

Seismic and Hydroacoustic Observations from Underwater Explosions off the East Coast of Florida



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Introduction

- The United States Navy is required to test the ability of new classes of ship to withstand explosions. During these shock trials, identical 10000lb underwater chemical explosions are detonated close to the hull of the vessel undergoing testing.
- In 2016, five explosions were detonated close to two ships (the USS Jackson and the USS Milwaukee). Similar shock trials were also conducted in 2001 (USS Winston Churchill) and 2008 (USS Mesa Verde).
- In terms of monitoring compliance with the Comprehensive Nuclear-Test-Ban Treaty, as some ground-truth (GT) information exists, the explosions provide an opportunity to assess the capability of the International Monitoring System (IMS) to detect, locate and characterise small yield underwater explosions (body wave magnitudes around 3.5).

The Explosions

- The test area is defined by a minimum 600ft (182 m) water depth and a maximum distance of 100 nautical miles (185 km) east of the Mayport Naval Station.
- Four of the 2016 explosions were reported in the Reviewed Event Bulletin (REB) produced by the International Data Centre.
- Signals are observed on IMS seismic and hydroacoustic sensors and US Geological Survey seismometers in the Eastern US.

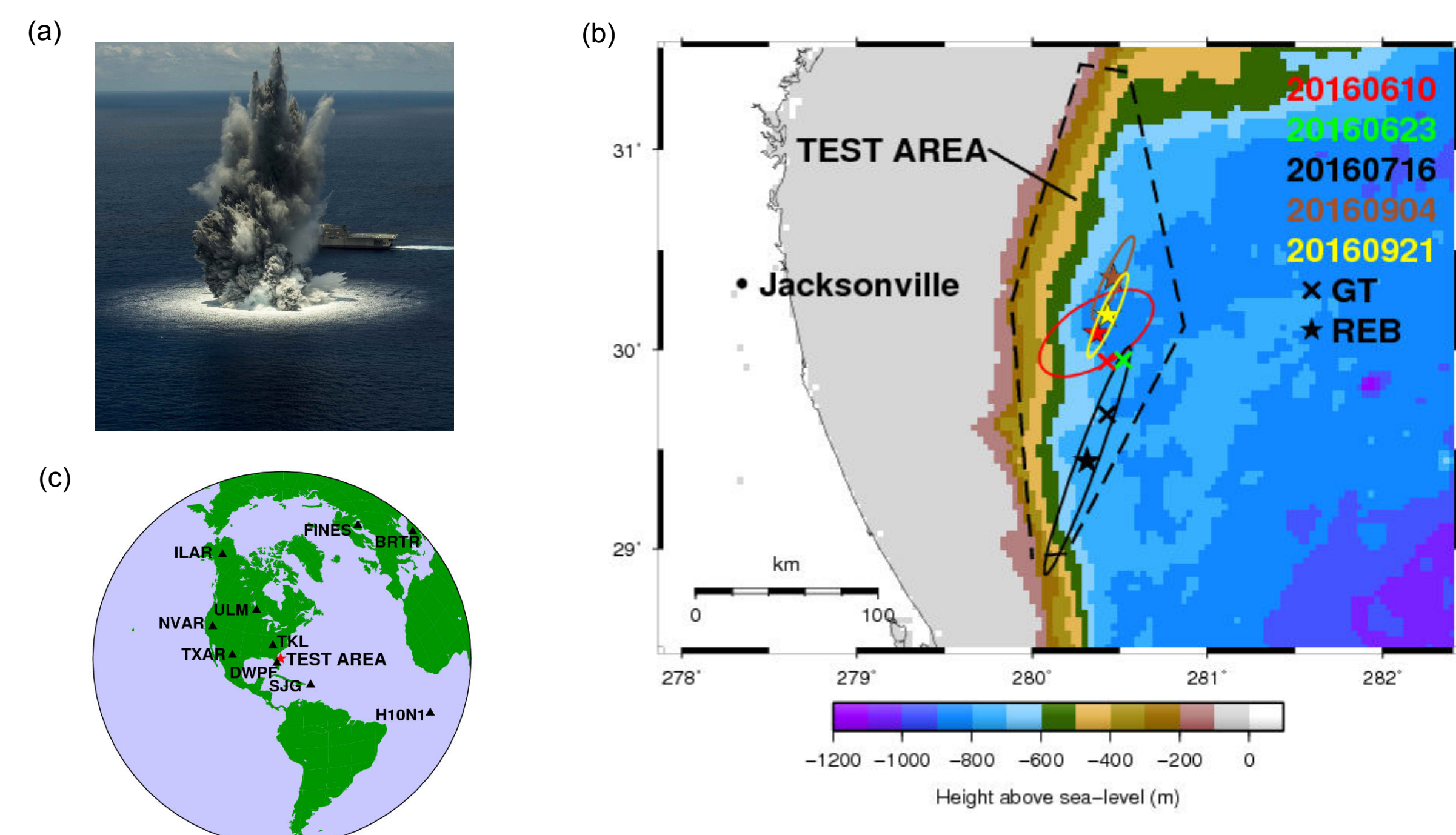
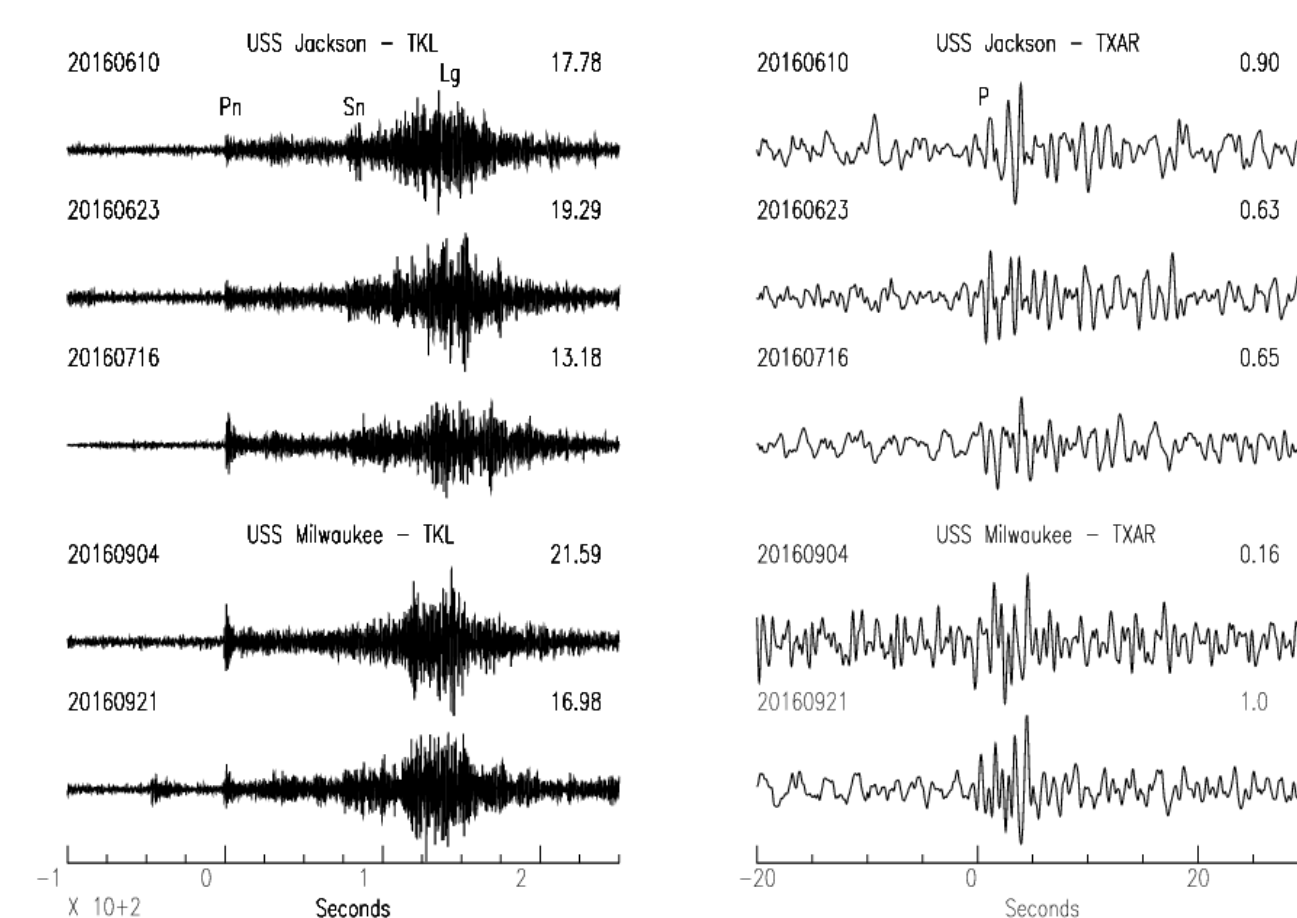


Figure 1: (a) Image showing the USS Jackson undergoing a shock trial (courtesy of the US Navy). (b) NEIC epicentres, and REB epicentres and uncertainty ellipses of the five shock trials conducted in 2016. Ground-truth epicentres are also shown where available. (c) Locations of IMS stations with seismic and hydroacoustic arrivals in the REB for the 2016 explosions. PKPbc was also observed at IMS stations ASAR and WRA in Australia. The location of Global Seismographic Network station DWPF is also shown.

Seismic Observations

- For all the 2016 explosions, signals are clearly observed at TKL and TXAR.
- At most teleseismic stations the signal-to-noise ratios of P are low.

Figure 2: Observed seismograms at TKL ($\Delta=6.5^\circ$) and TXAR ($\Delta=20.9^\circ$) for the 2016 explosions. The seismograms have been converted to a common instrument response and bandpass filtered between 1 and 4.5 Hz.



Location Comparisons

- GT locations were not available for the 20160904 and 20160921 explosions.
- Epicentres for these 2 explosions are estimated using the Bayesloc (Myers *et al.*, 2007) multiple-event location algorithm using different combinations of fixed GT epicentres.
- Along with GT locations and hand-picked seismic and hydroacoustic arrival times for the 20160610, 20160623 and 20160716 explosions, we also use GT location and arrival time data from three earlier explosions (20010603, 20010611, 20080913).
- With 3 epicentres fixed, the mean mislocation for events with GT locations is between 2 and 12.5 km.

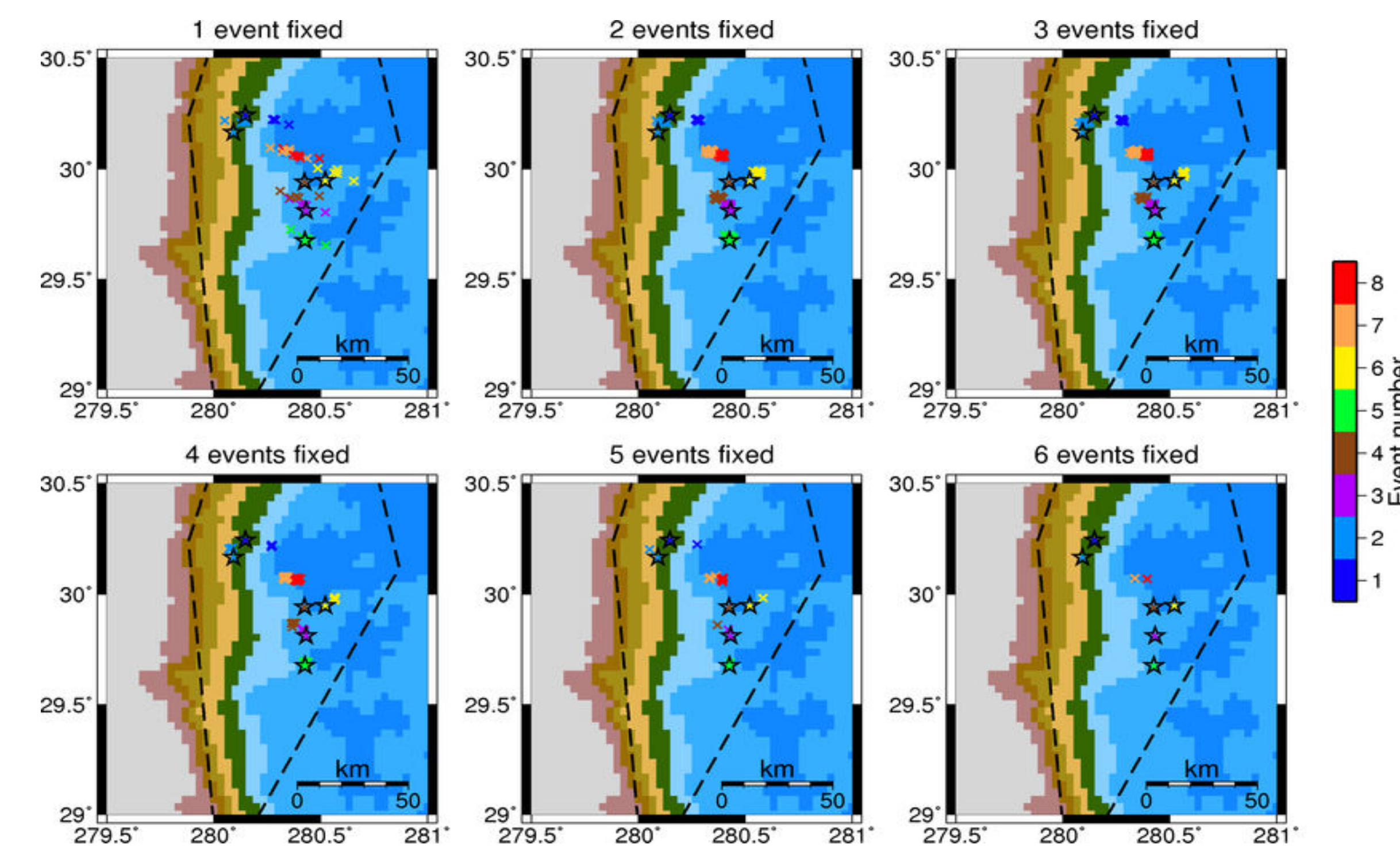


Figure 3: Relocated epicentres (crosses) estimated using different combinations of fixed GT epicentres. The GT epicentres are displayed as open stars. Event numbers are in chronological order.

Source Characterisation and Yield Estimation

- Spectra recorded at TKL and DWPF show clear scalloping as a result of interference between the primary shock and bubble pulse in the water.

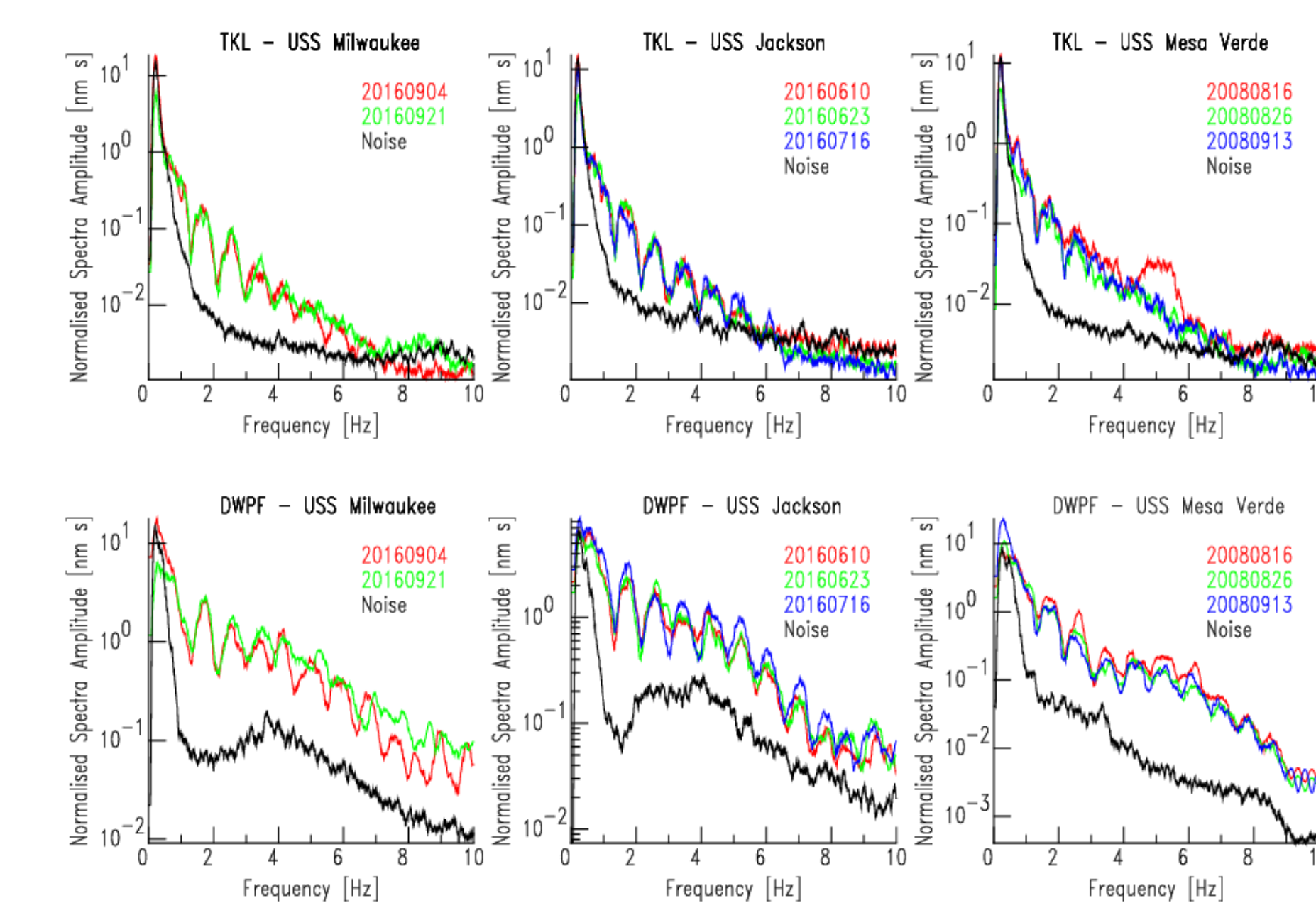


Figure 4: Amplitude spectra recorded at TKL and DWPF. The amplitude spectra are calculated for a common instrument response using a 200 second time window that includes Pn, Sn and Lg.

- The predicted bubble pulse frequency, f_b , can be calculated using the known yield (6759 kg), W , and detonation depth (61m), h .

$$f_b \approx \frac{(h + 10)^{\frac{2}{3}}}{2.11W^{\frac{1}{3}}}$$

- The observed value of 0.85 Hz is consistent with the predicted value of 0.88 Hz.

- The National Earthquake Information Service published M_L s of 3.7 and 3.8.
- If a correction is made for the salinity of the seawater near Florida, the M_L -yield relationship in Gitterman (2001) for the Dead Sea predicts yields of 5595 and 7045 kg. This is in reasonable agreement with the known TNT equivalent yield of 6759 kg.

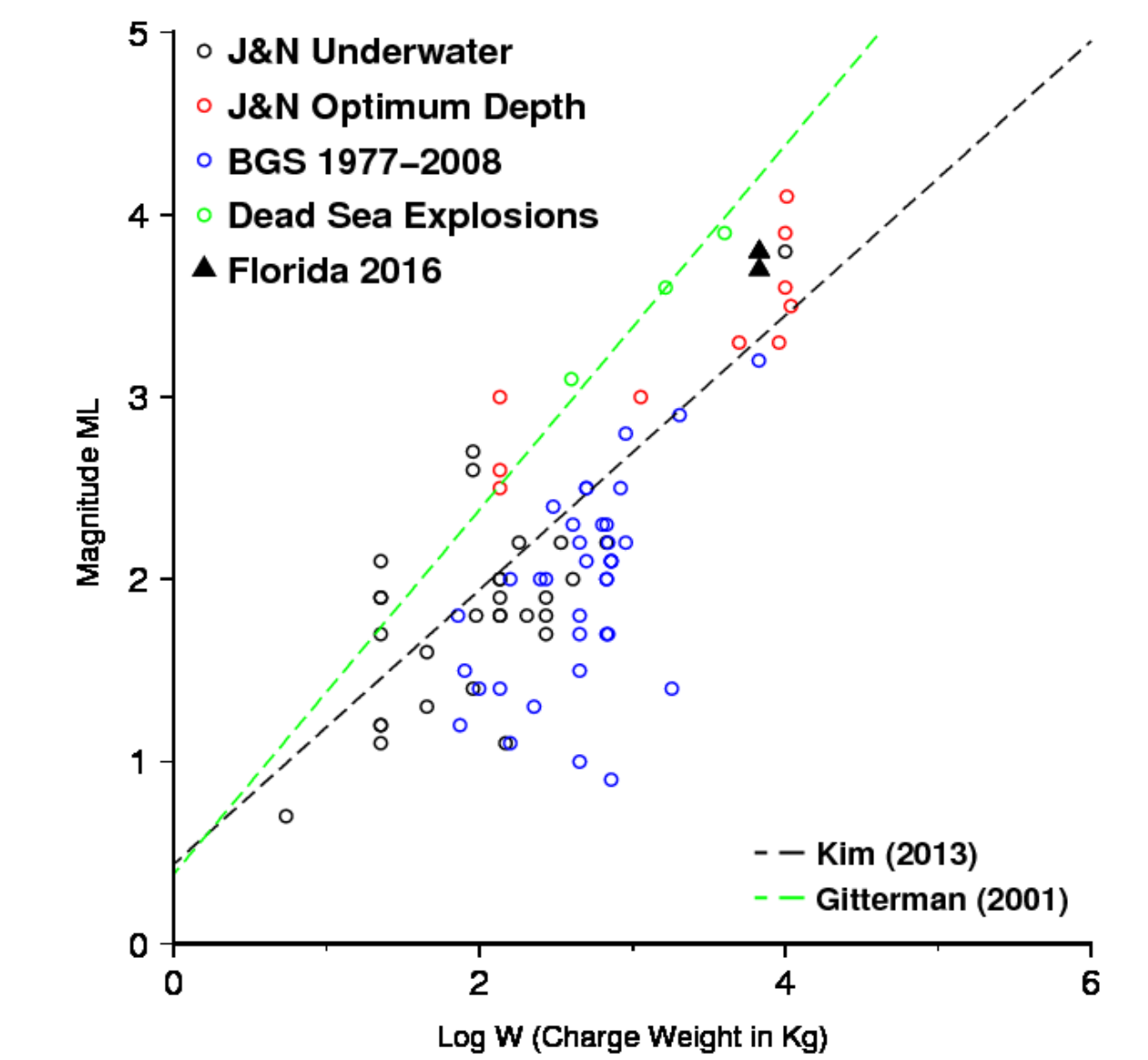


Figure 5: Charge weights and seismic magnitudes for various underwater explosions. J & N explosions are from Jacob and Neilson (1977), the BGS explosions are from Booth (2009), and the Dead Sea explosions are from Gitterman (2001).

Hydroacoustic Observations

- Signals are observed at the IMS hydrophone station H10 off Ascension Island.
- Scalloping of the spectra caused by the bubble pulse is not always seen clearly at H10. This could be due to propagation effects along the path.

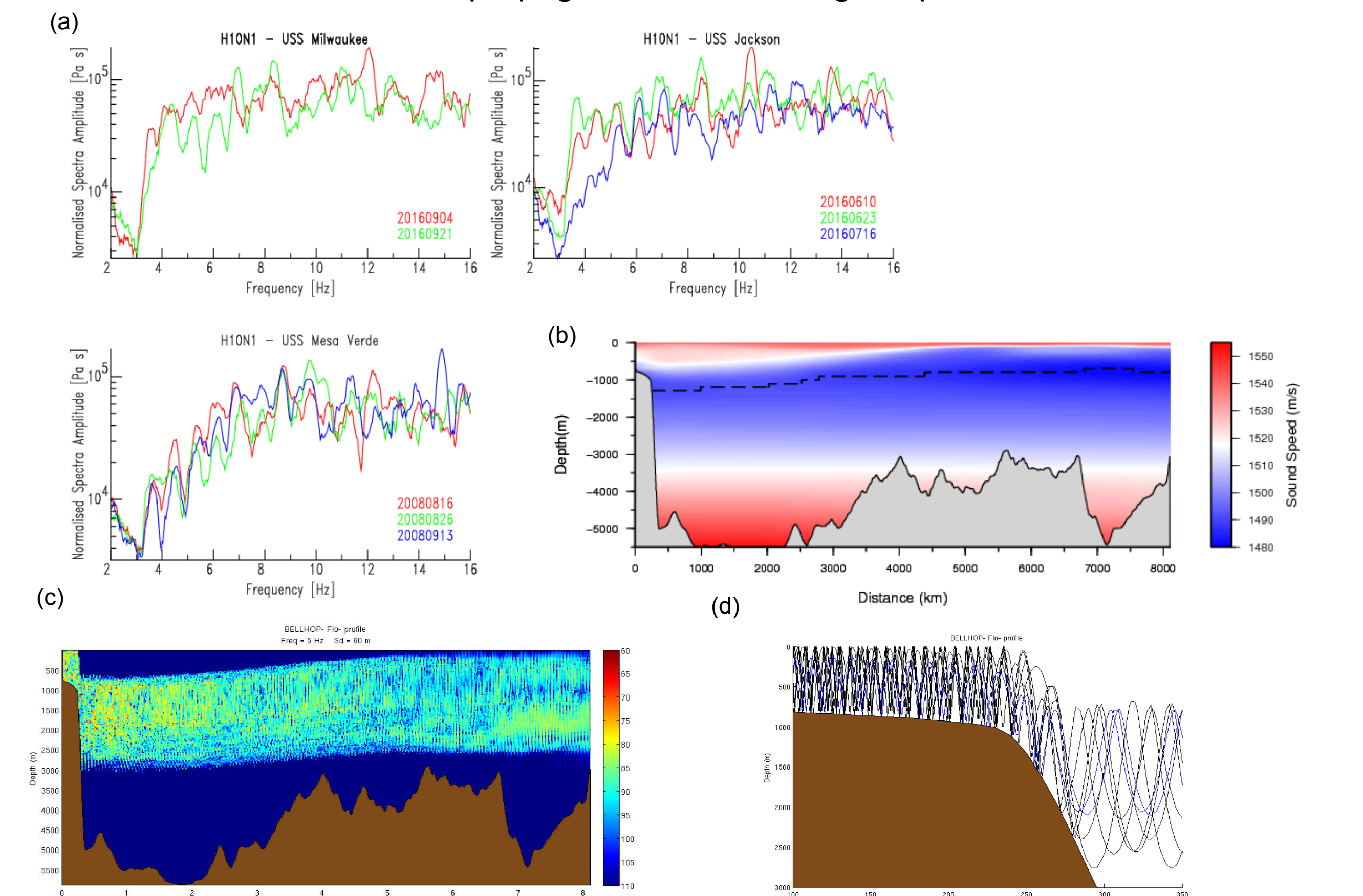


Figure 6: (a) Observed amplitude spectra at hydrophone H10N1 for the 2008 and 2016 explosions. (b) Ocean sound speed profile (2009 World Ocean Atlas) and bathymetry along the great circle path from the test area to the H10N1 hydrophone. The dashed line is the axis of the Sound Fixing and Ranging Channel. (c) Transmission loss (in dB) predicted from ray tracing using BELLHOP (Porter and Buckner, 1987) for a source at 60m depth along a path from the location of the 6 June 2016 explosion to hydrophone H10N1 using a 2D sound speed model. (d) Ray paths predicted by BELLHOP close to the source region.

Conclusions

- US Navy shock trials provide a good opportunity to compare hydroacoustic and seismic observations from underwater explosions.
- Spectra recorded by seismic stations in the Eastern US show clear evidence of the bubble pulse at a frequency which is consistent with ground-truth data.
- The absence of clear bubble pulse observations in some of the spectra at IMS hydrophones highlights the need for using both seismic and hydroacoustic data.

References

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