The seismological signature of cyclonic storms through the ears of a sensor array

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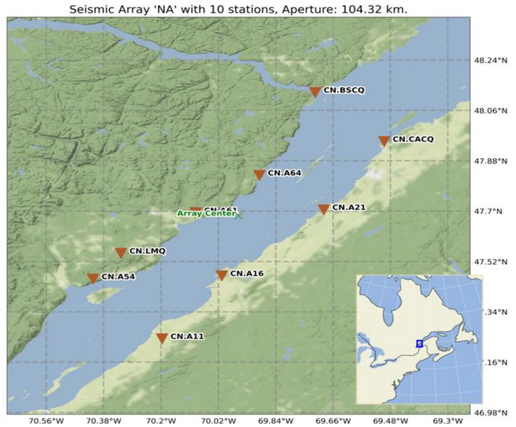
Listening to cyclones from afar...

Large **surface gravity waves** can interact with the seafloor underneath and trigger faint but measurable seismic signals known as **ocean microseisms,** often regarded as **ambient seismic noise.** Cyclonic storms (e.g. **hurricanes,**) are major (non-stationary) sources of the former, thus allowing to **track and study** storms by means of their corresponding microseisms

1. How exactly?

- **Polarization beamforming** [1], a robust coherence-based array processing technique is used to analyse diverse wave types separately
- Virtual **land arrays** composed of seismometers of the WWSSN close to the North Atlantic are used

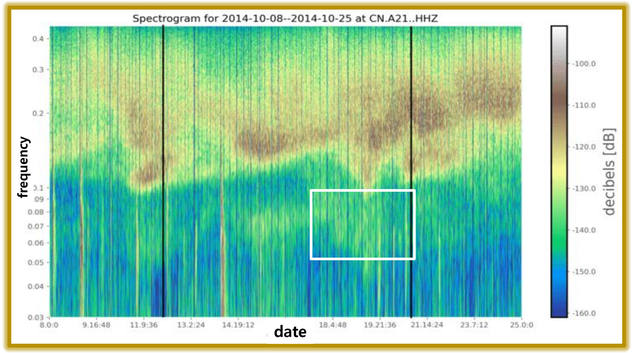


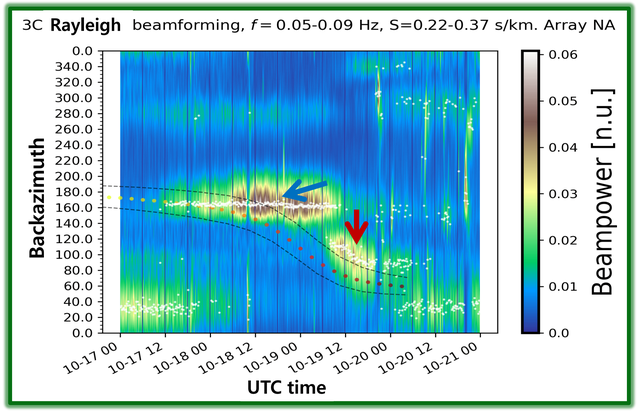
Up: One of the virtual arrays used in this study (near Québec, CA)

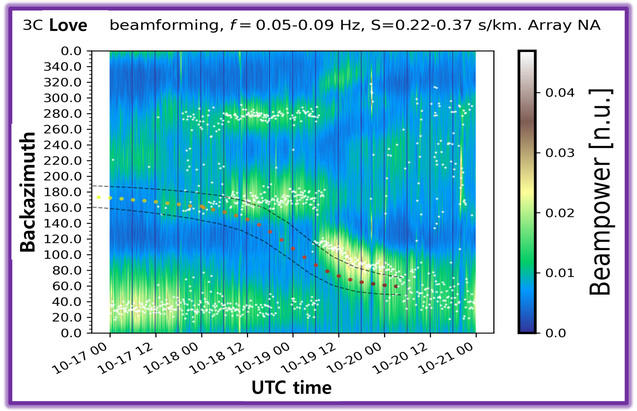
- The **microseismic band** (**0.05-0.16 Hz**) is considered **[Fig A]**
- The analyses hinge on **surface waves** (**Rayleigh** and **Love**) which, contrary to P-waves**,** do not constrain source remoteness, albeit being more energetic

A. Right: **Spectrogram** of one of the stations of "**NA**" array, depicting formation/disipation dates (**black lines**) of hurricane C4 **Gonzalo** in 2014. The white rectangle marks the (microseismic) time~-frequency window considered in the figures below.

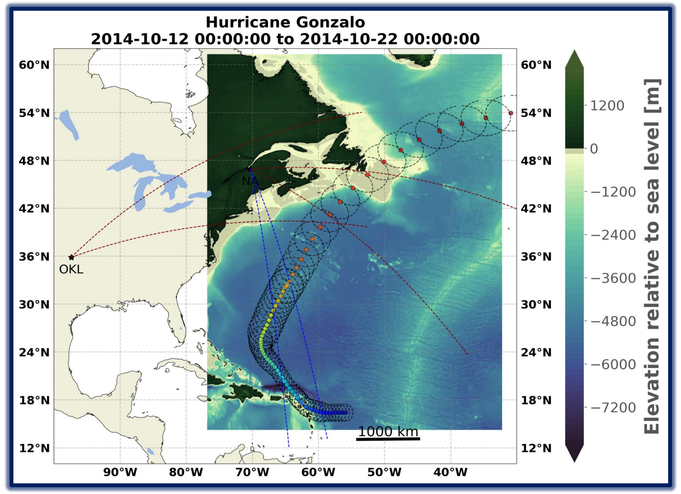
B. Below, left (right): **retrograde Rayleigh** (**Love**) wave **polarization beamforming analyses** at the **primary microseismic band** (0.05 to 0.09 Hz), showing the expected bearing towards the *eye* of hurricane Gonzalo (rainbow-colored dots between dashed black lines). Results at higher frequencies are similar but somewhat noisier. **Beampower** is a measure proportional to the combined coherency and energy of the superposed wavefields







C. Right: **Track** of hurricane Gonzalo (with same rainbow dots convention of the figures above) along with projected lines with 5-azimuth–degree deviation to each side of the **best-matching backazimuths** of the beampower maxima, as observed at two arrays. These correspond in time to the **blue** and **red** arrows in the figure above. Bathymetry map is included for reference



2. What did we find?

- **Clearer storm signatures** are observed for **surface waves** as opposed to P waves. **Rayleigh** and **Love waves share source time and direction of arrival [Fig B]**
- Some signatures are **related to the cyclone's rear quadrant or trailing swells [Fig B]** as noted too by [2]
- **Storm microseisms are intermittently excited at localized regions [Fig C]**, mostly around shallow continental shelves and slopes (see also [3,4]), virtually independent on storm category
- In most cases **no detection was achieved at large array separations [Fig C].** A detection threshold of ~2000 km is often cited [5]
- This hampers a reliable and continuous inversion of cyclone tracks, but provides insights into **the physical mechanisms behind microseisms**

3. We envision that...

- Storms can be treated as natural seismic sources for **local inversions** (e.g. **seabed bathymetry/ geology** or **ocean wave spectrum**). The complex interplay between these is not yet fully resolved (see e.g. [5])
- These inversions will likely require **near-field** observations (e.g. [2]) using **dense**, **widespread sensor layouts** (e.g. OBS, DAS)
- Improved detection and understanding of oceanic microseisms could contribute greatly to mechanically **coupled atmosphere-ocean-solid earth models**

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References:

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