

DE LA RECHERCHE À L'INDUSTRIE



**SnT 2019**  
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

# ANALYSIS OF HYDROACOUSTIC SIGNALS ASSOCIATED TO THE LOSS OF THE ARGENTINIAN ARA SAN JUAN SUBMARINE

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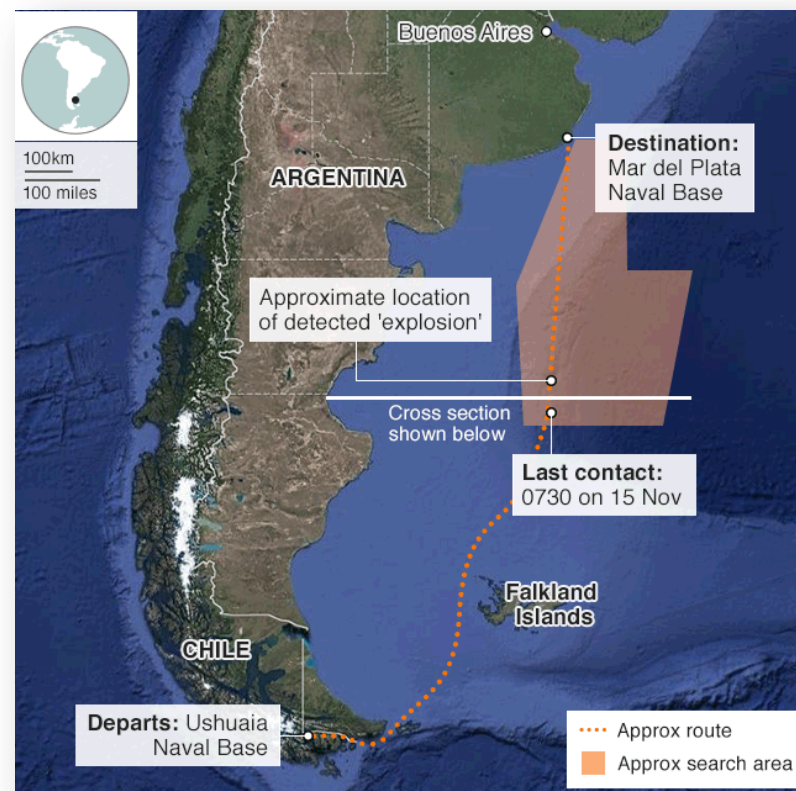
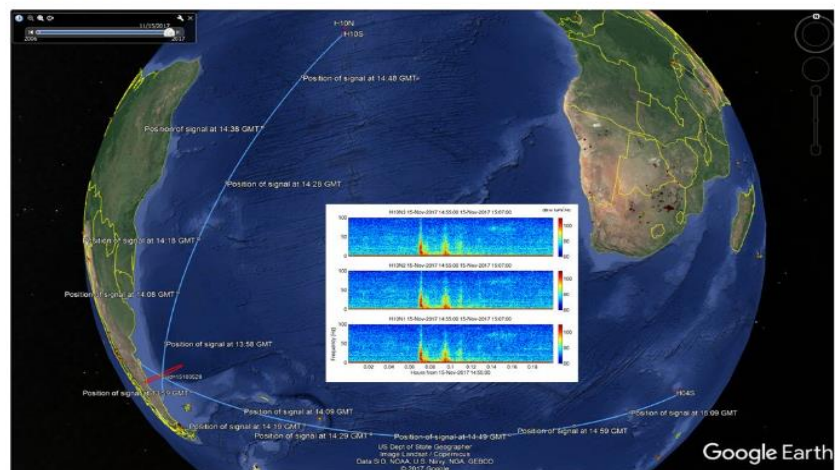
- 15 Nov 2017 – 07h30 Local Time : Last contact
- « *Our hydroacoustic network detected an unusual signal near the last known position of [#missing San Juan](#) [#submarine](#)* »

[L. Zerbo's tweet of 23 Nov 2017]

➔ Motivation for French NDC to work on that event



Our hydroacoustic network detected an unusual signal near the last known position of [#missing San Juan](#) [#submarine](#). The signal from an underwater impulsive event was detected 15 Nov 13:51 GMT, Lat -46.12 deg; Long: -59.69 deg. Details & data shared with Argentinian authorities.

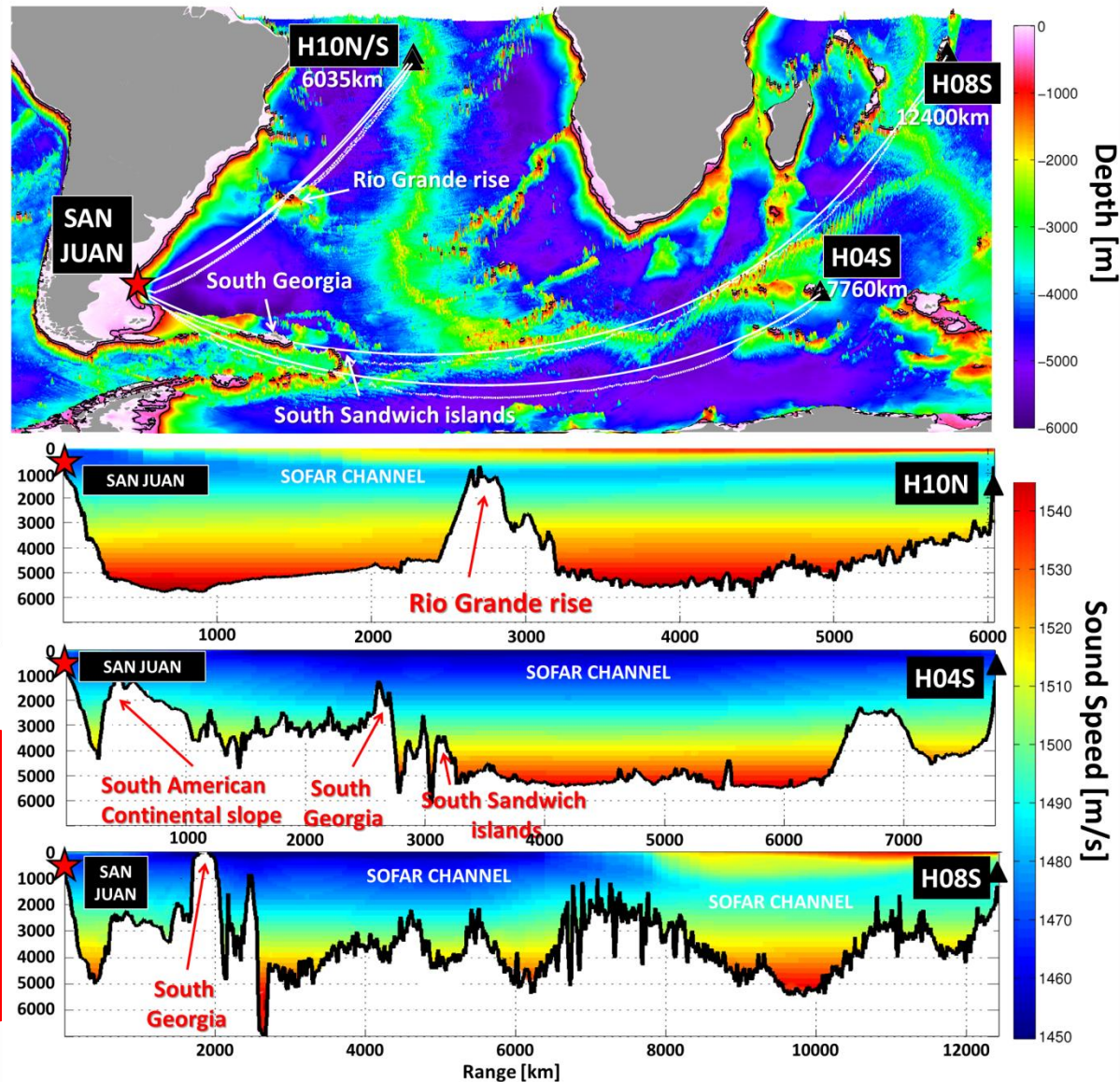


- 1<sup>st</sup> Dec 2017 : Controlled grenade explosion conducted by Argentinian Navy
  - Well known source position
  - Inaccurate origin time
- 16 Nov 2018 : Submarine wreck was found

# BATHYMETRIC FEATURES

- Paths to **H10N** and **H10S** (Ascension Island, 6 000 km) are **partially blocked** by Rio Grande Rise
  - Warming SOFAR channel
- Path to **H04S** (Crozet Island, 7 760 km) is **clear**
  - Stable and cold SOFAR channel
- Path to **H08S** (Diego Garcia, 12 400 km) is **totally blocked** by South Georgia

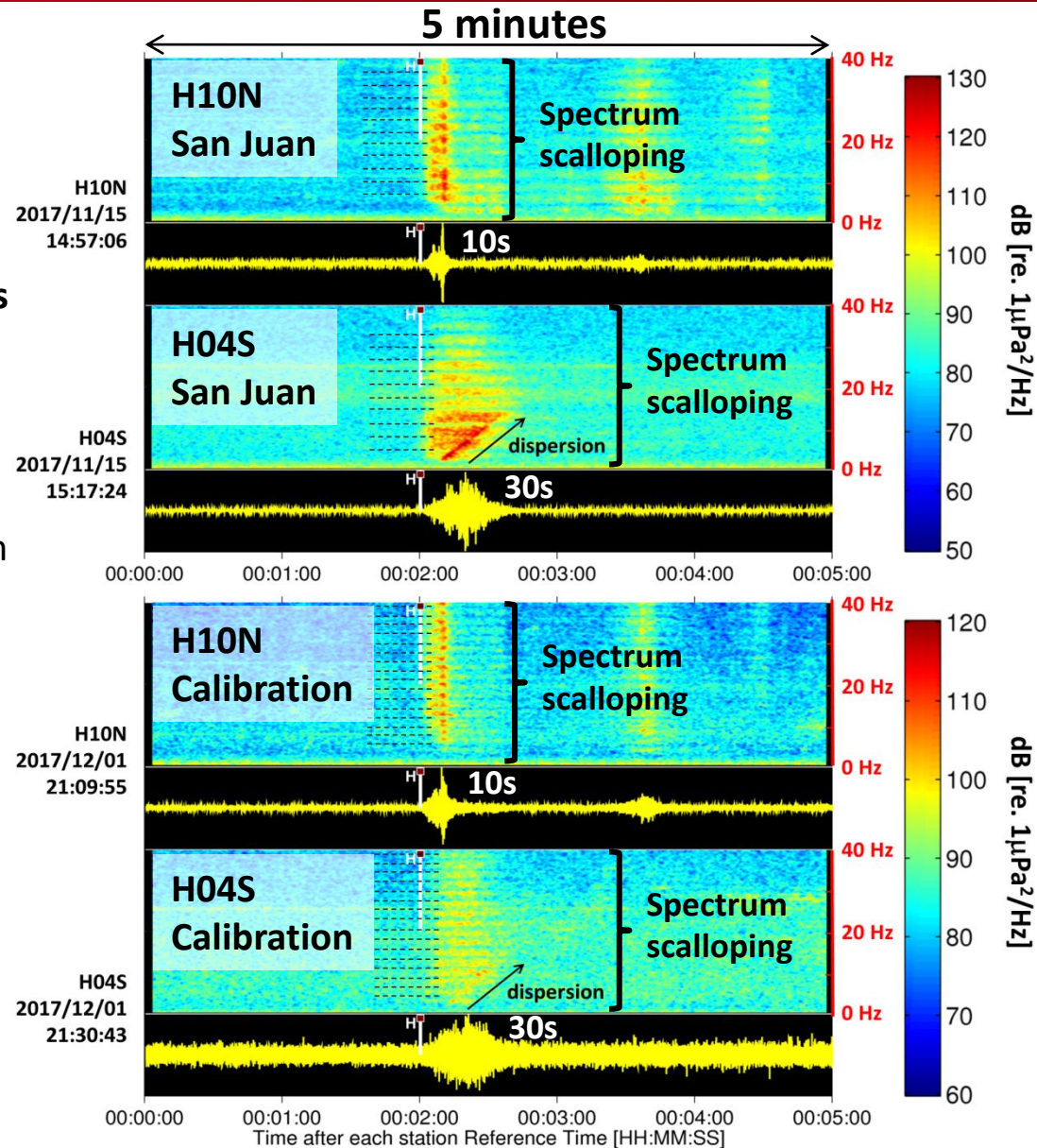
San Juan and Calibration events are detected at the **3 closest IMS hydroacoustic stations** (triplets of hydrophones), between **6 000 km and 8 000km**



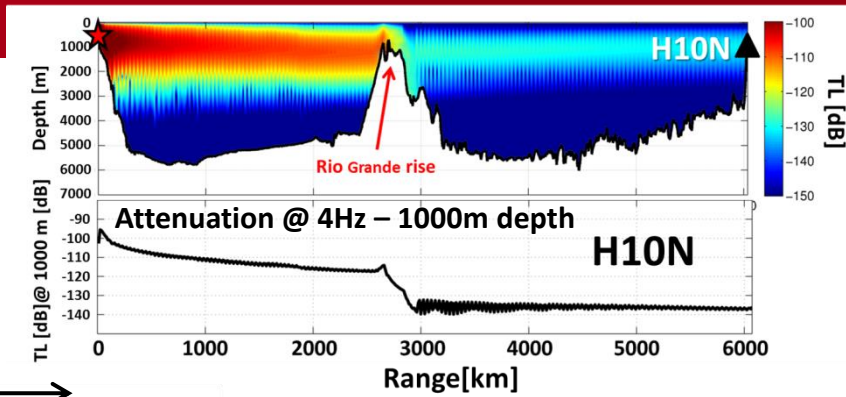
# SIGNALS AND FREQUENCY FEATURES SAN JUAN VS CALIBRATION EVENTS

- Signals exhibit long range **propagation signatures** generated by **impulsive source**
  - **Short duration** arrivals (10 s – 30 s)
  - **Broad band signals** (1 Hz – 80 Hz)
  - **Strong dispersion** at H04S
  - **Larger amplitudes** for San Juan signals
- Signals exhibit spectrum scalloping features potentially associated to **explosive-like events**
  - Different bubble pulses values for both events

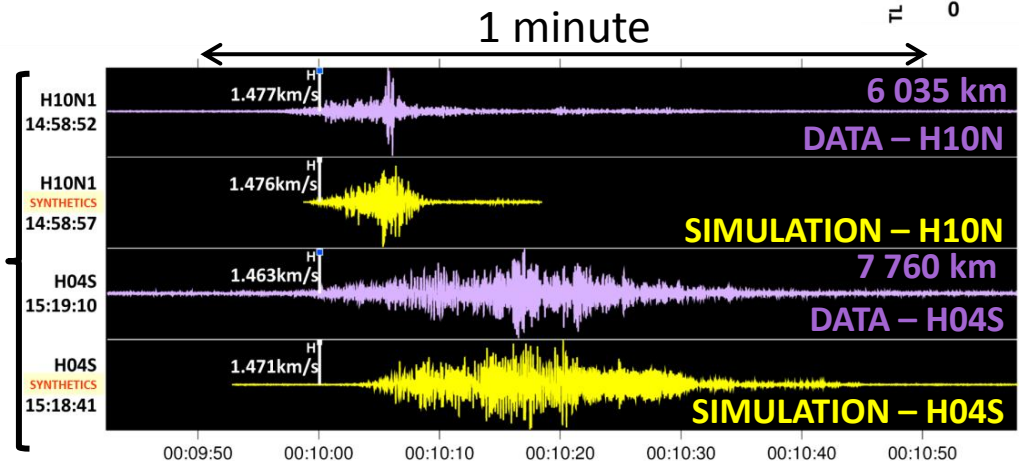
**Comparisons of San Juan with calibration grenade confirm an impulsive source (explosive ?) and a larger energy for San Juan**



- **Range-dependant Parabolic equation modelling to H04S (6 000 km) and H10N (7 700 km)**
  - Transmission loss @ 4Hz
  - Broad band **full waveform modelling** [up to 30 Hz]

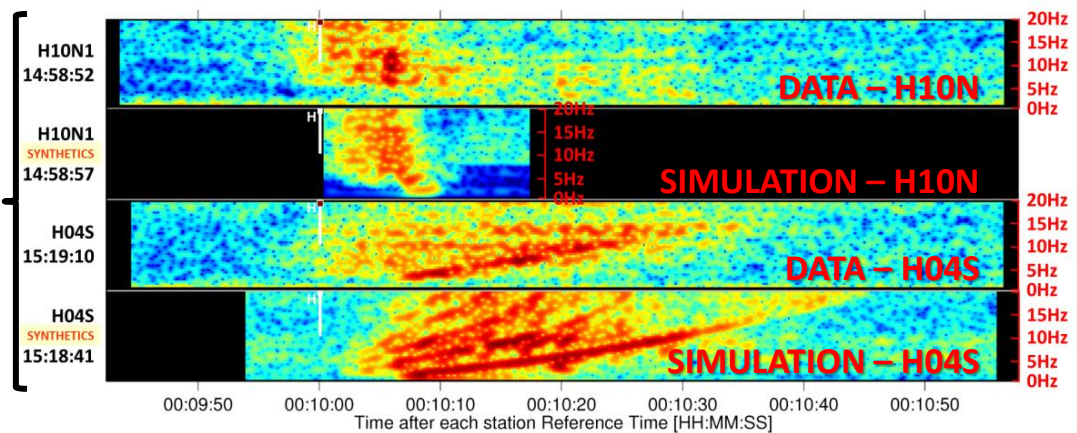


Comparable shapes and durations



**Simulations validate observed signal shapes, durations and frequency contents and so the hypothesis of an impulsive event**

Comparable frequency contents



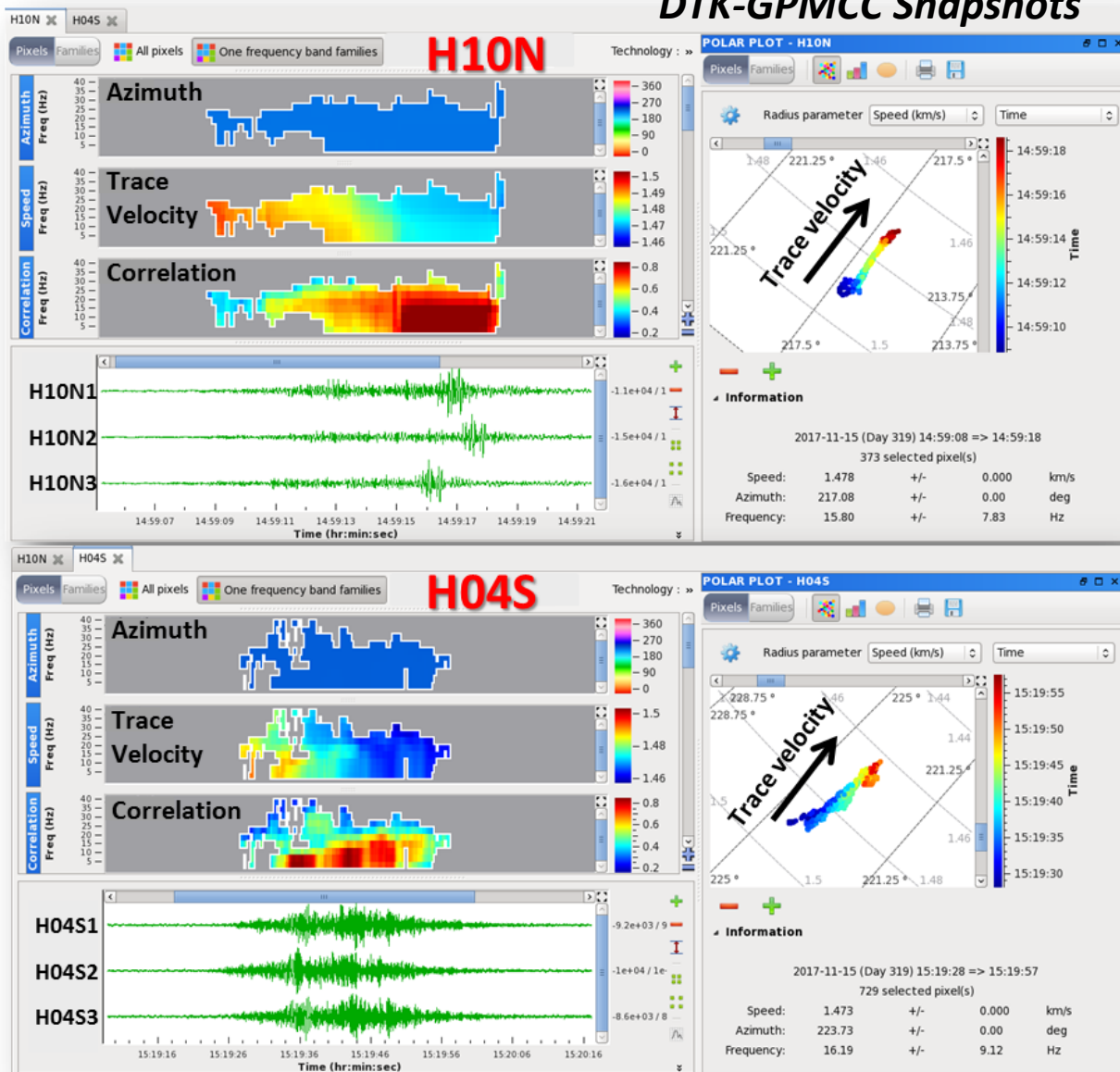
- **However :**
  - Simulations are not sensitive to event depth and mechanism
  - Velocity models do not explain arrival times (Cannot be used to constrain efficiently the location)

# ARRAY PROCESSING ON SAN JUAN FIRST ARRIVALS

## DTK-(G)PMCC ANALYSIS

### DTK-GPMCC Snapshots

- Use of **DTK-GPMCC** to process interactively the data in [1 Hz – 40 Hz] frequency band
  - Packaged in NDC-in-a-Box
  - New hydroacoustic support
  - *Funded by CTBTO*
  - **Visit DTK booth n°9!**
  
- PMCC analysis provides **high resolution picture of coherent acoustic wavefield** in time-frequency space



- **Detection results highlight detailed propagation features**
  - Well defined back-azimuth (within  $0.1^\circ$ )
  - Time variation of trace velocity
  - Frequency dispersion

## LOCATION FROM FIRST ARRIVALS

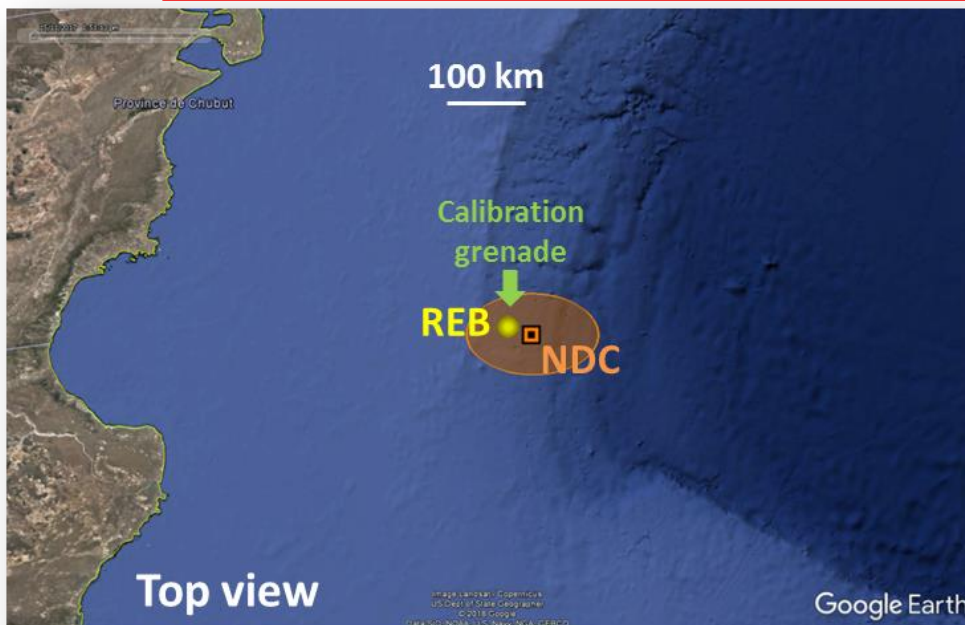
## ➤ Badly constrained problem

- Only **3 stations (H10N, H10S, H04S)**
- Very large propagation ranges  
(6 000 km to 8 000 km)

## ➤ Location results are very sensitive to uncertainties

- **Model uncertainties**
  - ➔ Velocity models (5m/s), azimuth deviations (0.5°)
- **Measure uncertainties**
  - ➔ Picking: time, azimuth (0.3°)

➔ NDC location is close to REB solution  
Location ellipse remains very large : 13 000 km<sup>2</sup> (170 km x 100 km)



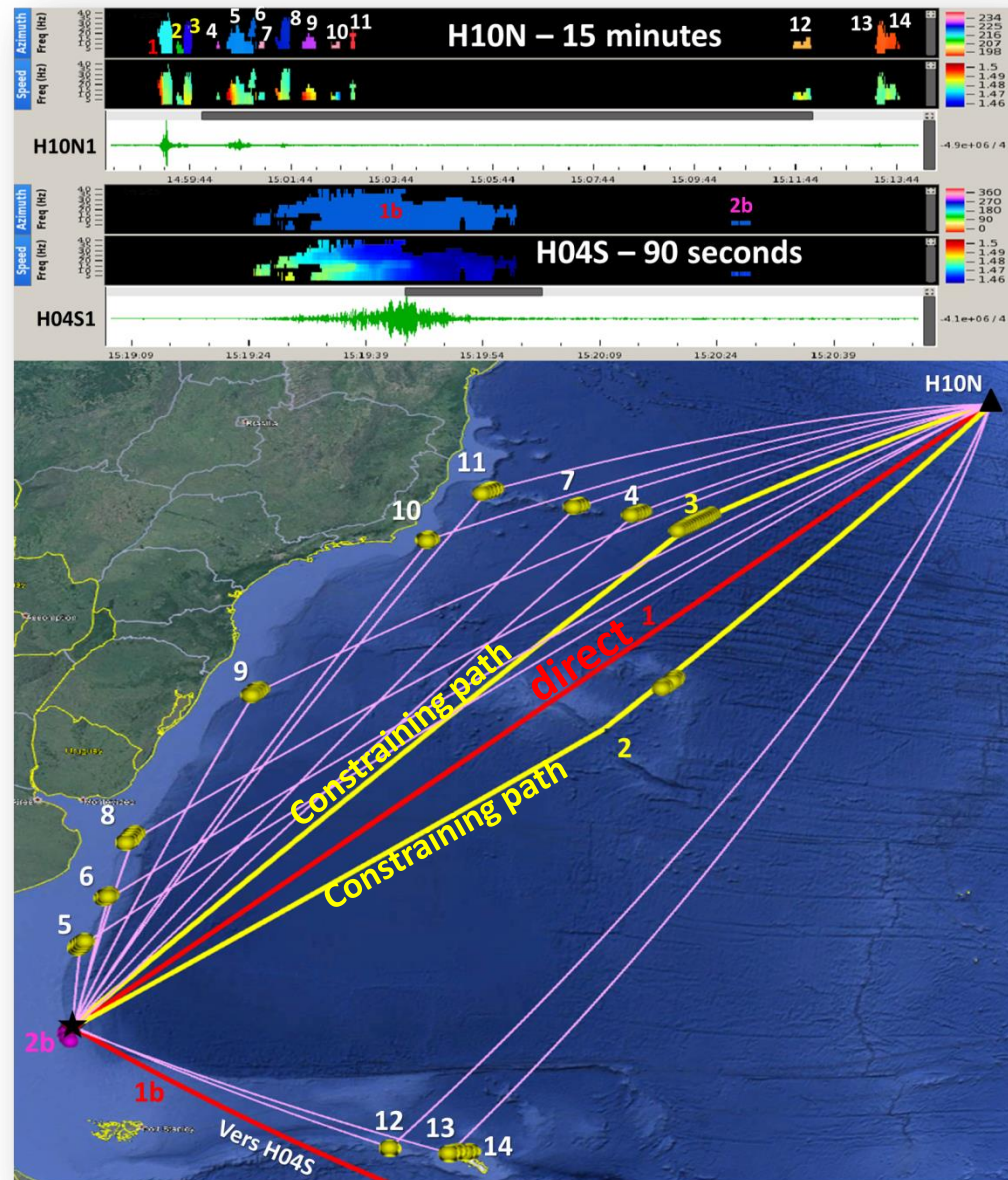
# REFINING THE LOCATION INTERPRETATION OF LATE ARRIVALS

- DTK-(G)PMCC processing allows to identify 14 late arrivals associated to San Juan event on H10N and H04S
  - They correspond to reflections on bathymetric structures
    - ➔ Islands (3, 13, 14)
    - ➔ Sea mounts (2, 4, 7, 12)
    - ➔ South American continental slope (5, 6, 8, 9, 10, 11, 2b)

**Only small size « point source » reflectors are really constraining the source location**

➔ Paths 2 & 3 are selected, even if corresponding signals and detections are small

*« The devil is in the details »*



# RELOCATION WITH 2 FIRST REFLECTED ARRIVALS JOINT INVERSION OF SAN JUAN AND CALIBRATION GRENADE EVENTS

## ➤ Joint inversion of both San Juan and calibration parameters

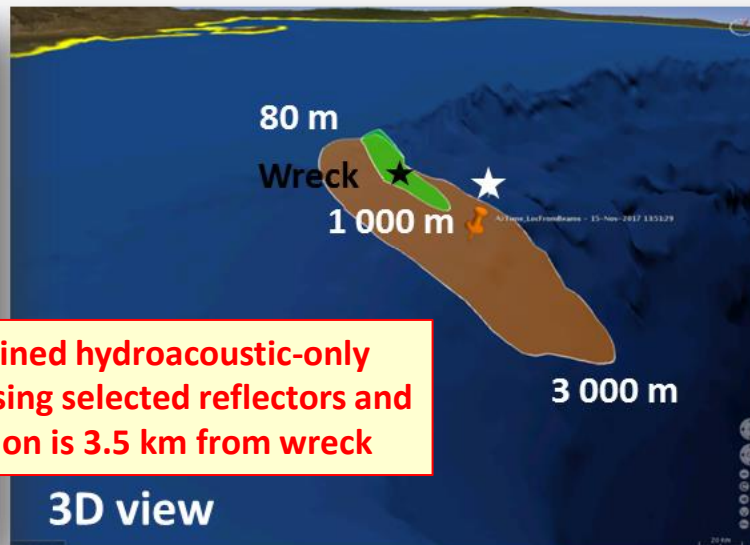
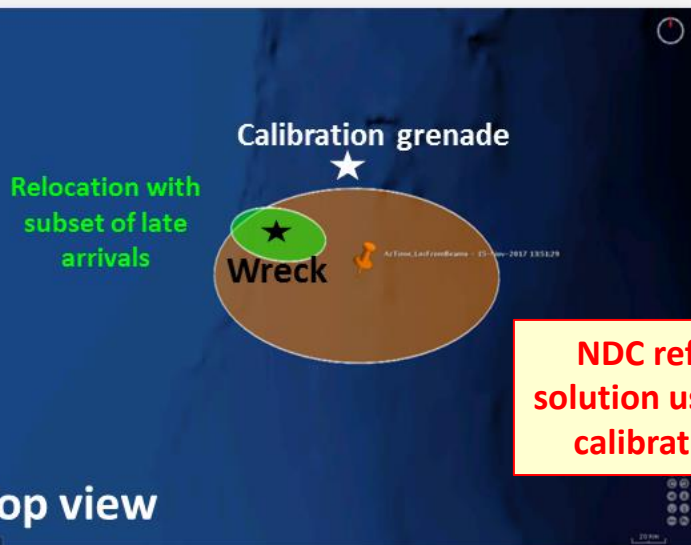
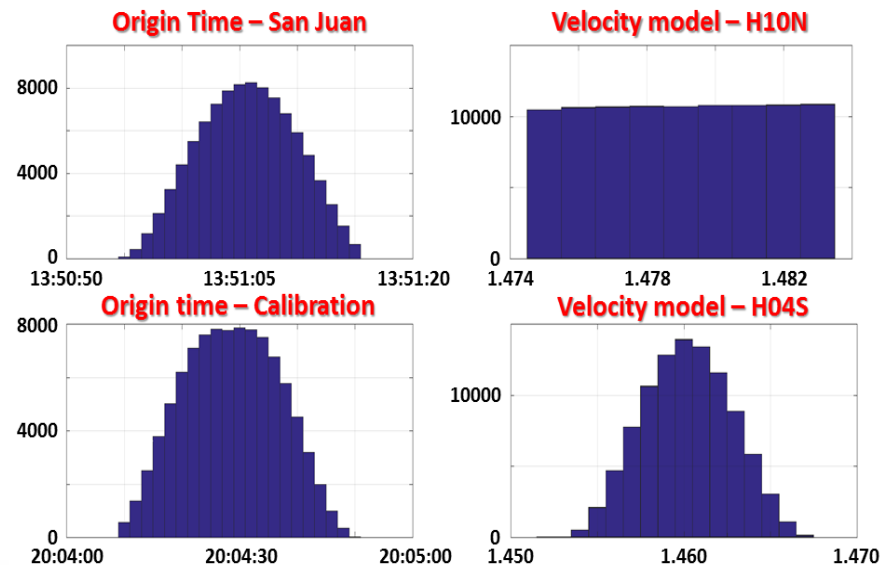
### ■ 6 unknowns

- ➔ Lat, Lon, Origin time of San Juan
- ➔ Origin time of calibration
- ➔ Velocity models for H10N/H10S & H04S

### ■ 7 measures

- ➔ San Juan (4 measures)
  - H10N : 1 direct, 2 reflected
  - H04S : 1 direct
- ➔ Calibration (3 measures)
  - H10N : 1 direct, 1 reflected
  - H04S : 1 direct

*a posteriori* distributions



**NDC refined hydroacoustic-only solution using selected reflectors and calibration is 3.5 km from wreck**

Relocation ellipse  
**1 400 km<sup>2</sup>**  
(57 km x 30 km)

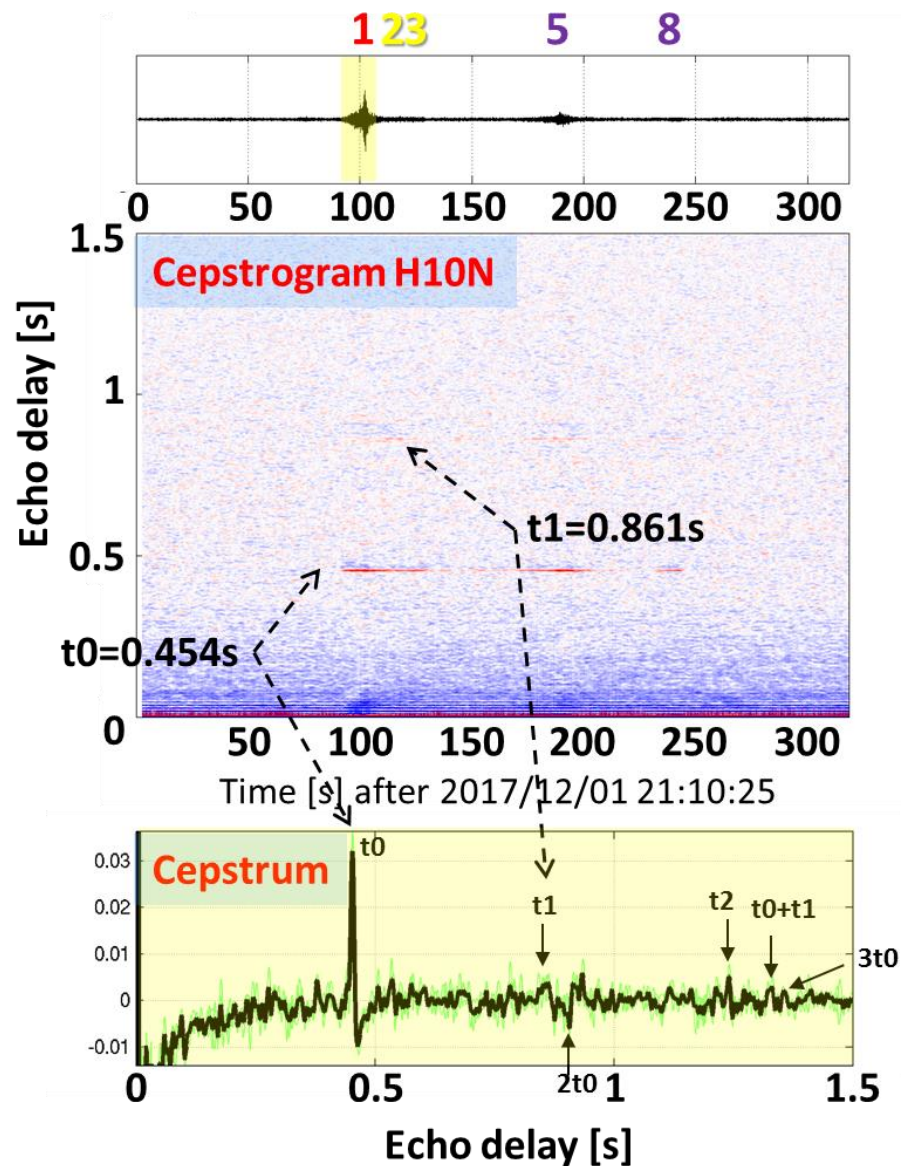
- **Cepstral analysis** : Signal processing technique to **detect echos** in a signal
  - Used in **hydroacoustics to detect and discriminate explosive sources** (detection of bubble pulsations)

Echo label	Measured value (s)	Theoretical value (s)
t0	0.454	0.454
t1	0.861	0.874
2t0	0.906	0.908
t2	1.243	1.293
t0+t1	1.329	1.328
3t0	1.355	1.362

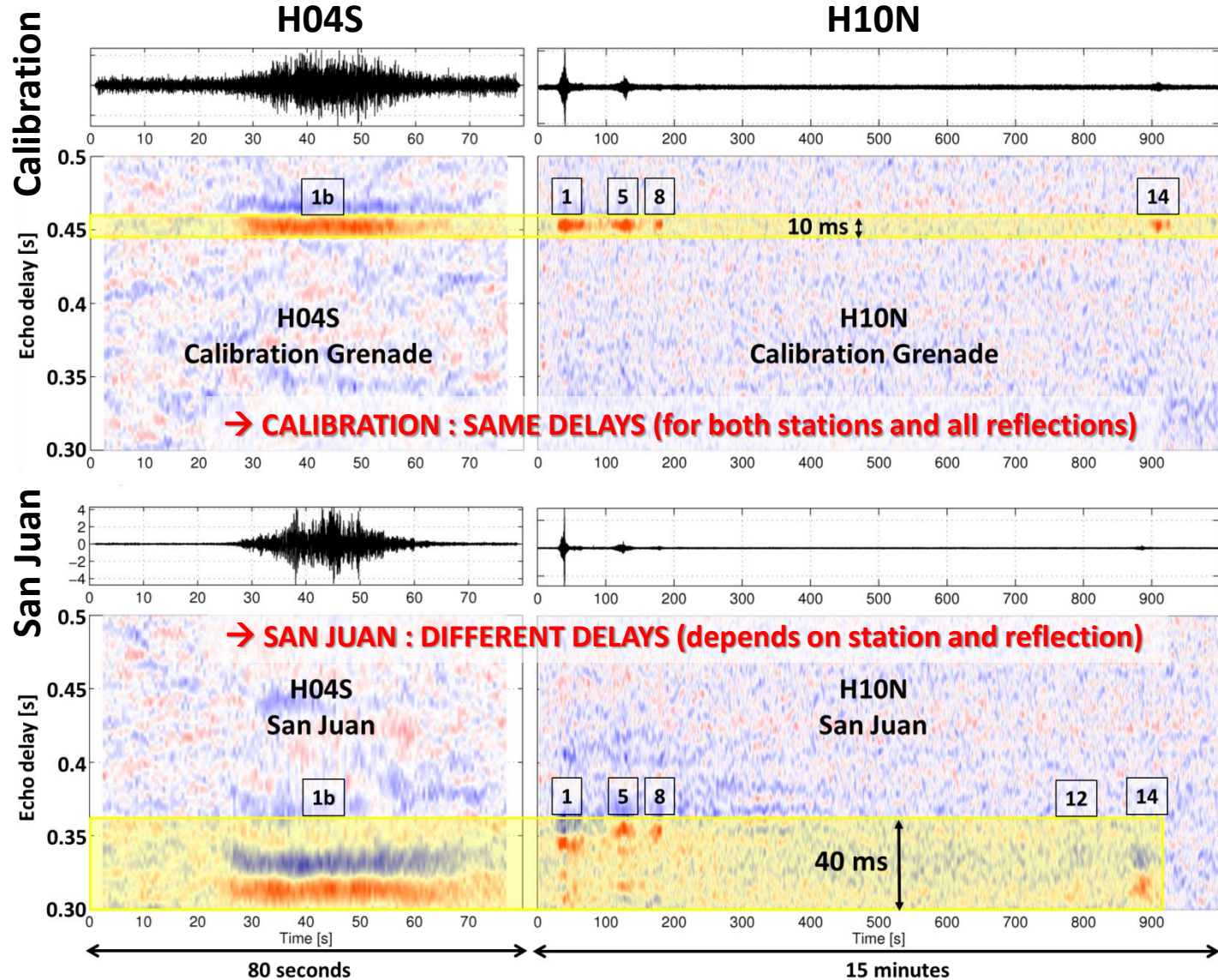
6 first cepstral peaks are explained by theory for a 108 kg @ 33m explosion

All first cepstral peaks associated to calibration grenade are explained by simulation  
→ This step validates the method

- First cepstral peak is observed on reflected phases



# CEPSTRAL ANALYSIS SAN JUAN VS CALIBRATION GRENADE



➤ Detailed analysis of echos (time delays) at H10N and H04S for direct and reflected arrivals

- Calibration grenade : Same delays ( $454\text{ms} \pm 1\text{ms}$ )
- San Juan : Different delays ( $314\text{ms} \rightarrow 354\text{ms}$ )

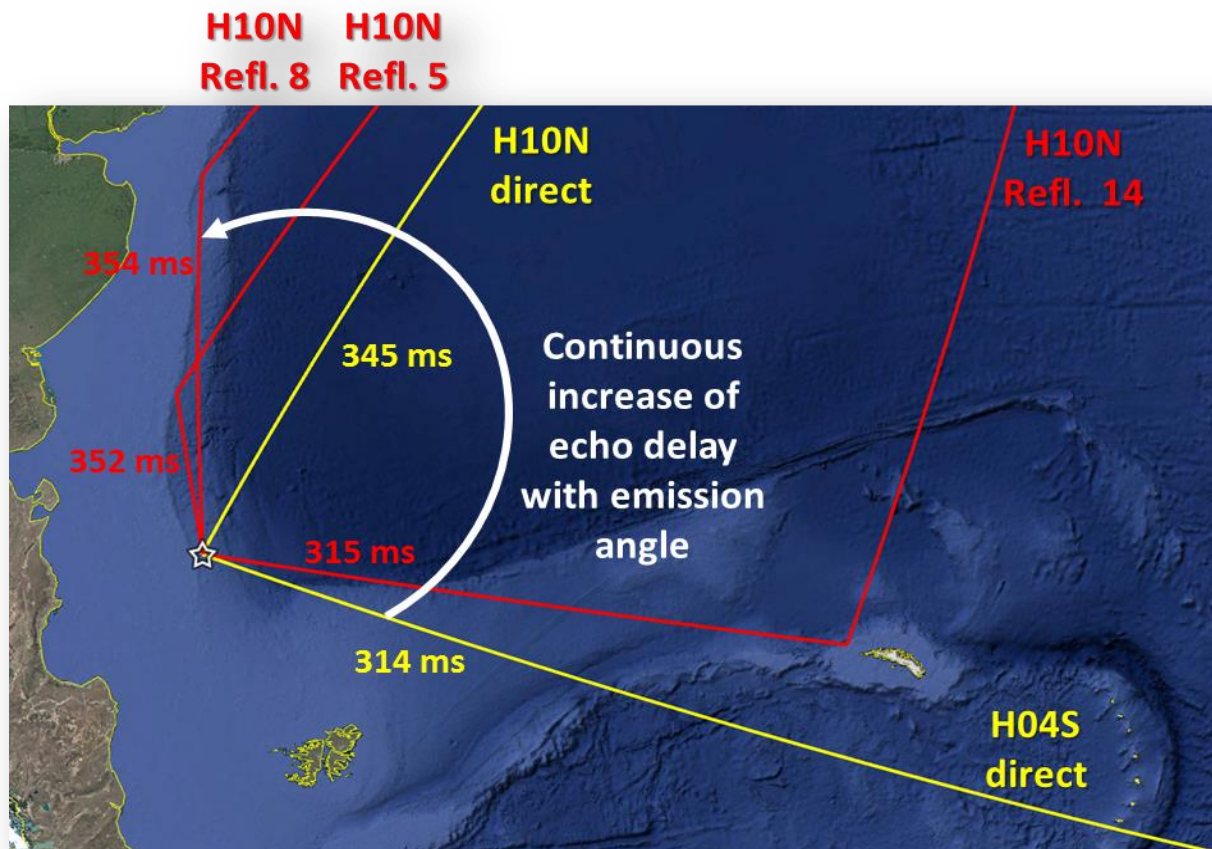
**For San Juan event, the anisotropic behavior of measured delays is not consistent with explosive source**

# INTERPRETATION OF THE DIFFERENT ECHO DELAYS TOWARDS A SOURCE SCENARIO ?

- Echo delays vary continuously with emission angle
- Differences could be associated to a « **source effect** »
  - **Analogy with seismology** : source time function durations at different stations depend on rupture size and cinematics (observation for large earthquakes)
- First cepstral peaks would not be associated to a bouncing effect but to the **occurrence of 2 distinct events**

The directivity of the echo pattern may be interpreted as 2 distinct events (implosions) very close in space and time.

- Ongoing study...



- Comparison of signal shapes, durations and frequency contents for San Juan and calibration grenade events allows to **confirm the occurrence of an impulsive event** (small scale complexity is not resolved from that comparaisons)
- This hypothesis is also **confirmed by full waveform modelling**
- **DTK-(G)PMCC**, part of **NDC-in-a-Box**, has been **extended to process hydroacoustic data** (recent evolution funded by CTBTO)
- Fine tuned **DTK-PMCC detector analysis reveals « hidden » signal features** in San Juan signals that are determinant for constraining event location. **Found location using hydroacoustic data is 3.5 km from submarine wreck**
- **The directivity of the echo pattern measured by cepstral analysis may be interpreted as 2 distinct events (implosions) very close in space and time**



