SeaTEM – A New Airborne Electromagnetic System for Bathymetric Mapping and Seafloor Characterisation

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Summary
The potential for using airborne electromagnetic (AEM) methods for measuring water depth has been demonstrated from data acquired from several surveys over shallow coastal waters in Australia. These AEM surveys were undertaken using both fixed-wing time-domain and helicopter (time and frequency domain) commercial systems. Some survey data was also interpreted to delineate the bedrock-sediment boundary which was in general agreement with marine seismic studies. These commercial AEM systems are designed for mineral exploration and are not optimized for marine surveying. Furthermore, these commercial AEM systems do not track the position of the towed sensor (bird). This research has now been extended by developing a helicopter time-domain AEM system (SeaTEM) which will include real-time kinematic tracking of the towed bird. Here we present data taken from the very first airborne trial over shallow water in Broken Bay (Australia). Preliminary interpretation of this dataset identifies the known bathymetry and depth to bedrock.

Introduction
The Defence Science and Technology Organisation (DSTO) has been investigating the use of AEM for bathymetric mapping in shallow coastal waters to support hydrographic operations (Vrbancich, 2004; Vrbancich et al., 2005a,b). This technique, referred to as airborne electromagnetic bathymetry (AEMB) (Zollinger et al., 1987), is expected to be particularly useful in turbid seawater and in the surf zone where LIDAR methods are restricted because of the severe attenuation at optical frequencies in these waters. In clear water, laser airborne depth sounding is preferred because of the higher spatial resolution compared to AEM systems (Reid and Vrbancich, 2004; Reid et al., 2006). In the one-dimensional (1D) approximation, AEM data is interpreted in terms of a layered-earth model, usually consisting of two layers (representing seawater and sediment) overlying a resistive basement (bedrock). The model parameters are the layer thicknesses and electrical conductivities, and the conductivity of the basement. The conductivity of seawater is not expected to vary significantly with the addition of suspended soil material which leads to water turbidity, or with the addition of bubbles caused by surf action. Thus we expect AEMB to be applicable in either turbid coastal waters, and/or waters subjected to ocean swell, both of which are common in Australian waters.

An example of the AEMB method from data acquired from a survey in Sydney Harbour is shown in Figure 1, for line L1005. The upper panel (Figure 1) shows a conductivity-depth section from stitched 1D inversion of rescaled time-domain AEM data where layered-earth model parameters (except basement conductivity) were allowed to float (Vrbancich and Fullagar, 2007a). The known water depth profile, corrected for tide, is shown in yellow. The water depth obtained from AEM data is identified as the depth of the boundary between the upper conductive section (pink) and the less-conductive intermediate section (sediment layer, green, or exposed rock, blue), and generally shows sub-metre agreement with the known bathymetry. The white and orange profiles show the depth to bedrock estimated from marine seismic data and compares favourably with the depth to resistive basement in the conductivity depth section, identified by the boundary between the sediment layer
and resistive basement (dark blue). The bottom panel in Figure 1 (Vrbancich and Fullagar, 2007b) is similar to the upper panel, however in this case, the inversion assumed a fixed known water depth and water conductivity in an attempt to improve the interpreted depth to basement and to investigate variations in sediment conductivity. (Note the different conductivity scales used in Figure 1 for upper and lower panels.) Rescaling of data was necessary in order to compensate for calibration errors which seriously compromised initial efforts to interpret the data (Vrbancich and Fullagar, 2004). This example shows that with properly calibrated instrumentation, the AEMB method can provide accurate water depths and has the potential to be used for remote sensing of sediment thickness and for delineating coarse scale features of bedrock topography in areas of shallow water.

**Figure 1.** Water depths and depths to bedrock derived from AEM data.

**Methodology**

The three principal issues associated with the use of AEM for bathymetric mapping identified in previous studies by Vrbancich and coworkers involve instrument calibration errors, tracking bird motion, and optimization of sensor system design and survey methodology for operation in a marine environment. The development and testing of the SeaTEM system is expected to address all three issues and will take place over 3 years. The SeaTEM development consists of three stages. One stage consists of a series of ground tests and static tests over seawater with the aim of optimising the design and geometry of the transmitter and receiver loops, and minimizing errors arising from instrument calibration. Another stage consists of the construction of a prototype helicopter time-domain AEM system, referred to as SeaTEM(0), based on previous knowledge acquired from using the commercial HoistEM system (Boyd, 2004) for AEMB surveys in Australian coastal waters. A third stage addresses the issue of bird motion. An airborne testing rig fitted with inertial navigation, dual frequency GPS and radar and laser altimetry sensors was constructed and flight-trialed over seawater for measuring bird attitude and height above seawater (Kratzer and Vrbancich, 2007). These auxiliary sensors will be incorporated into the SeaTEM(0) system during 2007. The SeaTEM(0) prototype is approximately 18 m long and 22 m wide, with a transmitter loop area of 204.4 m² and a nominal moment of 50080 A m². The waveform comprises 5 ms bipolar pulses (25 Hz fundamental frequency) with a quasi-trapezoidal current pulse (exponential rise 750 µs time constant,
approximately 4 ms constant current, and a 25 μs turn-off ramp). Decay voltages are measured over 121 channels binned into 21 windows with mid-times ranging from 87.375 μs to 10.55 ms from the start of current turn-off. Window start and end times can be varied within certain constraints. Transmitter current is battery powered.

Figure 2. SeaTEM(0) lift-off, Broken Bay.

The first fully operational flight test of SeaTEM(0) was carried out over shallow waters in Broken Bay, approximately 40 km north of Sydney, in 2006 (Figure 2). We present the preliminary interpretation of some data from this survey by comparing the inverted depths of the first two layers, assumed to be seawater and sediment, with water depths and depth to bedrock obtained from digitized depth contours on available charts. Broken Bay has a flat seafloor consisting of sediment layers of variable depth ranging from very shallow (or absent with exposed reef rock), extending to depths in excess of 100 m.

Figure 3. Inverted seawater and sediment depths for L8220 – known water depth, blue; inverted upper layer depth (d1), black; estimated depth to bedrock, orange; inverted depth of second layer (d2), green. Note that parameter d2 is artificially depth limited to 100 m during inversion. Depth to bedrock (orange), derived from 10 m depth contours, is unreliable in very shallow regions at edge of bay area. Bedrock depth extends to about 190 m at 6284000 mN. Inverted depths were obtained from rescaled AEM data, using a similar procedure to that used by Vrbancich and Fullagar (2007a,b) for HoistEM data from Sydney Harbour. SeaTEM altimetry is about 32 m above sea level.
Seawater conductivity was measured during the survey and this was used as a fixed parameter during inversion. Figure 3 shows the inverted layer depths for line L8220 assuming a 2-layered earth model overlying a resistive basement.

Conclusions
The inverted depths shown in Figure 3 represent the initial findings obtained from the very first operational SeaTEM survey over seawater, and as such, the system has not yet been fully tested. However, the results are nevertheless very interesting and encouraging. The inverted bathymetric profile plots the raw inverted depths with no averaging or filtering and shows overall good agreement with known water depths, and detects the subtle variations in depth at about 6286000 and 6288000 mN. The noisy inverted depth profiles are unusual and unexpected, and are under investigation. AEMB surveys have never been previously undertaken in open waters subject to moderate swell conditions as found in Broken Bay during this survey. EM decay profiles appear to be well correlated with altitude variations, however the laser altimeter used for height measurements over seawater has a much smaller footprint than the EM footprint and altimetry sampling errors may arise from sea state conditions. Inversion of AEM data using minor variations in measured altimetry of less than 0.5 m gives rise to significant variations in inverted depths (up to about 5 m), especially in water deeper than 25 m. The inverted depth of the second layer whilst noisy nevertheless follows the estimated depth to bedrock down to about 80 m. It is anticipated that the use of two laser altimeters (located at the extremities of the 18 m beam) together with radar altimetry which provides a larger footprint will enable more accurate altimetry information in areas subject to ocean swell and choppy seas. This modification together with attitude sensors for tracking bird motion will improve the accuracy of inverted layer depths.

References