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Abstract

The International Monitoring System (IMS) is based on four technologies: seismic, hydroacoustic, infrasound and radionuclide. The hydroacoustic network, which consists of underwater hydrophone stations and T-stations (on-land seismometers), is essential for the detection and location of underwater sources. Hydrophone stations are more sensitive than T-stations and provide azimuth information therefore they are more capable of detecting events and locating events. The Indian Ocean is the only area covered by three hydrophone stations, thanks to the recently installed HA04 at Crozet Islands. During their routine analysis of seismo-acoustic events analysts focus on either associating hydroacoustic signals (T-phases) to seismic events or on verifying automatically formed hydroacoustic events from H-phase detections. This study provides an overview of events recorded by hydroacoustic stations located in the Indian Ocean (HA01, HA04 and HA08) since the recent deployment of the new HA04 station.

Introduction

The IMS hydroacoustic network comprises of two different types of stations: 6 hydrophone and 5 T-stations. Hydrophone stations detect signals with hydrophones floated in the Sound Fixing and Ranging (SOFAR) channel above an anchor on the sea floor with a cable to nearby land for data and power transmission. Hydrophones are grouped in triplets to provide stations with redundancy and directional capabilities. The separation between the hydrophones in a triplet is approximately 2 km and the frequency band of hydrophone stations is 1-100 Hz (the Nyquist frequency is 125 Hz). T-stations are seismic stations placed in coastal regions. They record seismic waves generated by conversion of underwater signals at the coast slope. T-stations are situated close to the shore where depth is increasing fast to minimize signal attenuation. These stations are not configured to provide information about the signal azimuth. Their frequency band covers 0.5-45 Hz. Almost all hydroacoustic stations are placed close to or on small islands. Therefore, except HA01, they are equipped with two sensor locations to avoid bathymetric blockage by the host island. Hydrophone stations are much more sensitive than T-stations, they have directional capability and record broader signal spectra. Unfortunately, hydrophone stations are quite difficult to maintain and very expensive to install. Once there is a failure of any underwater part it takes a great effort to repair it, especially if the fault is close to the sensor. The Indian Ocean is the only area covered by three hydrophone stations thanks to the recently reinstalled HA04 at Crozet Island. HA04 was reintroduced to the International Data Centre (IDC) Operations in May 2017. This study provides a summary of events detected by the Indian Ocean stations of the hydroacoustic IMS network during the HA04 testing period and during one month following promotion of HA04 to the IDC operations.

Pure hydroacoustic events included in the IDC LEB bulletin

A series of signals of H phase characteristics was recorded on 14 and 15 May 2017. Short duration signals were separated by 1 min intervals; this activity lasted for several hours. The origin of these signals is unknown but similar activity, observed at HA11 and HA03 in late 2016 was attributed to a controlled source seismic experiment (SnT 2017, T.1.4-P3). Activity off coast of Sumatra was detected by H08S and H04N. Several events were included in the Late Event Bulletin (LEB) but they did not meet Reviewed Event Bulletin (REB) criteria as they were recorded by only two stations. Signals recorded at H08S and H04N are shown in Fig.1, and the associated events are located along one of the confidence ellipse axes, which was over 2000 km long as both stations are situated south-west from events' location (Fig.2). Location of LEB events is shown in Fig.3. Detailed analysis of this sequence showed that the actual location of hydroacoustic signals source was shifted North-East within the error ellipse which explained why events were not recorded at HA01.

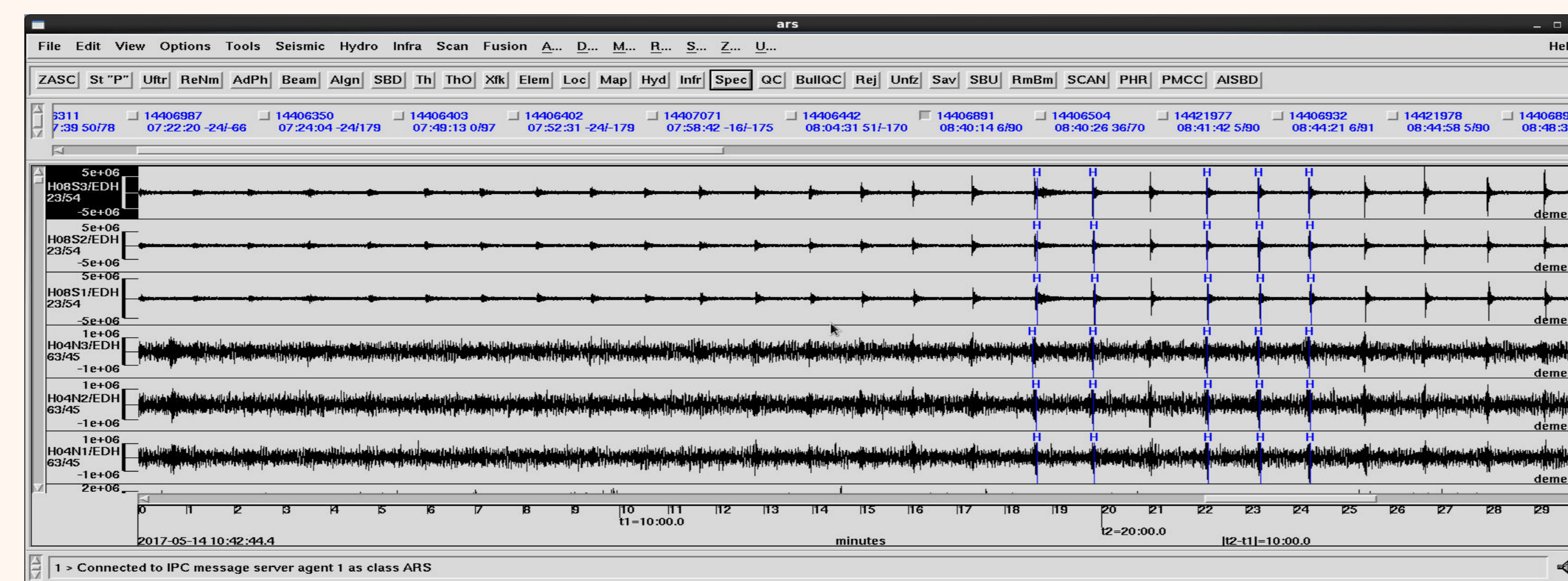


Fig.1. Indian Ocean activity recorded at H04N and H08S on 14-15 May 2017

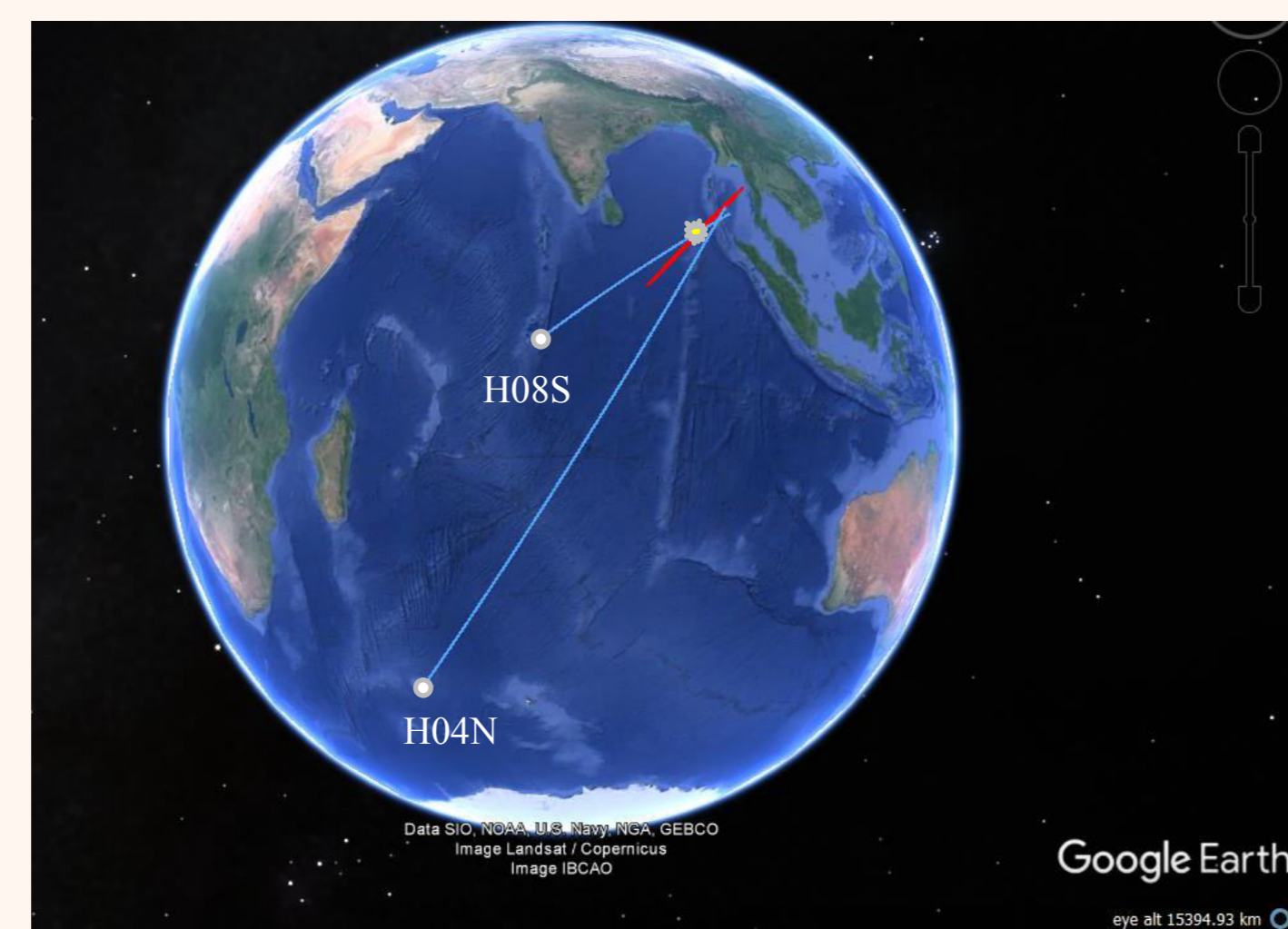


Fig.2. One of events recorded at H04N and H08S; waveforms shown in the Fig.1, error ellipse marked in red

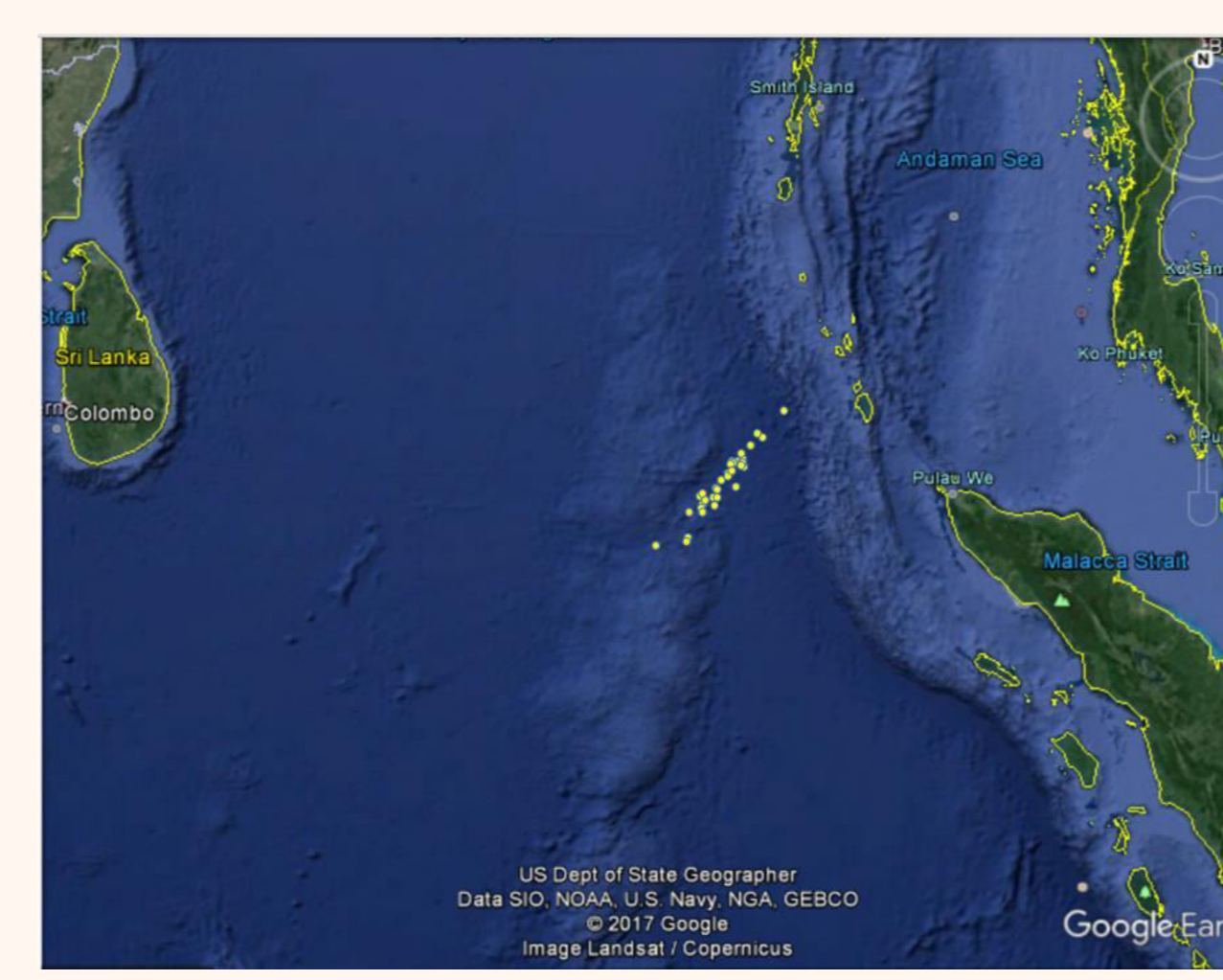


Fig.3. Location of events recorded at H04N and H08S marked with yellow dots; waveforms shown in the Fig.1

Events observed during testing period of HA04

Since HA04 was reintroduced to the IDC operations only events recorded at seismic stations with hydroacoustic phase associations have been reported in the REB. At the same time more than 300 hydroacoustic phases were identified as H and could be potentially used to form pure hydroacoustic events. During the testing period of HA04 analysts found several events recorded only at hydrophone stations. Location of some events was in areas previously observed by H01W and HA08. Signals associated to pure hydroacoustic events were characterized by short duration and broad band frequency spectrum. Cepstral peak was normally not observed. We assume that volcanic activity could be the source of these signals, however, we were not able to find information confirming our assumptions. Comparison between signals generated by pure hydroacoustic events and shallow seismo-acoustic events from a spreading ridge is shown in Fig.4.

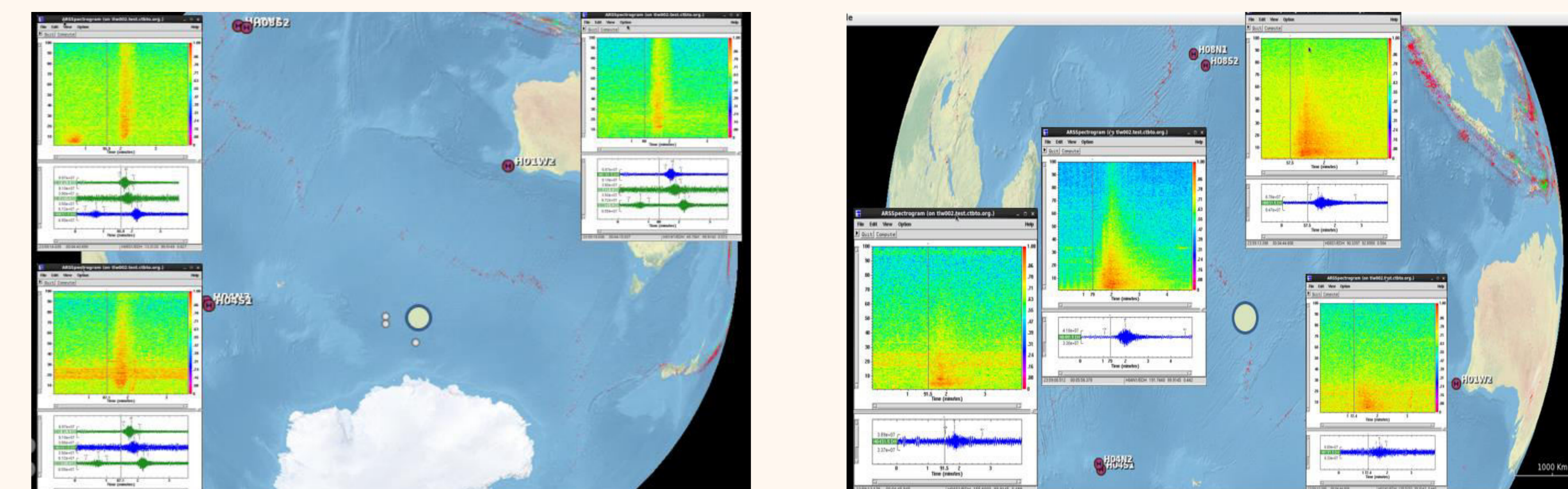


Fig.4. Signals generated by two shallow events : based purely on hydroacoustic observations (left) and seismo-acoustic event (right)

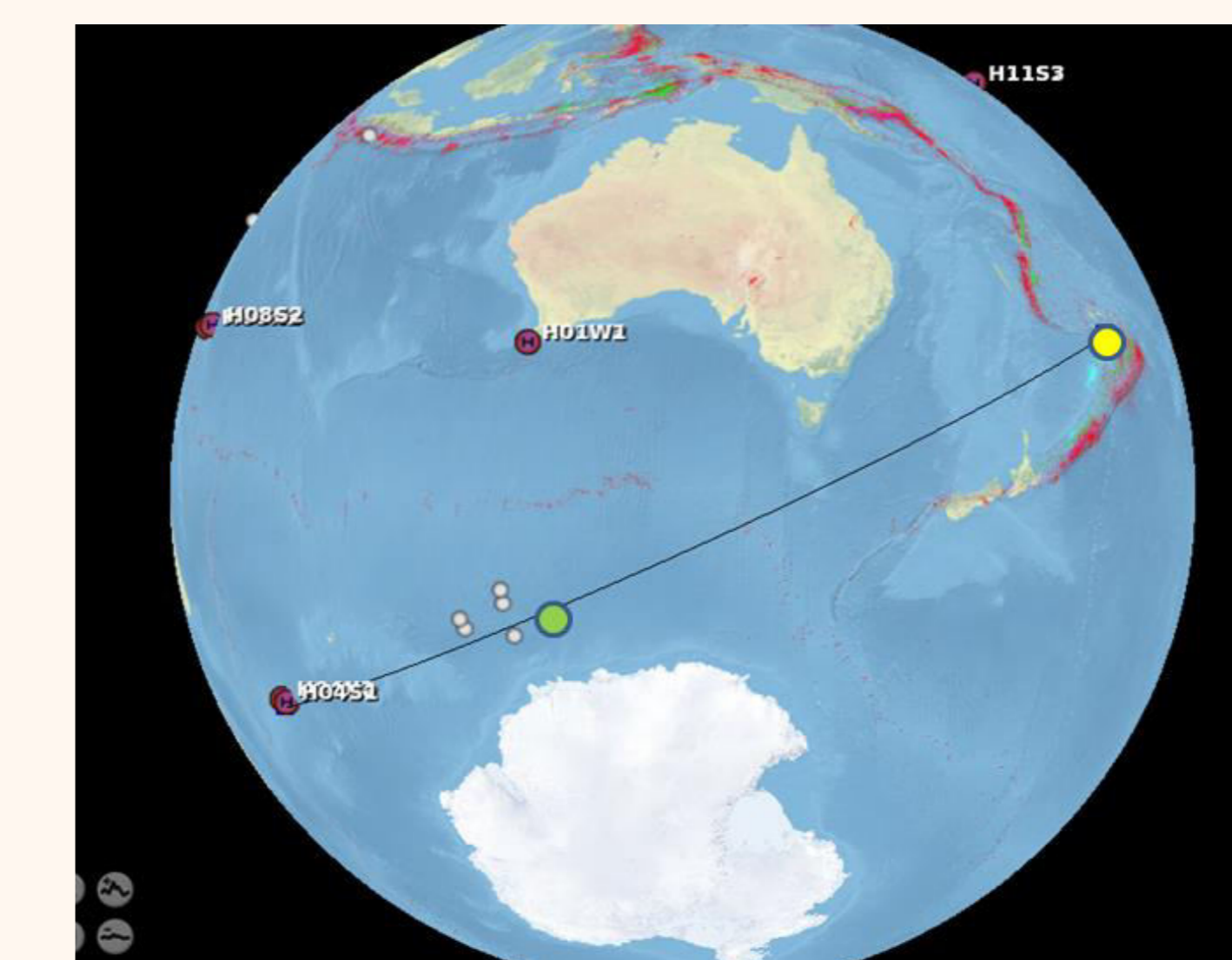


Fig.5. Location of a valid seismic event with wrongly associated detection at H04S (yellow) and location of actual source which generated signal at H04S (green).

During the HA04 testing period we noticed that arrivals which belong to pure hydroacoustic events may be incorrectly associated to valid seismic events. In one example an H04S phase generated by a shallow event near Antarctica was associated to a deep event from Fiji area. It was possible to find corresponding arrivals at H01W and H08S and locate a shallow, pure hydroacoustic event together with the investigated H04S detection. It may be beneficial to form a certain class of pure hydroacoustic events (not only in-water explosions) to avoid false associations.

We also observed that signal may be detected at a triplet for which hydroacoustic signal propagation path is predicted as blocked. It took place in a situation when an island was partially blocking propagation of underwater signal towards H04S. Observed signal was attenuated and back azimuth differed from predicted value. This situation occurred in the past, especially for events from Sumatra detected at H08N.

REB seismo-acoustic events detected by Indian Ocean IMS Hydroacoustic stations

During one month after reintroduction of HA04 into the IDC Operations 5% of REB events were detected by at least one of 3 stations situated in the Indian Ocean, all of them were seismo-acoustic (no pure hydroacoustic events). REB events were detected by H01W, H04N, H04S and H08S. H08N was not sending data during this period. Due to the blockage of hydroacoustic signals there are differences in event distribution per station. As expected H04S detected events from Sandwich Islands, southern Atlantic and areas south of Australia, H04N covered areas of the northern Indian Ocean, H08S the northern Indian Ocean and south of Australia, H01W south of Australia and part of the Pacific Ocean. All stations covered coast of Sumatra and all except H04S middle part of the Indian Ocean. Hydroacoustic stations detected a few seismic phases generated by large seismic events. Location of events detected by each station is shown in Figs.6-9.

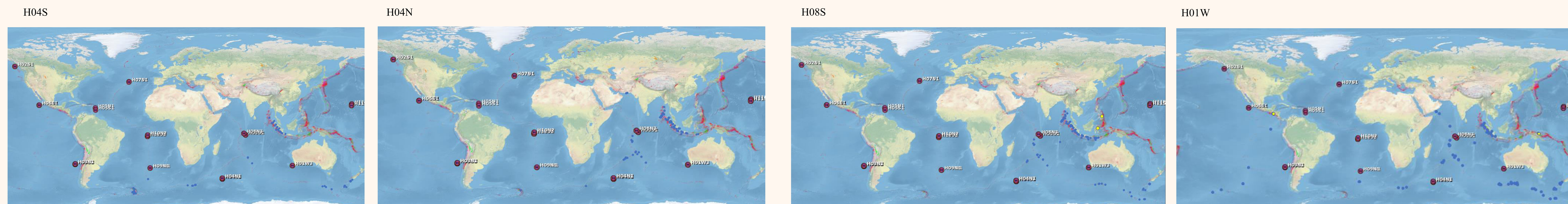


Fig.6. Seismo-acoustic REB events detected by the Indian Ocean network of IMS hydroacoustic stations; location of events with associated acoustic phases is marked in blue, seismic phases with yellow; data recorded between 11/05/2017 and 10/06/2017