

Directional Information from Signals Undergoing Hydroacoustic Blockage

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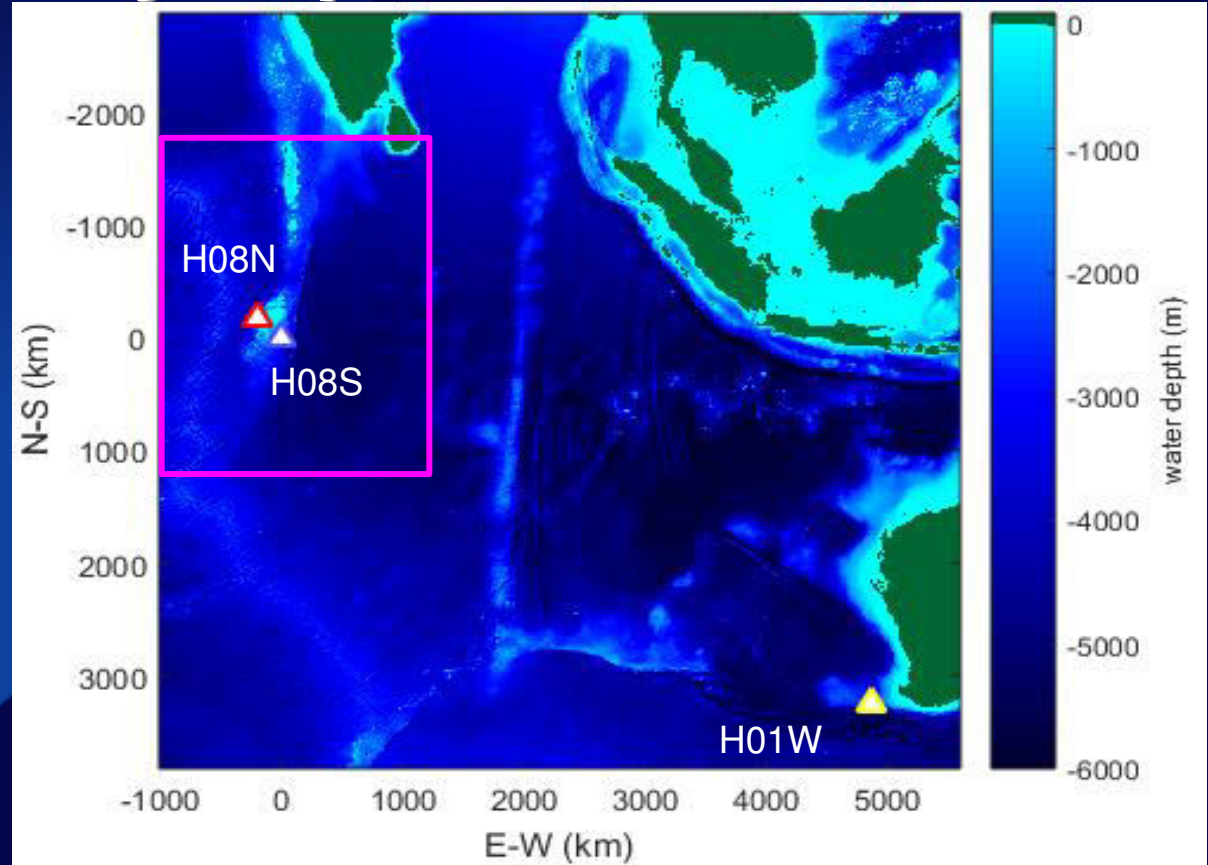
UNIVERSITY of WASHINGTON
Applied Physics Laboratory



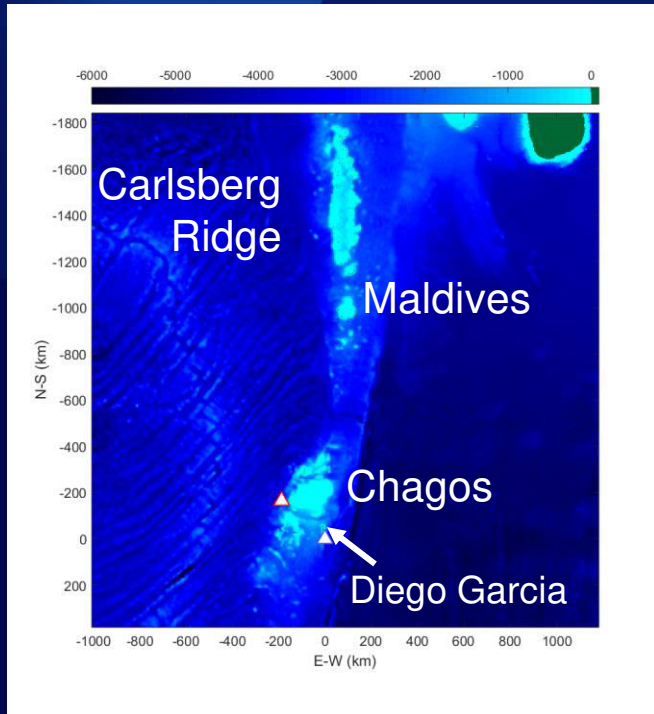
Study of CTBTO hydrophone stations in Indian Ocean

With focus on 3 hydrophone triads:

- **H08N** Diego Garcia North (*inoperative in 2014*)
- **H08S** Diego Garcia South
- **H01W** Cape Leeuwin



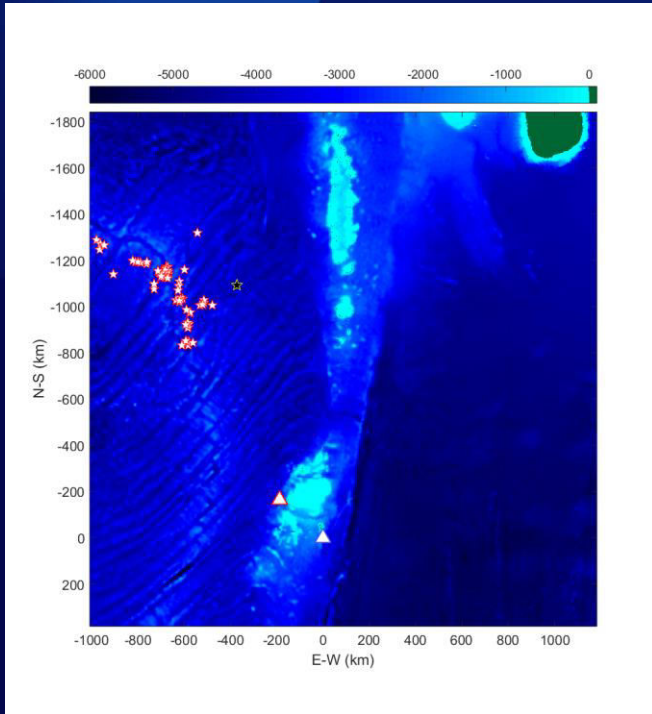
Hydroacoustic blockage at Diego Garcia (H08)



Seismically active
Carlsberg Ridge
(sources of opportunity)

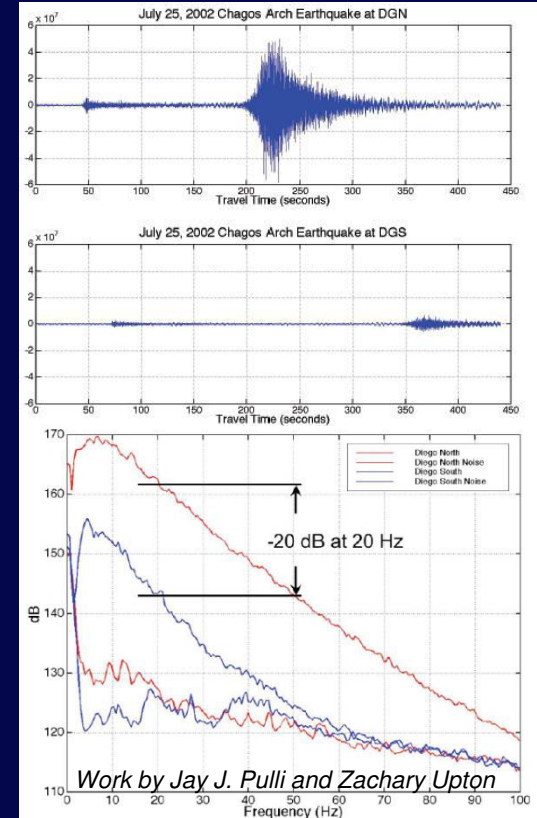
“Line of sight” coverage
for H08 stations
affected by shallows of
Chagos Archipelago

Hydroacoustic blockage at Diego Garcia (H08)



★ cataloged seismic events along Carlsberg Ridge (2000-2014)

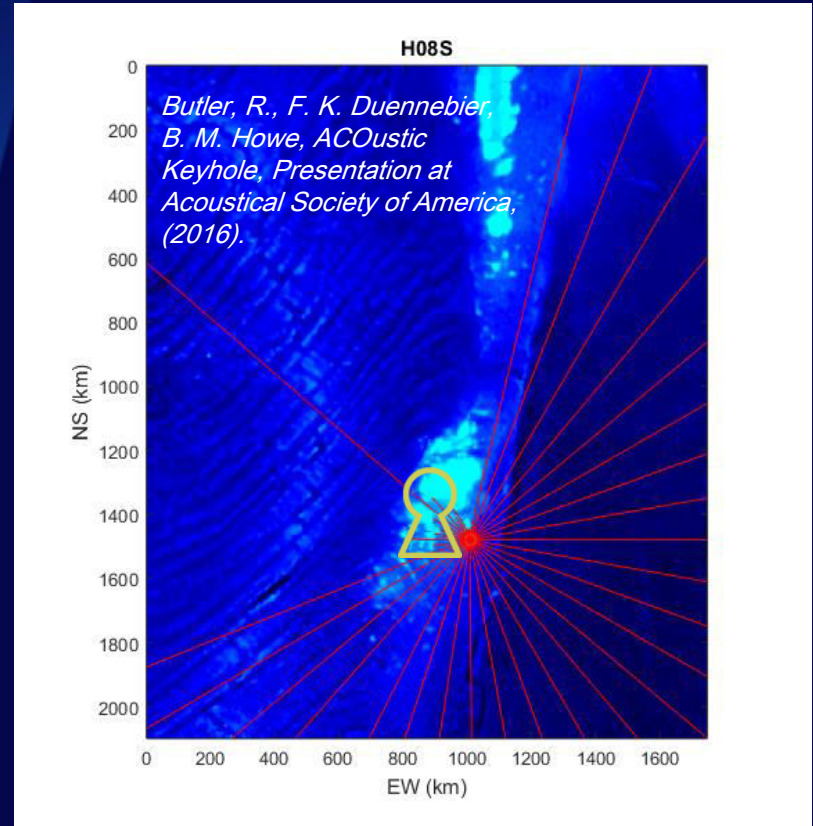
CTBT stations have shown T-phases can be measured on both North and South stations – with coupling into sound channel occurring near source



How do T-phase signals reach the blocked side of Deigo Garcia

How is this possible?

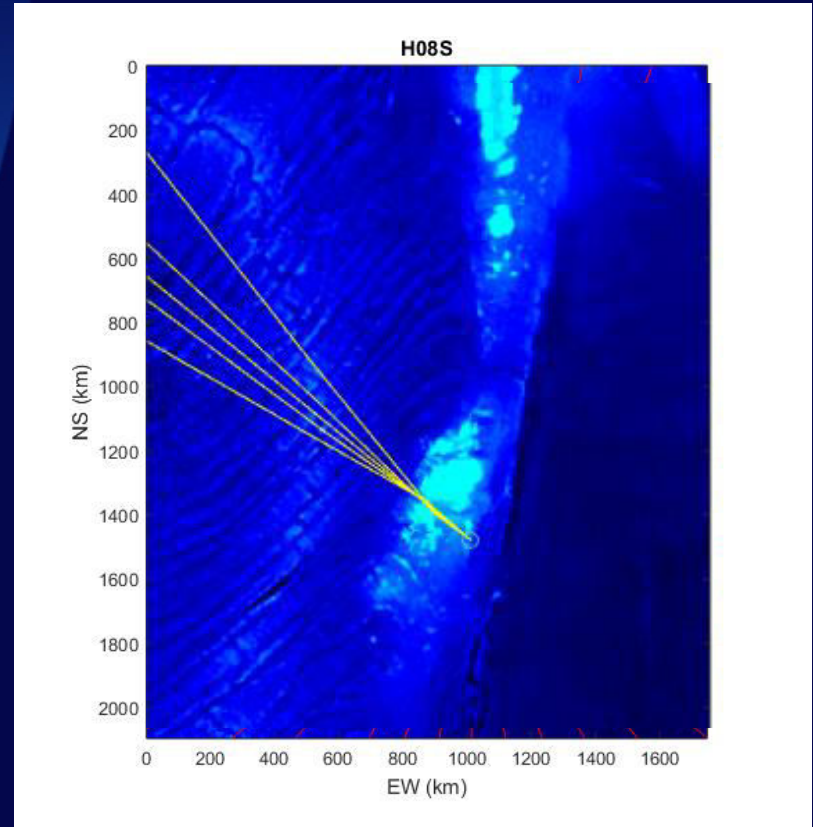
- **Acoustic Keyhole (not quite blocked)**
- Bathymetric refraction
- Diffraction



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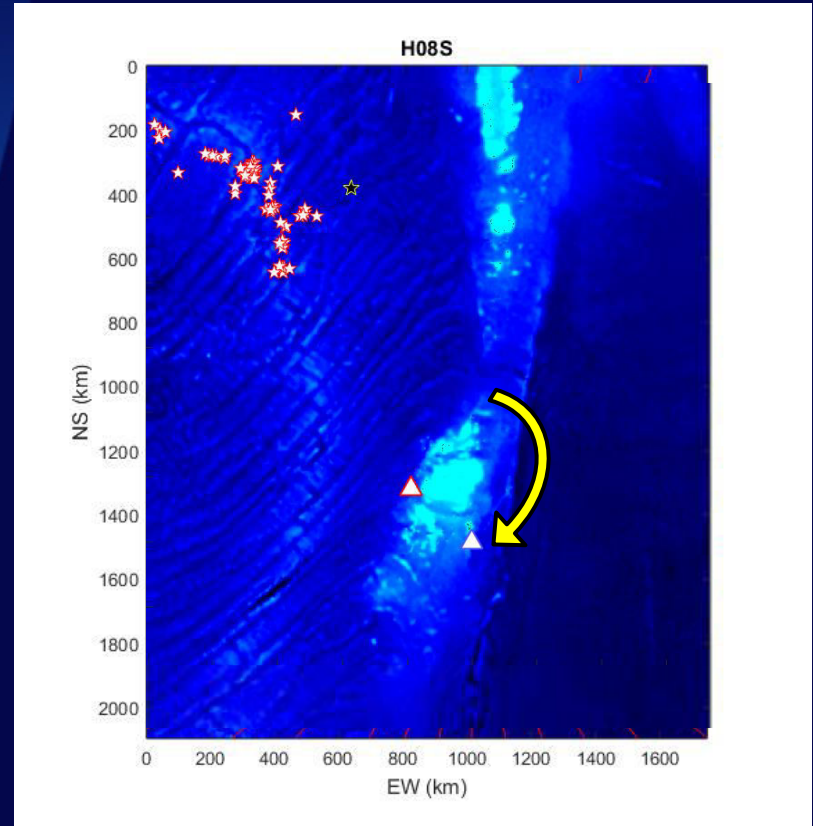
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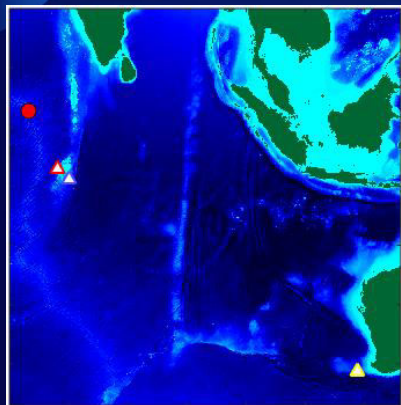
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- **Diffraction**



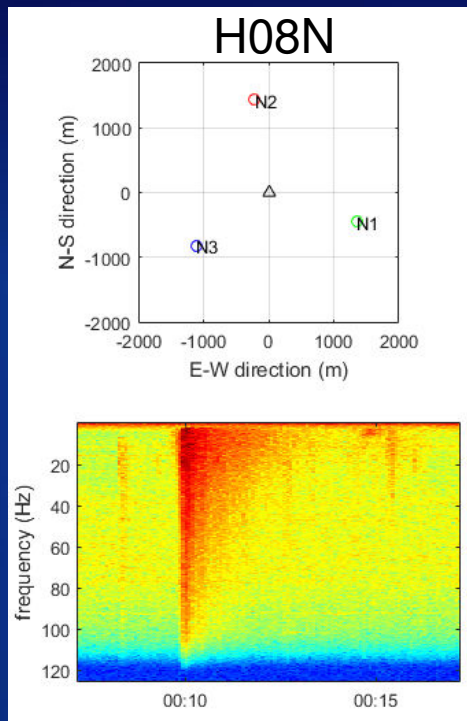
Comparison of clean and blocked arrivals



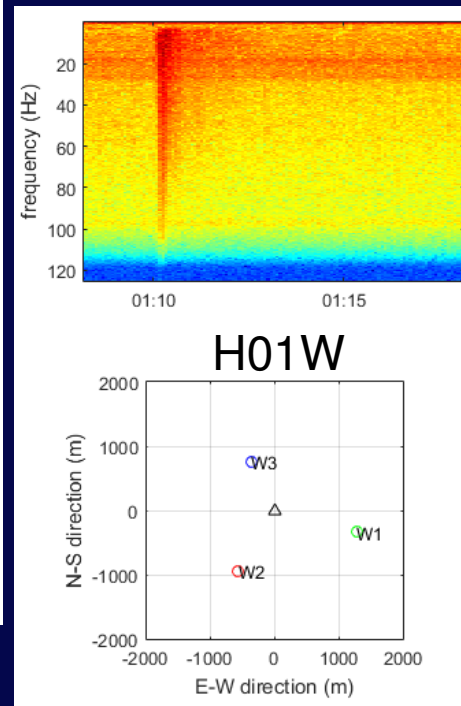
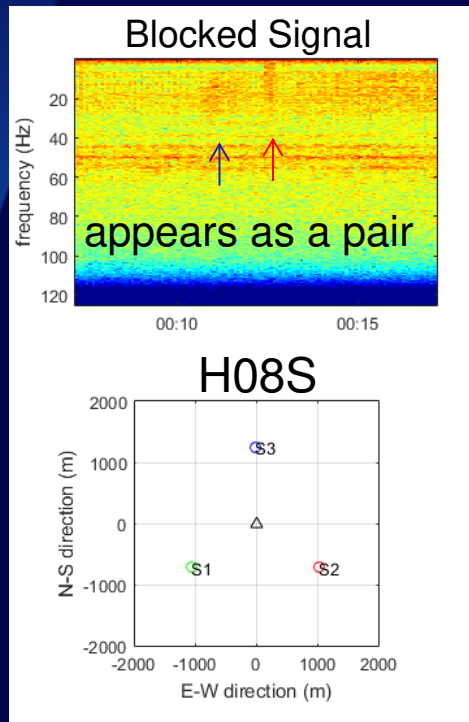
Blocked signal at DGS (H08S)

- High frequency absent
- Pair of arrivals separated by ~1 minute

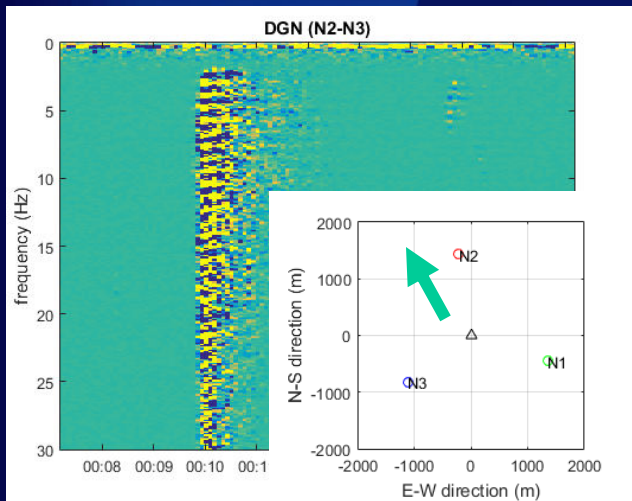
CTBTO SnT2017



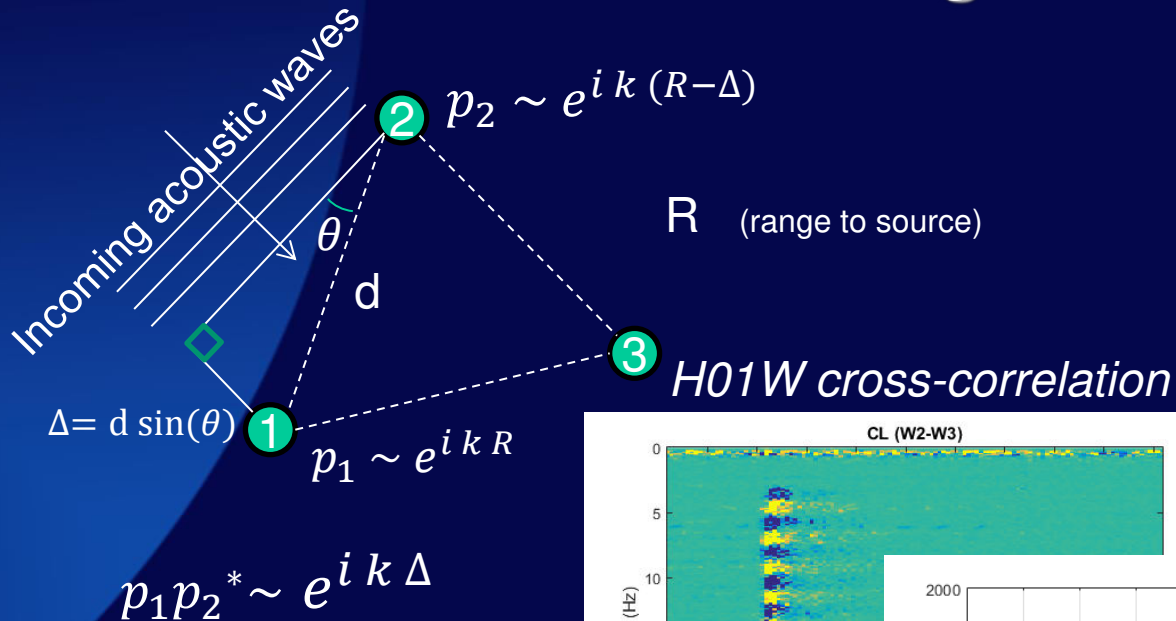
Earthquake on July 5, 2010 @ 23:58



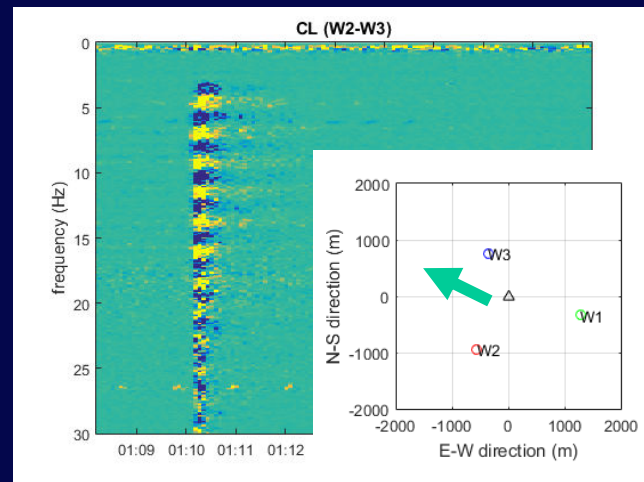
Directional information from unblocked signals



H08N cross-correlation

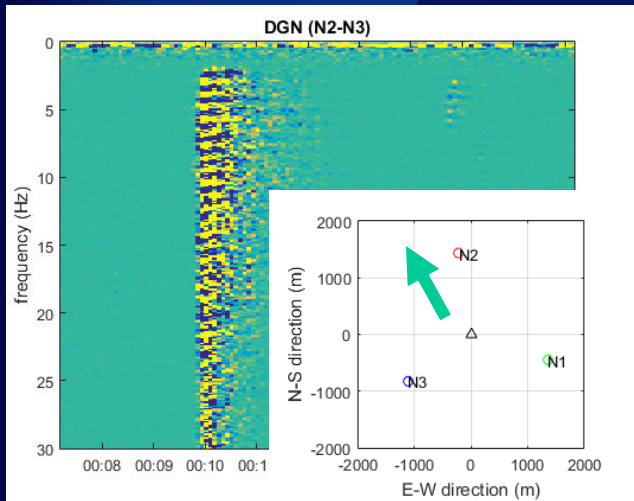


Cross correlation of broadband signals have a pattern in frequency (Δ / c) from which to estimate arrival angle

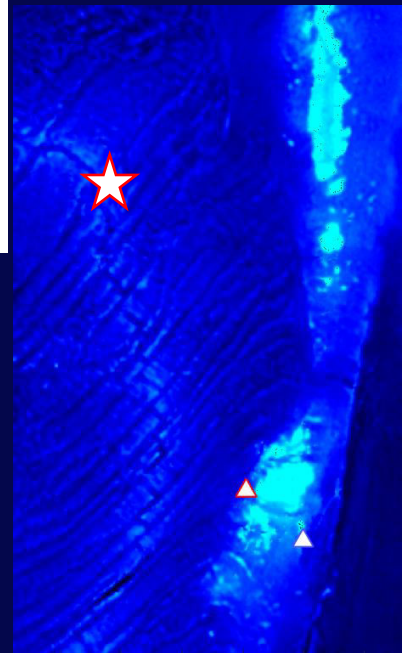
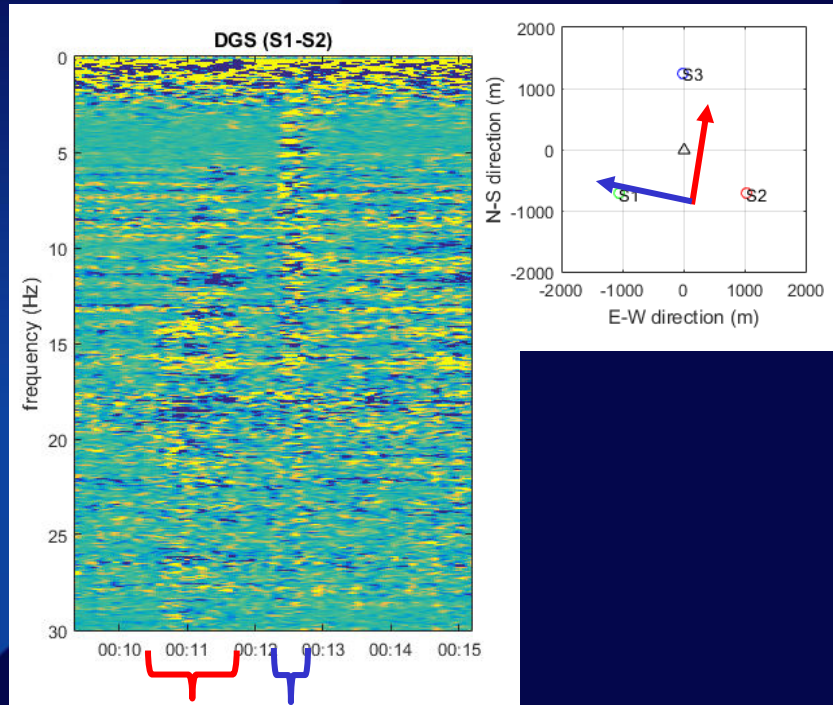


Directional information within blocked signals

H08S cross-correlation



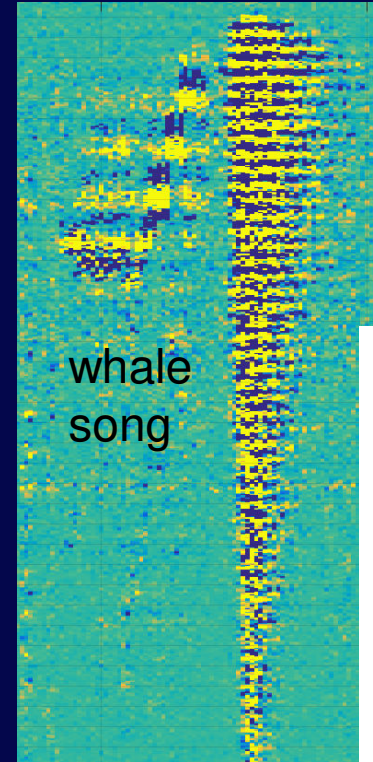
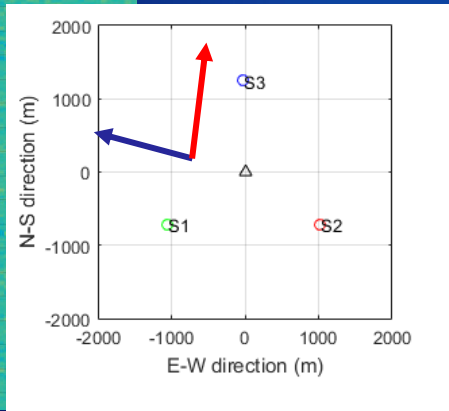
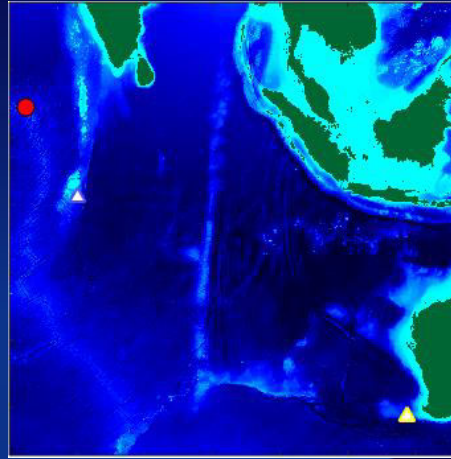
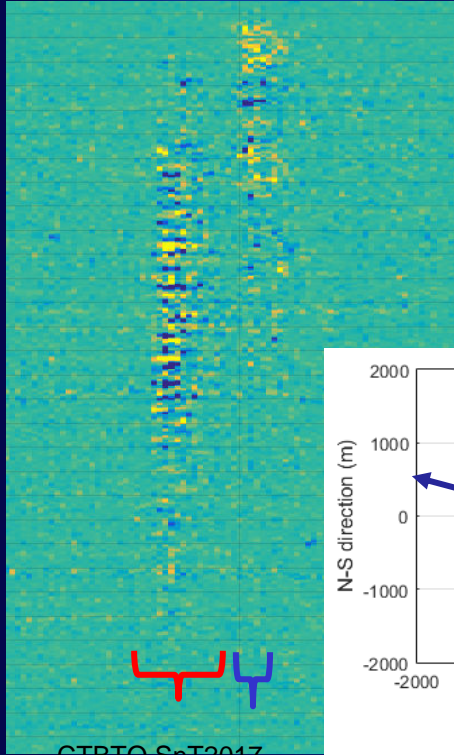
H08N cross-correlation



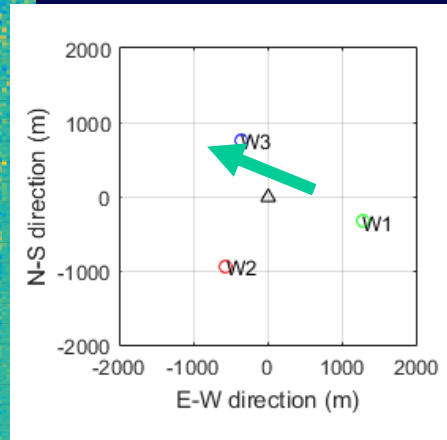
Two arrivals: first from north, second from west

Detections when H08 North Station is inoperable

Earthquake on March 7, 2014 @ 07:40



playback sped up 20X

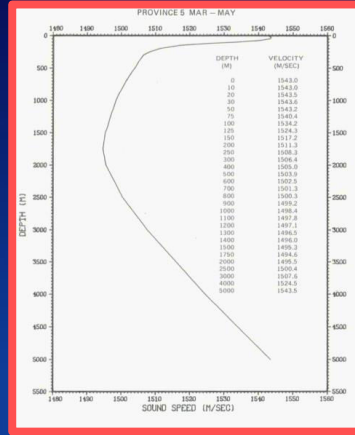


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Deepwater sound speed profile in the study area

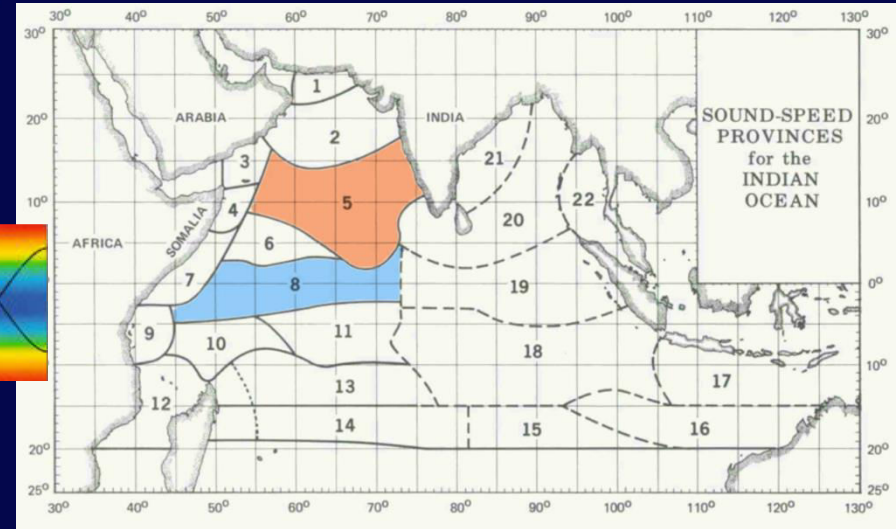
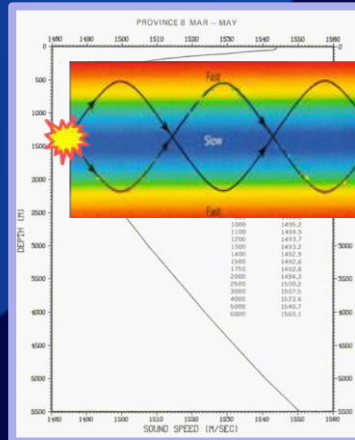
A bit on propagation:

- To maintain phase continuity sound refracts away from higher sound speed
- Propagation at shallow angles never interacts with the surface or bottom



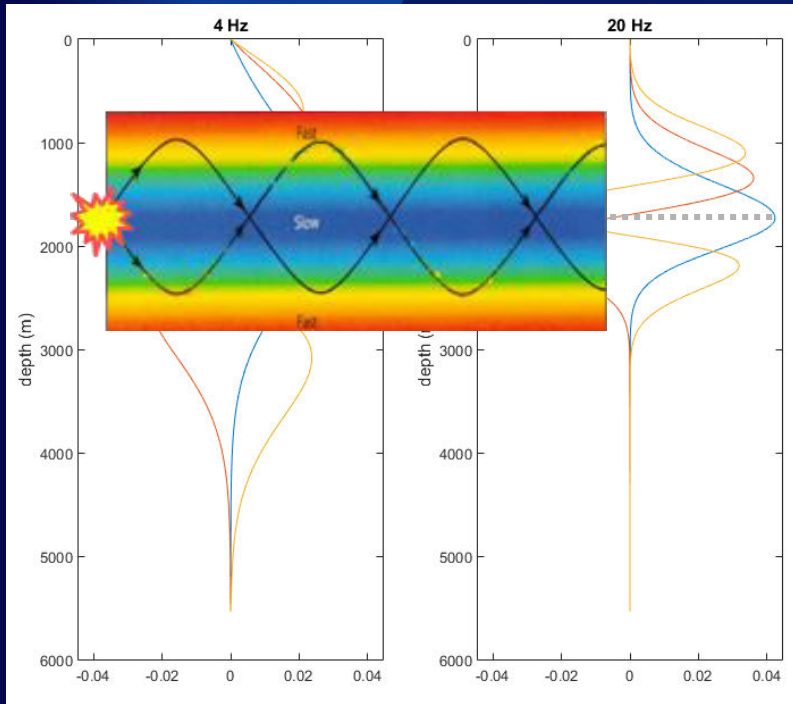
Stable sound speed profile

- minimum 1492 m/s @ 1500 m depth
- >1540 m/s at surface and 5000 m depth



J.G. Colborn, "Soundspeed distribution in the Western Indian Ocean" NUC TP 502 (1976)

Deepwater modeshapes in the Indian Ocean



Modes represent propagation of a pair of up and down going waves at an angle where the energy coherently adds

The higher modes correspond to steeper angles, and support longer 'tails'

The 'tails' of a particular mode are longer at lower-frequency, and propagation will *feel* the effect of the bottom

Mode support at the sea surface indicates surface interaction (and energy scattering)

Hydroacoustic propagation from deep water into shallower water

Deep water propagation

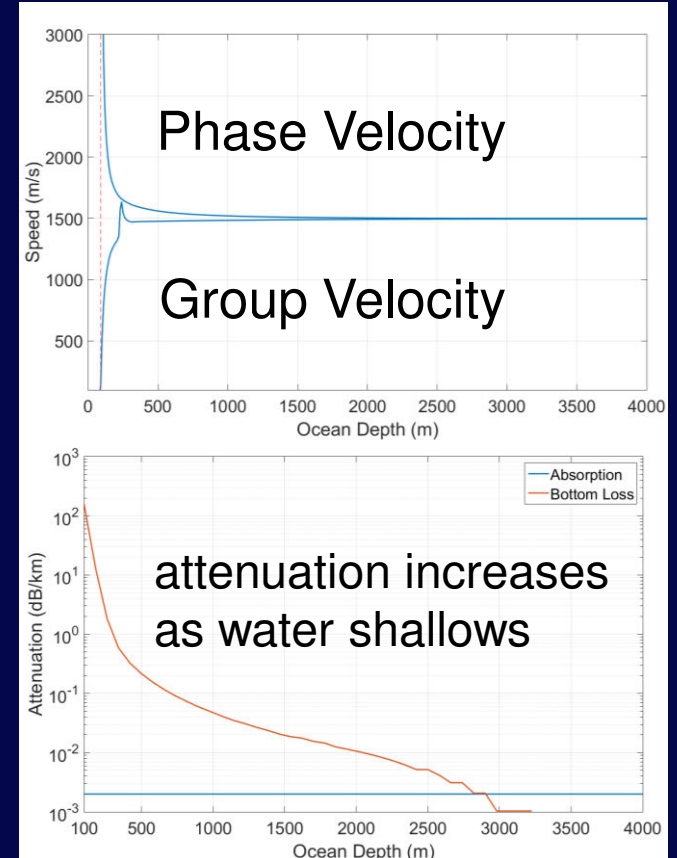
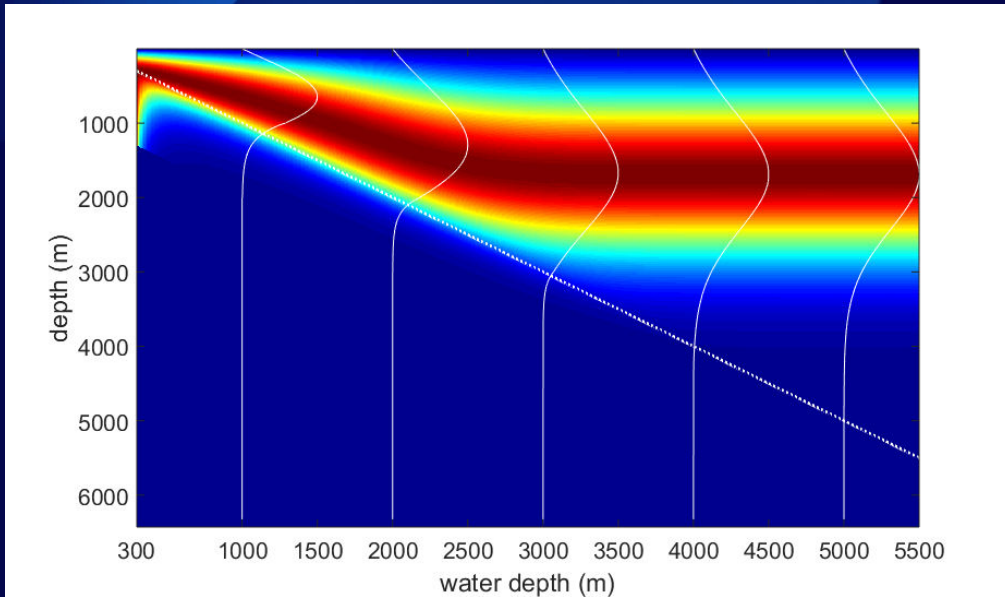
T-phases coupled into modes of the **Deep Sound Channel** (or **SOund Fixing And Ranging** channel) propagate great distances with little attenuation

Shallow water propagation (relative to wavelength)

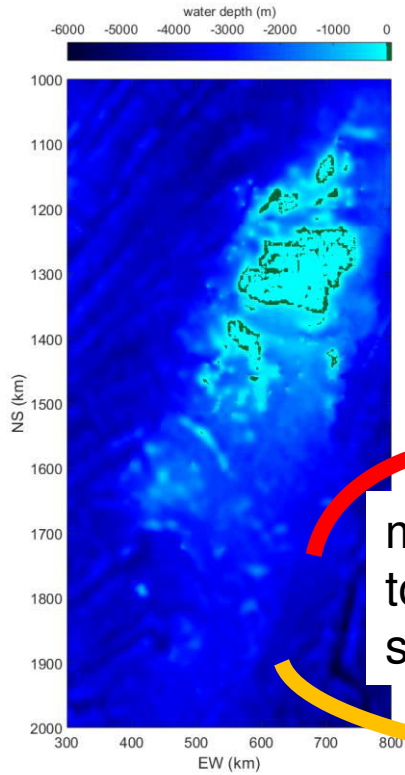
When modes interact with sea-floor, propagation speed depends on water depth and attenuation increases

Mode properties relative to water depth

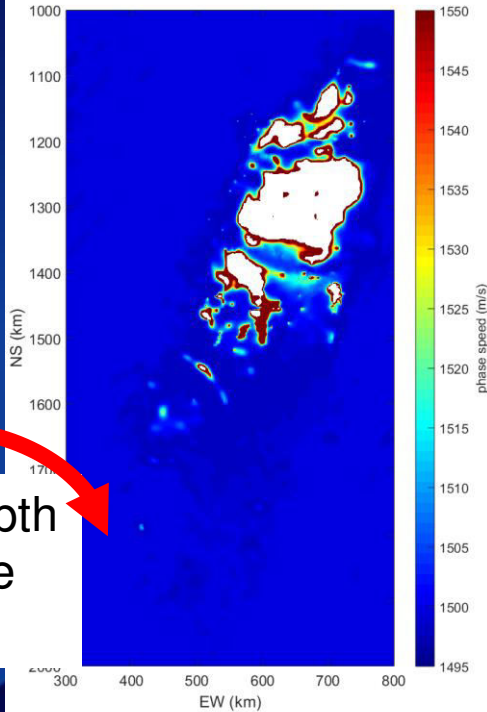
4 Hz sound
(very little water absorption)



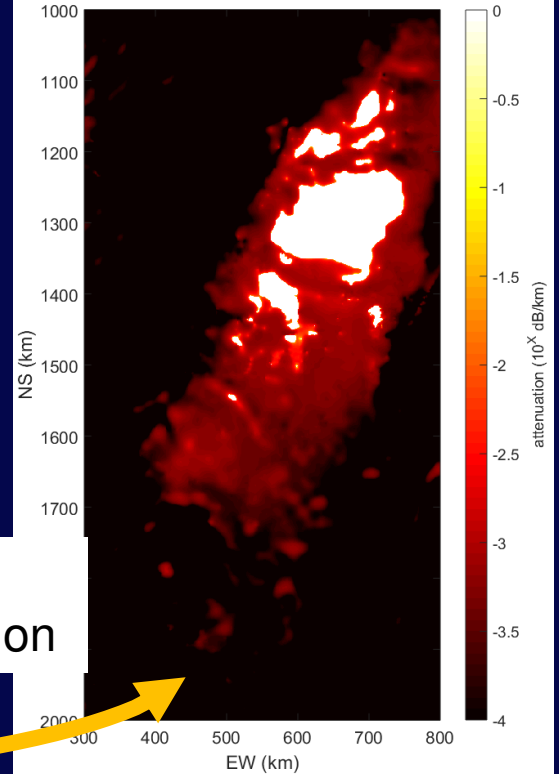
Modeling blocked propagation in horizontal plane



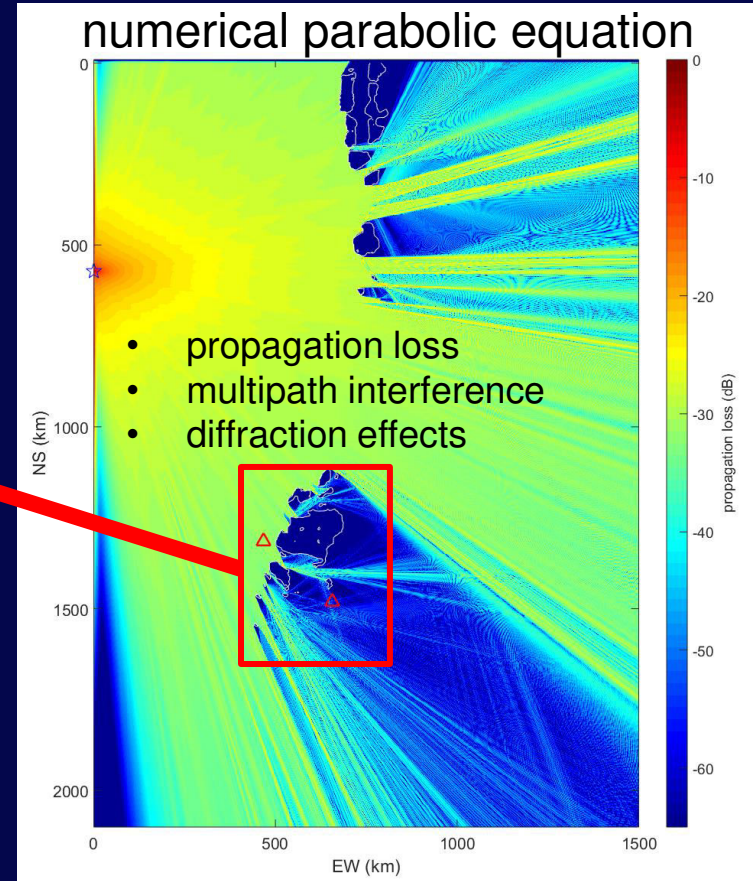
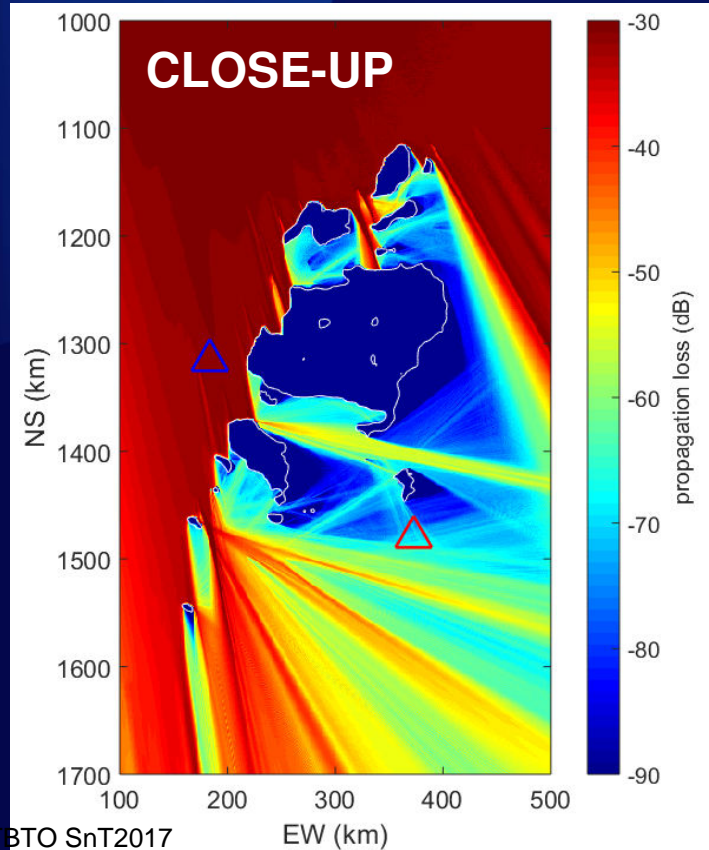
map depth
to phase
speed



...and
attenuation

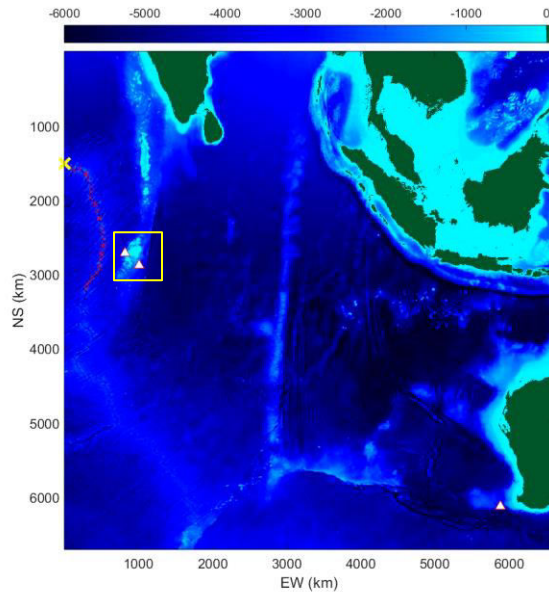


Propagation from a source: rays and PE

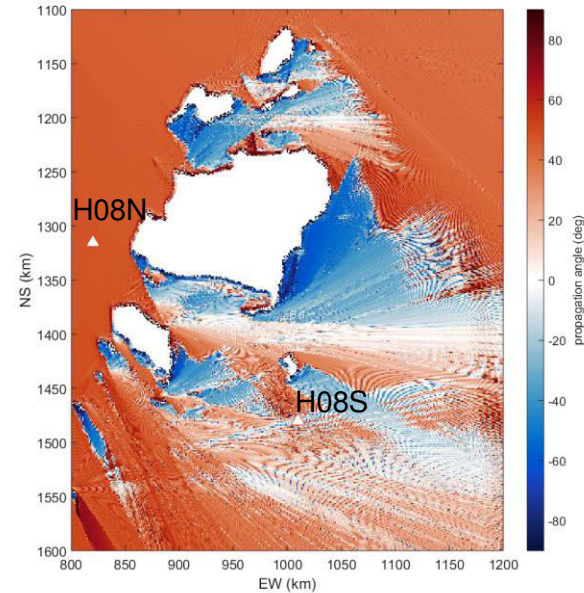


Propagation angle for sources along Carlsburg Ridge

Source location (yellow x)



Propagation angle

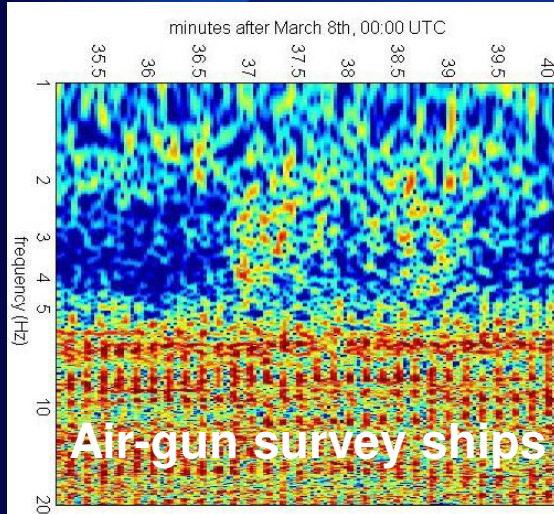


Blocked propagation observed with an unknown signal

Pair of arrivals



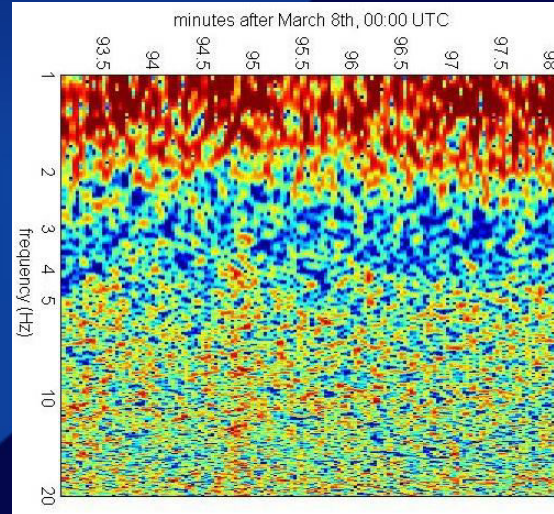
Deigo Garcia South (H08S)



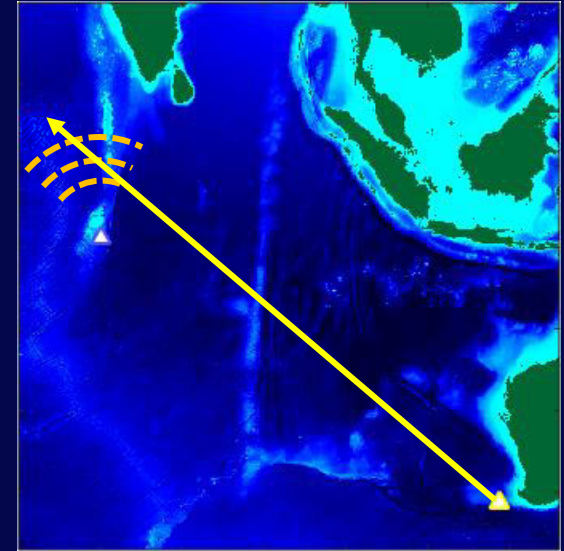
One arrival from NW
(amongst many from south)



Cape Leeuwin (H01W)



March 8th 2014 - UTC



No earthquake in catalogue for this event

Last Transmission of MH370 engine at
00:19:37 UTC

*Sound from CTBTO Hydrophone of Interest
to Search for Missing Flight MH 370,
CTBTO youtube channel*

Splash noise as other non-seismic signals



Image from: <https://pennyhow.wordpress.com>

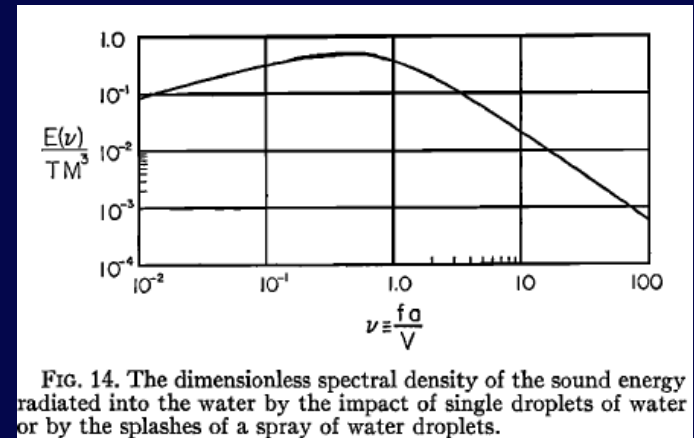
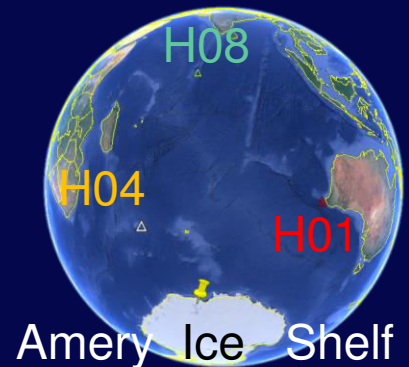


FIG. 14. The dimensionless spectral density of the sound energy radiated into the water by the impact of single droplets of water or by the splashes of a spray of water droplets.

G. J. FRANZ, *J. Acoust. Soc. Am* 1959

Indian Ocean stations
are well suited for
monitoring calving
events in Antarctica



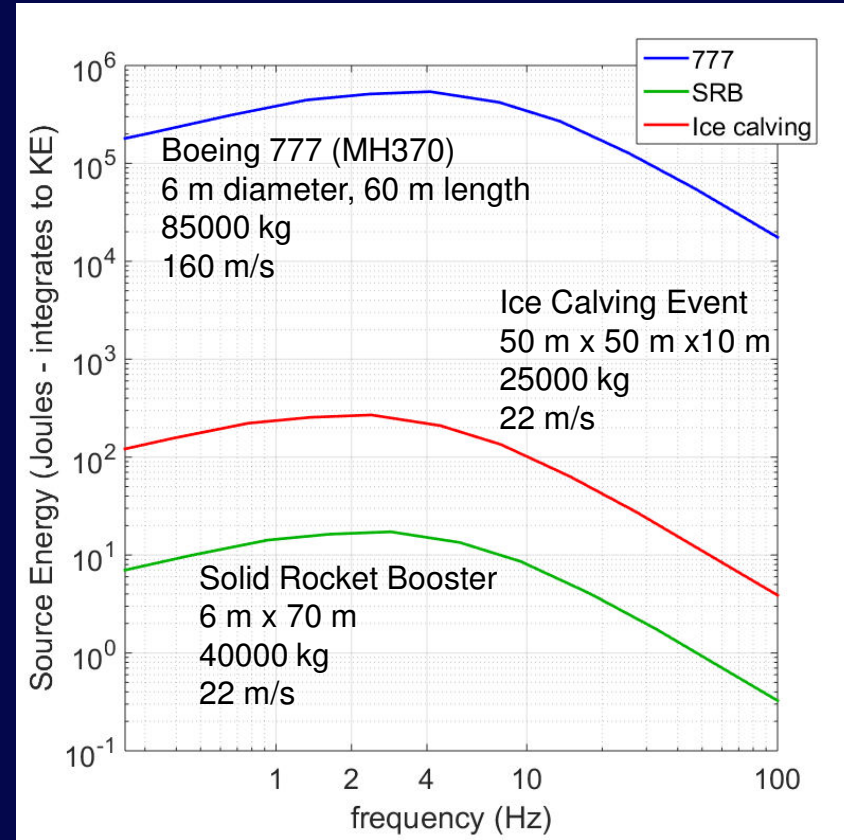
Splash noise as other non-seismic signals

SRB splash-down

(cavity collapse at 1.2 sec)



Suspect orientation of MH370 crash



Summary

Sound can be detected on the far side of island when there is no direct “line of sight” to the source

- high frequency content is attenuated (frequency < 30 Hz survive)
- at Diego Garcia South (H08S), sources from the North-West show
 - a split into two arrivals separated in time by ~1 minute
 - higher frequencies arrive first from the east, and lower frequency second from the west delayed

When ½ of station goes offline, “blocked” detections on far side can still assist in source localization until station is repaired

New algorithms for detection of “blocked” signals should be developed with a combination of models and data-mining the vDEC database