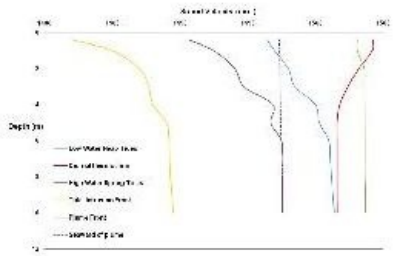
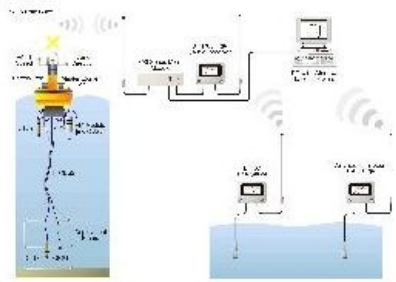
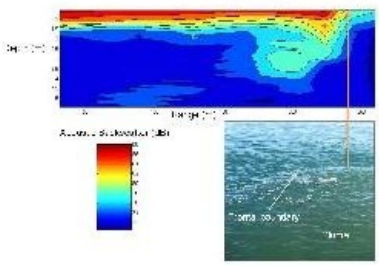
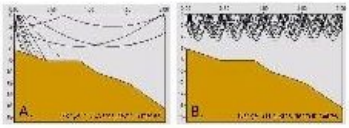
EFFECT OF ESTUARINE ENVIRONMENT ON SOUND SPEED PROFILE

Sonar Propagation in Statified Waters









Ports, harbours and naval bases are often located in estuaries, where river discharge and tidal stirring strongly affect the sound velocity profile. Scales of temporal and spatial variability are often particularly short, resulting in abrupt changes to the acoustic environment. Such small-scale estuarine sound velocity structures and temporal changes have significant impacts on sound propagation and therefore must be described and quantified in order to optimise sensor performance.

The authors illustrate the impact of water column variability on high-frequency sonar propagation in the acoustically challenging estuarine littoral. Field data drawn from a temperate latitude estuary illustrate fluctuations in key oceanographic parameters over different temporal and spatial scales. A two-dimensional acoustic range prediction model is utilised to identify and analyse the effects of environmental variability on coverage and range for a generic high-frequency forward-looking sonar system.

Salinity Profile
The acoustic environment in estuaries changes over very short scales. The salinity profile determines the halocline depth, the stratification and the form of the sound velocity profile and hence the coverage of any sonar system. The predictable acoustic environment associated with well-mixed estuarine conditions presents few problems for sonar operators. However, the development of even a moderate-gradient halocline - as little as 0.25 practical salinity units (PSU) per m - modifies propagation patterns significantly, particularly for near-surface systems. Coverage for bottom-mounted systems such as some harbour-protection sonar instruments could also be expected to change significantly over a tidal cycle.

Coupling environmental data to an acoustic model can illustrate the influence exerted by water column variability on sonar coverage. Field data collected in the Dart Estuary were used to drive the HODGSON acoustic propagation model to illustrate these effects.

Estuary Stratification
Estuarine type is a function of tidal mixing, bathymetry and river discharge and estuaries are categorised according to their density stratification. The estuarine continuum describes well-mixed, partially mixed and highly stratified estuaries. In estuaries it is primarily salinity which controls density and hence stratification levels; sound velocity gradients in estuaries are therefore closely related to stratification.

High levels of stratification are associated with marked positive sound speed gradients (> 0.5ms-1 per m), with the steepest gradients (as high as 3.0ms-1 per m) occurring in the halocline. Conversely, low stratification generates only weakly positive sound speed profiles. Well-mixed estuaries are subject to strong tidal mixing processes and often have high width-to-depth ratios. In these estuaries, low stratification results in predictable, weakly positive (~0.017ms-1 per m) sound velocity gradients. In partially mixed estuaries sound velocity gradients are altered by varying tidal ranges and fluvial discharge.

HODGSON Model

The HODGSON model is a generic range prediction model utilised operationally by the Royal Navy. It allows an operator to input variable parameters such as frequency, depth, beam angle, sea state, wind speed and wave height. The sea surface is modelled as a reflector and rays undergo attenuation based on frequency and surface roughness. Bottom losses are calculated using bottom loss curves which relate to frequency and grazing angle. Range-dependent absorption losses are modelled as a function of frequency, temperature, depth and salinity.

Field Studies

In the last decade, estuarine temperature, salinity and sound velocity data have been collected by scientists from the University of Plymouth. The field site for these measurements was the Dart Estuary in southwest England, where the semi-diurnal tide typically ranges from 1.8m to 5.2m over the spring-neap tidal cycle.
A range of representative sound velocity profiles from the Dart Estuary is shown in Figure 1.

Studies conducted using an oceanographic observatory (Figure 2) confirmed the temporal variability of the sound velocity profile in the estuary. Seasonally, episodic autumnal and winter river discharges increase stratification levels and consequently sound velocity gradients. Over fortnightly scales, a stratification-destratification cycle is observed, resulting in steep sound velocity gradients (1.0ms-1 per m) during neap tides and shallow gradients (0.017-0.025ms-1 per m) during spring tides.

The highest annual levels of stratification and hence the most severe positive sound velocity gradients are observed when the passage of autumnal or winter depressions coincides with neap tides. On an intratidal basis, the flooding tide reduces stratification until levels reach a minimum around high water; at this time sound velocity gradients are also minimised. During the ebb, tidal straining increases stratification and the period surrounding low water is associated with maximum gradients in sound velocity.

Effects of Fronts

Estuarine fronts commonly occur towards the mouth of estuaries and can increase stratification significantly, leading to the development of severe horizontal and vertical sound velocity gradients (e.g. as high as 5.0ms-1 over 10m horizontally). A variety of fronts formed in the Dart Estuary under different tidal and river discharge conditions. These fronts only exist for a period of 2-3 hours and significant water column changes are evident over periods shorter than 1 hour. Laterally, major changes in the vertical structure occur over distances of less than 10m.

Plume fronts form when brackish, buoyant estuarine water discharges into the coastal sea. They form episodically in association with high river discharge events, and are best developed under calm weather conditions and low sea states. The structure of a typical plume, obtained from high-resolution (mode 12) acoustic Doppler current profiler (ADCP) backscatter, is shown in Figure 3.

Tidal intrusion fronts develop close to low water during periods of spring tides, when coastal waters enter the estuary on the flood tide and plunge beneath the lower salinity (hence lower density) estuarine water. A characteristic ‘V'-shaped foam and debris line is evident on the surface (Figure 4), and a marked halocline develops below the front.

In both frontal types, a rapid transition into new acoustic environments is experienced at the frontal boundaries with very strong upward refraction in the frontal zone itself. Sharp haloclines can develop in plumes very close to the sea surface, resulting in severe sound velocity gradients (~3.0ms-1 per m) at depths of 1-3m.

Effect of Temperature

Situations occur where temperature can exert a significant influence on the sound velocity profile. The development of diurnal thermoclines during appropriate conditions in summer months may induce negative sound velocity gradients (e.g. Figure 4) in the upper part of the water column. Additionally, positive temperature-depth profiles can be observed during autumn and early winter when seawater temperatures exceed river water temperatures. Alternatively, during late spring and early summer, river water temperatures exceed seawater temperatures and negative temperature gradients are observed.

Sonar Deployment

Low or reduced levels of stratification can be associated with well-mixed estuaries, spring tides, low freshwater discharge and high water. When these conditions prevail, a mildly upward-refracting acoustic environment develops and sonar instruments can potentially cover the entire water column. Interaction with the seabed and the surface will occur, reducing the range (Figure 5a).

Highly stratified conditions can be associated with fjords, high freshwater discharges, low tidal ranges and the period close to low water. They are acoustically characterised by marked positive sound speed gradients, particularly in the halocline. In these environments, sound can be trapped above the halocline and ducted at the surface (Figure 5b). Good surface coverage can be obtained, and surface and volume losses predominate. However, it may be difficult to cover the seabed and lower water column unless variable depth systems are deployed. Choosing the depth of deployment for sonar systems is critical in such environments, and needs to be adapted to the changing level of stratification within an estuary.

Conclusions

Errors in target position and range for multi-beam sonars are well documented. However, for forward-looking systems such as harbour-protection sonars, environmental uncertainty can cause problems in achieving the necessary coverage in order to acquire and track a target. Much of the coverage deficit could be ameliorated using beam-steering techniques, but this would need to be modified continuously to take account of the variations in the sound velocity field.

The dynamic nature of the sound velocity profile means that range-dependent, real-time sound speed profile data are essential to predict coverage accurately; the only realistic source of the required density data is from a model. Future work in this area will concentrate on quantifying the variability in the acoustic fields in very shallow water areas, using coupled hydrodynamic and acoustic models. The end goal is to ensure that enhanced knowledge of water column variability leads to improved tactical decision making.

Further Reading

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