THE CURRENT STATUS OF HYDROACOUSTIC DATA PROCESSING AT THE INTERNATIONAL DATA CENTRE

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ABSTRACT

After the installation of Release 3 of the International Data Centre (IDC) application software, development and maintenance of the existing and new software modules was taken over by the IDC. In 2002, when only three IMS hydroacoustic stations were operational, an Ad Hoc Expert Group for the Evaluation of Hydroacoustic Data Processing at the IDC was formed under the auspices of the Provisional Technical Secretariat of the CTBTO. The report and recommendations of the Expert Group list various areas of potential improvement and are used as guidance for IDC hydroacoustic software development. Progress was made in several of these areas.

A software package, including environmental data sets, for long range hydroacoustic propagation modeling was acquired, which is primarily used to compute seasonally varying radial 2D (or Nx2D) tables of travel-times and transmission loss for hydrophone and land-based T-phase stations. Some of the travel-time tables display deviations of up to about 100 s compared to the previously used constant wave speed model. A new software module along with parameter changes was implemented as part of the detection and feature extraction sub-system. It includes cepstral analysis used for identification of bubble pulses from explosive in-water sources. In order to improve the performance of the automatic phase identification sub-system for hydrophone stations, a wider range of frequencies is now used to compute hydroacoustic arrival features. Parameters of the rule-based phase identification sub-system were tuned and a significant reduction of erroneous identifications was achieved. A number of upgrades of the azimuth estimator were inspired by the Progressive Multi-Channel Correlation (PMCC) algorithm. In a related effort, relative hydrophone positions were refined to improve the accuracy of azimuth and slowness estimates. The new version of the azimuth estimator can also compute a slowness outside the typical range of hydroacoustic phases; hence, it is now called the Hydroacoustic Azimuth and Slowness Estimator (HASE) and thus contributes to the automated identification of seismic arrivals on records of hydrophone triad stations, which is currently being tested. Other synergy effects between the three waveform technologies are being studied and will contribute to data fusion processes. New interactive review tools for hydroacoustic data are being developed to be compatible with the methods used in automatic processing.

OBJECTIVES

The International Data Centre's (IDC's) automatic hydroacoustic data processing pipeline consists of the following subsystems (excluding applications which handle data formatting, storage, dissemination and the like): Detection and feature extraction (DFX), channel based phase identification (StaPro), multi-channel processing for azimuth and slowness estimation (HASE), network processing/data fusion (GA – Global Association). This basic structure has not been changed since the delivery of the original software suite from the Prototype International Data Centre (Hanson et al., 2001) and—except for the HASE application—is in principle also used for processing seismic and infrasound data. IDC interactive review is performed using the Analyst Review Station (ARS) as the core application.

RESEARCH ACCOMPLISHED

Areas of Hyroacoustic Development

Parametric Information

A software package—including environmental data sets—for long range hydroacoustic propagation modeling was acquired, which is primarily used to compute seasonally varying radial 2D (or Nx2D) tables of travel-times and transmission loss for hydrophone and land-based T-phase stations. A Matlab based GUI is used to prepare a series of input files for the hydroacoustic propagation model Kraken to compute all radials. Some of the travel-time tables display deviations of up to about 100s compared to the previously used constant wave speed model. An example table for the northern triad of IMS hydrophone station HA10 is shown in Figure 1.

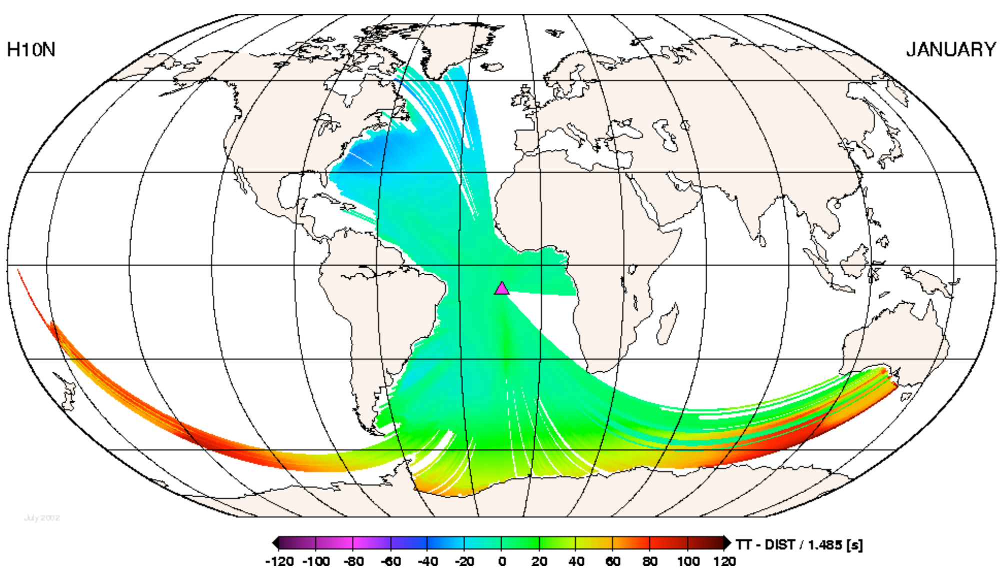


Figure 1. Reduced radial 2-D travel-time table for the northern triad IMS hydrophone station HA10 valid for the month of January.

Detection and Feature Extraction

A new software module along with parameter changes was implemented as part of the detection and feature extraction sub-system. It calculates a number of timing estimates (arrival time, start time, termination time, peak time, etc.) and includes cepstral analysis (see Figure 2) used for identification of bubble pulses from explosive in-water sources. In order to enhance the performance of the subsequent automatic phase identification for hydrophone stations, a wider range of frequencies (1–110Hz) is now used to compute hydroacoustic arrival features.

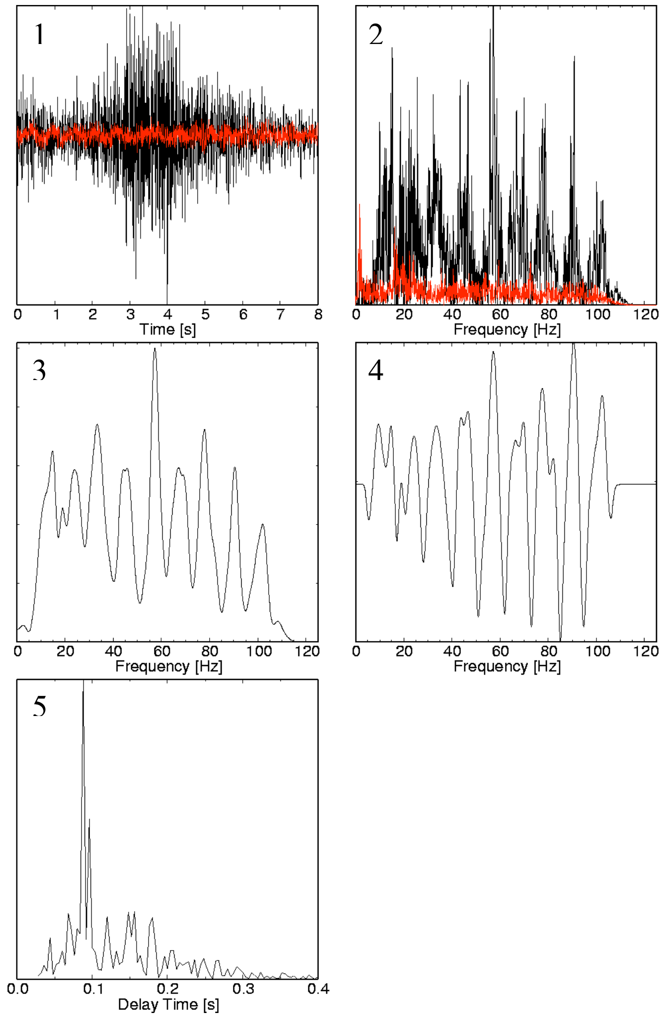
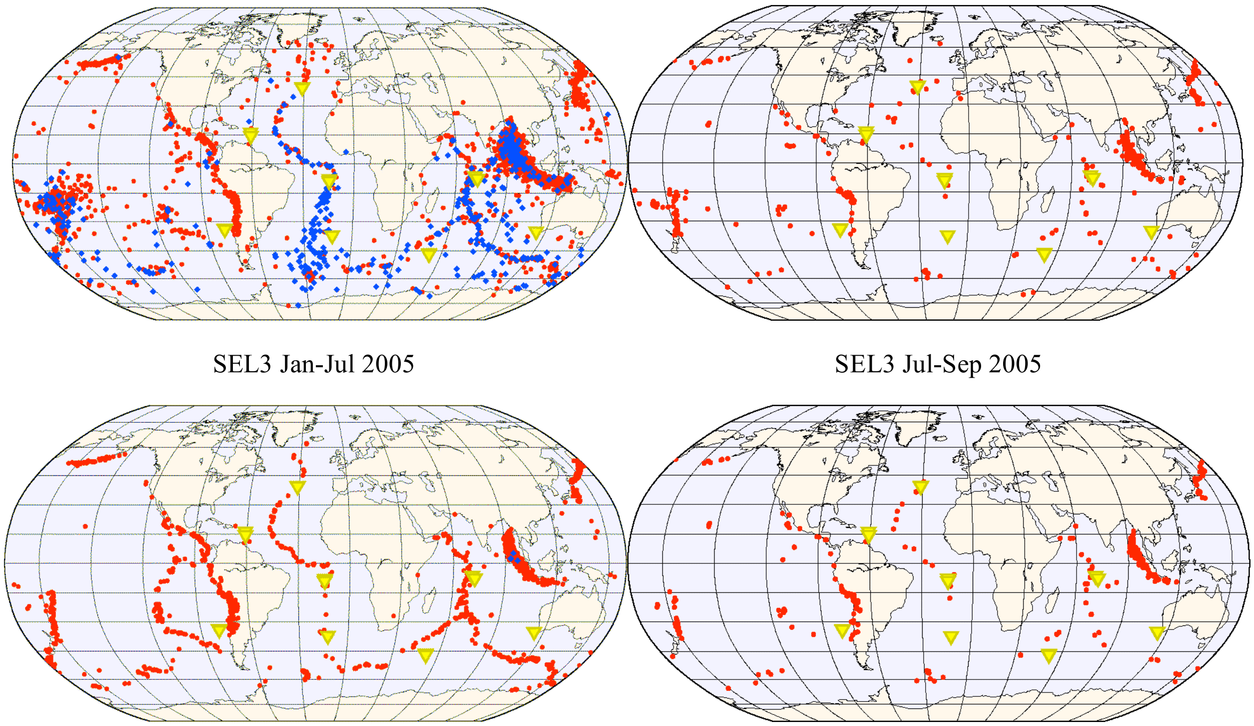


Figure 2. Data example showing five stages of cepstral analysis performed by DFX: (1) raw signal (black) and leading noise (red), (2) spectra of signal (black) and noise (red), (3) smoothed and noise corrected spectrum, (4) logarithm of the detrended spectrum, and (5) cepstrum showing the period of the bubble pulse.

Phase Identification

Parameters of the rule based phase identification sub-system were tuned on the basis of extensive data analysis and supported by an external contract. A significant reduction of wrong identifications was achieved. In particular, fewer ground coupled T phases are now wrongly identified as H phases, which by definition originate from in-water sources. This has a major impact on the automatic network processing since H phases, in contrast to T phases, contribute to defining and locating event hypotheses (see Figure 3). Today fewer false events are built on the basis of H phases.



SEL3 Jan-Jul 2005 | SEL3 Jul-Sep 2005

REB Jan-Jul 2005 | REB Jul-Sep 2005

Figure 3. Epicentre distribution with information on associated phases for the periods before (left frames) and after (right frames) the implementation of changes to the configuration of the rule-based phase identification. Only events with associated hydroacoustic phases are displayed. The upper frames show epicenters from the automatic bulletin (SEL3) and the lower frames epicenters from the reviewed event bulletin (REB). Red dots: Events with no associated defining H phases. Blue dots: Defining H phases associated. After the changes to the phase identification were implemented the automatic bulletin started to resemble the reviewed bulletin more closely.

Multi-Channel Processing/Azimuth and Slowness Estimation

When detailed analysis of hydrophone triad data started at the IDC, a systematic bias in azimuth and wave speed residuals was observed for some stations when the original receiver positions of hydrophone triads from the deployment cruises were used in multi-channel processing. In order to eliminate this bias, azimuth and wave speed residuals from a set of well constrained events were inverted for the relative receiver positions (one element was fixed at its position), leading to a considerable improvement of the accuracy of azimuth and wave speed estimation. The standard deviation of azimuth residuals is now on the order of 1 degree. So far the relative receiver positions of the hydrophone triads HA01, HA08 (north and south), HA03 (north only) and HA10 (north and south) were reviewed. The example given in Figure 4 shows the input and output residuals as well as resulting receiver positions for the hydrophone station HA01.

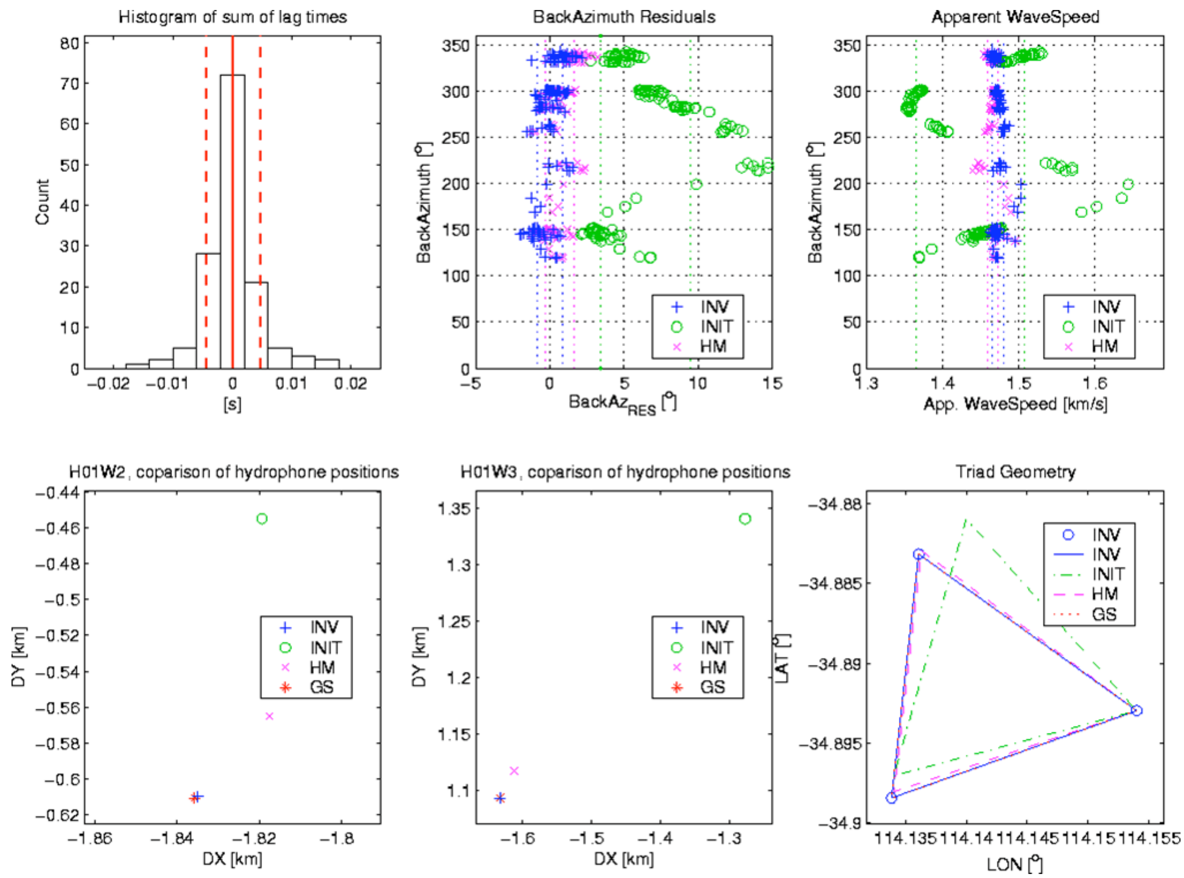
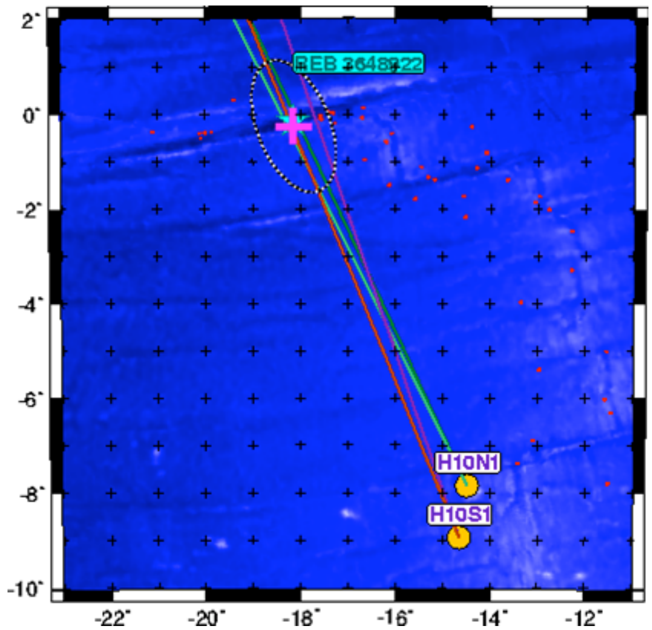


Figure 4. Refinement of the relative hydrophone positions of HA01 (Cape Leeuwin, AU). Top left: Consistency of lag times of the data used in the inversion procedure. Top centre/right: Back-azimuth and wave speed residuals before (green circles) and after (blue plus symbols) the inversion, compared with the results of a study done by Newton and Grenard (purple crosses). Bottom left/centre: Differences in relative receiver positions, also compared with the results of a grid search approach. Bottom right: Comparison of original and resulting triad geometries. The blue circles depict the positions that are now used in IDC operations.

A number of upgrades of the azimuth estimator were inspired by the PMCC algorithm (Cansi, 1995; Graeber and Piserchia, 2004). A derivative of PMCC has previously been implemented in DFX to process infrasound data at the IDC. As in PMCC, sliding correlation windows in different frequency bands are employed to find the most consistent azimuth and slowness estimates and only data windows which display a high degree of consistency (or a small sum of lag times) are considered. However, while PMCC declares detections on the basis of consistent signal coherency and is thus applied to continuous streams of data, HASE uses the conventional DFX detections to focus the analysis on relatively short data segments, which greatly reduces the resources required to process the data.

The new version of the azimuth estimator may also compute a slowness value outside the typical range of hydroacoustic phases and thus contributes to the automated identification of seismic arrivals, which is currently being tested at the IDC. So far, using rather conservative thresholds, about 30 seismic arrivals have been successfully detected per month on the stations HA08, HA01, and HA10. Very few (1–2) false identifications were made. Lag time corrections for the hydrophone mooring geometry were introduced to improve azimuth and slowness estimates of seismic phases and the preliminary results are encouraging (Figure 5). Further systematic differences between observed and predicted azimuth and slowness (Figure 6) are attributed to unknown properties of the seafloor and will be corrected in a way that is similar to what is currently done for seismic stations.



O-time	O-lat	O-lon	O-depth	smajax	sminax	strike	GAP
2006/04/08 22:03:04.9	-0.2550	-18.1340	0.0	162.9	84.8	158.9	356.1

Figure 5. A single hydroacoustic station (HA10) location using arrival times and azimuth estimates (given by the coloured lines) from Pn and T phases compared to the corresponding location of the IDC's reviewed event bulletin (REB). Note the very good agreement of the two independent locations and the highly consistent azimuth estimates obtained for the four arrivals.

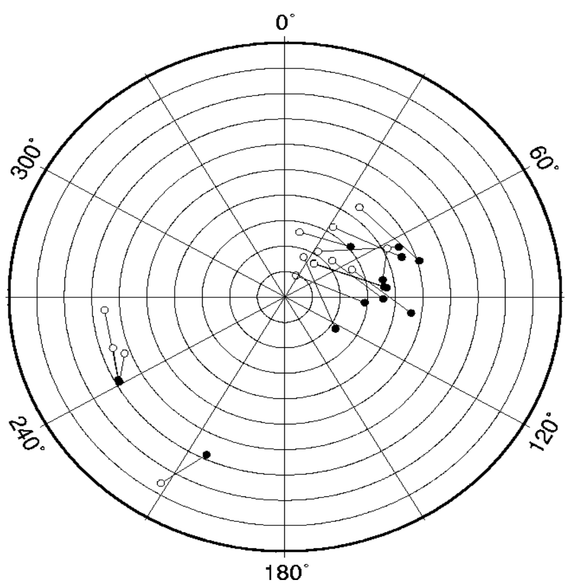


Figure 6. Polar plot showing the systematic differences between observed and predicted azimuth and slowness for the southern hydrophone triad of HA08. The concentric rings depict the slowness at intervals of 2 s/deg. Black circles show the predicted values, white circles the measured values.

Network Processing

Some minor changes were made to the global association (GA) sub-system, which was initially designed for seismic data, to facilitate the creation of events from hydroacoustic associations only. The need for the changes became obvious when a comparably strong in-water explosion was clearly observed at all three Indian Ocean hydrophone stations in May 2004 (Figure 7), while the event was not built by the automatic system. After the changes were implemented, the event was successfully built when the data was reprocessed off-line. Events like this are often used for testing purposes, even though the ground truth information is unfortunately not available.

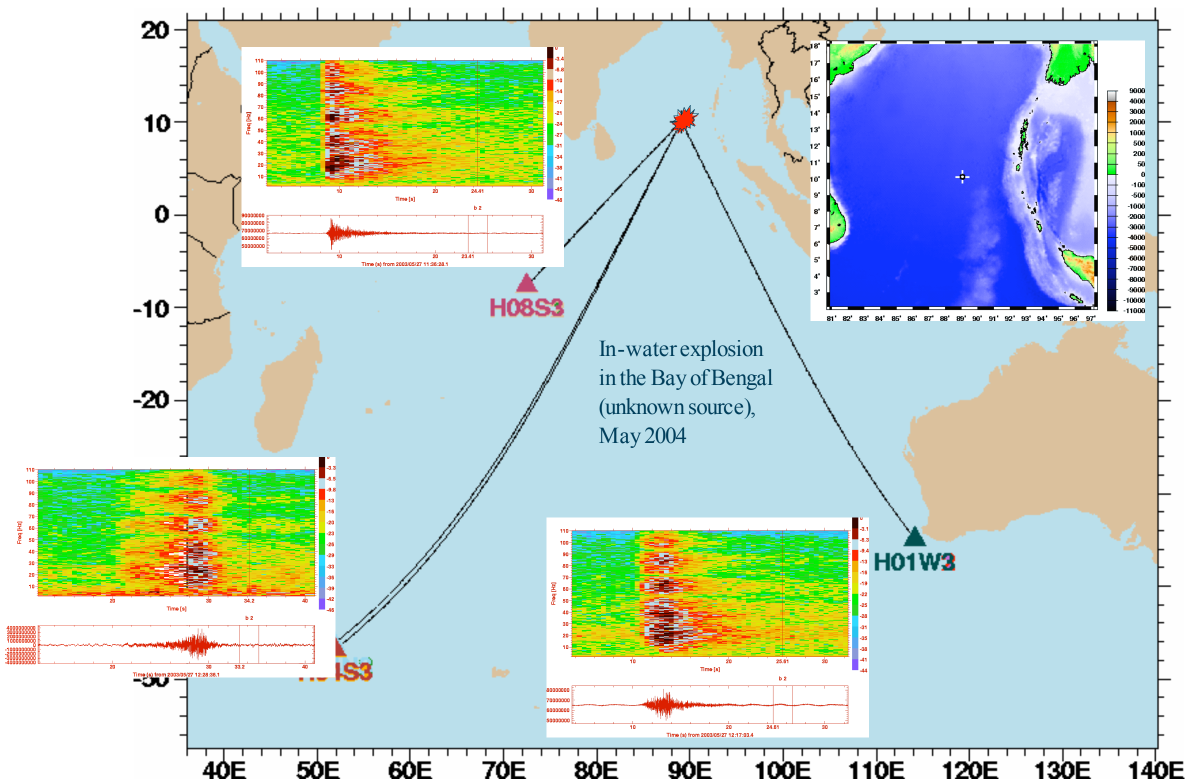


Figure 7. In May 2004 strong signals from an in-water explosion were observed at all Indian Ocean hydrophone stations. The event was formed automatically once some minor changes to GA were implemented. The location shown here was obtained off-line using the modified software.

Interactive Review Tools

New interactive review tools are being developed to enhance processing of hydroacoustic data and to be compatible with the methods used in automatic processing. A spectrogram tool, which is of essential importance for hydroacoustic phase identification and arrival time estimation, has been included in ARS. A prototype interactive cepstral review tool has been developed on the basis of the software module that was developed for automatic detection and features extraction (Figure 8). A new azimuth and slowness review tool will be developed using the experiences made with HASE and DFX-PMCC.

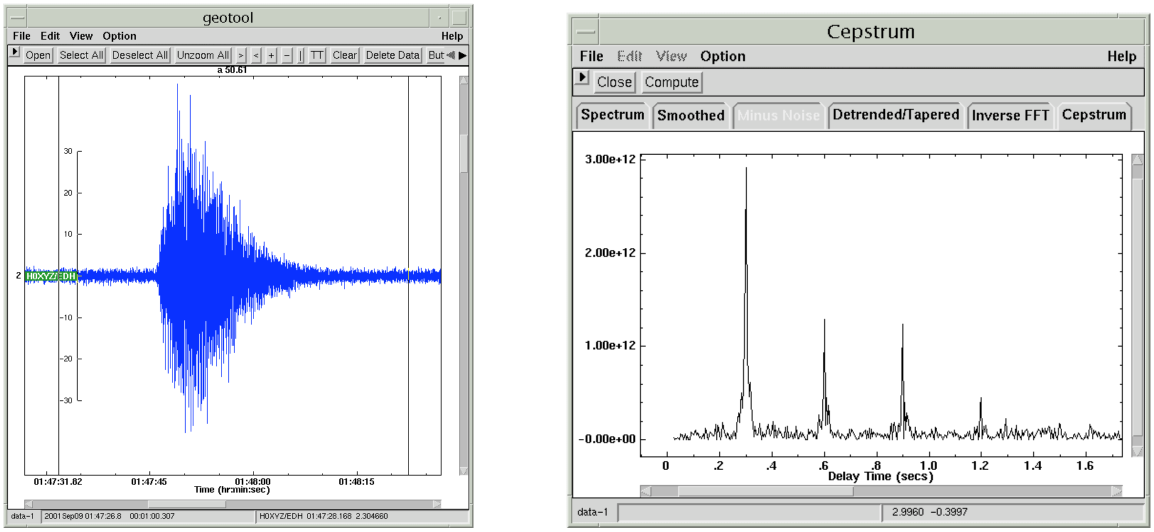


Figure 8. Screen shots of the prototype cepstral review tool. Processing parameters may be changed and intermediate stages of cepstral analysis can be displayed for better control of the final results.

CONCLUSIONS

Development of hydroacoustic data processing has made significant progress since the first IMS hydroacoustic stations became operational. Several pieces of the original software were upgraded or replaced. Parametric information such as the travel-time tables and the relative hydrophone positions was added or tuned. Today the results of the automatic processing more closely resemble the reviewed event bulletin, which implies that there is less work to be done on hydroacoustic data during interactive analysis. Future development may result in a major reorganization of the processing sequence in order to further enhance multi-channel processing and to facilitate the use of synergy effects between the three waveform technologies. Interactive review tools will be designed to not only provide the required functionality and accurate results, but also to streamline the routine processing.

DISCLAIMER

The views expressed herein are those of the authors and do not necessarily reflect the views of the CTBTO Preparatory Commission.

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