Acoustic Remote Sensing of Extreme Sea States

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Abstract/Introduction

Extreme sea states from storms, landslides, ice-quakes, meteorite fall, submarine explosions, and earthquakes, are associated with a sudden change in water pressure. Consequently, acoustic-gravity waves (AGWs) may radiate carrying information on those states at the speed of sound. Using remote sensing of AGWs, we propose an early detection system for such extreme sea states, similar to the proposed early warning system for tsunami [1].

A closed form expression was developed for the pressure induced by an impulsive source at the free surface (the Green's function) from which the solution for more general sources can be developed. In particular, we used the model of a "once a year" meteorite ocean impact event [2] as a source and calculated the induced AGW signature.

Fundamental Equations

We define the velocity potential $\Phi(x,y,z,t)$ and free surface elevation $\eta(x,y,t)$ for the problem and let $\zeta(x,y,t)$ be the impulsive free surface source term with support $\mathbb{S}_\zeta$. The speed of sound in water is c, g the acceleration due to gravity, ρ the density of water, r the radial distance from the origin to the sensor, $\varpi = 2\pi f$ is the *representative wavenumber/frequency* and $P(x,y,z,t)$ is the pressure.

$$\begin{cases} \nabla^2\Phi = \dfrac{1}{c^2}\dfrac{\partial^2\Phi}{\partial t^2}, \quad -h \le z \le 0 \text{ and } (x,y,t) \notin \mathbb{S}_\zeta \\ g\dfrac{\partial\Phi}{\partial z} + \dfrac{\partial^2\Phi}{\partial t^2} = 0, \quad \text{and}, \eta = -\dfrac{1}{g}\dfrac{\partial\Phi}{\partial t}, \quad \text{for } z = 0 \text{ and } (x,y,t) \notin \mathbb{S}_\zeta \\ \dfrac{\partial\Phi}{\partial z} = 0, \quad z = -h \quad -\infty < x,y,t < \infty \\ \dfrac{\partial\Phi}{\partial z} = \dfrac{\partial\zeta}{\partial t}, \quad z = 0, \text{ and } (x,y,t) \in \mathbb{S}_\zeta \end{cases}$$

Equation 1 - Problem

$$G(r,z,t) = -\left(\frac{c\rho[\varpi^2 - g]}{\pi^3 g}\right)\left\{\left\{\frac{1}{r}\{F' + rF''\}\right\}\right\}$$

$$F = \frac{-\pi}{2} J_0\left[\left\{\frac{\pi}{4h}\right\}\left(ct - \sqrt{(ct)^2 - r^2}\right)\right] Y_0\left[\left\{\frac{\pi}{4h}\right\}\left(ct + \sqrt{(ct)^2 - r^2}\right)\right]$$

Equation 2 - Green's Function

$$\zeta(x,y,t) = \begin{cases} A(r)\sin(2\pi f t), \; 0 \le \sqrt{x^2+y^2} \le R, \quad 0 \le t \le T \\ 0, \; otherwise \end{cases}$$

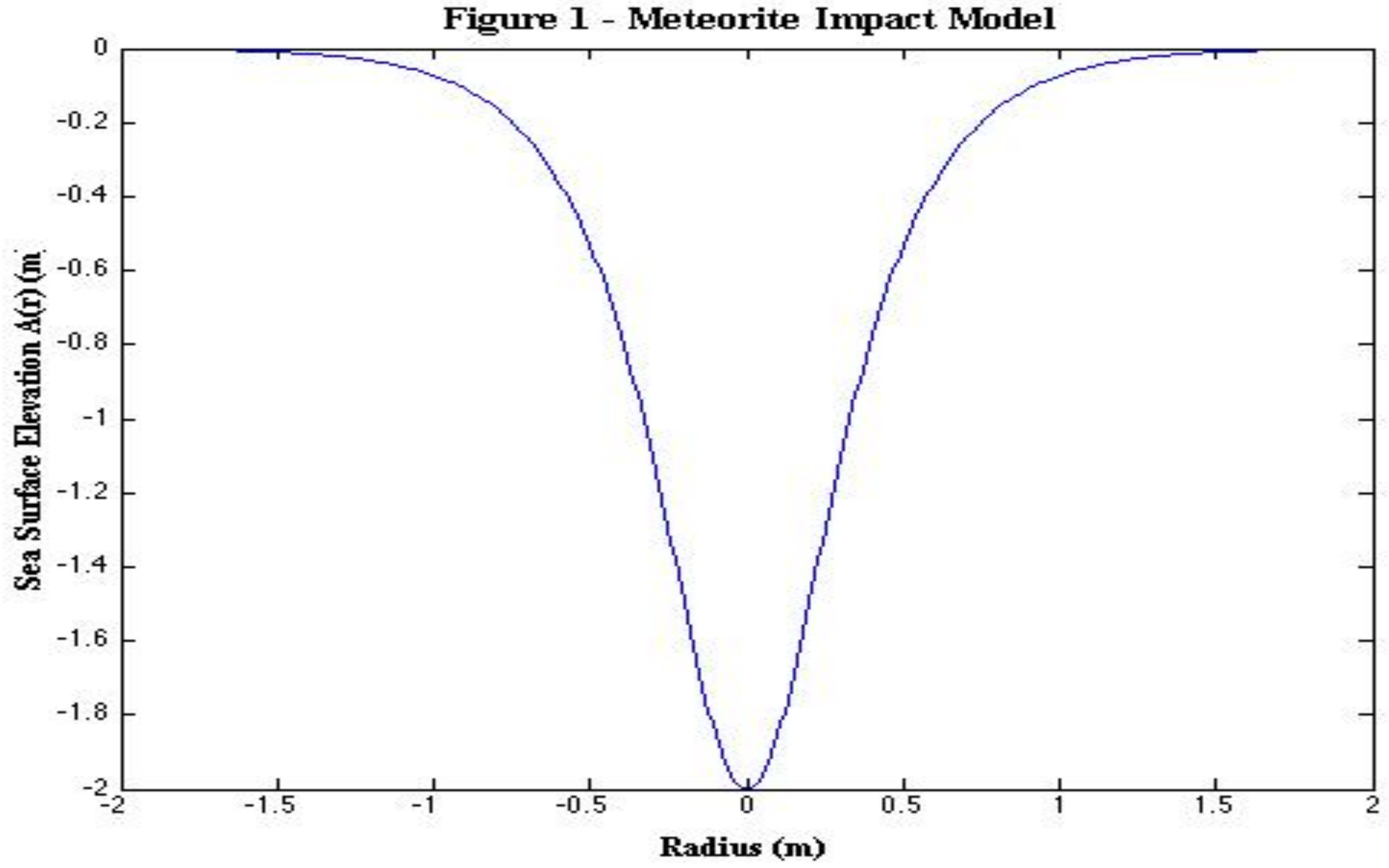
$$P(x,y,z,t) = \iiint_{-\infty}^{\infty} G(x',y',z,t')\,\zeta(x-x',y-y',t-t')\,dx'dy'dt'$$

Equation 3 - Source and Solution

Meteorite Impact Model

Based on a model of a "once a year" ocean meteorite impact event and assuming an average impact speed of 17 km/s [2], we take a radial symmetric source with the hyperbolic secant profile function A(r) shown in Figure 1 and a period of 0.471 ms. The depth is 4000m and the radial distance to the observer is 1000 km and we assume that the meteorite maintains its initial speed until it is completely submerged.

Figure 1 - Meteorite Impact Model



Results

The AGW pressure signal for the meteorite impact of a stony asteroid of diameter 4 m and impact speed of 17 km/s is given in Figure 2 and its spectrum is given in Figure 3.

Figure 2 Pressure vs time for AGW of meteorite impact

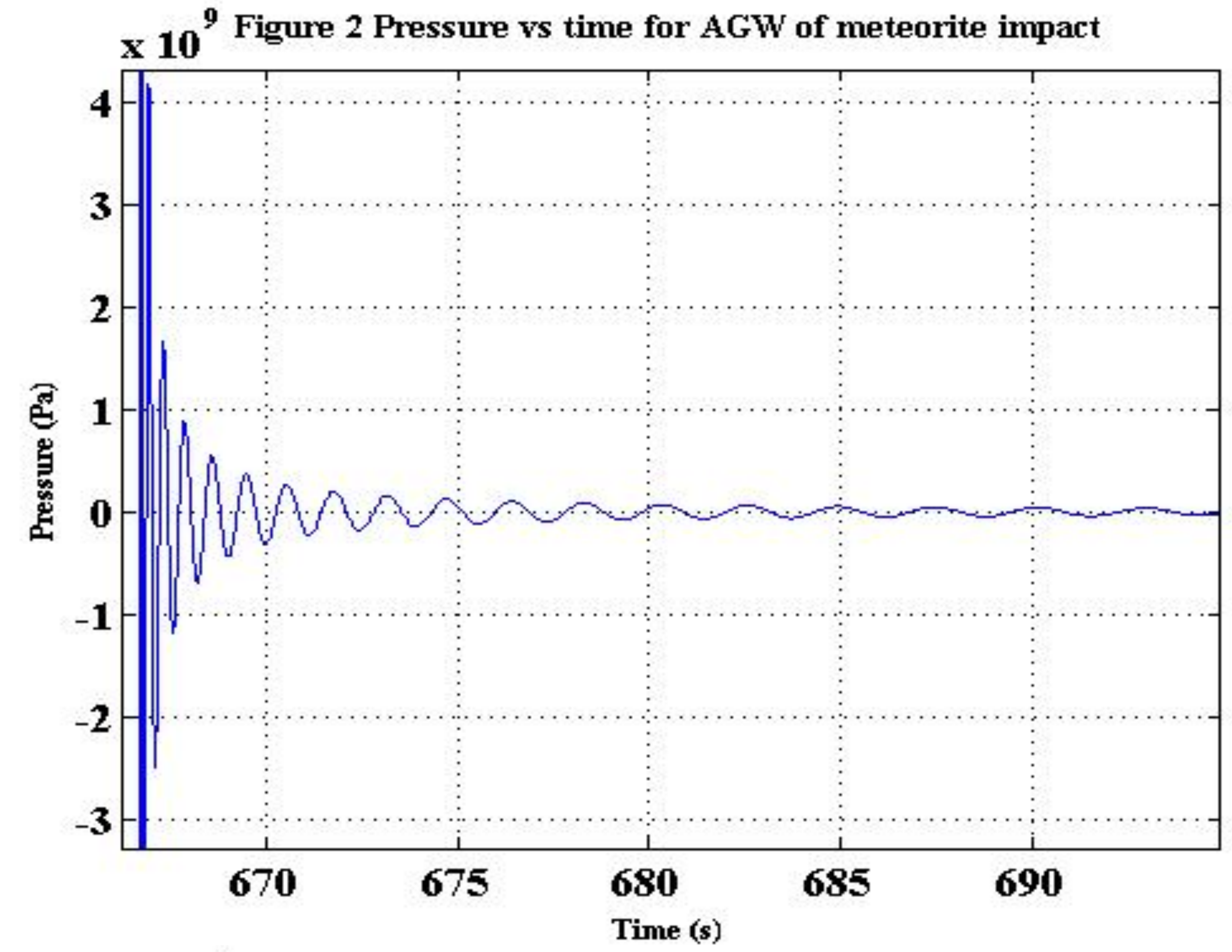
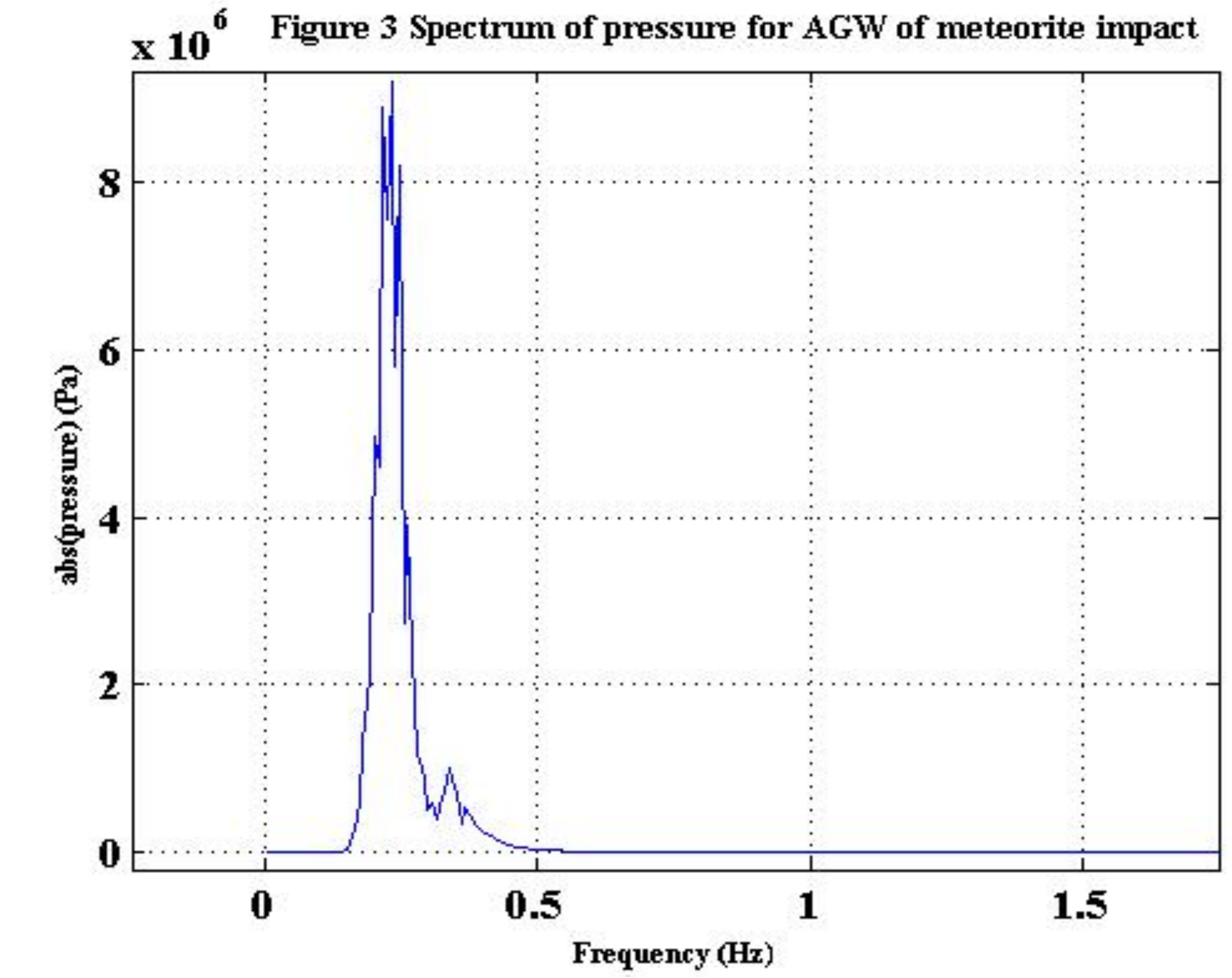


Figure 3 Spectrum of pressure for AGW of meteorite impact



Conclusions

The AGW pressure generated by an extreme sea state, such as the ocean impact of a typical meteorite, is measurable and detectable and therefore makes this method particularly attractive for remote sensing of such extreme sea states.

References

[1] Hendin, G. and Stiassnie, M., Tsunami and acoustic-gravity waves in water of constsnt depth reference, *Physics of Fluids* 25, 086103 (2013)

[2] Marcus, R., Melosh, H.J., and Collins, G., "Earth Impact Events Program", Imperial College London/ Purdue University *(2010)*