Innovative downhole geophysical methods for high frequency seawater intrusion dynamics monitoring

MEDISTRAES

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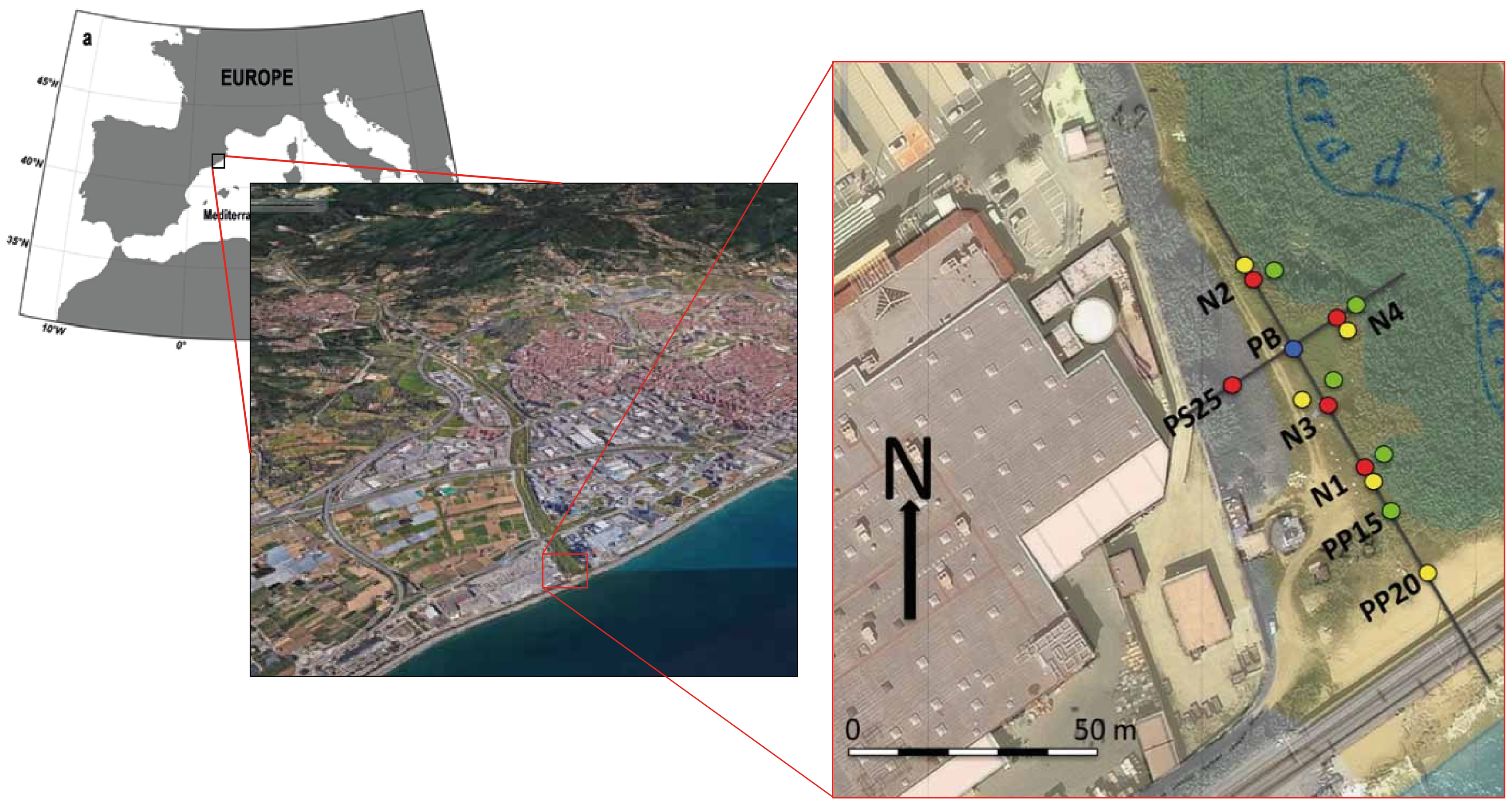
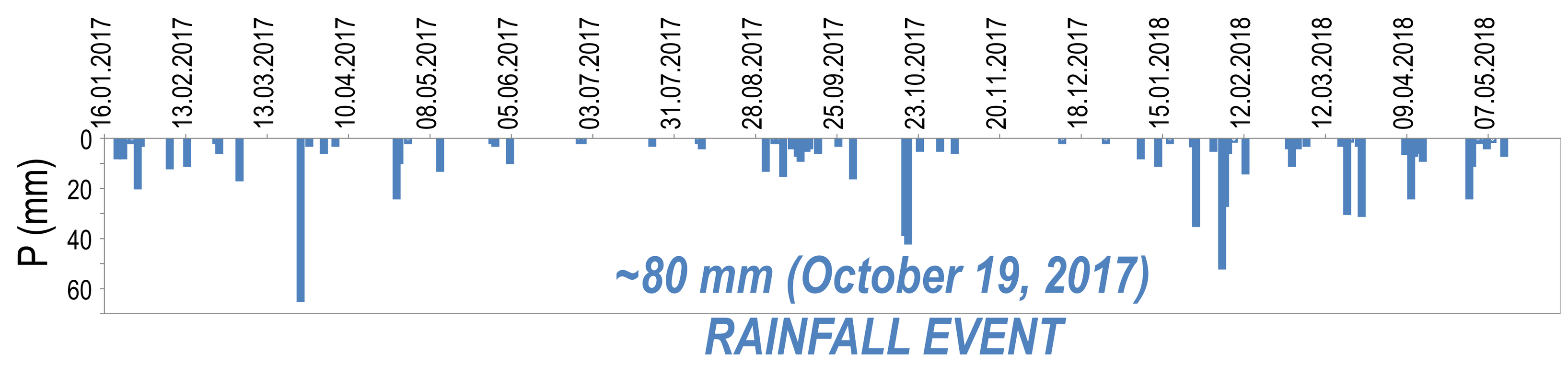




ABSTRACT

The detailed characterization of salt water intrusion is a key to understand both submarine groundwater discharge and manage often intensively exploited groundwater resources in coastal areas. With the objective to study the response of a coastal aquifer to a series of boundary conditions, a new experimental site has been developed through a clastic aquifer located north of Barcelona (Spain). This hectometer scale site is located 50 m from the seashore and equipped with 17 nearby shallow holes, with depths ranging from 15 to 28 m.

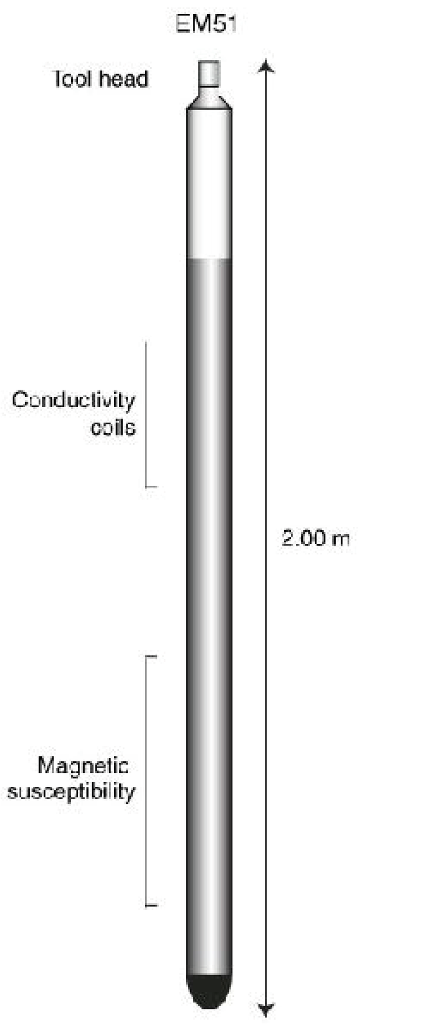
In order to study not only the sedimentary structure but also the response of the aquifer to a set of natural boundary conditions, downhole geophysical measurements have been deployed over the past 3 years in an innovative manner, either in a time-lapse or stationary manner. The downhole measurements are complicated by the unconsolidated nature of the sediment, obliging to perform all measurements through PVC. Also, the granitic nature of the sediment prevents clays identification from a direct use of gamma ray profiles. For this, constituting minerals (quartz, albite, feldspar, microcline, illite) were identified from X-ray diffraction on cores, and spectral gamma logs used to determine the illite fractions from Th/K ratios.

In time lapse, high frequency electrical resistivity induction measurements show that preferential flow paths through the aquifer can be identified in a fast and reliable manner. Also, changes in depth of the fresh to salt water interface (FSWI) are precisely described, either in response to marine tides, or to a short but intense mediterranean rain event. Changes on the order of than 1.70 m are obtain in less than a day of heavy rain. Overnight as well as seasonal changes such as months of dryness are also illustrated due to the variability of pore fluid salinity and temperature, even over short periods of time such as tens of minutes.

In stationary mode, the spectral natural gamma sensor located in front of the FSWI fluctuation zones records changes in front of all radioactive peaks (from K, Tl, Bi, but also Ra with Rn) during intense rain events such as that of October 18-19, 2017. This places constraints on Ra and Rn production rate during such an event, leading to trace fresh water outpour into the sea.

Very High Frequency (VHF) Time-Lapse Logging (TLL) of Formation Electrical Conductivity

Induction Logging Tool (GeoVista)



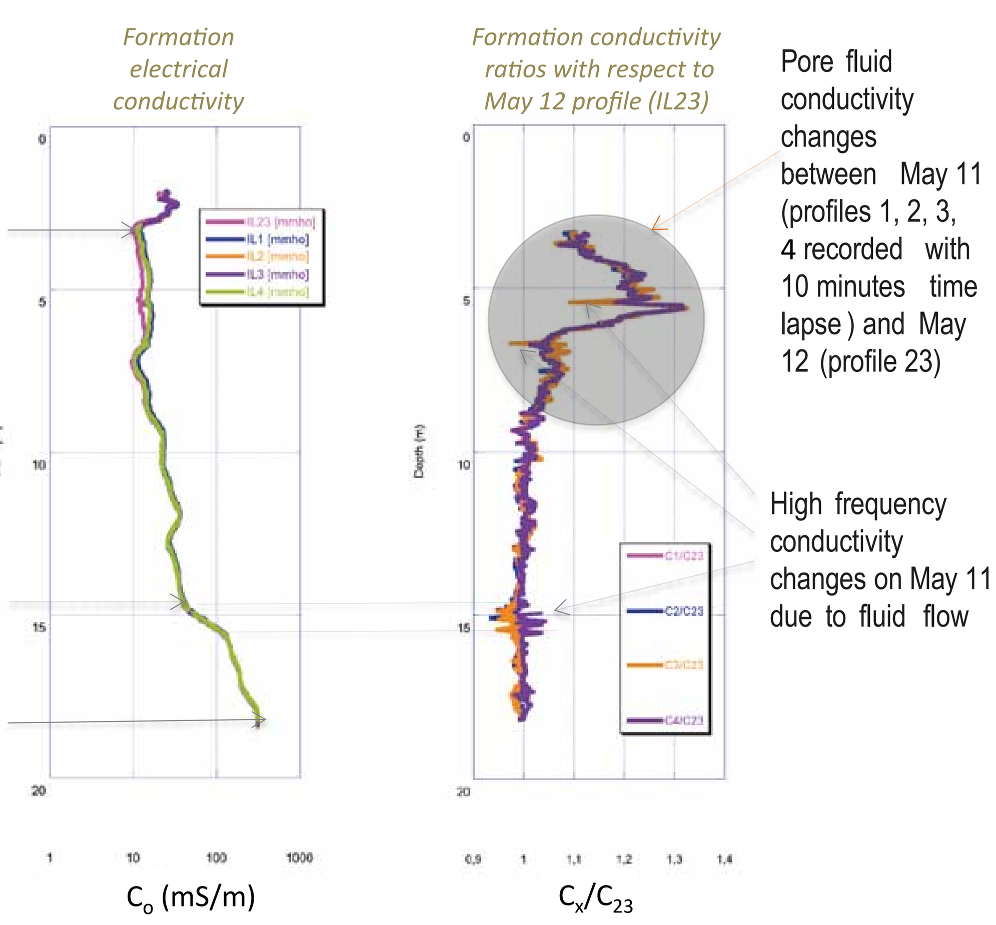
Natural variability over night (N3 yellow hole)

$$C_0 = \frac{C_w}{F} + C_s$$

$C_w \approx 800$ µS/cm *

$C_w \approx 3200$ µS/cm *

$C_w \approx 25\,000$ µS/cm *

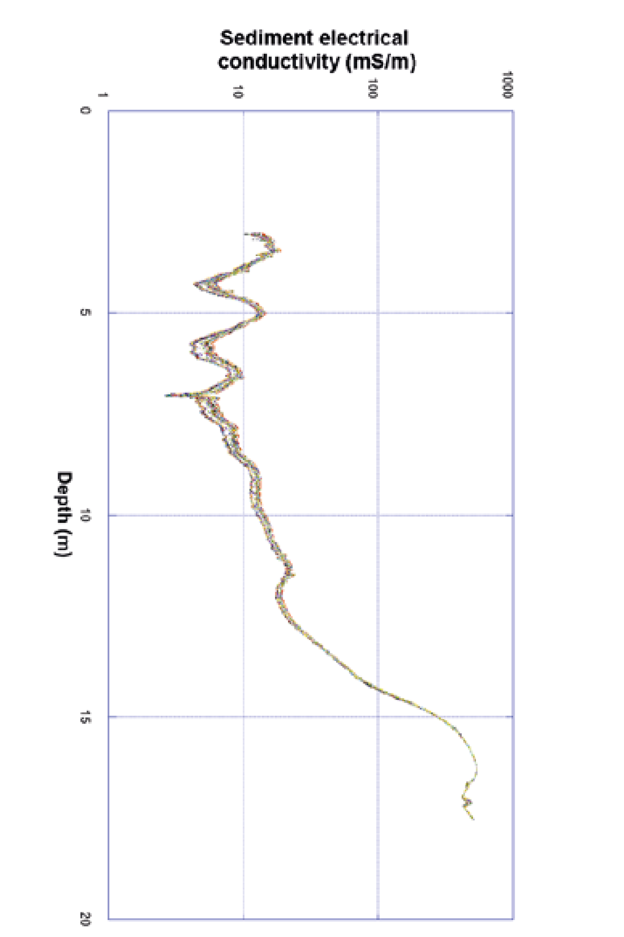


** (using Ø=0.35, hence F=8 with m=2, and neglecting Cs at this analytical early stage)*

Conductivity changes are measured between profiles recorded every 10 minutes and due to small changes in groundwater temperature and/or salinity over time.

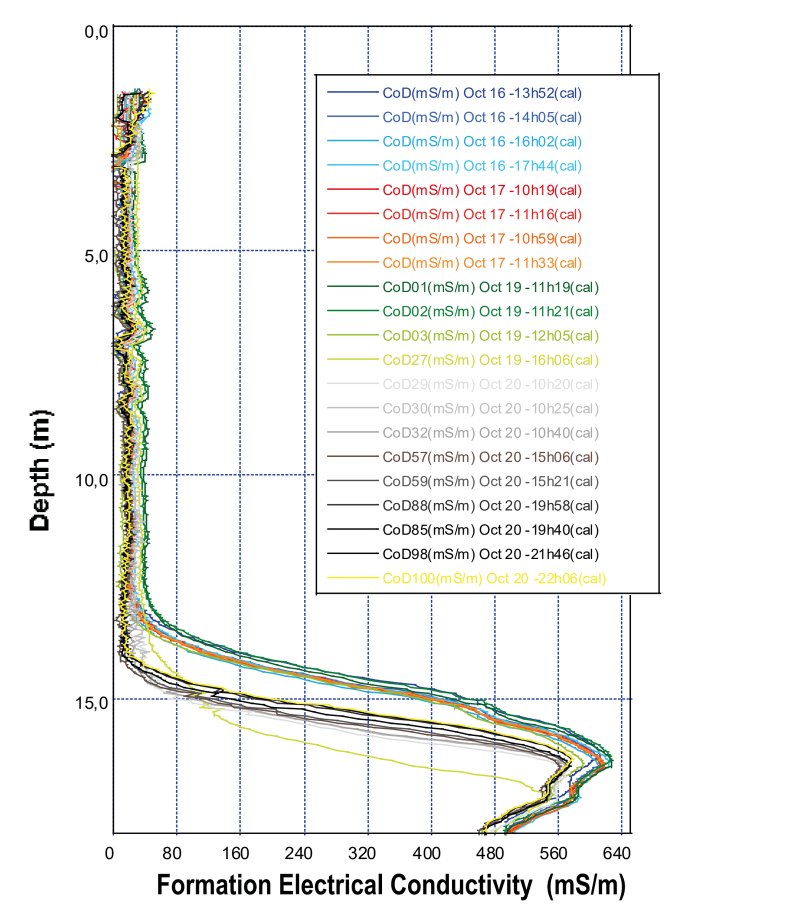
Preferential flow paths not identified by CHERT and or FO-DTS are imaged both at shallow depth (3 - 7 m) in fresh water and in the SWI transition zone (15 m depth). A larger change (30 %) is imaged overnight comparing profile 23 on May 12 (in pink) to earlier ones on May 11 (1, 2, 3, 4).

Tidal forcing : 24 hours monitoring each 20 minutes (July 30, 2016) in N3 (yellow hole)



Over 100 profiles were recorded in about one day. Little changes are obtained in the salt water zone below 15 m depth. Significant changes are measured in the fresh water zone with cyclic pattern above 8 m depth.

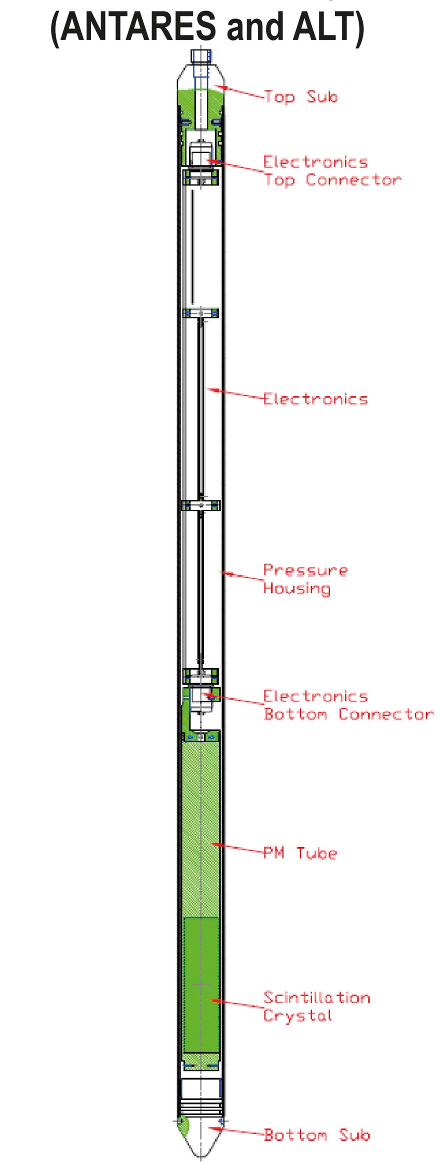
Intense rainfall event (80 mm in a day) on October 19, 2017, with baseline on October 16. VHF TLL in N4 (yellow hole)



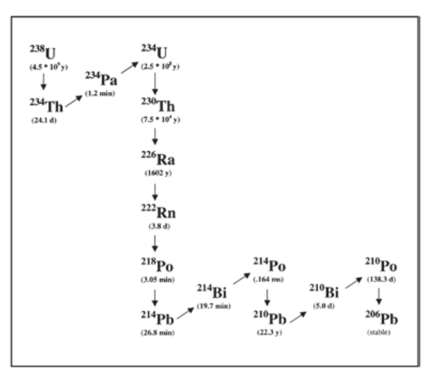
After baseline recorded on October 16 and 17, 2017 (blue and red curves), over 100 profiles were measured during and after the intense rainfall event. The recordings had to be interrupted at 4 PM on October 19, as the experimental site was being flooded by the Argentona river. The FSWI dropped down 1.7 m in less than 4 hours during the rainfall event (green curves), then went back up 0.9 m during the following day (grey and black curves).

Stationary Spectral Gamma Ray Logging (at 15 m in N4 green hole)

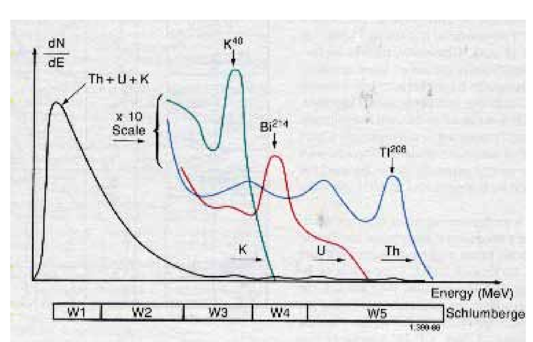
Spectrum Gamma Ray Tool (ANTARES and ALT)



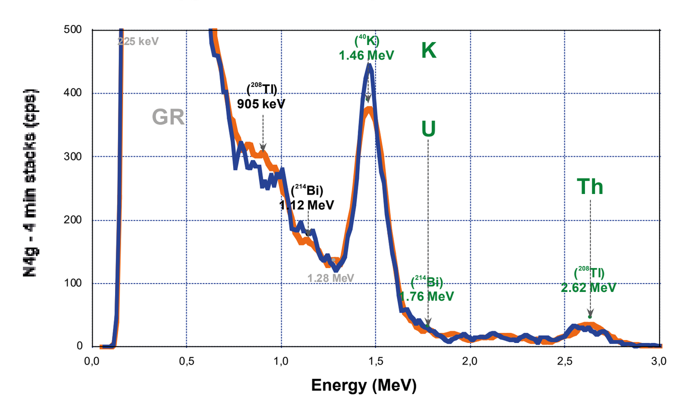
U radioactive decay chain



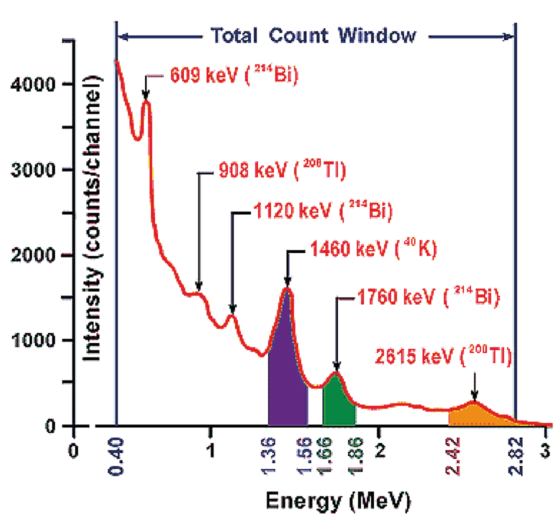
Spectral breakdown of total GR into 3 major components



Comparison between 4 min stacks (Oct 17 baseline / Oct 20) in N4 (green hole) at 15 m depth

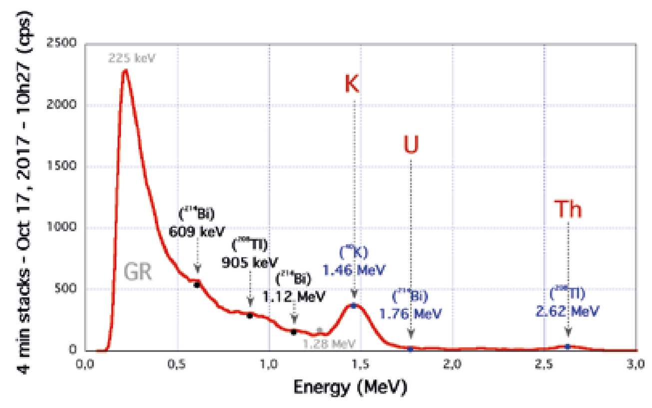


Spectrum Gamma Ray reference

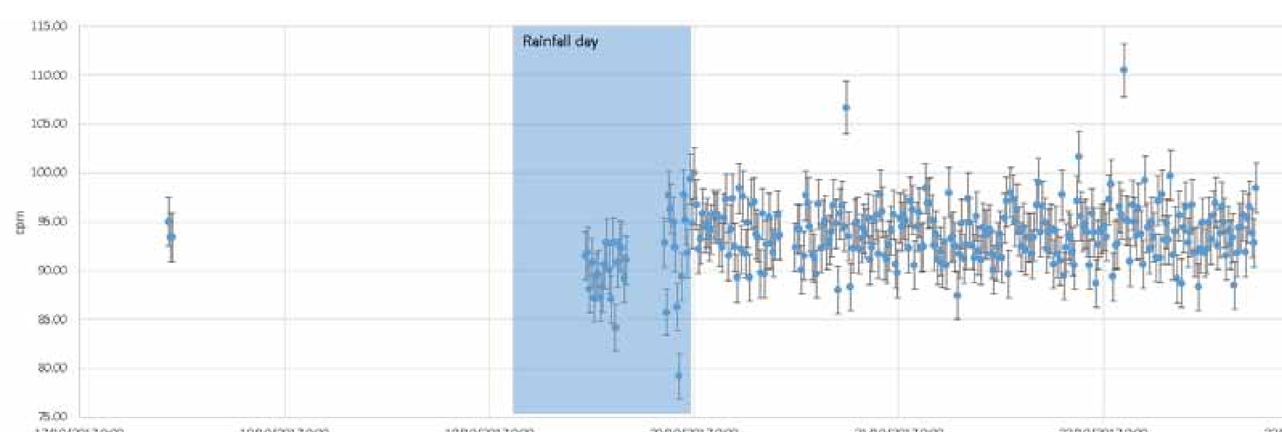


Top : U radioactive decay chain including radium and radon contributions.
Bottom : Gamma Ray reference energy spectrum for U, Th and K.

N4 (green hole) 4 min stack



Top : Gamma Ray reference energy spectrum for U, Th and K, as discretize in 5 energy windows in standard SGR logging
Bottom : Spectrum recorded at 15 m depth during a 4 minutes stack on October 17, 2017 with BGO crystal. The 256 windows discretize the spectrum between 50 keV (channel 0) and 4050 keV (channel 255). Even for a such a small time interval, all major peaks are detected.



Top : Comparison between energy spectra recorded first during the baseline on October 17 (orange curve), and just after the rain event (blue curve). Significant changes are observed, even for a short stacking interval.
Bottom : Changes over time of Gamma radioactivity, before, during and after the rain event, using 15 minutes stacking intervals. Significant drop is measured during the rainfall period due to Radon release into groundwater in the FSWI zone, when exposed to fresh water.