

Geometrical model for the “Croissant” multi-component DAS sensor

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Summary

In 2023, the "Croissant" was developed and tested as a low-cost, permanent, multi-component fiber sensor for Distributed Acoustic Sensing (DAS), designed to capture the full strain tensor of impinging wavefields. Three Croissant sensors were deployed at the Carbon Management Canada's (CMC) Newell County Field Research Station (FRS). This research aims to analyze field data from a multi-offset and multi-azimuth source-receiver configuration and to develop a geometrical model that generates synthetic data to predict the signals detected by the Croissant. Initial field data revealed high amplitudes in the vertical components, while the horizontal components exhibited comparatively lower amplitudes. These findings suggest the potential oblique incidence of the wavefield on the sensors, with implications of refracted wave arrivals. The Croissant geometrical model required new parametrization of the fiber path and considered previous observations to generate synthetic data closely resembling the field data, such as an upgoing ray path impinging the sensors. With this additional physical detail, we conclude that the Croissant effectively functions as a point receiver, and the generated synthetic data supports our assumptions and qualitatively reflects field data.

Theory

The natural response of DAS systems to elastic wave motion is highly directional, meaning they are most sensitive to longitudinal (or normal) strain aligned with the fiber's axis (Mateeva et al., 2014). In practical terms, this means the fiber responds primarily when stretched or compressed along its length. For instance, if a P-wave strikes the fiber perpendicularly, inducing strain at 90 degrees to the fiber axis, minimal response is expected. To mitigate this broadside insensitivity, altering the fiber geometry is an effective strategy (Mateeva et al., 2014; Kuvshinov, 2016).

Motivated by Innanen et al., 2018, Hall et al., 2022 and Takekawa et al.'s, 2022 work, the Croissant was designed measuring 1x1x1 m (Figure 1), wrapped around two 2D plastic frames that were buried vertically at right angles. The fiber is not tensioned on the frames, and ground compaction is relied upon for coupling. The Croissant's experimental design aims to overcome the limitations of previous directional DAS sensors by capturing the full strain tensor, including vertical motion, and offering easier deployment than previous designs (Hall et al., 2022).

For testing, data were recorded the day after burial, using a 120 m radius source line with 24 Vibe Points (VP). The objective was to understand the field data response from this multi-offset, multi-azimuth source-receiver configuration and to develop a geometrical model that generates synthetic data to qualitatively predict the signals expected to be sensed by the Croissant.

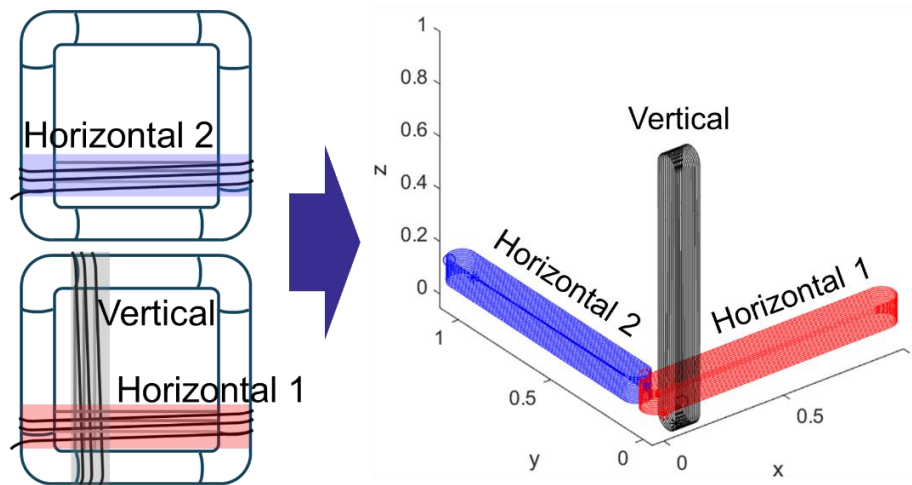


Figure 1. Design of fiber wrapped around plastic frames (left). Parametrization results of wrapped fiber in three components (right).

Preliminary observations from the Croissant field data revealed high amplitudes in the vertical components and lower amplitudes in the horizontal components in the first breaks for all 24 shots. These findings suggest an oblique incidence of the wavefield, leading to strong vertical component amplitudes, and imply the presence of head-wave arrivals (e.g. Figure 2).

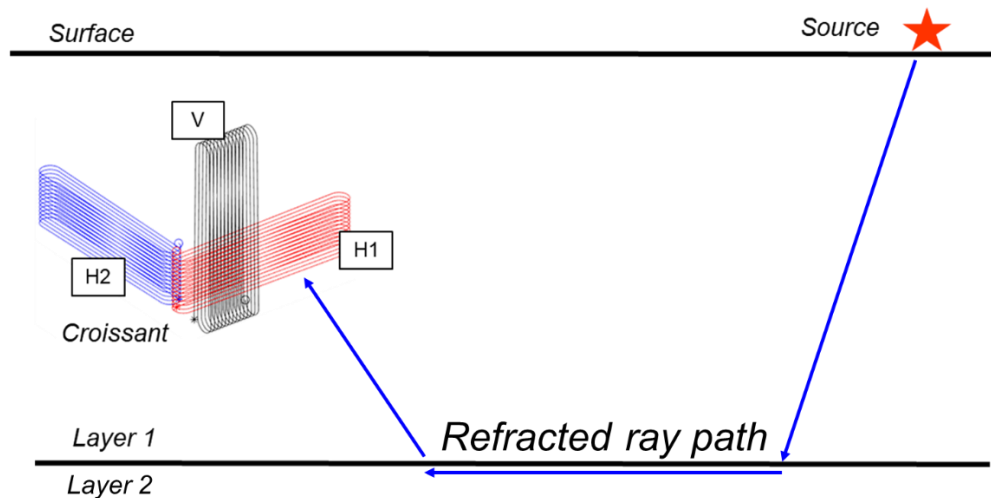


Figure 2. Sketch of a refracted ray path impinging on the Croissant sensor.

Croissant Parameterization

To model the field data, a parametrization of the Croissant fiber loop was carried out considering the dimensions, position, and distance of the Croissant sensors with respect to each other and each Vibe Point (Figure 3). This is important so synthetic data traces are generated in the same order as the field data.

The geometrical or synthetic model code was developed by Innanen (2016) and modified for this project, and includes the following components:

1. A homogeneous elastic Earth volume with defined V_p and V_s values for layer 1 and 2
2. A DAS fiber embedded in an input snapshot of a 3D elastic wavefield
3. A DAS fiber loop defined by three coordinate vectors (x, y, z) , generated by the Croissant fiber loop parametrization and discretized into small segments
4. The definition of gauge length and the calculation of tangent, normal, and binormal vectors
5. Twenty-four evenly spaced sources, each with a defined moment tensor and wavelet
6. DAS channel spacing definition
7. Generation of the associated synthetic shot gather

Including a second layer with higher P-wave velocity creates an upgoing ray path impinging on the sensor (Figure 2), resulting in a higher amplitude in the vertical component in the synthetic shot gathers measured at each sensor (Croissant 1, 2, and 3). This modification is physically reasonable and is required to create synthetic data that matches the field data as expected.

Croissant fibre Loop

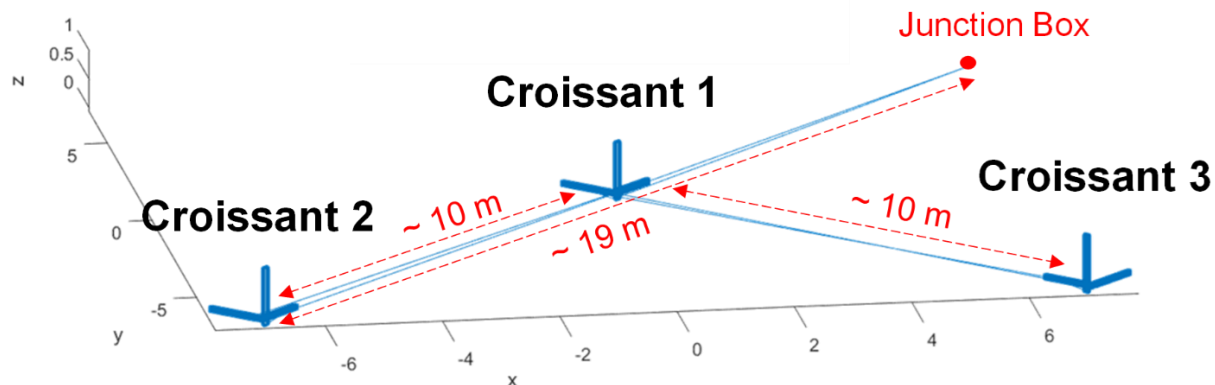


Figure 3. Result of the Croissant fiber loop parametrization

Results

Field data analysis indicates that the Croissant sensor is fully operational as a point sensor, effectively capturing meaningful amplitudes interpreted as refracted arrivals. Notably, clear directionality is observed on the Vertical (V), Horizontal 1 (H1), and Horizontal 2 (H2) components. Additionally, the synthetic data showcases an operational DAS geometric model, with the Croissant system being well-parameterized. The responses obtained align consistently with the field data respect the higher amplitudes in the vertical components, reinforcing the reliability of the findings (Figure 4).

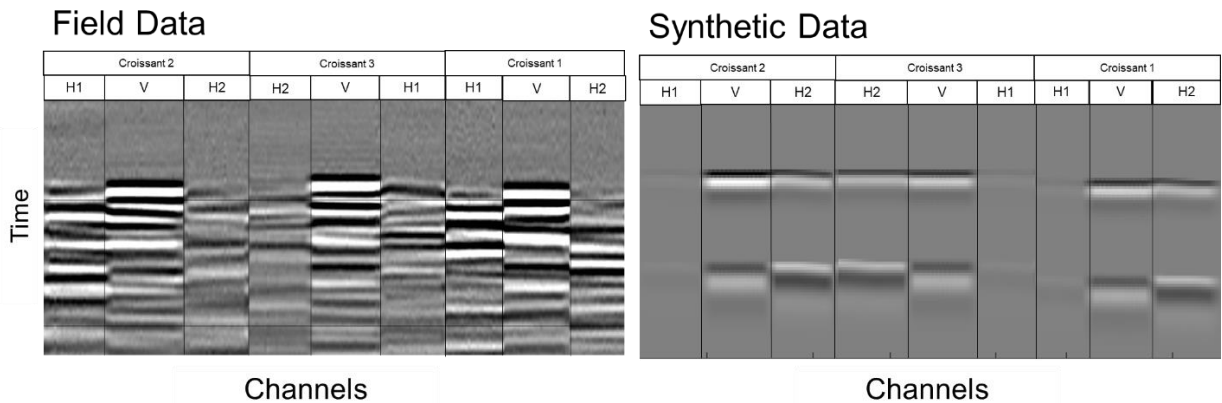


Figure 4. Field data shot gather (left), and synthetic data shot gather (right).

Acknowledgements

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