# Temperature and strain monitoring in Reykjanes geothermal field, Iceland, using quasi-distributed fiber-optic sensing

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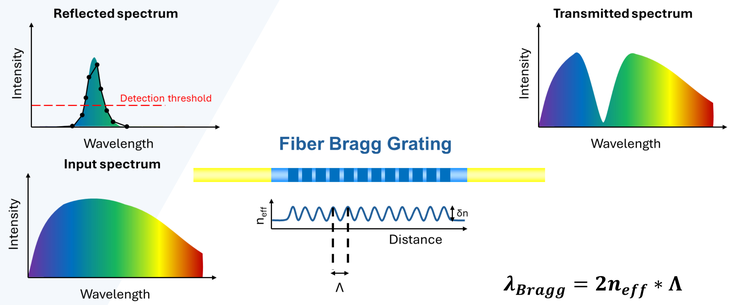
## • *What's a Fiber Bragg Grating ?*



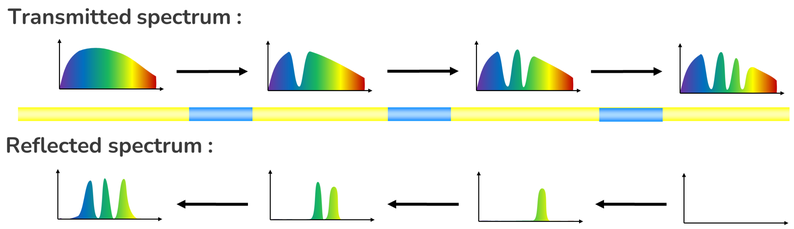

$$\lambda_{Bragg} = 2n_{eff} * \Lambda$$

A **Fiber Bragg Grating (FBG)** is a permanent and periodic (**Λ**) change in the core refractive index ($n_{eff}$) that leads to a **strong light reflection** at a **specific wavelength**.

**Strain** and **temperature** variations lead to changes in the refractive index and grating period (**Λ**), causing a **wavelength shift** :

**10 pm/°C**
**1.2 pm/με**

## • *How to turn it into a quasi-distributed sensor ?*




To turn the fiber-optic into a **quasi-distributed sensor**, Bragg reflectors are inscribed at **different wavelengths** and at **different locations**. Each FBG **reflects a portion of the spectrum like a bandpass filter**.
Up to 20 FBGs can be connected on the same fiber!

The number of sensed fiber can be increased using an optical switch. Since each fiber is interrogated independently, **hundreds of FBGs can be sampled from the same interrogator**!

## • *Comparison between Fiber Bragg Grating and the Distributed Acoustic Sensing*

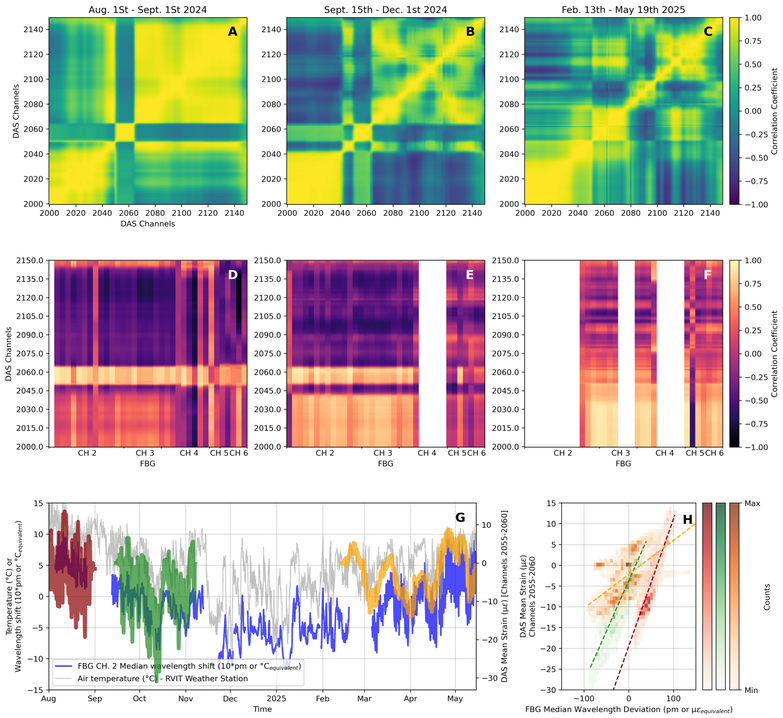



Fig. 1 : A, B and C : Correlation coefficient matrices of the DAS channels correlated with themselves for the different sensing periods. D, E, and F : Correlation coefficient between the DAS channels and the FBG sensors on the channels 2, 3, 4 and 6. G : Time series of the median wavelength shift over all the FBG temperature sensors on channel 2 (blue). Air temperature recorded at RVIT weather station located 1.5 km away from the deployment site (Grey). The red, green and yellow are corresponding to the strain obtained from the different DAS interrogation periods. H : Linear regressions between the median wavelength shift over all the FBG temperature sensors on channel 2 and the average strain over the DAS channels ranging from 2055 to 2060 for the 3 different sensing periods. The different colorscales correspond to the different sensing periods and match the line colors on the panel G.

The **FBG** and the section of a telecom fiber interrogated by a **Distributed Acoustic Sensing** (DAS) show **similarities** (Fig. 1). Some part of the **DAS data are well-correlated with FBG temperature sensors** which are air-temperature driven.

However, the correlation coefficients between the FBG and DAS, as well as within the DAS itself, are changing over time. **These changes occurred close to the 1st of April 2025 eruption!**

## • *April 1st, 2025 Svartsengi Eruption*

Observing the **ground deformation** using FBG, DAS and GNSS (Fig. 2) caused by a **volcanic eruption** !

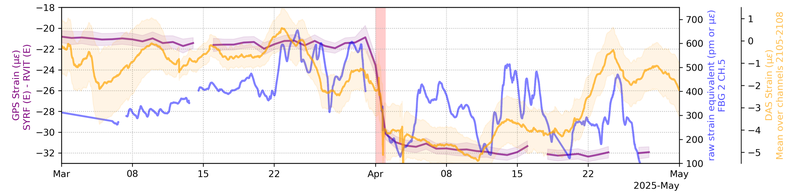



Fig. 2 : Strain recorded by the FBG strain-pad mounted diagonally on the channel 5 (blue) and the mean strain and its standard deviation gathered over the DAS channels 2105 - 2108 (orange). Computed strain from the GNSS stations for the east component and its error (purple). The red overlaid period corresponds to the eruption that occurred at Svartsengi on the 1st of April 2025. An abrupt change in strain is observed for the three different technologies deployed in the field.

## • *Periodic signals :*

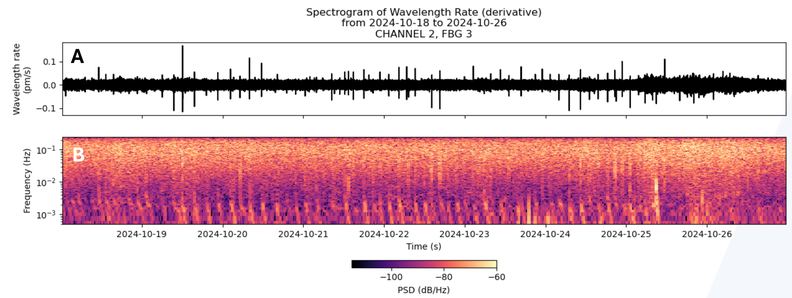
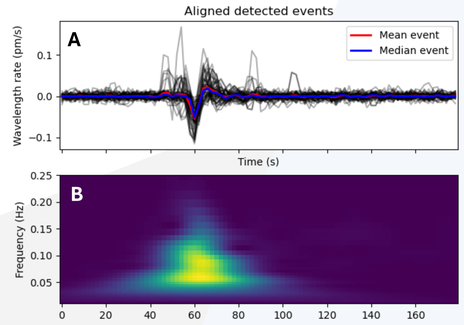



Fig. 3 : A : Time series in strain rate from the third FBG strain-pad located on channel 2 and installed horizontally in-ground between the October 18th, 2024, and October 26th, 2024. The signal shows periodic variation with a cycle length of 3 to 4 hours. B : Spectrogram of the above signal computed using 66-minute windows with 75% overlap.

Fig. 4 : A : Stacked events of the periodic signal above for the FBG 3 on channel 2. The events were triggered using STA/LTA algorithm. The 90 events were observed and aligned using the time lag determined from the cross-correlation function between the events. Finally, the median and averaged event has been computed. B : Continuous wavelet transform of the mean curve between $1e^{-4}$ Hz and 0.25Hz.

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**Supplementary:** Temperature and strain monitoring in Reykjanes geothermal field, Iceland, using quasi-distributed fiber-optic sensing

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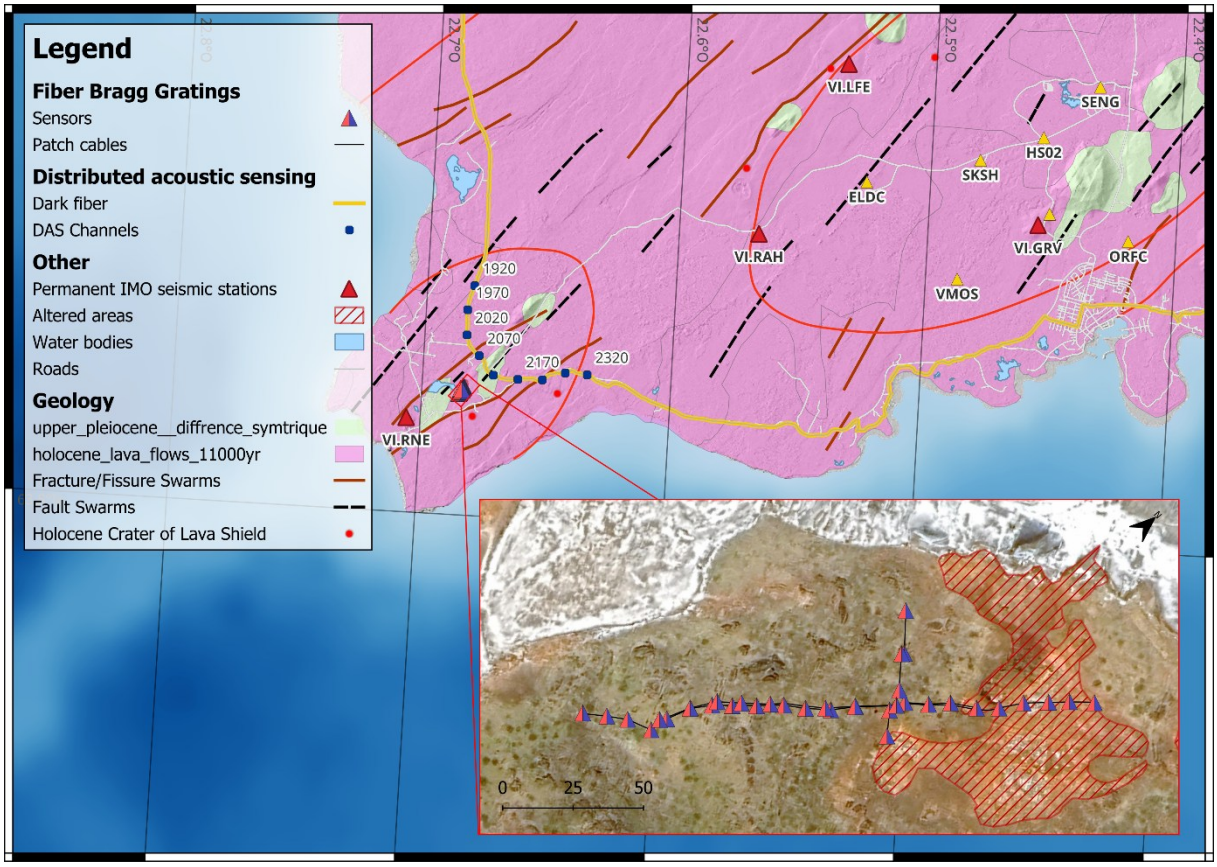


*Figure 1 : Deployment map showing the locations of Fiber Bragg Grating sensors, dark telecom fiber (copyright: Li et al (2024) under Creative Commons Zero v1.0 Universal) sensed by a DAS and the GNSS permanent network. The deployment took place in the Reykjanes Peninsula in Iceland and more specifically at the Gunnuhver geothermal area. Copyrights: Geological settings map : Náttúrufræðistofnun Íslands – Icelandic Institute of Natural History. Tekið saman af Hauki Jóhannessyni og Kristjáni Sæmundssyn retrieved on the April 30 2026 ; Location of the GNSS stations and seismic permanent network: Icelandic Meteorological Office - Veðurstofa Íslands under Attribution-ShareAlike 4.0 International (CC BY-SA 4.0) ; The satellite imagery : Google Inc, Google Satellite, retrieved on the April 30 2026.*

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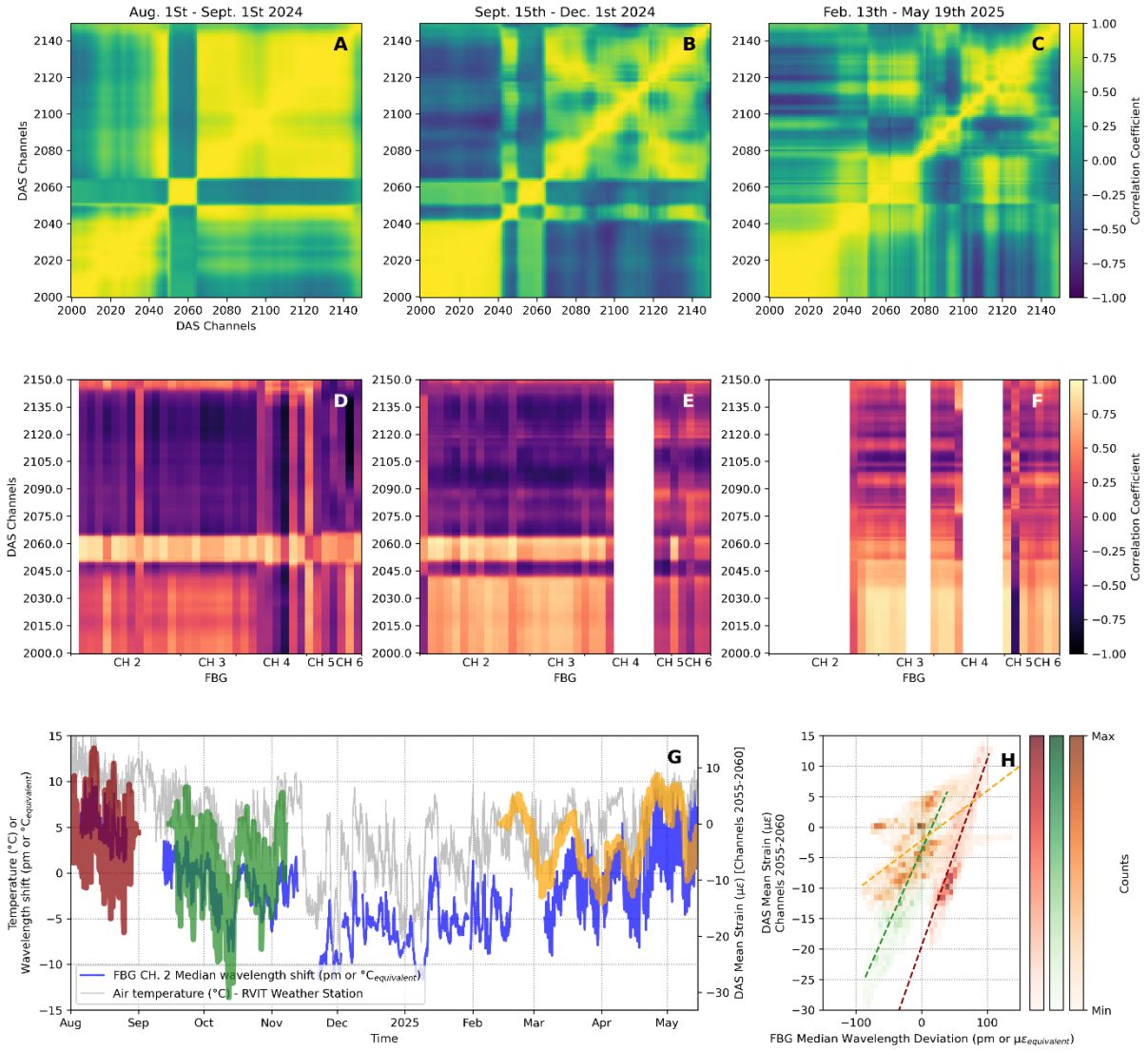


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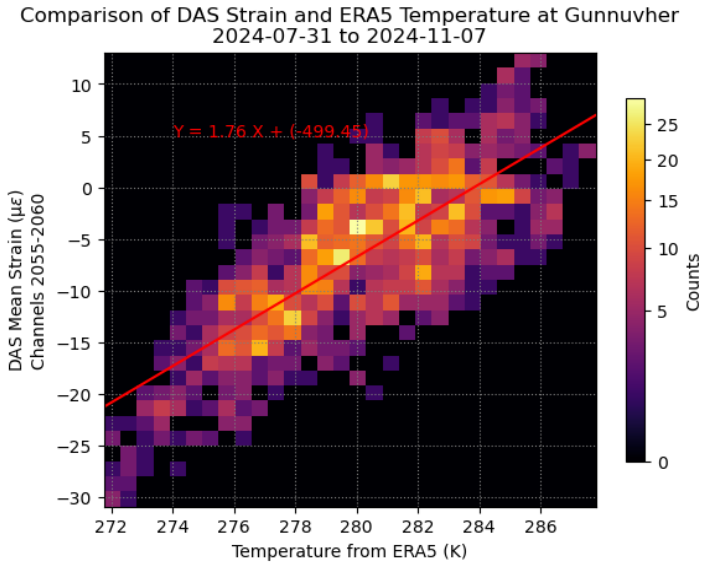
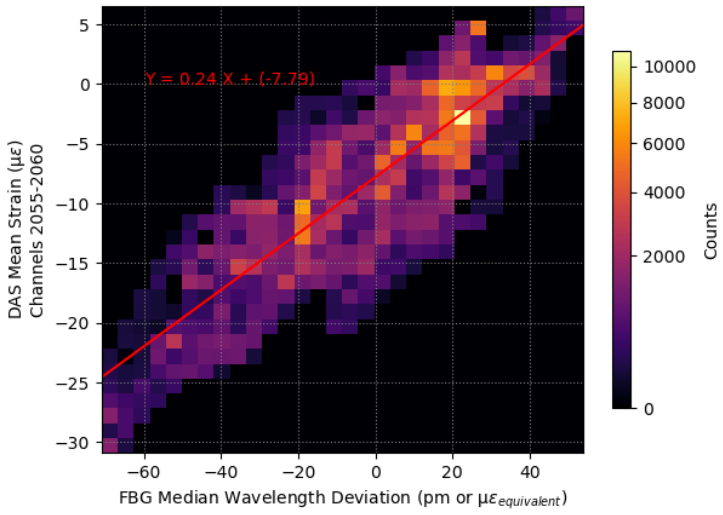



*Figure 3 : Comparison between the averaged strain recorded on the channels 2055-2060 with the DAS and the ERA5 temperature reanalysis model (Copernicus Climate Change Service, 2023 ; Hersbach et al 2018).*

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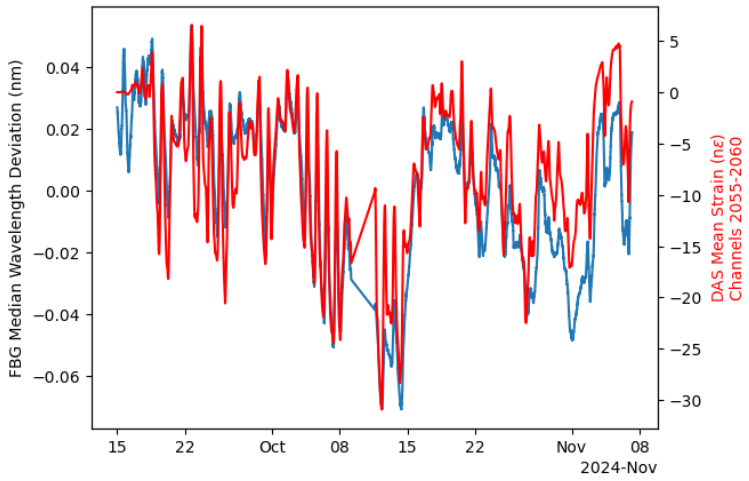


*Figure 5 : Averaged strain time serie recorded on the channels 2055-2060 with the DAS and the wavelength shit time serie gathered with the FBG on the channel 2.*

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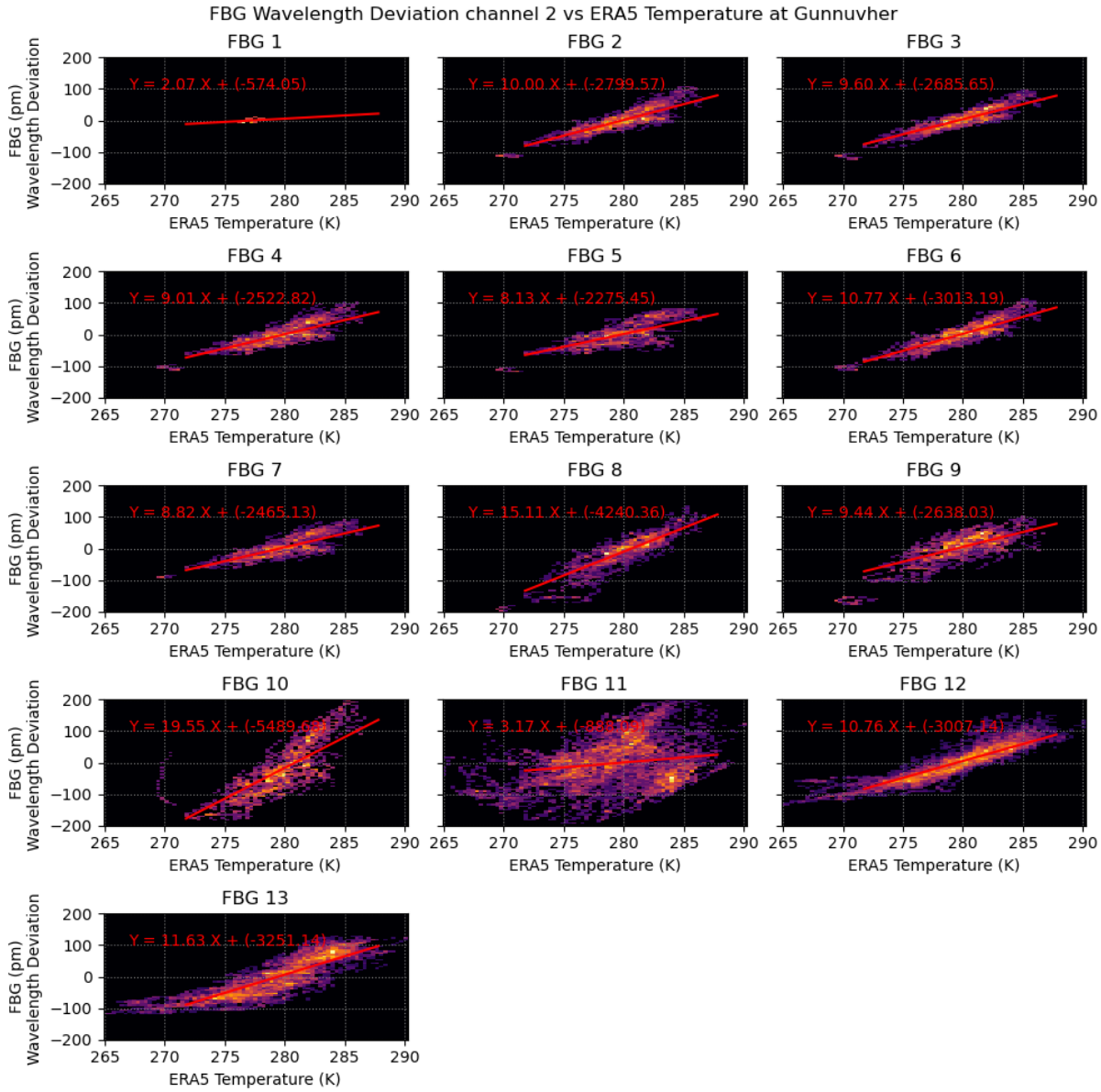


*Figure 6 : Comparison between the wavelength shift from all the FBG located on channel 2 and the ERA5 temperature reanalysis model (Copernicus Climate Change Service, 2023 ; Hersbach et al 2018).*

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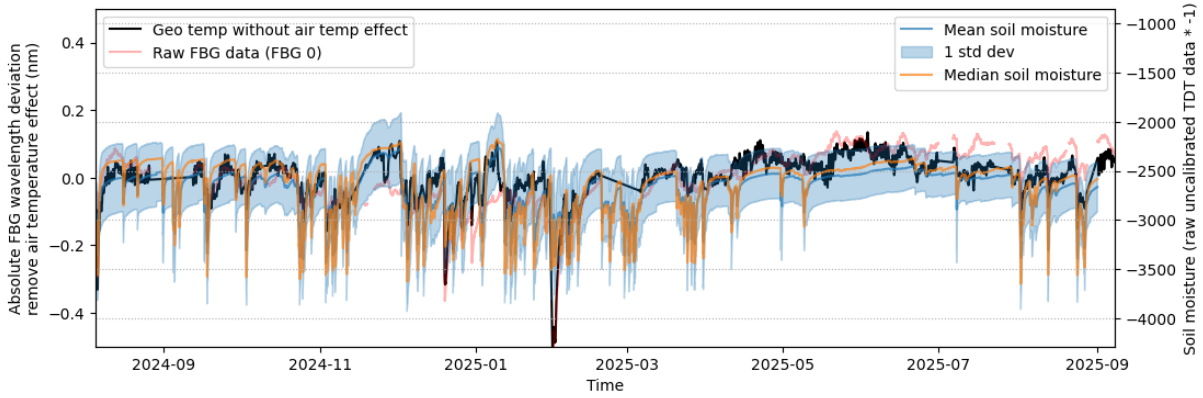


*Figure 7 : Wavelength shift from the FBG 1 on channel 5 located near a steam vent (black and orange). The blue and orange curves are corresponding to the uncalibrated soil moisture retrieved from the TOMST sensors deployed on site.*

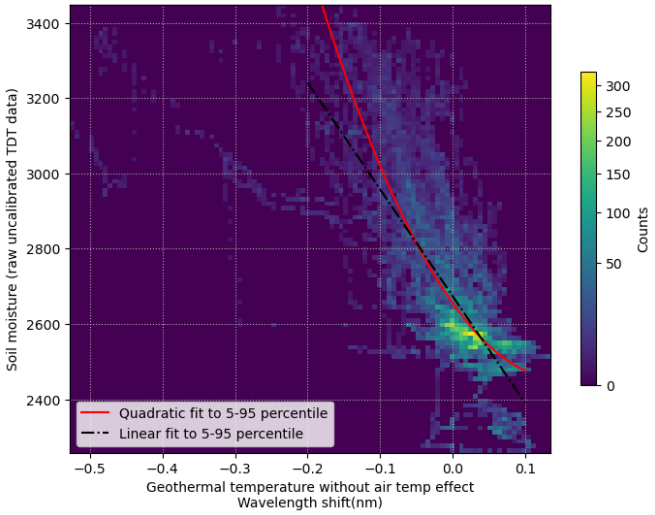


*Figure 8 : Quadratic and linear regression between the temperature recorded from the FBG 1 on channel 5 after removing the air temperature effect and the soil moisture averaged over all the TOMST sensors deployed on site.*

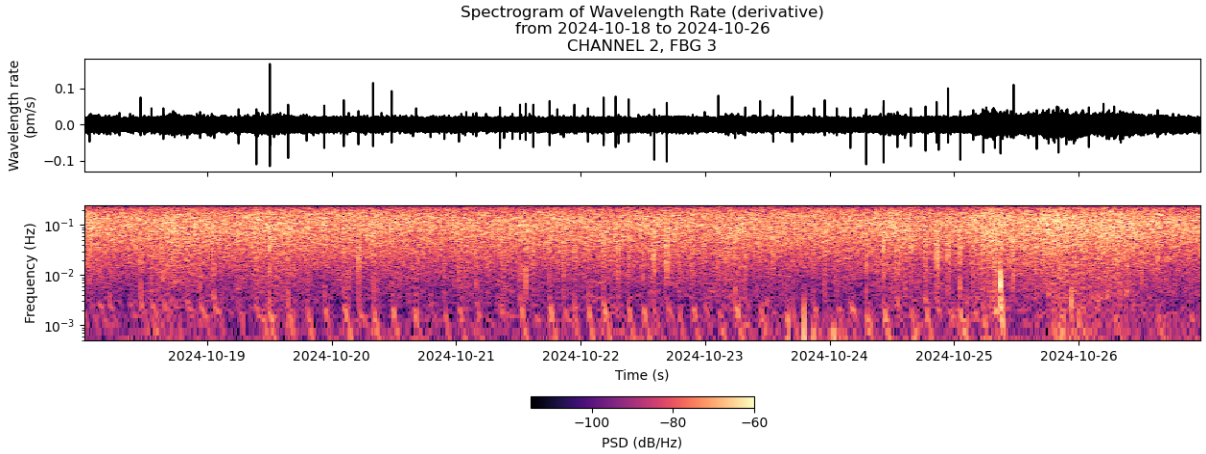


*Figure 9 : Time series in strain rate from the third FBG strain-pad located on channel 2 and installed horizontally in-ground between the October 18th, 2024, and October 26th, 2024. The signal shows periodic variation with a cycle length of 3 to 4*

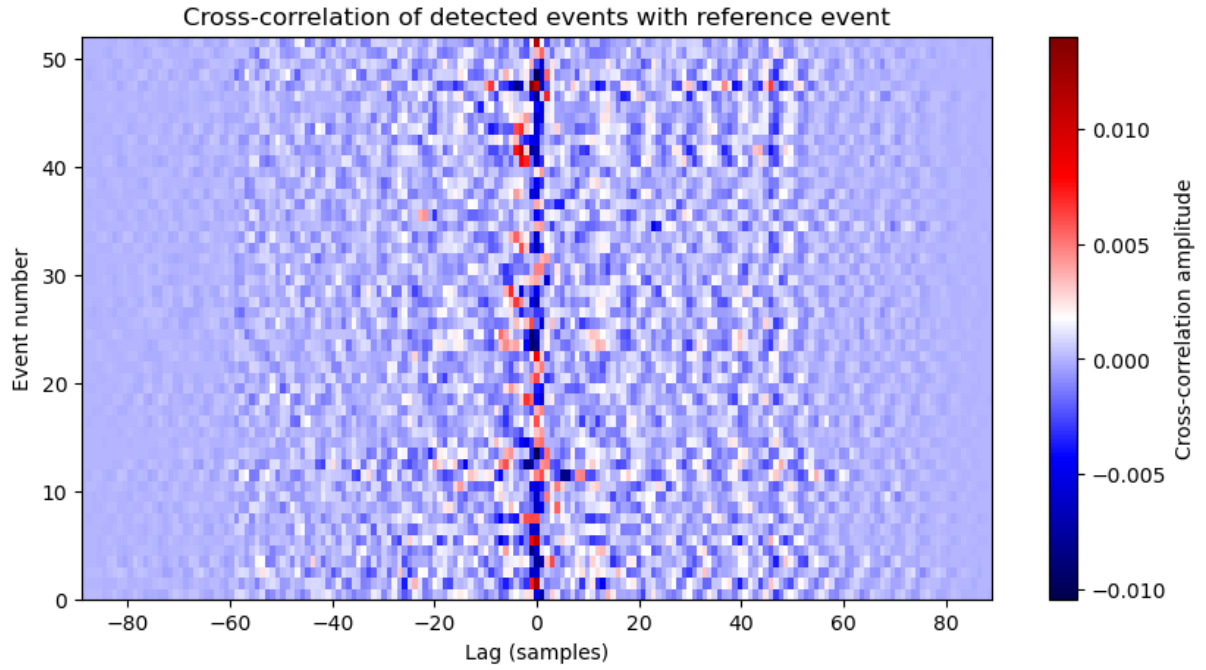


*Figure 10 : Cross-correlation function between the first and all the event triggered on FBG 3 located on channel 2 between the October 18th, 2024, and October 26th, 2024.*

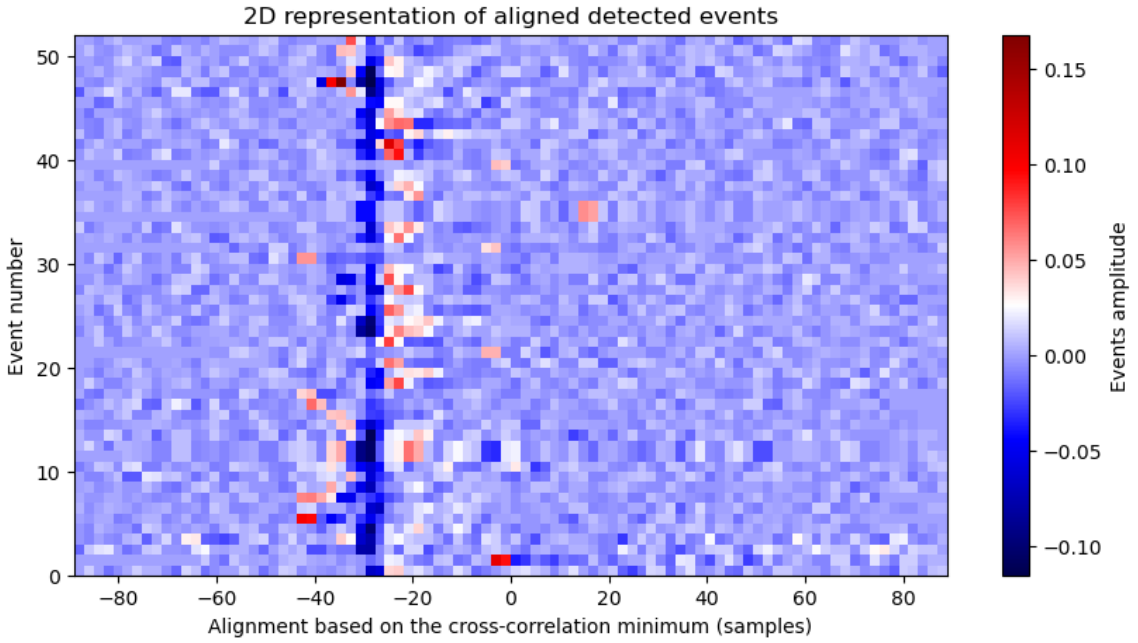


*Figure 11 : Aligned events from FBG 3 located on channel 2. The alignment has been performed using the time lag obtained from the cross-correlation function (fig. 10).*

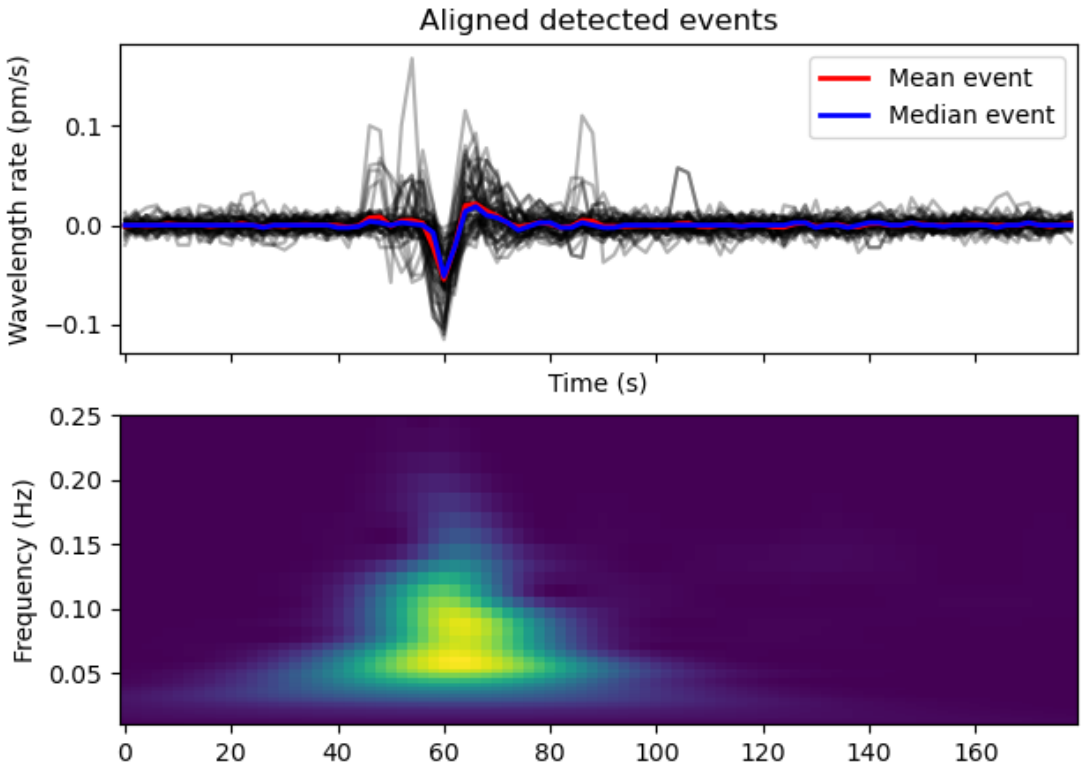


*Figure 12 : A. Stacked events of the periodic signal above for the FBG 3 on channel 2. The events were triggered using STA/LTA algorithm. The 90 events were observed and aligned using the time lag determined from the cross-correlation function between the events. Finally, the median and averaged event has been computed. B. Continuous wavelet transform of the mean curve between $1e^{-4}$ Hz and 0.25Hz.*

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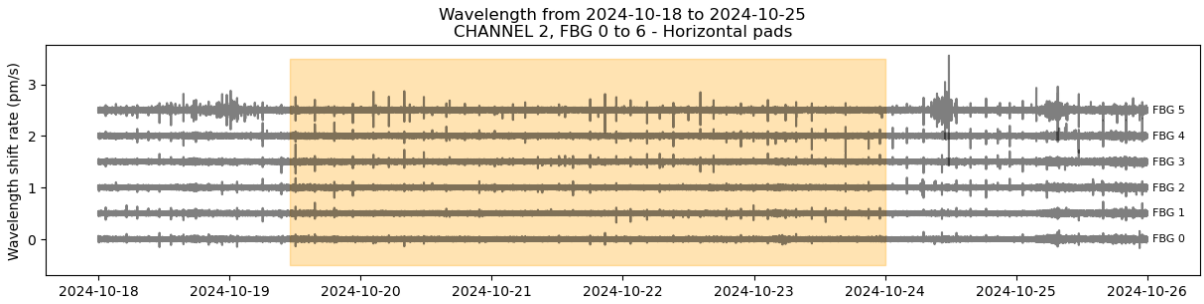


*Figure 13 : Time series in strain rate from all the FBG strain-pad located on channel 2 and installed horizontally in-ground between the October 18th, 2024, and October 26th, 2024. The overlaid period is consisting to the range of interest and used for computing the following figures (fig. 14 and 15)*

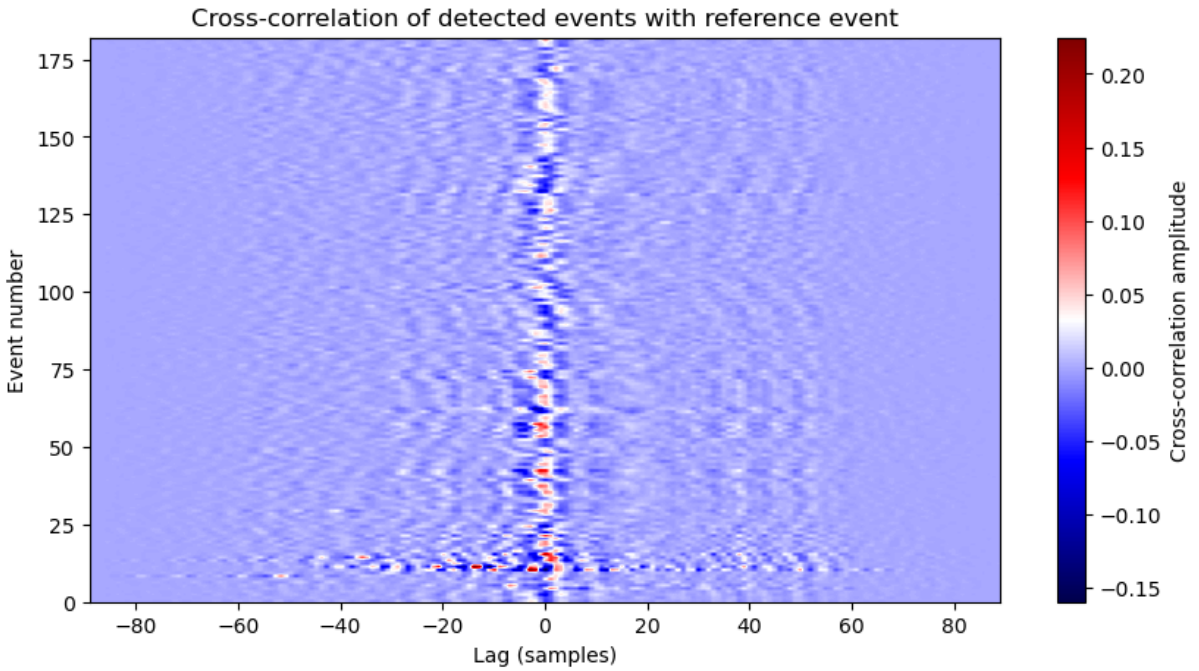


*Figure 14 : Cross-correlation functions between the first and all the events triggered in October for all the FBG on channel 2.*

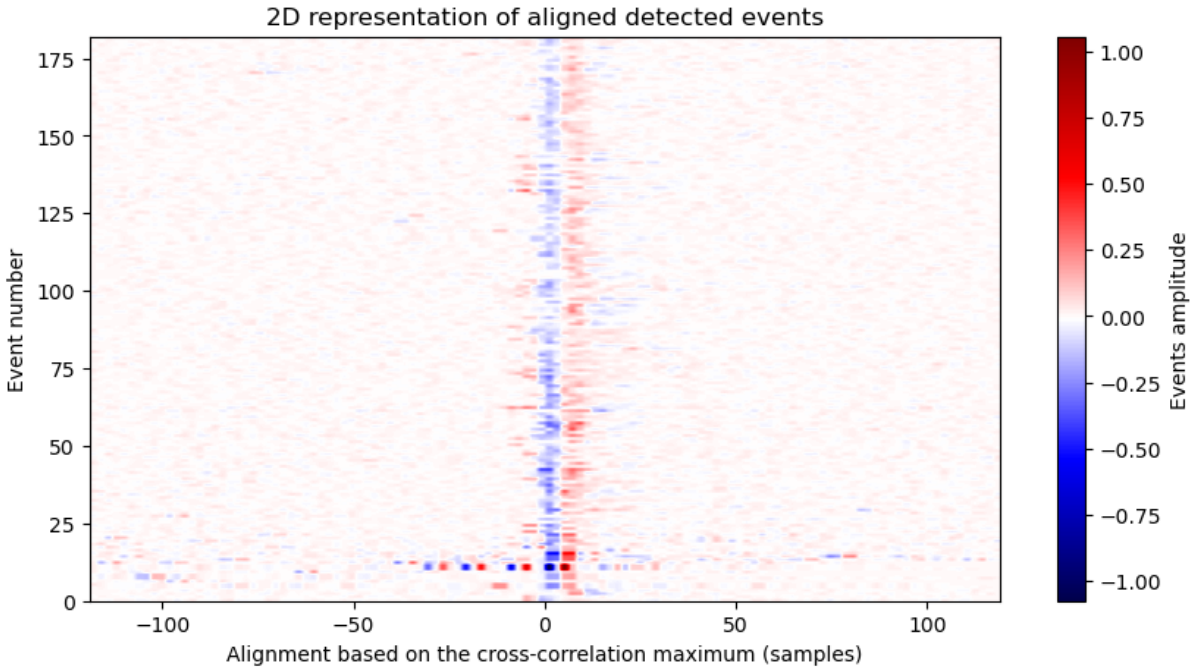


*Figure 15 : All the events aligned gathered from all the FBG on channel 2 using the time lag obtained from the cross-correlation in the Fig. 14.*

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