Sonar behaviour in non-terrestrial ocean exploration

Conference or Workshop Item

SONAR BEHAVIOUR IN NON-TERRESTRIAL OCEAN EXPLORATION. J. R. C. Garry and M. C. Towner, Planetary and Space Sciences Research Institute, The Open University, Milton Keynes, England, (J.R.C.Garry@open.ac.uk, M.C.Towner@open.ac.uk)

Introduction: A small number of moons in the solar system may harbour large bodies of liquid water beneath their surfaces. Of these, the postulated 'ocean' that may lie under Europa's crust is of particular interest and the utility of acoustic remote-sensing is discussed with emphasis on use in a Europan sea.

Sonar as payload: The Huygens probe *en route* to Titan carries a 15 kHz non-beam forming sonar [1] that delivers a signal of ~80 dB (ref 20 μPa) in the laboratory. In the event of landing in a sufficiently deep body of liquid, the sensor works as a bathometer, inferring the 'sea' depth from the echo's delay. However, the sensor's onboard compression method also stores information about the echo profile, giving clues to the roughness of the seafloor.

Visual sensing of a subsurface is severely hampered by optical extinction at all but the closest of ranges, with a few tens of metres marking the practical limit in clear terrestrial seas. Acoustic techniques offer attractive advantages over optical methods for identifying the extent and large-scale structure of a sea. With their larger wavelength, acoustic signals are less affected by size-dependent scattering and refraction from localized turbulence. Absorbtion phenomena are generally also weaker by orders of magnitude, 100 $dBkm^{-1}$ being the largest loss at 500 kHz from sea-water's viscous relaxation, and this loss mechanism falls away 100-fold per frequency decade at lower frequencies[2].

Sonar behaviour - acoustic attenuation: Particulate suspensions dissipate acoustic energy by essentially the processes of scattering and absorbtion whether in a terrestrial or Europan sea. If the problem of suspended matter is left aside, there is potential for enhanced absorbtion through unusual sea chemistry. The concentration of salts in a liquid alters the attenuation behaviour of the solution. However, monovalent salts such as NaCl produce little absorbtion, and only divalent-divalent salts such as $MgSO_4$, are significant absorbers. Absorbtion by such solutions occurs in specific frequency ranges, as shown below for the terrestrial sea.

Salt	Absorbtion region
$MgSO_4$	10^5 Hz
$CoSO_4$	5×10^5 Hz
MgS_2O_3	2×10^5 Hz
$MnSO_4$	2×10^6 Hz

Table 1 - Absorbtion as a function of frequency for 2-2 electrolytes, adapted from [3]

Sonar behaviour - noise: Terrestrial seas host a variety of biological and artificial acoustic sources that give rise to a noise spectrum shown in figure 1.

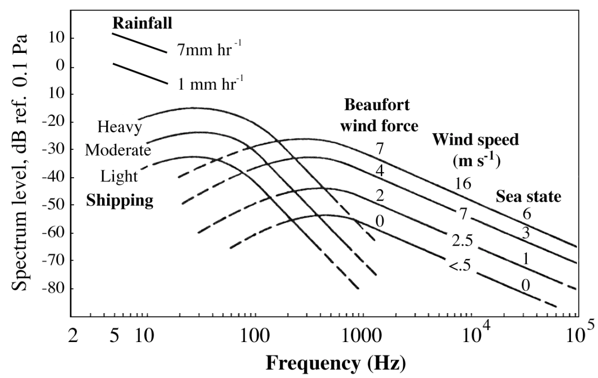

Figure 1 - Terrestrial sea noise spectrum, adapted from [2] and [4]

Despite the total lack of the above familiar noise generators, ice-skinned satellite oceans are unlikely to be quiet locales. One obvious noise source is from the cracking of the overlying crust, driven either by tidal flexure or diurnal thermal expansion and contraction. The energy released in the generation of a fissure scales with both the area of the cleft surface and the tensile strength of the material - for water ice, fissuring 1 m^2 yields around 1 MJ [5] with little strain rate dependence.

A second source of noise may arise from meteorite bombardment of the brittle crust. Without data for the meteor population at large masses around Jupiter, the Devine model [6] indicates that the number density of 'large' (gramme-mass and heavier) bodies at Jovian heliocentric distances is comparable within an order of magnitude to that at 1 AU from the Sun[1]. Seismic data from the Apollo missions showed that 10 kg and larger bodies struck the moon on average every 5 days, and impacts have been considered as seismic sources for other planetary bodies [7]. A body in a near-circular orbit at a Jovian heliocentric distance impacts Europa at speeds between 35 $km\,s^{-1}$ and 8 $km\,s^{-1}$: the maximum speed being almost three times higher than the equivalent head-on scenario for the Moon. With such giga-Joule impacts occuring every few days, the thickness and stiffness of the crust will determine the detection limit and hence the noise floor for this acoustic source.

[1] Comparing only the 'core' and 'asteroidal' populations of the Devine model.

Sonar behaviour - gradients: The pressure in a planetary sea is essentially a linear function of depth, *d*. Given a relationship between the speed of sound, *c*, and the local pressure, the gradient ∂c/∂d, can be estimated for a body such as Europa. Using a model for *c* in terrestrial seas [8], the surface gravity of Europa (1.31 m s^{-2}) would, for an isothermal sea of terrestrial composition, give ∂c/∂d as ~2.2 m s^{-1} km^{-1} instead of ~16.3 m s^{-1} km^{-1} as found on Earth. This shallower gradient implies that acoustic signals should suffer less refraction than in Earth's seas.

If a minimum value for *c* is encountered at some depth in a sea, then that depth forms the axis for a channel which acts as a conduit for acoustic signals and permits cylindrical, rather than spherical propagation [9]. Raypaths passing into higher or lower regions, with raised local sound speeds, are refracted back to the channel axis and suffer a greater delay than rays that propagate at constant depth. If acoustic channels exist in Europa's seas they will create longer lag-times for off-axis paths than on Earth; an impulsive source in such a conduit will generate signals that decay more slowly than in a terrestrial sea.

However, without the surface heating found at low latitudes on Earth, which leads to raised values for *c* near the sea surface, a subsurface sea on Europa may have a monotonically rising gradient, ∂c/∂d, and thus acoustic channels at depth will not exist. It is more likely that a half-channel will be formed in an isothermal convective zone directly under the crust. This liquid should have the lowest local value for *c*, and thus sound will be preferentially trapped against the underside of the overlying crust, propagating with a cylindrical wave-front and suffering exponential decay from multiple reflections with the crust's underside [10]. This half-channel should be several times thicker than is found on Earth, because of the smaller local gravity which reduces both the pressure gradient and ∂c/∂d.

Admittedly, such speculation is made in the near-absence of facts: the heat flowing through the crust limits the degree of cooling that the upper water layer experiences, which in turn sets the thickness of water which is driven to convect and so remain isothermal. Crustal properties may not be elucidated till the arrival of a dedicated Europa radar mapping mission.

Conclusion: Depth-profiling of either the underlying 'seabed' or the underside of the crustal material of Europa are both tasks that are well suited to an acoustic ranging system. Differences between terrestrial seas and those which may lie beneath the surface of Europa are probably quantitative in nature, with the exception of the absence of many noise sources. No immediate engineering obstacles are foreseen for the operation of a sonar-like package on Europa if access to its subsurface can be accomplished.

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