CHIMNEY OBS DATA CORRECTIONS - shot and receiver location from direct arrival travel times

Consider an OBS on the sea floor at a true location (Xr,Yr, Zr) where Zr is the water depth at the OBS location and X,Y are local co-ordinates. For a shot located at (Xs,Ys,Zs) the direct arrival travel time is given by

$$T(s,r) = ((Xs - Xr)^2 + (Ys - Yr)^2 + (Zs - Zr)^2)^{½} / V_w \quad (1)$$

where V_w is the water velocity.

First arrival times were picked, initially using the GI air gun data set, for a number of receivers, and fit to equation (1). Examination of the arrival times from shots close to the OBSs indicated a probable timing delay in the system. For most OBSs, the water depth was known to within 1 m from the bathymetry survey. Measurements of water velocity in the region result in average values of ~1490 m/s (*cruise report;* Bull, 2017).

The direct arrival was observed to arrive up to 6 ms earlier than predicted for a zero offset shot, which would require the source to be at a depth of ~10 m below sea level, in contrast to the nominal 2 m towing depth. This was considered to be too large a depth error to be true, and so we conclude that there is a timing delay somewhere in the recording/shot triggering system. Equation (1) is therefore modified to

$$T(s,r) + \tau_r = ((Xs – Xr - \delta x_r)^2 + (Ys – Yr - \delta y_r)^2 + (Zs - Zr)^2)^{½} / V_w \quad (2)$$

where τ_r is a receiver specific delay time and δx_r & δy_r are corrections from the receiver drop locations X_r & Y_r to the actual position on the sea floor.

A grid search algorithm is used to calculate the sum of squared residuals (SSR) between the observed direct arrival times and times predicted by equations (1) & (2) at every point on a grid. The output solution was the set of parameters giving the smallest SSR. The water velocity may be set as a variable in the procedure, but a value of 1490 m/s was found to be a good solution for all receivers, so the water velocity was fixed to this value. The water depth was not included in the grid search as sea floor dips are small and differences in depth between the drop locations and actual locations were already within the accuracy level of 0.5 m expected from the fitting program.

Travel times calculated using the optimal receiver locations determined by the grid search algorithm fit the observed travel times with a root mean square (RMS) residual error of several ms. This is larger than the picking uncertainty and suggests that additional variables are required. Closer examination of the residuals showed a variation between the different shot lines recorded at the OBS. It was clear from the asymmetric distribution of the residuals that there were also uncertainties in the shot locations, which may arise due to feathering, tidal variations, wave height variations and/or gun depth variations. In principle a correction could be applied to every shot if direct arrival times were picked on all receivers for all shots. However, this not trivial once the direct arrival is overtaken by the first emergent refractions, which occurs at shot offsets of ~650m.

It was assumed that a feathering correction and a combination of depth and timing errors could be considered as constant for each shot line. Variations in shot depth, tidal corrections and wave height corrections would have a very similar effect on travel times as a shot delay correction, and it would not be robust to solve for both.

It was, therefore, assumed that shot positioning uncertainties could be approximately corrected by using a constant (x,y) positional correction and a constant delay time for each shot line. The (x,y) correction corresponds to a constant feather over the sail line and the delay time accounts for the average corrections for gun depth, tides and wave heights, together with any timing errors on the gun trigger system. This can be expressed as

$$T(s,r) + \tau_r + \tau_{sl} = ((Xs + \delta x_{sl} - Xr - \delta x_r)^2 + (Ys + \delta y_{sl} - Yr - \delta y_r)^2 + (Zs - Zr)^2)^{1/2} \ / \ V_w \quad (3)$$

where τ_{sl} is a shot line specific delay time and δx_{sl} & δy_{sl} are shot line specific corrections to the shot x & y co-ordinates. The positioning solution requires estimating corrections δx_r & δy_r to correct each receiver to its seafloor location, estimating δx_{sl} & δy_{sl} to account for feather on each shot line and delay times for each receiver and shot line τ_r & τ_{sl}.

Shot line corrections and delay times were also calculated using a grid search algorithm as for the receiver positions. An iterative approach was adopted with receiver positions specified and then shot line corrections estimated using the updated receiver locations. Receiver locations were then revised using updated shot locations and so on. At each iteration the search range was narrowed and increment decreased until locations were determined to within 0.5 m and delays to within 0.25 ms (1 sample). For the GI guns the resulting positions yielded model travel times to fit the observed travel times with an RMS error of around 0.5 ms and maximum errors of around +/- 3 ms.

The entire process was repeated for the Squid sparker, Dura sparker and Bolt airgun data sets. For these sources, an automatic picking algorithm was used to allow for efficient determination of travel times for offsets up to 650 m. The same approach was followed for these data sets and a good fit obtained. The receiver locations determined from the different data sets were, however, different, with several meters variation between locations determined by the different source types. It was decided that a unique receiver location should be determined. The Squid sparker data set was selected to be the reference data set. The receiver locations were therefore set by the solution obtained from the Squid sparker direct arrival times. These locations were then input into the grid search solutions for the other source types and revised receiver delays and shot line corrections determined. The RMS time error of less than 1 ms indicates that the receiver locations have an uncertainty of less than 1.5 m. The process was performed for OBSs 1-25.

For each source, the below text files are provided, containing the following information:

- Source_Final_Shots.txt
  final shot co-ordinates in lat-long from seismic vessel
- Source_Final_Shots_XY.txt
  final vessel shot co-ordinates in X-Y WGS84 UTM Zone 31N
- Source_Final_Shots_XY_SL.txt
  updated shot locations including shot line number, shot depth and shot delay
- Source_Receiver_Locations.txt
  final receiver locations based on Squid data but with source specific delay times