SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

CTBTO
PREPARATORY COMMISSION

Remote detection of hydroacoustic signals potentially associated with the sinking of SS El Faro using CTBT IMS hydrophone data

METZ[1], Dirk, NIELSEN[2], Peter L., ZAMPOLLI[2], Mario, HARALABUS[2], Georgios

[1]Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan
[2]Preparatory Commission for the CTBTO, Vienna, Austria

Poster No. P1.3-331

POSTER

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Motivation

MOTIVATION

On average, 3-5 large ships are lost at sea every month[1]. Most maritime accidents take place in coastal waters or harbors, but some occur at high seas. In such cases, information on the last position of the vessel and the timeline of events is often limited, yet critical for accident analysis.

In this ePoster, we investigate whether shipping accidents, for instance the 2015 sinking of SS El Faro, can be detected by the hydroacoustic waveform component of the International Monitoring System (IMS).

[1]Allianz Safety and Shipping Review 2019

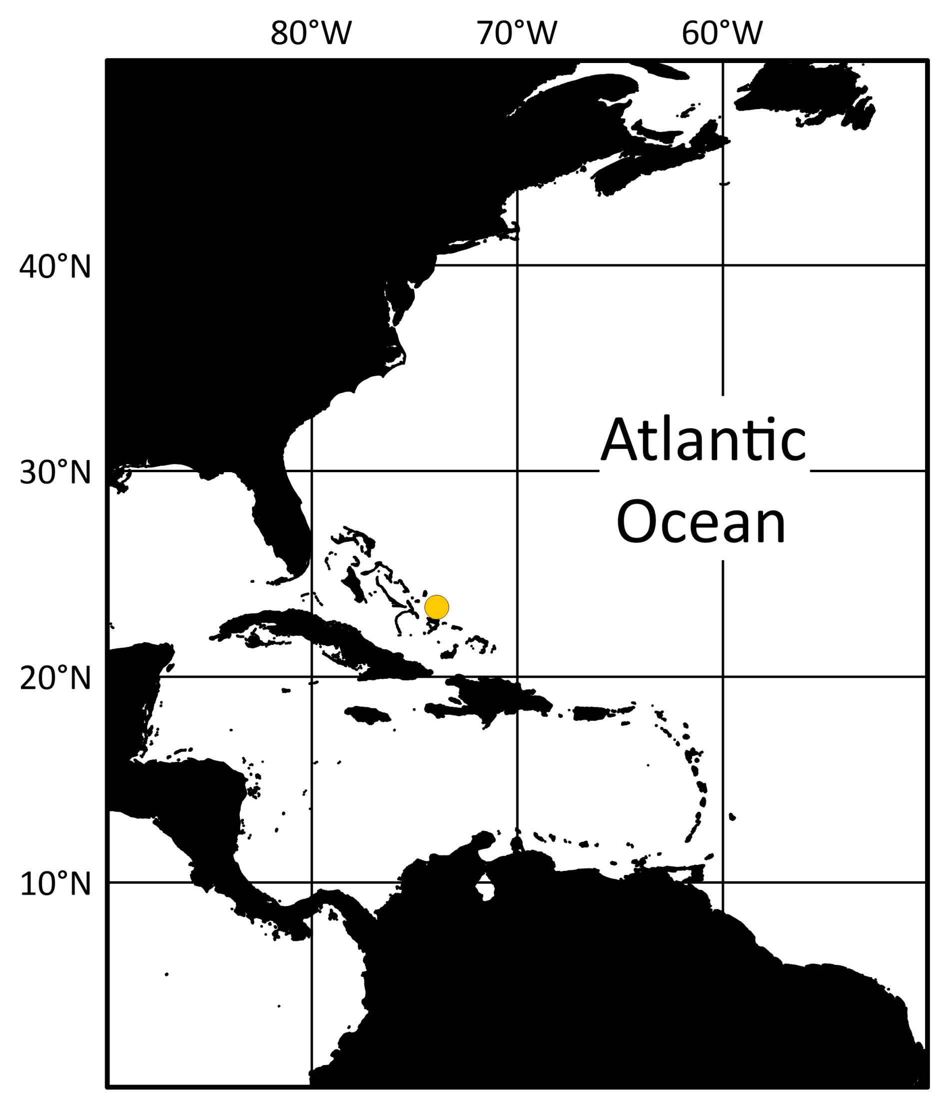
Hydroacoustic signals linked to the sinking of SS El Faro

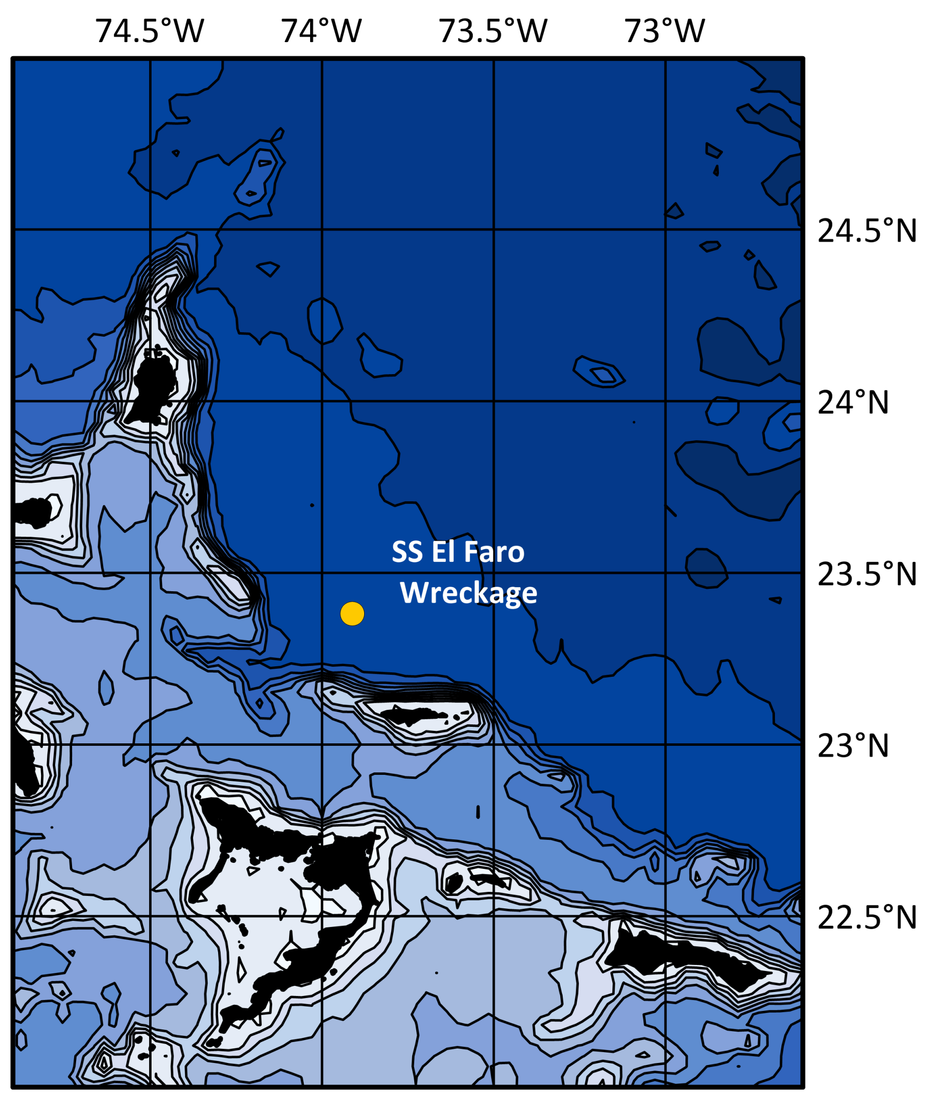
Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

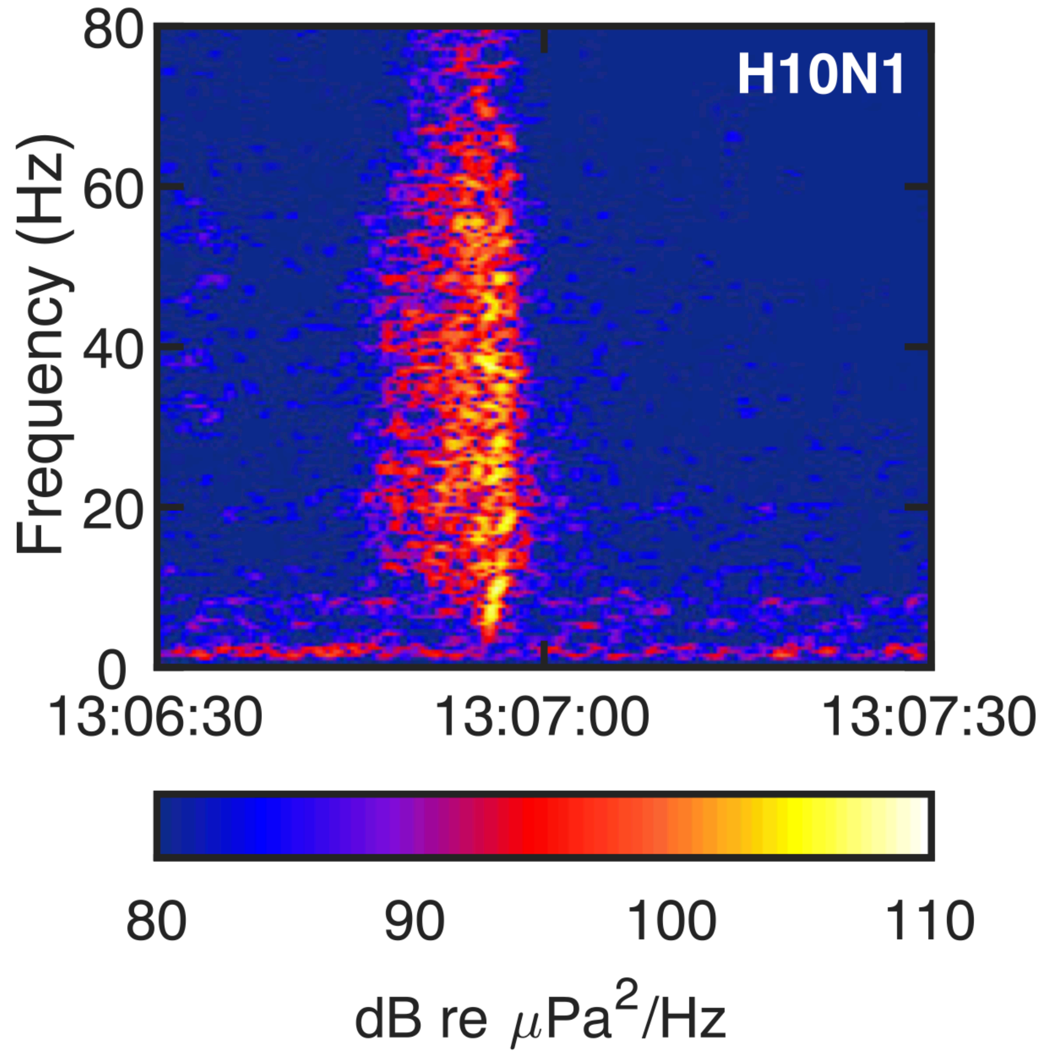
Introduction

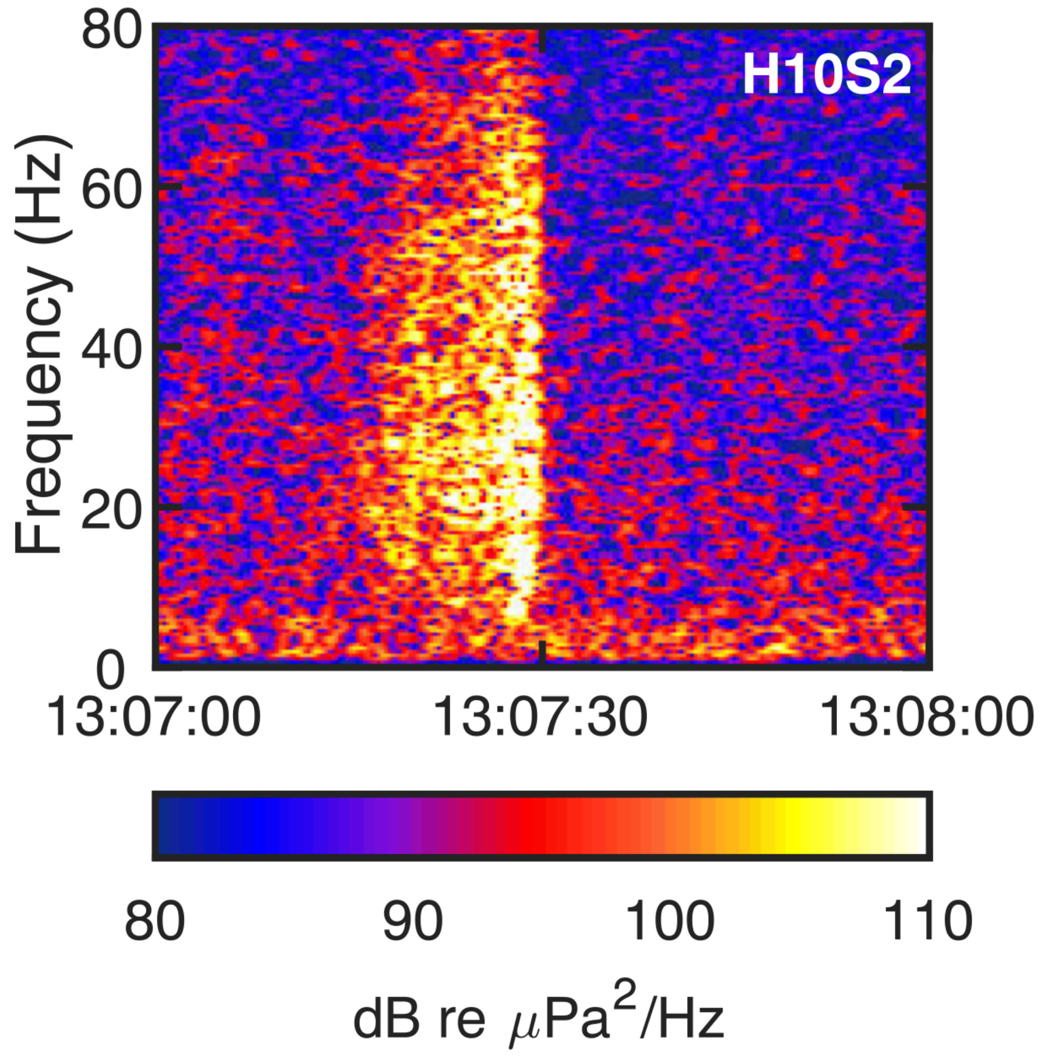
INTRODUCTION

- On 1 Oct 2015, the cargo steamship SS El Faro sank approx. 120 km east of Long Island, The Bahamas, during Hurricane Joaquin.
- SS El Faro's Emergency Position Indicating Radio Beacon (EPIRB) was activated at 11:35 UTC, but did not include a GPS fix. Underwater searches eventually located the wreckage and recovered the Voyage Data Recorder (VDR). VDR readings suggest that the ship sank at or shortly after 11:40 UTC[2].









- Hydrophones of IMS station H10, Ascension Island, recorded a broadband, high-frequency arrival from the direction of the last known position of SS El Faro around 13:07 UTC, i.e. approx. 85 min after the vessel had sunk.

→ Is this signal related to the accident?

[2]NTSB Accident Report NTSB/MAR-17/01

SnT 2021
CTBT: SCIENCE AND TECHNOLOGY CONFERENCE

Poster No.: P1.3-331

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Hydroacoustic Observations

CTBTO
PREPARATORY COMMISSION

OBSERVATIONS

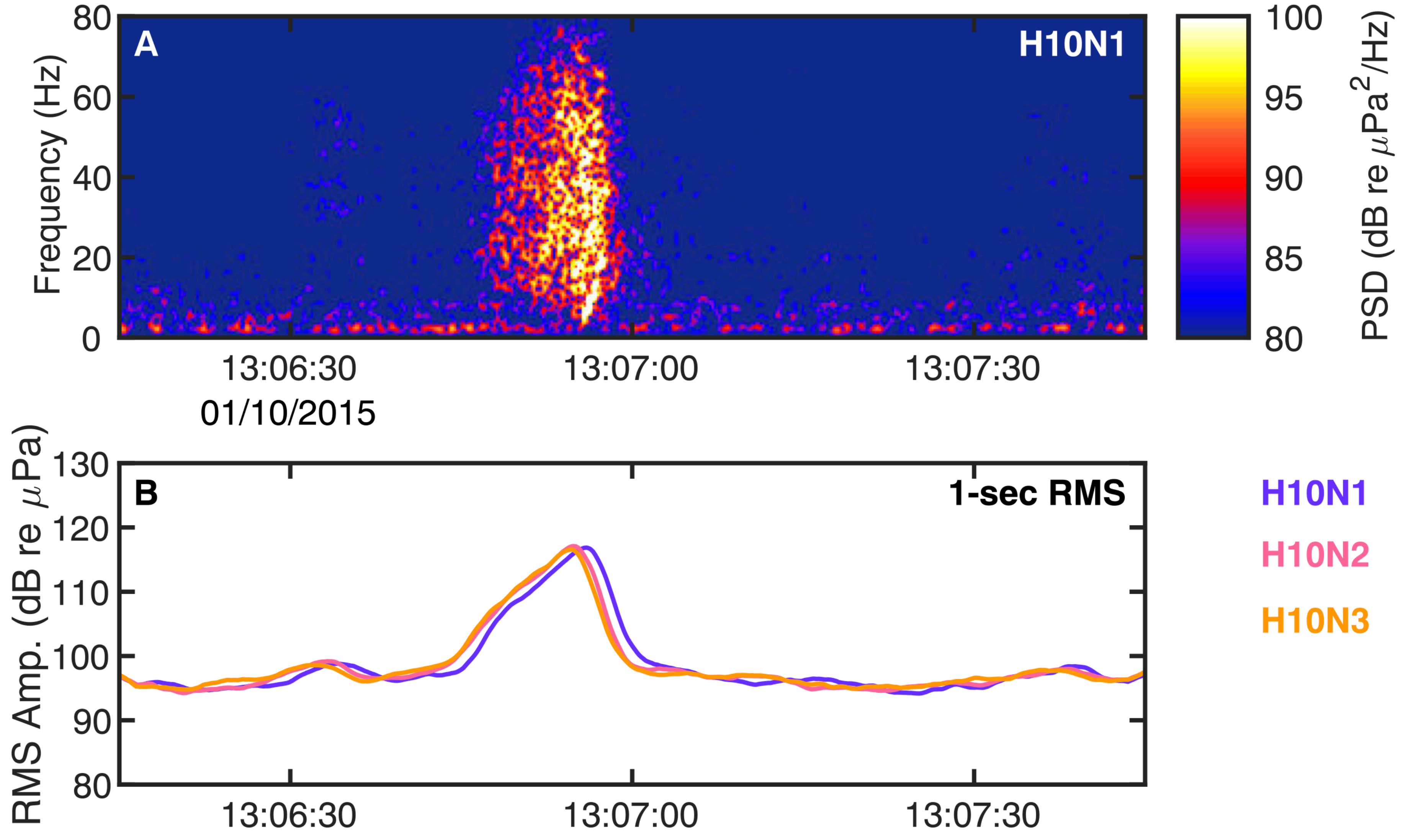


Fig. 4-1: H phase recorded on 1 Oct 2015 at IMS array H10N.

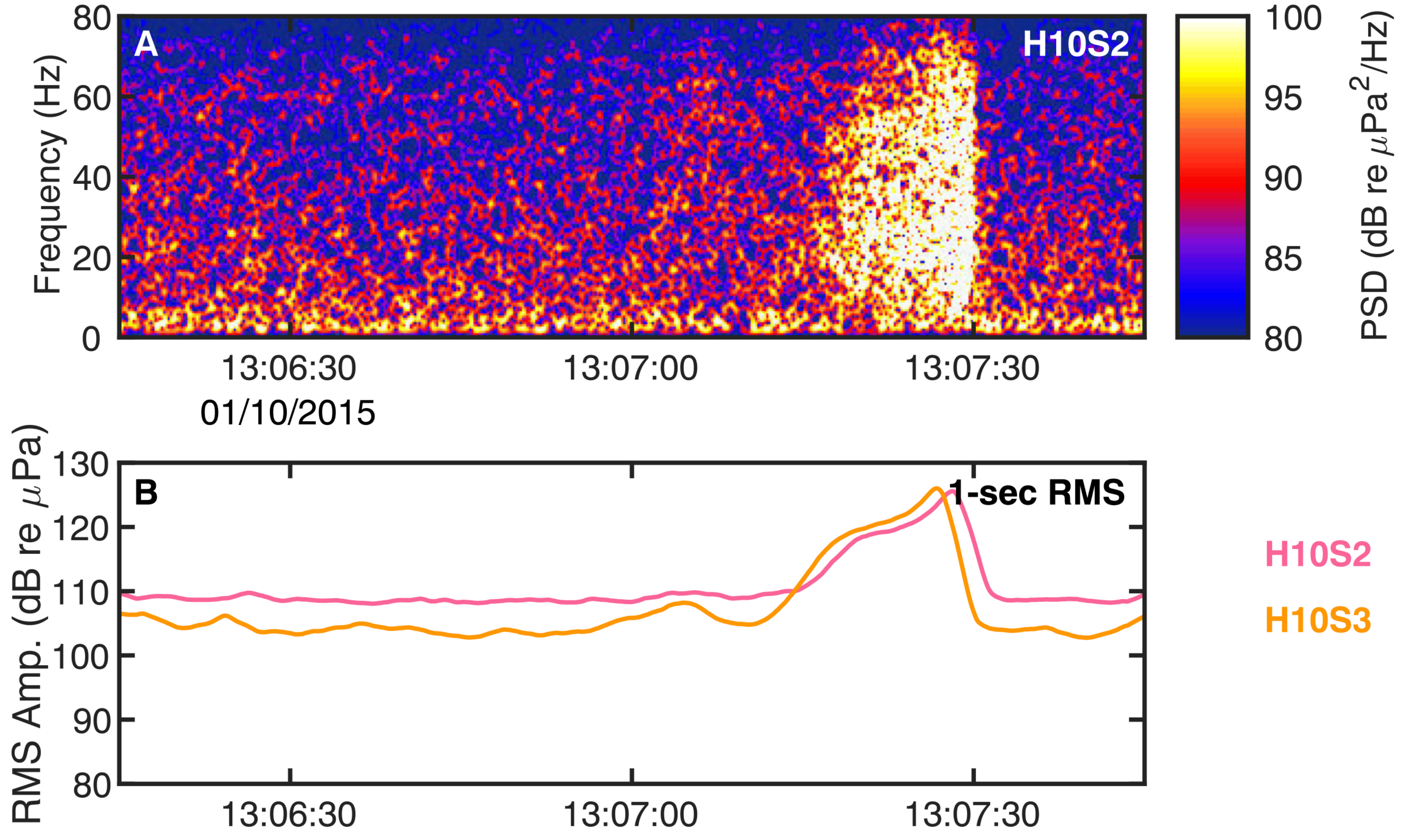


Fig. 4-2: H phase recorded on 1 Oct 2015 at IMS array H10S.

- 10-sec long, broadband impulse observed at all hydrophones of IMS station H10, Ascension Island, around 13:07 UTC.
- Arrival automatically detected by *DFX* and classified as H phase by *StaPro*, i.e. potential in-water source. No (natural) seismic origin associated during analyst review.
- Energy signature typical for long-range SOFAR propagation of in-water sources, as lower-order modes create a distinct ‘finale’

- No arrival recorded at land-based T phase stations at the Azores (H07N/S) or other island seismometers, leaving only two arrays of one station (H10) for location
- At H10S, only two elements operational due to cable damage; both suffer from high noise levels

→ <u>Challenging conditions for event analysis</u>

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Direction-of-Arrival (DOA) Estimation - H10N

DOA - H10N

DTK-PMCC Processing:

- Progressive multi-channel correlation of the incoming wavefront indicates a back azimuth corresponding to the location of SS El Faro
  → PMCC detections stable to within ≤ 0.1°
- Sound speed is within ±3 m/s of nominal local minimum, indicating SOFAR propagation
- Arrival structure is well resolved in the PMCC results: Lower-order modes travel near the sound speed minimum, experience little attenuation, and arrive last, creating a distinct, coherent crescendo towards the end of the coda[3]

Implications for Location Estimate:

- Arrival time picks of in-water phases should be placed on the crescendo, as travel time grids used for event location are typically sampled along the depth of minimum speed in the water column

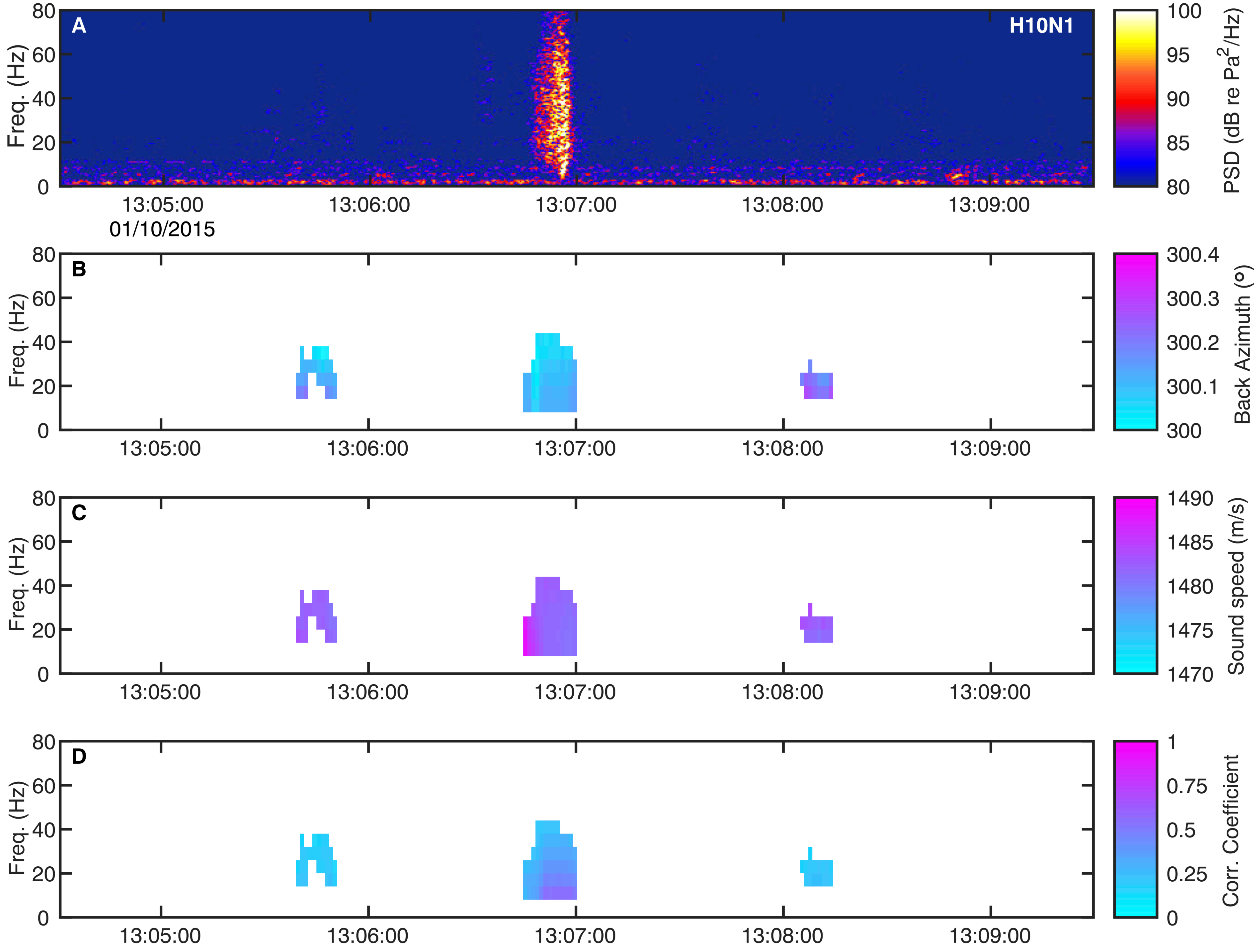


Fig. 5-1: PMCC results for H10N (6-Hz-wide bands from 2 to 80 Hz, 12-sec, 90% overlap).

[3]cf. deGroot-Hedlin, Blackman, and Jenkins (GJI, 2009)

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Direction-of-Arrival (DOA) Estimation - H10S

DOA - H10S

"Two-Element Array" Processing:

- Only two hydrophones of H10S available for direction-of-arrival estimation
  → Inversion via PMCC not feasible
- Lag-time estimate *Δt* derived from cross-correlation of waveform data allows for an angle-of-arrival estimate θ through

  (I) $\theta_{ij}(\Delta t) = \cos^{-1}(c * \Delta t / d_{ij})$,

  where *d* is the distance between the hydrophone elements *i,j*.
- Range-dependency of the cosine function resolved by comparison with H10N arrival
- Calculation in (I) requires a priori estimate of sound speed *c* at the array
  → World Ocean Atlas (Fig. 6-2)

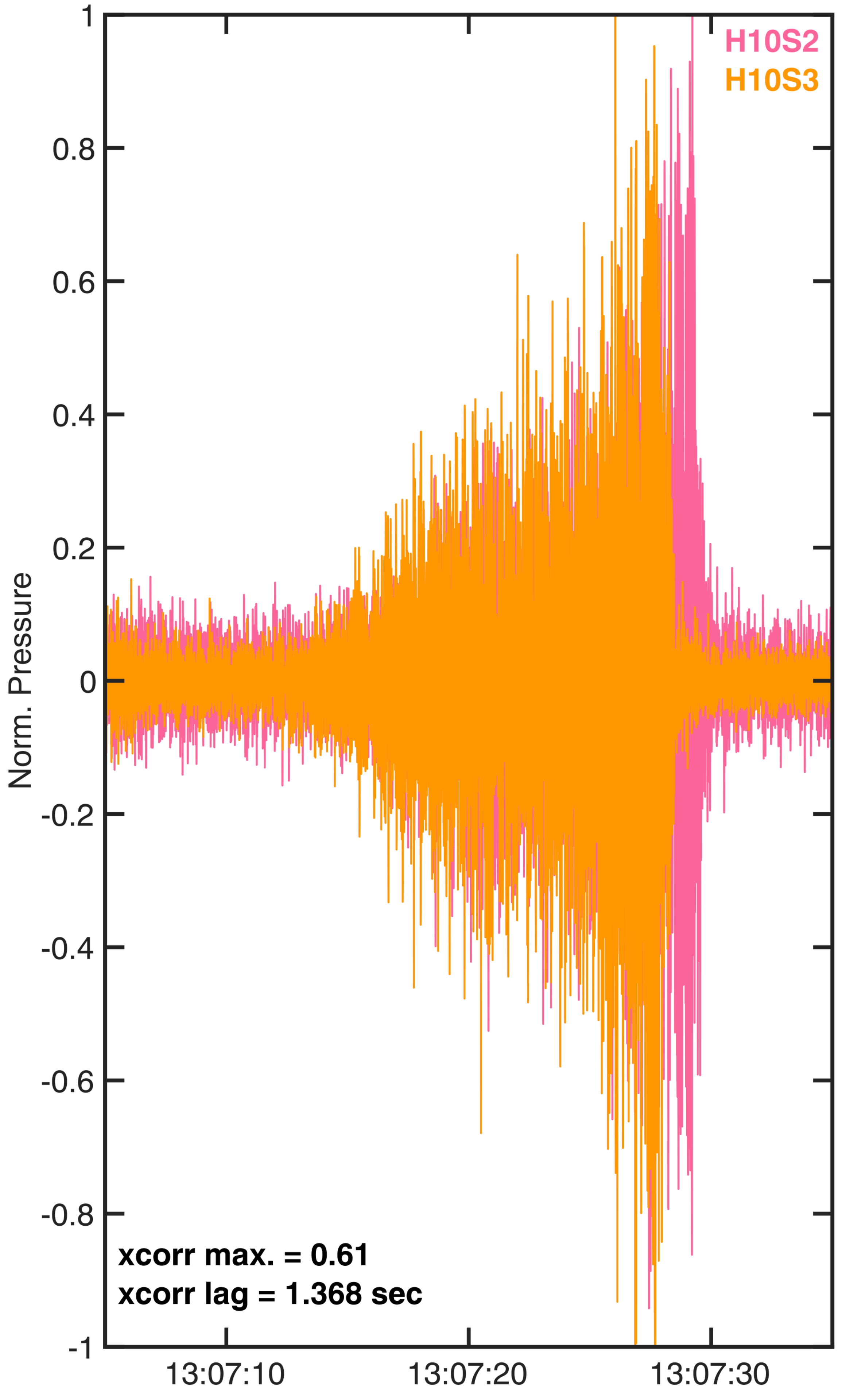


Fig. 6-1: H10S2, H10S3 waveform data and cross-correlation results.

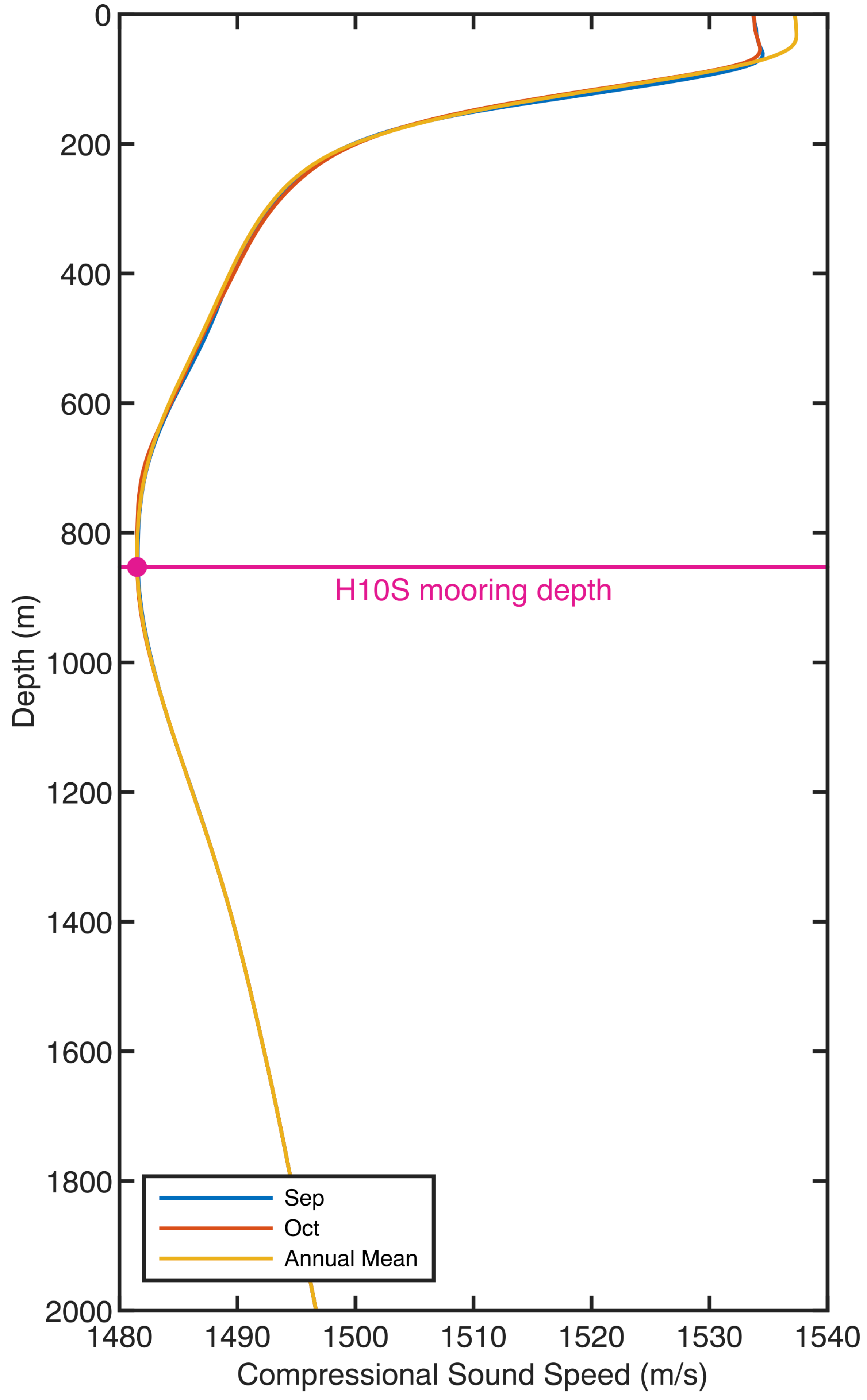


Fig. 6-2: Water column sound speed profile at H10S, 2009 World Ocean Atlas.

Hydroacoustic signals linked to the sinking of SS El Faro

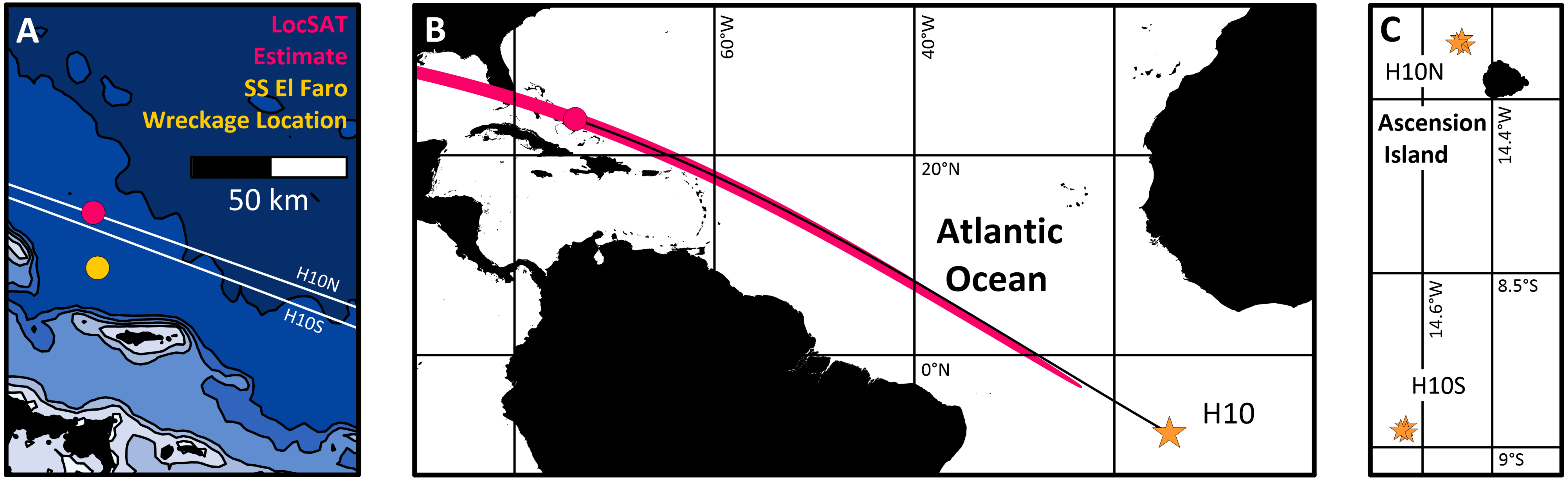
Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Location Estimate

LOCATION

Event Location and Timing:

- Estimate for location and origin time obtained using the LocSAT extension of Geotool (eNIAB)
  - → Assumes mean SOFAR axis sound speed 1485 m/s (from World Ocean Atlas, H10 to last known position of SS El Faro)
- The solution agrees with VDR data and wreckage location, but is poorly constrained (red 90% confidence region) due the low number of time picks and back azimuths, as well as the lopsided station geometry (max. gap between the two arrays: 359°!)
  - → Event origin estimate is within 25 km of the confirmed position of the SS El Faro wreckage
  - → Origin time is 11:44:41 UTC, i.e. 5 min after VDR ends and 9 min after EPIRB activation

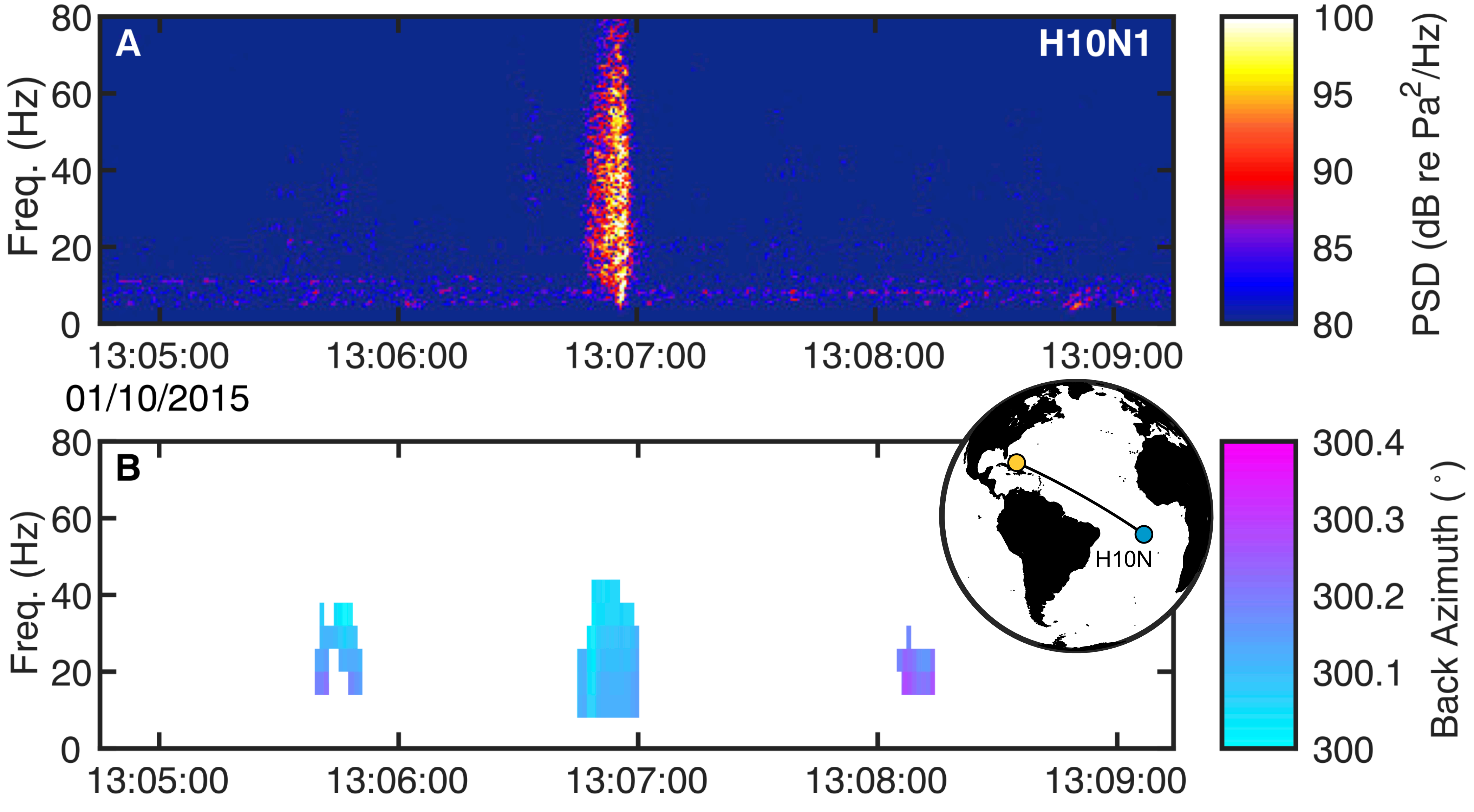


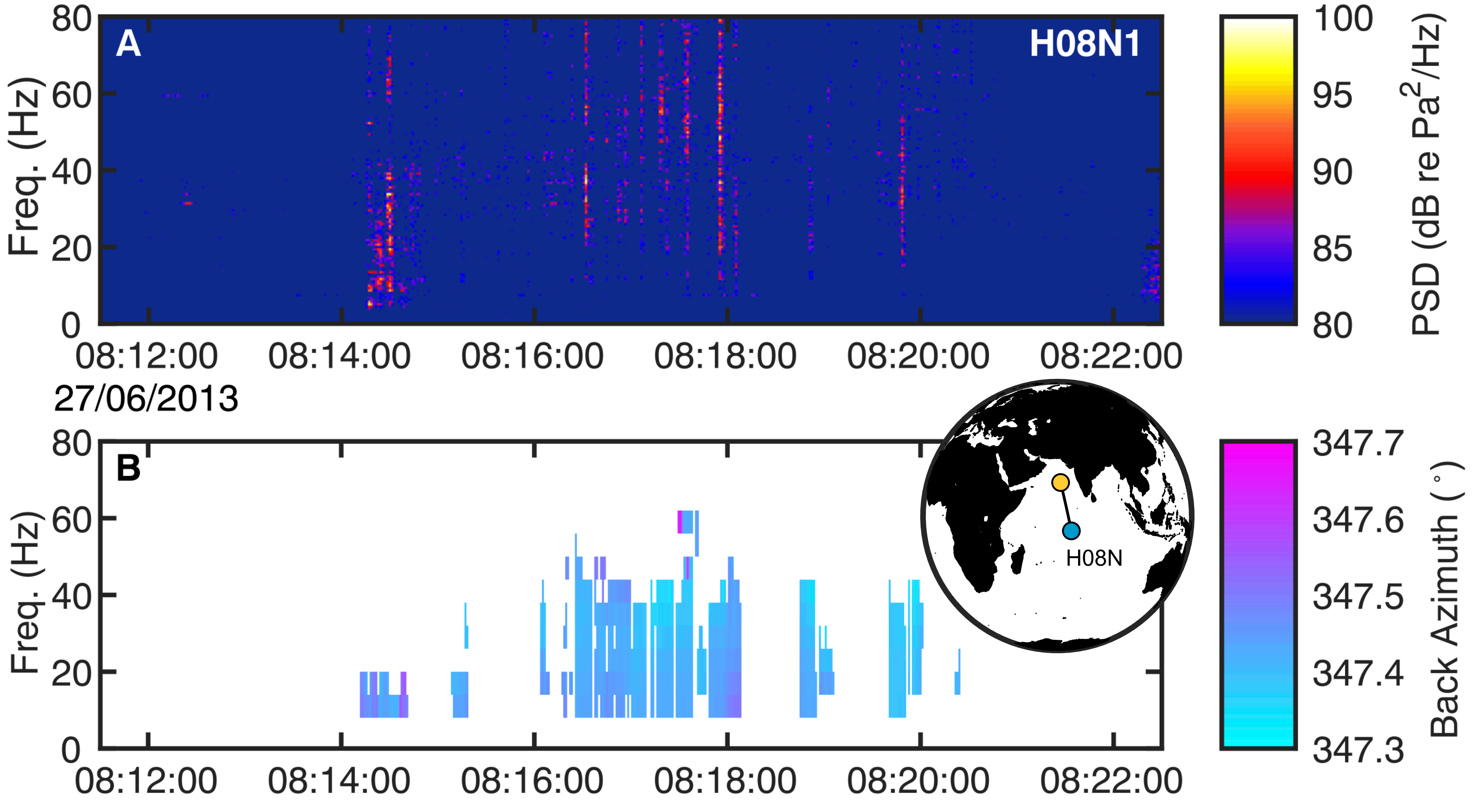
Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Comparison of Hydroacoustic Arrivals: SS El Faro - MOL Comfort

COMPARISON





SS El Faro - 1 Oct 2015, 11:40 UTC or shortly after (23.38°N 73.91°W):

- Steam-powered roll-on/roll-off cargo ship (31,500 GT)
- Acoustic event observed by two hydrophone arrays, but of the same station: Located, but poorly constrained solution due to long distance and unfavorable station geometry
  → Source-receiver range: Approx. 7,330 km to H10N
- Mean PMCC detections within 0.1° of the geodesic back azimuth
- Single, 10-sec long, broadband arrival without distinct cepstral peak (‘bubble pulse’), accompanied by two weaker transients
  → Break-up of vessel upon/during descent? Failure of boiler unit?

MOL Comfort - 27 June 2013, 07:48 UTC (14.43°N 66.43°E):

- Diesel-powered, medium-size container ship (86,500 GT)
- Acoustic event observed by only one IMS array: Not locatable, but eyewitness reports and telemetry are in excellent agreement with arrival time and azimuth (< 30-sec and < 0.1°, respectively)[4]
  → Source-receiver range: Approx. 2,350 km to H08N
- Mean PMCC detections indicate a series of high-frequency, 5-10-sec long transients over the course of 8 min. Amplitudes are lower than those of SS El Faro, despite 5,000 km shorter range and larger size
  → Bulkheads / containers reaching crush depth?

[4]MOL Comfort Update No. 12 (MOL Mitsui O.S.K. Lines, 2013)

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

DISCUSSION

- Results from IMS H10 hydrophone data analysis are in excellent agreement with the confirmed wreckage location and reconstructed timeline of the sinking of SS El Faro[5]:
  - → Event origin time: 5 min after VDR ending, 9 min after EPIRB activation
  - → Location estimate: Within 25 km of the position of the wreckage
- Large uncertainty region due to unfavorable station geometry, long source-receiver distance (approx. 7,330 km), and limited number of time picks/back azimuths
- DTK-PMCC processing offers exceptional resolution of the arrival structure and back azimuth
  - → PMCC detections are accurate to within 0.1° for a source at the site of the wreckage
- SS El Faro's wreckage was found with the bridge and main stack detached, though post-event analysis of the ship's structural integrity indicates that break-up was unlikely to have occurred while being afloat[6]. Hence, the acoustic event observed at H10 could be related to the break-up of SS El Faro during descent, and/or (explosive) failure of the steam-powered propulsion system.
  - → ROV inspection of the wreckage notes damage to the boiler casing and surrounding bulkheads[7].
  - → However: A distinct cepstral peak ('bubble pulse') is not observed. Further analysis is needed!
- Comparison with the 2013 sinking of MOL Comfort suggests that acoustic signatures of shipping accidents can vary noticeably, and may depend on the type of incident, ship-built, rate of descent etc
  - → Not all accidents are equally detectable/locatable by IMS instruments!

[5]cf. NTSB Illustrated Digest SPC-18-01
[6]CSRA Dynamic Analysis and Sinking Report
[7]cf. NTSB El Faro Wreckage Examination, p. 139 ff

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

CONCLUSION

The acoustic event recorded by IMS hydrophone station H10, Ascension Island, is most likely associated with the 2015 sinking of SS El Faro

Using IMS hydrophone data, only a minimal number of assumptions is required to successfully locate and study low-magnitude, in-water events, even at megameter source-receiver distances and when few receivers are available

Under favorable conditions, IMS data can provide supporting evidence for salvage operations (location) and accident analysis (timeline)

Hydroacoustic signals linked to the sinking of SS El Faro

Metz, D., Nielsen, P. L., Zampolli, M., Haralabus, G.

Bye Bye

FINAL SLIDE

- End of ePoster presentation -

Thank you for your interest