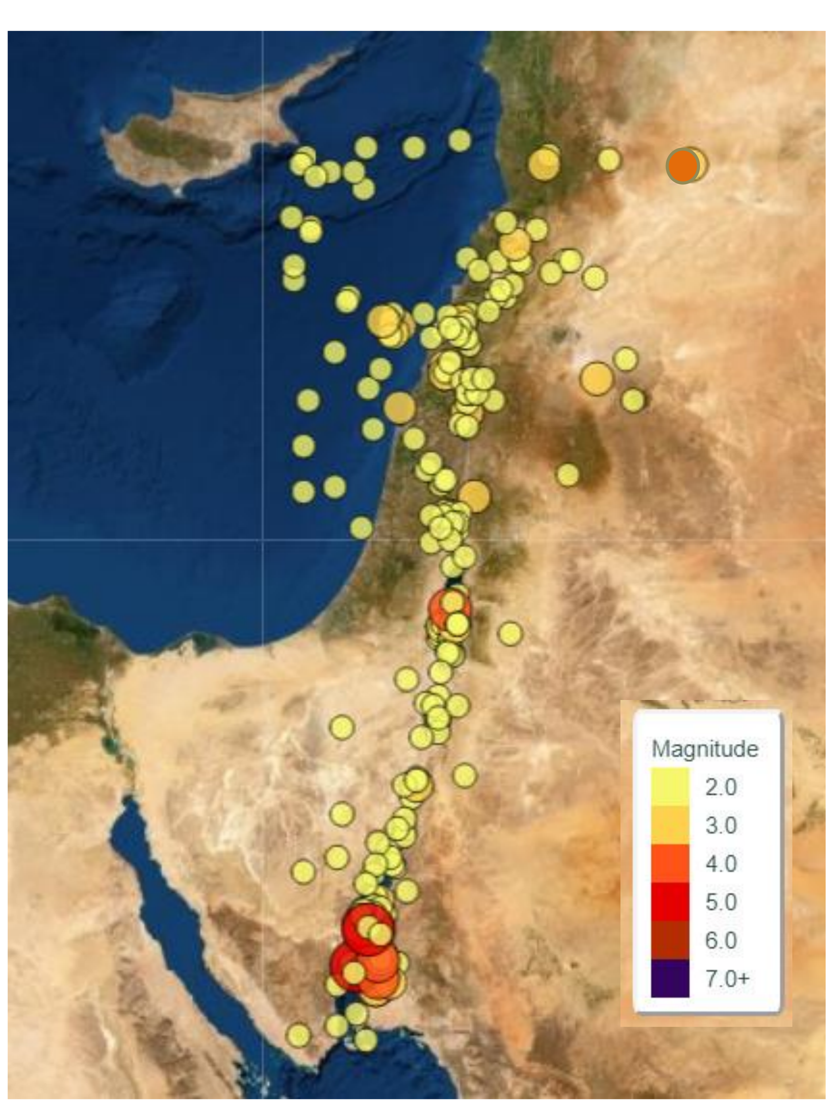
Figure 3: Radon early morning semi-diurnal signals are exhibited by the three Rn detectors with anti-correlations to the pressure (see arrows) in addition to their response to the daily temperature periodicity after noon (@ symbols).

Figure 4. The daily normalized values of the maximum of each parameter (except minimum for pressure) summarized for a period of **150 days**: 16/1 to 14/6/2015, (*Zafrir et. Al., 2016).



The lag time of about 2h between the maximum values of the two gamma detectors (10m and 60m depth) separated vertically by 50m **define the radon vertical velocity as 25m per hour** in the local subsurface porous media.

II - Radon Time Series versus Earthquake Events



In order to understand the capability of the radon monitoring system to isolate and characterize the impact of tectonic driving forces on radon behavior, the recorded list of 259 earthquakes that occurred during the 848 days of 2015 to mid-2017 in the DSFZ region, is presented (**Fig. 5**).

Figure 5: 259 earthquakes with M>2 that occurred during the 848 days of 01-01-2015 to 01-05-2017 in the DSFZ region, S-N:28 to 35 and W-E: 34 to 38. The color legend attached to the map.

Very pronounced signals that were different in shape appeared during three disparate events which occurred during the above-mentioned two-and-a-half year time interval and are marked by **a**, **b** and **c** in **Figure 1**, and in **Figure 6**, **a1**, **a2**, **b**, and **c**, respectively.

III - Radon Time Series versus Earthquake Events

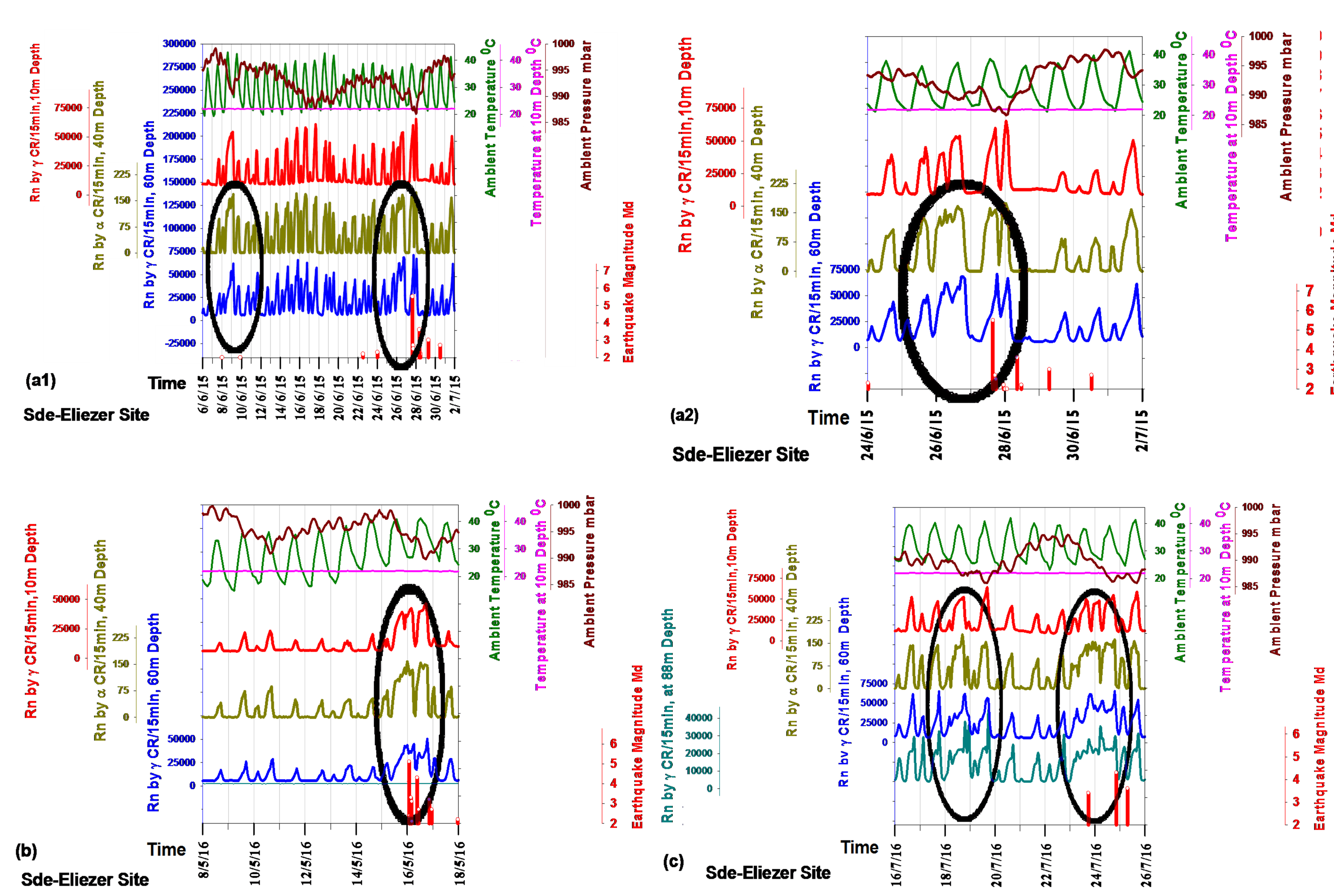


Figure 6: (**a1**) & (**a2**) The 26 June **broadened radon anomalous signal preceded by one day** the Nuweiba (in the Gulf of Aqaba) **M 5.5** earthquake that occurred on 27 June 2015. It was different from the periodic radon signals appearing usually once or twice a day. (**b**) The broadened radon signal appeared **14 hours before** the next Nuweiba **M 5.1** earthquake on 16 May 2016. (**c**) On 17 and 23 July 2016 two broadened anomalous radon signals appeared **7 and 2 days before** the Palmyra Syria **M 4.4** earthquake on 25 July 01:30 AM. The signal from the deepest detector at 88m depth became the most pronounced after the water level dropped to below 100m on 25 June 2016.

IV - The extraction method that relies on the modulation spectral analysis

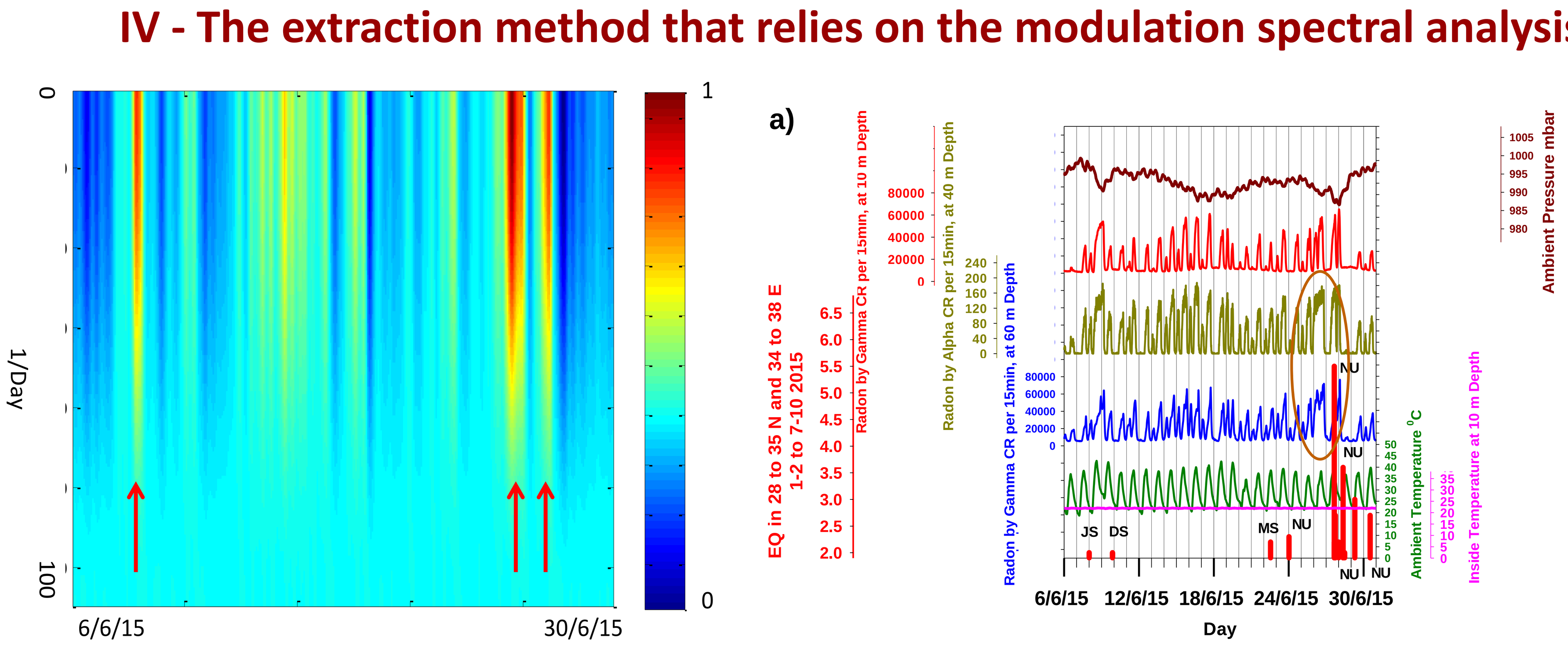


Figure 7: The reconstruction spectrogram of the **radon 60 m** time series, in two different time intervals, **a)** 6 to 30 June 2015, **b)** 2 to 21 August 2015. **The discrete and broadened radon peaks** are marked in the spectrograms with red arrows.

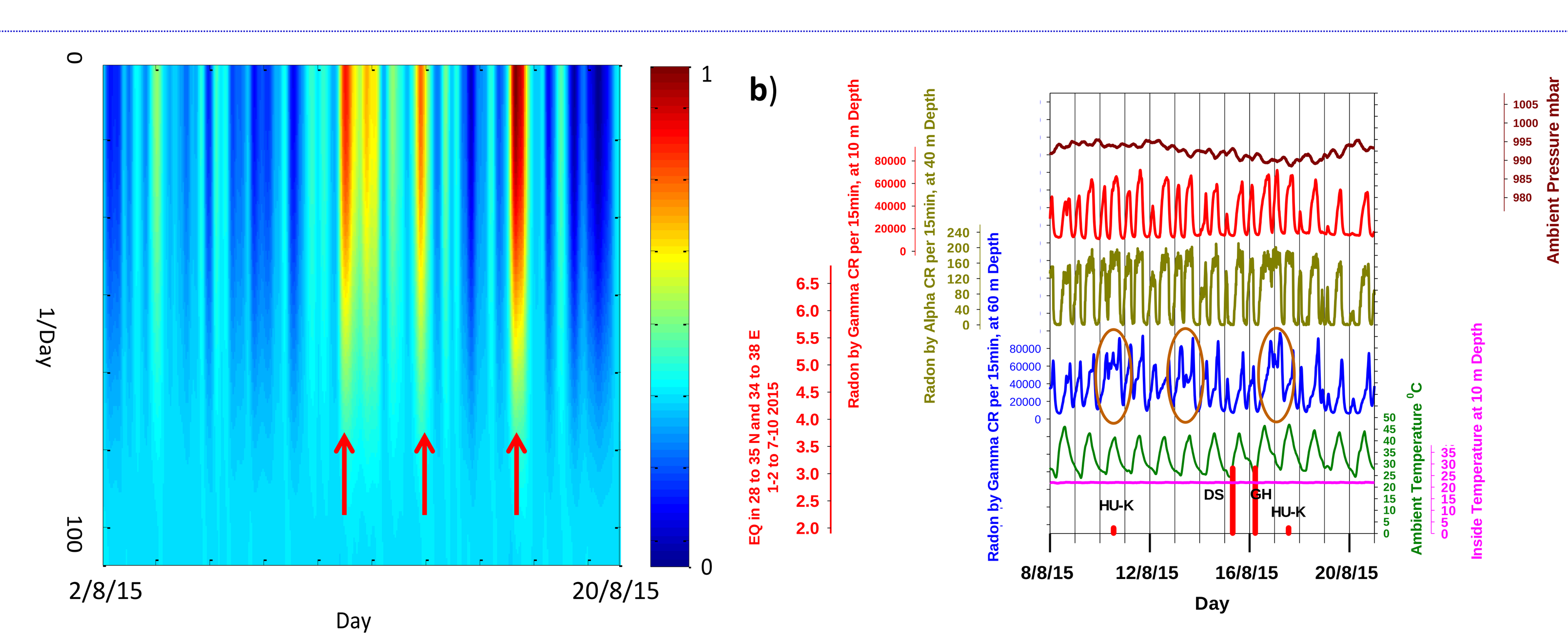


Figure 7: b) A phase space representation in which one may see simultaneously the temporal as well as the spectral information of a given signal.

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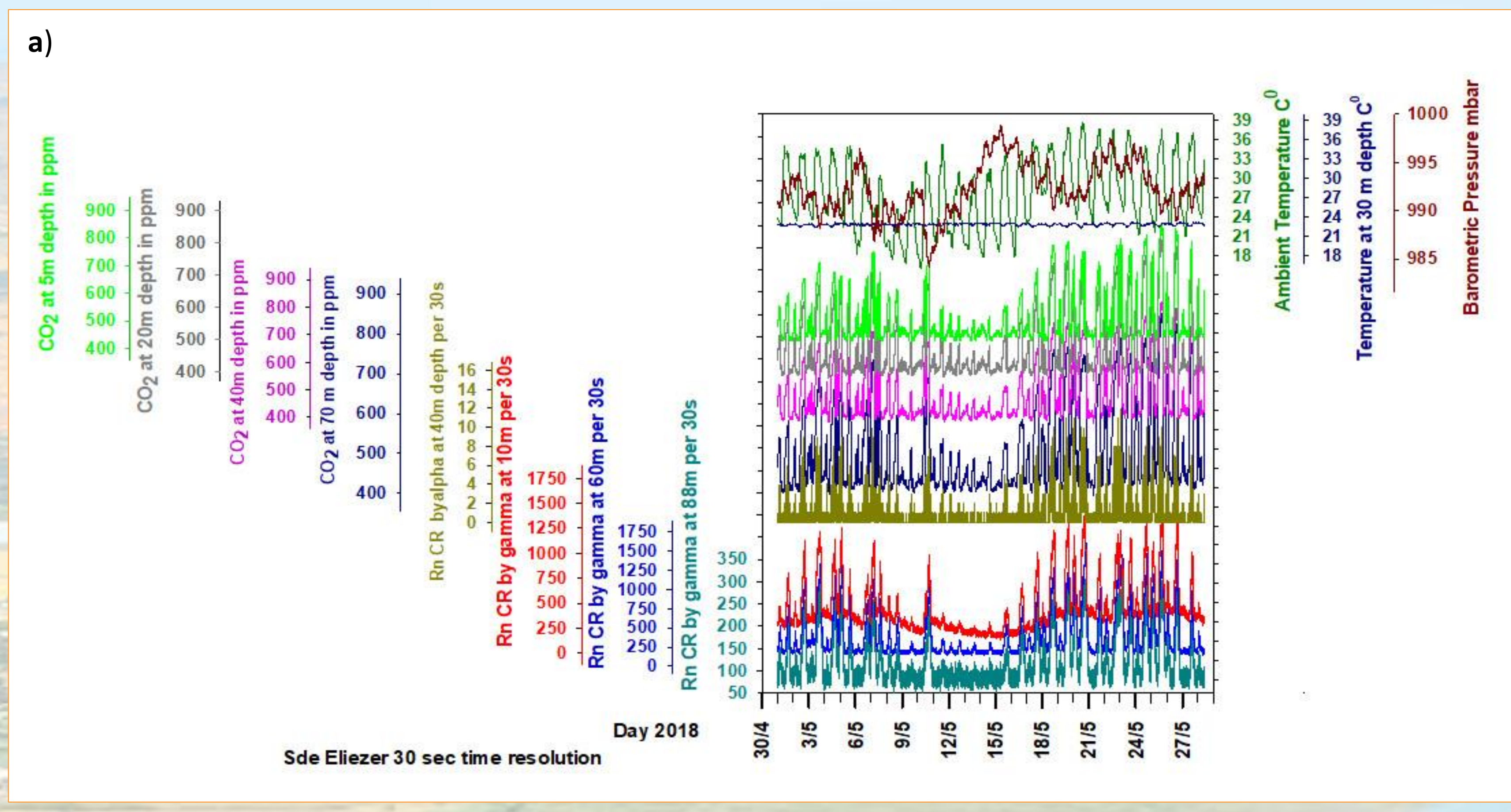
V - Radon and CO_2 in Depth



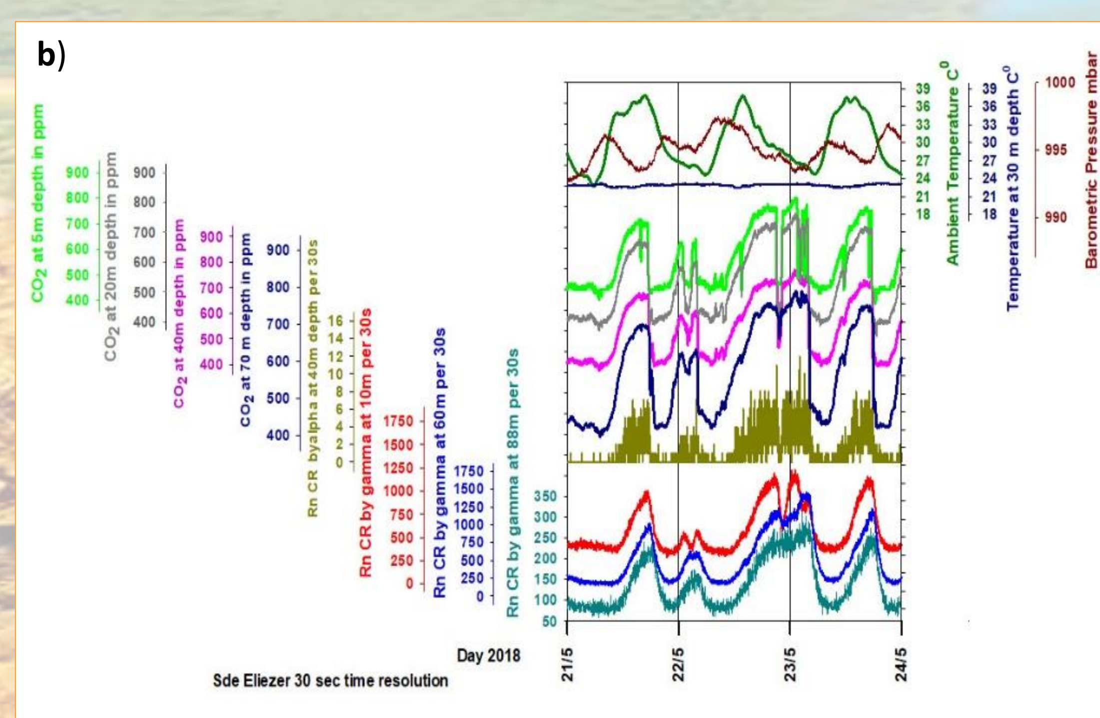


Figure 5: **a)** 27 days' time series during June 2018. Three additional CO_2 sensors that were downloaded to the depths of 5, 40 and 70m strengthened the conclusion that the two gases in depth behave in the same way, **b)** The improvement of the measurement time intervals to 30sec segments, led to discovering that the rate of changes in the width of the radon and CO2 signals in depth occur simultaneously.

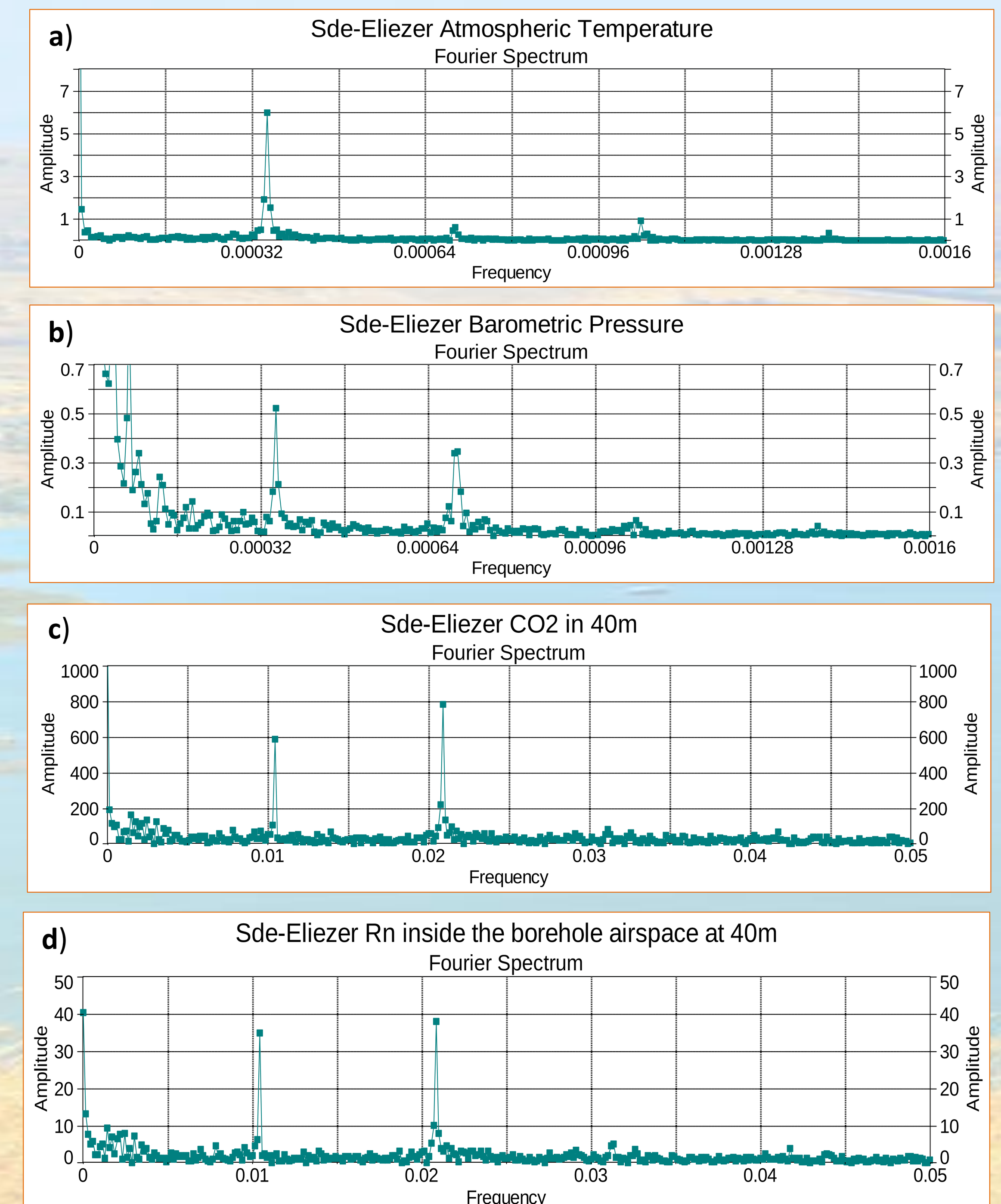
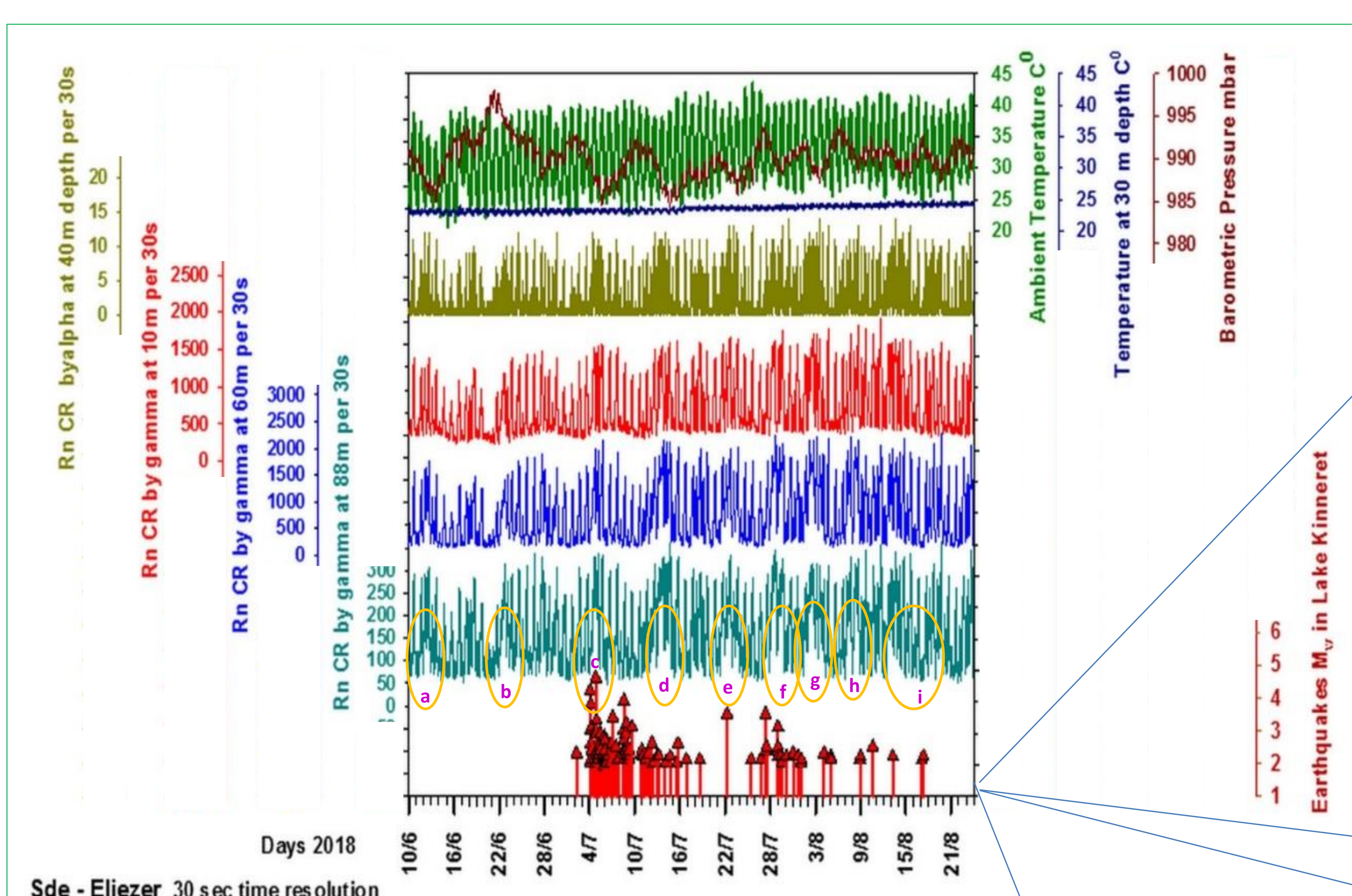
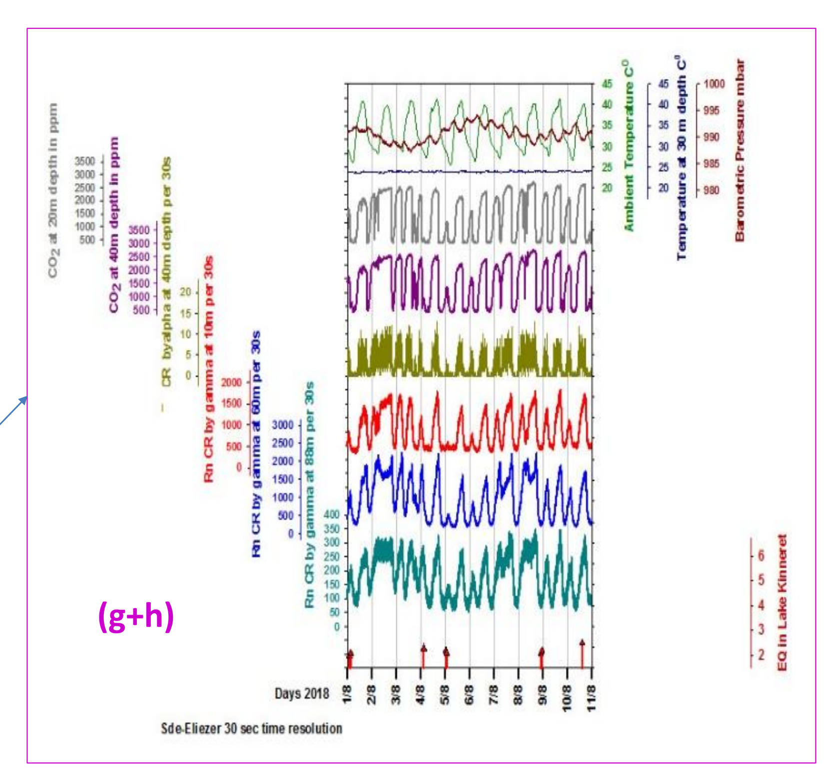


Figure 6: **a)** and **b)** The daily and semi daily periodograms of the temperature and pressure in frequency of cycles per day (30sec/24hour=0.000347 cycles per day and 0.000694 cycles per half a day); **c)** and **d)** the daily and semi daily periodograms of the CO_2 and radon within the air space inside the open well (as counted at 15min time intervals: 15min/24hour=0.0104 per day and 0.0208 per half a day). It reveals the similar response of both gases to the influence of the temperature and pressure, as the as the result of the climatic driving forces on gases at a depth of a few tens of meters

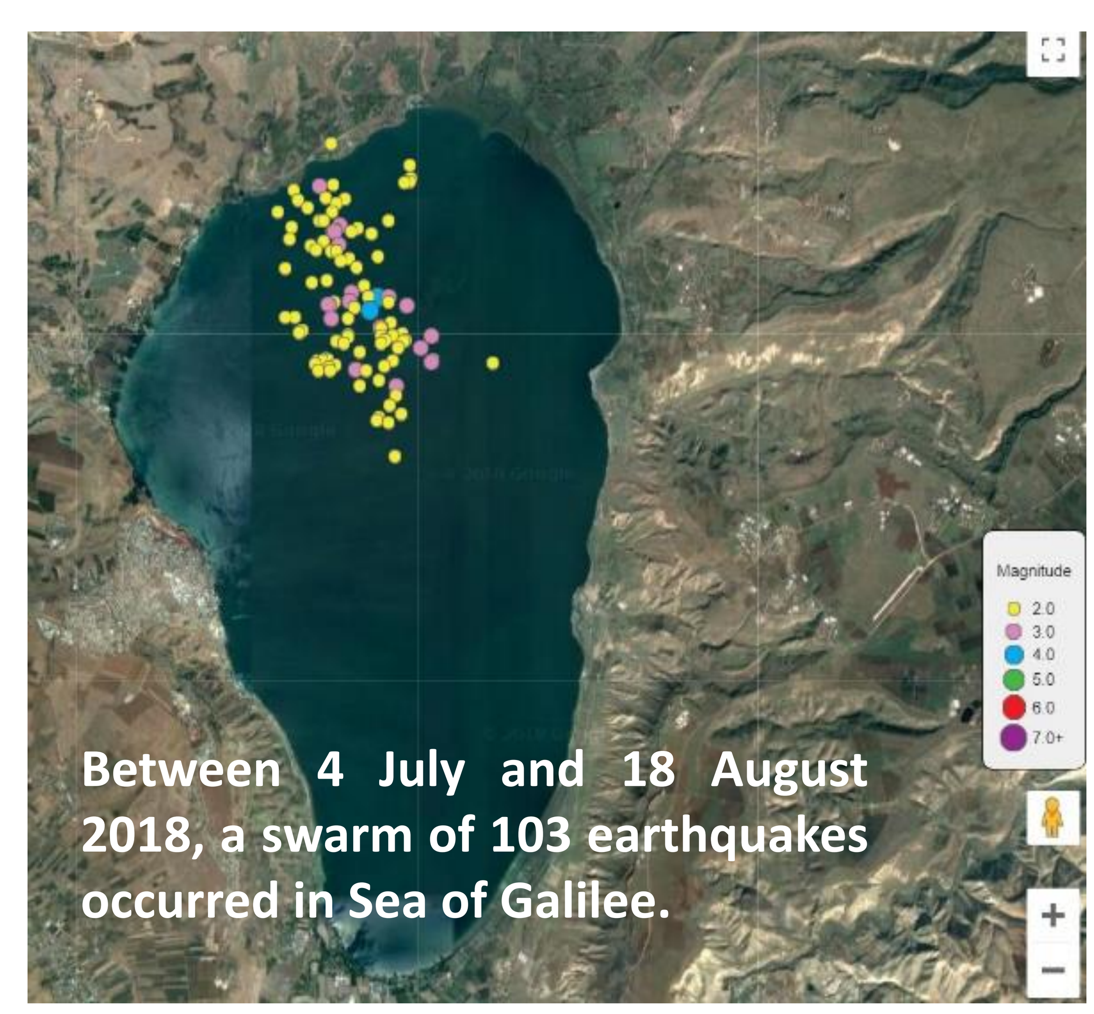
Vi - Radon and CO_2 as a Proxy for Investigating Tectonic Pre-Seismic Processes that Occur before Earthquakes - The Lake Kinneret Scenario

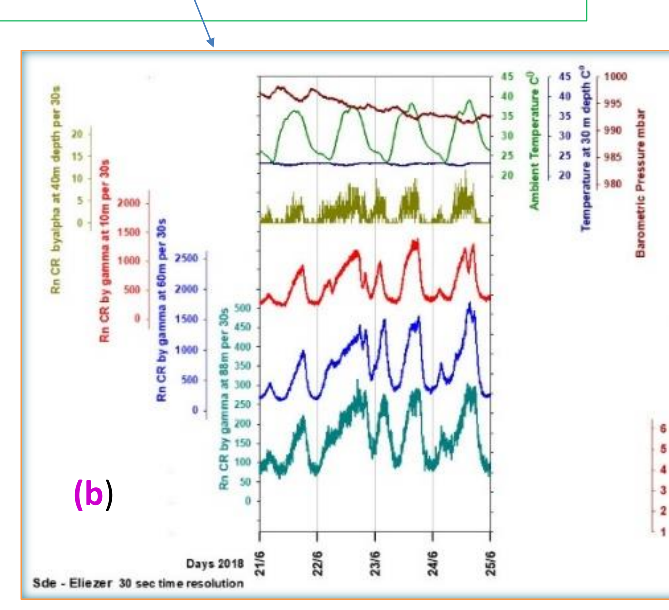


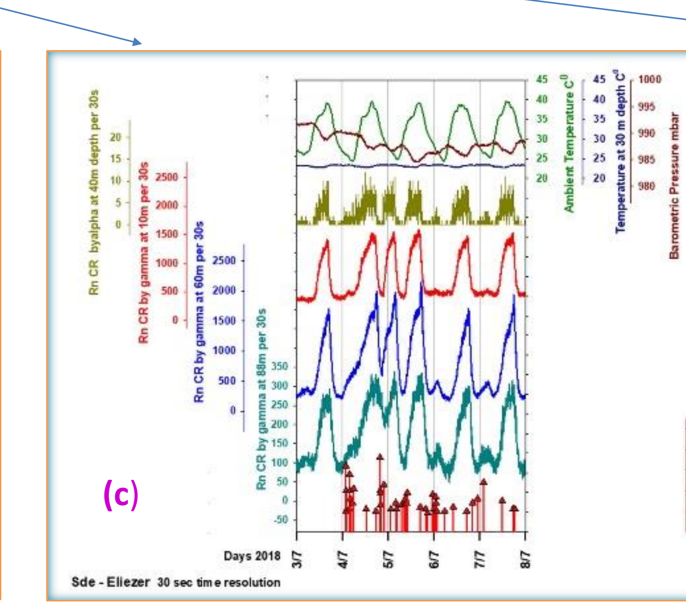
Time series interval of 75 consecutive days at the Sde-Eliezer site located about 30 km north of the Sea of Galilee that was under weak seismic activity during July and August 2018.

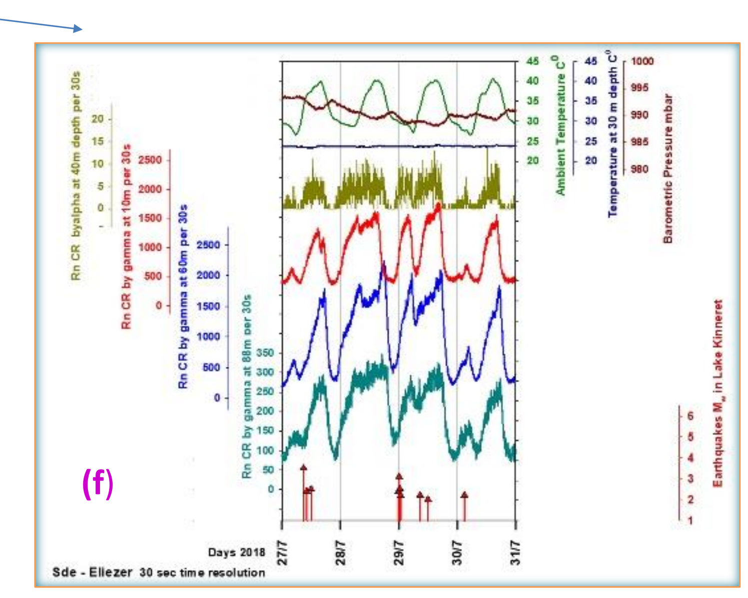


The CO_2 and radon corresponding simultaneously to the same rise time, fall time, and broadening time.

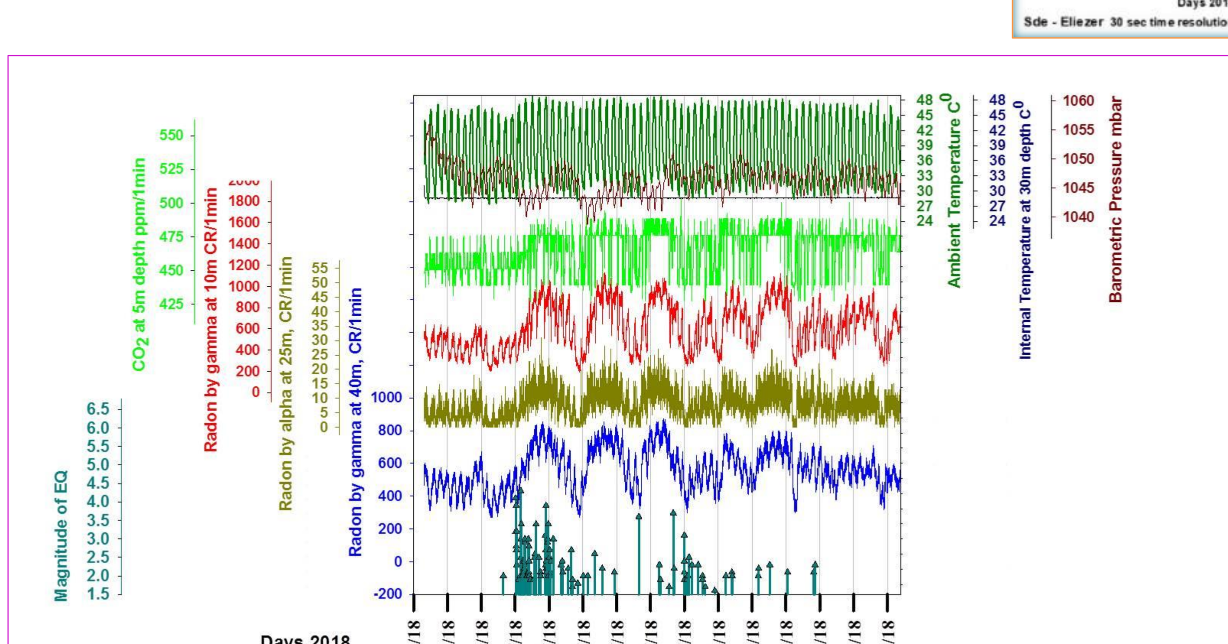








Three time intervals (of nine) with anomalous broadening signals



The radon signals that were measured at the Nahal Mor during 19 June to 29 August 2018. They exhibits a large broadening signals that last a few days together and then fade. It seems that the seismic tectonic activity in the north induces instability along the Dead Sea Fault rupture zones similar to those broadened signals at Sde-Eliezer.

Conclusions

Monitoring radon and CO2 at a depth of several tens of meters along the Dead Sea Fault Zone between the Dead Sea and the Hula Valley has led to a clear discovery of the phenomenon that both gases are affected by underground tectonic activity related to the pre-seismic processes producing earthquakes, even if they are weak.

* Zafrir, H., Y. Ben Horin, U. Malik, C. Chemo, and Z. Zalevsky (2016), Novel determination of radon-222 velocity in deep subsurface rocks and the feasibility to using radon as an earthquake precursor, *J. Geophys. Res. Solid Earth, 121, 6346–6364,* doi: 10.1002/2016JB013033.