Electromagnetic analogue models for tsunami propagation

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Abstract

Concepts drawn from electromagnetic theory are used to gain insights into tsunami initiation, propagation and scattering. It is suggested that the ocean represents the equivalent of a bounded waveguide medium. A relationship between the height of the water dome 'above' a propagating wave and the energy that the wave contains is conjectured, but there is clearly a relationship between the intensity of a subduction earthquake and the deep-ocean velocity of the associated tsunami

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1. Introduction

Any attempt to model tsunamis is fraught with problems, not least of which is an emotional one. How can you explain to someone in Japan, Indonesia or Sri Lanka that your concern is with deep ocean dynamics when they want to discuss how the littoral topography and local geography determined the damage that was caused by their particular disaster?

There are other problems associated with formulation. At some point a mathematical model was provided in terms of gravity waves and this has become the accepted lore in spite of its limitations or whether it is appropriate in a particular circumstance.

The questions which this author poses are fundamental

1. How is it possible to transmit the seismic energy to the water?
2. How is it possible for that energy to be conveyed over long distances without attenuation or dispersion?
3. What factors influence the time of transit between the generation of a tsunami and its delivery at some distant point?
4. What influences does the sub-oceanic topography have on a tsunami in transit?

Some of these questions have answers which are readily available in the literature. Others appear to be glossed over with an "its all down to gravity waves" response.

It is contended that new insights can be achieved by approaching the problem from the point of view of electromagnetic analogue models. This paper will present a series of concepts in electromagnetics and immediately relate them to tsunami propagation. The reader will have to be
prepared for frequent oscillations between different disciplines as the case is developed. A practical application of a numerical technique, Transmission Line Matrix (TLM) is used to indicate what happens when a particular wave-form approaches a littoral region. In so far as is possible the data which is available for real tsunamis will be used to provide comparisons with what is proposed here.

2. Brief introduction to relevant electromagnetic theory

2.1 Impedance

O'Connor [1] has provided a useful introduction which relates the concepts that we are about to cover over several disciplines:

"Generally in phenomena to which the wave equation applies it is found that there are two physical variables that can be associated with the wave. Each of these variables, on its own, obeys the identical wave equation (but with a common value of wave speed $c$). Furthermore the product of these variables has the dimension of power and the ratio is some kind of “impedance”. Typically, one of the wave variables can be considered as an “effort”, “force”, “pressure” or “across” variable, the other as a “flux”, “flow”, “velocity” or “through” variable. Waves arise when the temporal derivative of one of these variables is proportional to the (negative of the) spatial derivative of the second, and vice versa.

For example, the natural choice of two variables are the acoustic pressure, $p$, and the acoustic velocity, $u$. Then, applying Newton's second law to an element of fluid, one gets

$$ \frac{\partial p}{\partial x} = -\rho \frac{\partial u}{\partial t} $$

(1)

while the continuity relationship is

$$ \frac{\partial u}{\partial x} = -\kappa \frac{\partial p}{\partial t} $$

(2)
where $\kappa$ is the compressibility of the fluid. A pair of first order differential equations similar to these arises in many situations ranging from longitudinal and torsional motion of mechanical shafts to the propagation of signals on an electrical transmission line. By differentiating Eqns.(1) and (2) and combining them, the second order wave equation in either variable can be obtained.

$$
\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2} \quad \text{and} \quad \frac{\partial^2 p}{\partial t^2} = c^2 \frac{\partial^2 p}{\partial x^2}
$$

(3)

The proportionality “constants” in the two first order equations, such as $\rho$ and $\kappa$ above, are another pair of variables that typically arise in wave phenomena. These characterise the wave medium, and determine the wave speed and wave impedance. The latter is the ratio of the effort to flow variables in a freely propagating wave. Table 1 gives some examples of wave variable pairs and the corresponding medium variable pair.

<table>
<thead>
<tr>
<th>Wave type</th>
<th>Wave variable pair</th>
<th>Medium variable pair</th>
<th>Wave speed</th>
<th>Wave impedance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acoustic</td>
<td>acoustic pressure</td>
<td>compressibility $\kappa$</td>
<td>$\sqrt{\kappa/\rho}$</td>
<td>$\sqrt{\kappa \rho}$</td>
</tr>
<tr>
<td></td>
<td>acoustic. velocity</td>
<td>density $\rho$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stretched string</td>
<td>$-T \frac{\partial v}{\partial x}$</td>
<td>tension $T$</td>
<td>$\sqrt{T/\rho}$</td>
<td>$\sqrt{TP}$</td>
</tr>
<tr>
<td></td>
<td>$\rho \frac{\partial v}{\partial t}$</td>
<td>linear density $\rho$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>stress</td>
<td>Young’s Modulus $E$</td>
<td>$\sqrt{E/\rho}$</td>
<td>$\sqrt{Ep}$</td>
</tr>
<tr>
<td>in rod</td>
<td>rate of strain</td>
<td>density $\rho$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Torsional in rod</td>
<td>torque</td>
<td>Shear Modulus $G$</td>
<td>$\sqrt{G/\rho}$</td>
<td>$\sqrt{Gp}$</td>
</tr>
<tr>
<td></td>
<td>angular velocity</td>
<td>density $\rho$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transmission line</td>
<td>voltage</td>
<td>capacitance $^1 C^1$</td>
<td>$\sqrt{1/LC}$</td>
<td>$\sqrt{L/C}$</td>
</tr>
<tr>
<td></td>
<td>current</td>
<td>inductance $L$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electro-</td>
<td>E</td>
<td>permittivity $^1 \varepsilon^1$</td>
<td>$\sqrt{1/\mu\varepsilon}$</td>
<td>$\sqrt{\mu/\varepsilon}$</td>
</tr>
<tr>
<td>magnetic</td>
<td>H</td>
<td>permeability $\mu$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Looking at energy, and again taking acoustics as an example, the kinetic and potential energies in acoustic waves are respectively

$$
\frac{1}{2} \rho u^2 \quad \text{and} \quad \frac{1}{2} \kappa p^2
$$

(4)
and these are equal. As the wave propagates, energy is continuously changing form, from kinetic to potential and back again. With electrical waves, the interchanging energy types are electric to magnetic.

Figure 1 shows two counter-propagating electrical impulses, $f$ and $g$, on a transmission line between two points of inspection (nodes). The impulses represent samples of an “effort” variable. The second wave variable (the “flow” variable) at a point can be obtained from the “effort” impulse by dividing it by a constant, corresponding to the line “impedance”. While the effort variable represented directly by the impulse is typically a scalar quantity, such as acoustic pressure, the “flow” variable is typically a vector quantity, such as acoustic velocity, whose orientation (in 2-D and 3-D problems) is the impulse propagation direction along the line.

$$p = f + g, \quad (5)$$

$$u = (f - g)/Z \quad (6)$$

in the direction in which $f$ is travelling."
Z in the above is called the impedance and the expression has much in common with Ohm's law in electricity. In order to simplify the presentation discussion will be largely limited to acoustics and transmission lines

2.2 Boundary conditions

Most physical problems are governed either by initial or by boundary conditions. There are subtle differences between the boundary conditions for acoustic and electromagnetic problems, even if the character of the underlying physics is identical

2.2.1 Electromagnetic boundary conditions

The signal that is reflected at a discontinuity is given by a well-known relationship

$$\rho = \frac{Z_r - Z}{Z_r + Z}$$  (7)

(i) when a transmission line is terminated in an open-circuit we have $Z_T = \infty$ so that $\rho = 1$. This is equivalent to saying that at the termination the magnetic field vector $H = 0$, but the electric field vector $E \neq 0$.

(ii) when a transmission line is terminated in an short-circuit we have $Z_T = 0$ and thus $\rho = -1$. This is equivalent to saying that at the termination the electric field vector $E = 0$, but the magnetic field vector $H \neq 0$

2.2.2 Acoustic boundary conditions

(i) At a rigid boundary in acoustics we have zero velocity but maximum pressure. Any wave impinging on this boundary is reflected in-phase ($\rho = 1$).
At a free boundary in acoustics the pressure is zero and displacement velocity is maximum. Any wave arriving here will be reflected out of phase (\(\rho = -1\)). Unlike the situation in electromagnetics the location of the free boundary is not so precisely determined and the 'end-effect' in wind instruments such as the flute is an example of this.

3. The initiation of a tsunami wave

Let us imagine that we have a section of ocean floor which measures 1m\(\times\)1m where there are no obstructions in the vicinity and let us imagine that this suddenly drops below the rest of the floor by 1m. Now, if there were 5,000m of water above this point then the work done would be 5\(\times\)10^6 Joules. If time during which this work was done was short compared to the velocity of sound in water, then a very significant rarefaction shockwave would transmit hemispherically from this point. The component which moves vertically upwards would break the ocean surface first. This surface is a free boundary and once it starts to respond to the rarefaction, then it gains momentum. The surface will continue moving downwards even after the rarefaction has been cancelled and a compressional wave will be formed which will now propagate downwards until it hits the ocean floor. This being a rigid boundary causes the compressional wave to be reflected in phase and it continues upwards driving the sea surface upwards and thereby creating another rarefaction wave. So, it is only when this hits the ocean floor that we have had the transit of a complete wave. If the ocean depth is 5000m at the point of initiation, then the natural wavelength will be 20km.

Additionally, if we assume an acoustic velocity of 1.5km/sec, then the transit time is 3\(\frac{4}{3}\) sec. It is just possible that the natural response of the water/air interface might coincide with this; an
oscillator which is being driven at its resonant frequency and a tsunami with a large initial amplitude might be expected.

4. The ocean as an analogue of an electromagnetic waveguide

Until recently most inland telephone conversations over long distances were conveyed by means of microwave links. The signal was normally conveyed from source to the transmitter by means of a rectangular hollow waveguide as shown in figure 2a. These are frequently made of copper or brass and for low loss the inside might be coated with silver to ensure that the wave sees good $\rho = -1$ boundaries. A rectangular organ pipe would present rigid ($\rho = 1$) boundaries to an acoustic signal and this is shown in figure 2(b).

![Diagram](image)

Figure 2: (a) shows part of a rectangular section metal waveguide which can support multiple modes of which the lowest are shown where the rectangular cross-section corresponds to $\lambda/2$. (b) shows a $\lambda/2$ acoustic wave supported between two rigid boundaries with a node at the centre.

It will be noted in Figure 2(b) that the signal is symmetric about a centre line so that we could without any loss of generality draw half the figure is shown in figure 3. This is identical to the situation in the ocean except that the sea surface is a 'free'-boundary, which can deform unlike the
situation in the organ pipe. It is suggested that the entire energy can be supported in a wave where the depth of the ocean is equivalent to $\lambda/4$.

Figure 4: A quarter wave constrained to move between a free-boundary and a rigid boundary

### 4.1 Guide velocity vs free-space velocity

It is well-known [2] in electromagnetics that the velocity of a signal within a waveguide guide can be significantly less than $c$, the free-space velocity. In fact, the guide velocity is given by

$$V_g = c \sqrt{1 - \left(\frac{\lambda}{\lambda_C}\right)^2}$$  \hspace{1cm} (8)

where $\lambda$ refers to the wave in question and $\lambda_C$ is cut-off wavelength of the guide, the longest wavelength that can be supported between the two boundaries. In the case of a metallic waveguide such as in figure 2(a) $\lambda_C = 2d$, the height of the guide. Skin effects ensure that the constrained wave is slightly less than $\lambda_C$ and thus able to progress within the guide.

On this basis one could claim that the cut-off wavelength in the ocean, $\lambda_C = 4d$ where $d$ is the depth of the ocean. Again, if wavelength of the tsunami is equal to the cut-off wavelength, then there would be no propagation. So it is only because the sea surface is a deformable free-boundary that we have $\lambda < \lambda_C$
At this stage it might be useful to compare the velocities of some tsunamis and relate them to the concepts presented above.

Figure 4: Nova Scotia and Newfoundland (Canada) showing the epicenter of the Laurentan Gap earthquake in relation to the edge of the continental shelf

1. Laurentan Gap earthquake (www.heritage.nf.ca/law/tsunami29.html)

"At 5:02pm (local time) on Monday 18 November 1929, an underwater earthquake occurred on the southern edge Grand Banks, about 265 kilometres south of Newfoundland's Burin Peninsula. It measured 7.2 on the Richter scale and was recorded in locations as far west as New York and Montreal and as far east as Portugal. On the Burin Peninsula, ground tremors lasted for about five minutes but did not cause any serious damage to houses or other structures. . . . .

On the Grand Banks, the earthquake triggered a sizeable underwater landslide, which in turn forced a series of large waves across the ocean's surface. The tsunami moved towards
Newfoundland at speeds of up to 140 km/hr, before slowing to about 40 km/hr in shallower water.

At about 7:30 p.m., residents along the Burin Peninsula noticed a rapid drop in sea level as the lowest point of the tsunami's first wave, known as a trough, reached the coast. As the water receded, it exposed portions of the ocean floor that were normally submerged and caused boats docked at various harbours to tumble over onto their sides. Minutes later, three successive waves hit the shore and water levels rose dramatically. In most places, the sea level swelled three to seven metres above normal, but in some of the peninsula's long narrow bays, such as at Port au Bras, St. Lawrence, and Taylor's Bay, the water rose by between 13 and 27 metres.

2. Indian Ocean earthquake (26 December 2004)

The first earthquake was at 0058 UTC and other followed. These represented subduction along approximately 1600km of fault interface. Banda Acheh in Indonesia lies approximately 150km NW of the fault-line. The tsunami arrived at 0123 UTC which represents a velocity of 360km/hr or 100m/sec. The component travelling west arrived at the east coast of Sri Lanka at 0223 UTC which represents a velocity of 1107km/hr or 307.5m/sec

* Other reports (en.wikipedia.org/wiki/1929_Grand_Banks_earthquake) have speeds of 129km/hr at the epicentre and 105km/hr at landfall
3. Great East Japan Earthquake (11 March 2011)

Earthquake, 8.9 on Richter scale occurred at 0546 UTC with epicentre at 38.322°N, 142.369°E approximately 60km offshore. Although the associated tsunami arrived onshore within 10 minutes it was recorded at Kamaishi 26 minutes later. The distance gives it a velocity of 160km/hour or 44m/sec. On the other hand the component that travelled out across the Pacific had quite a different velocity. Using the distances to Guam, Midway, Hawaii and the predicted arrival times (www.dailymail.co.uk/news/article-1365243/Japan-tsunami-wreaks-millions-dollars-damage-Californian-harbours-US-west-coast.html) and it would appear that the velocity of the tsunami remained constant at about 900km/hr (250m/sec) over a distance of 6000km.
These three cases will be considered later in the discussion section of the paper.

4.2 Mode stripping

The wave shown in figure 3 is not the only one that could be propagated in such a waveguide. In fact any wave that satisfies the criterion \( d = (2n - 1)\frac{\lambda}{4} \) where \( n = 1, 2, 3 \ldots \) will propagate. Of course, equation (8) confirms that each will travel in the guide at different velocities and we will therefore have dispersion. It is in this context that the littoral topography may come to play a significant role. One of the bench-mark tests for any numerical scheme for modelling underwater acoustic propagation is the Buckingham and Tolstoy wedge [3]. Waves travelling in a uniform medium encounter a slope where the height of the water at any position starts to reduce. Let us imagine that in deep water it was possible to support a wave with four nodes. As the slope progresses this is no longer possible and there is a sudden transition to a wave with three node. The wave continues but as the guide can only support a wave with two nodes we get another transition. This is the process of 'mode-stripping' and eventually, when it comes even closer to the shore it is only possible to support a quarter wave. Looked at another way, the entire energy that was contained in a multi-node wave in deep ocean is now contained in a quarter wave which must therefore have a significantly greater amplitude.

The Buckingham and Tolstoy benchmark has been treated by Scott and de Cogan [4] using an analogue numerical scheme based on electromagnetics and the results are in extremely close agreement with the analytical predictions. This is attributed to the use of realistic boundaries
rather than the conventional step-wise boundaries as are used in many Cartesian system models. An example of mode stripping taken from [4] is shown in figure 6.

Figure 6: Pressure profile for depth versus range due to a 50Hz source located at mid-depth of deepest part (Buckingham and Tolstoy Benchmark test). Results obtained using the TLM numerical method with uniform (as opposed to stepped) slope boundary.

4.3 Further electromagnetic analogies for tsunamis

In spite of the title of this section it might be best to start with an acoustic analogy. If we were to detonate an explosive in air of constant temperature, then we might expect that the pressure wave from the explosion would fall of as the square of the inverse distance. This same law is indeed one of the cornerstones of electromagnetics. So, if instead of a point source we were to radiate an electromagnetic signal from a line source then the situation would be quite different and we would witness two effects. The signal strength along the axis of the source would be zero while the signal source at right angles to centre of the line would be a maximum. This can be
represented in a polar diagram and an example for the specific case of a dipole antenna is shown in figure 7(a).

![Diagram showing polar diagram and beam pattern for a dipole antenna with and without a reflector.](image)

Figure. 7: (a) the polar diagram of the signal propagating from a dipole antenna. (b) the beam pattern for a dipole antenna with a reflector

If a section of conducting material is placed behind the dipole so as to inhibit the propagation of signal in that direction, then all of the signal is constrained to go in one direction and the beam pattern is more oval and of greater amplitude (figure 7(b)). In the Yagi-Uda array as used for terrestrial TV many pieces of metal are placed in front of the dipole but unlike the reflector they are shorter than the overall length of the dipole. The larger the number of director elements the more elliptical the beam pattern becomes. The antenna therefore has greater gain and greater directionality. The final thing to note is that in the case of an infinite line source the intensity falls off as the inverse of the distance.
Given the speed of propagation of the Acheh fault in 2004, there is no doubt that it must be considered as a finite line source. There are those who contend that Bangladesh was protected by the continental shelf [5], but this begs the question about the regions south-west of the fault where there was relatively little impact. Using the analogies here there is no doubt that Bangladesh was located on the axis of a line-source. Further, it could be argued, (but it would need careful checking) that given the position of the fault and the local topography the Indonesian continental shelf could have acted as a very effective reflector. Everything that is contained in the pictures in figure 8 are consistent with propagation from a line-source.

Figure 8: (a) shows USGS graphic of the wave forms of the 2004 Indian Ocean Tsunami (http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake_and_tsunami#cite_note-10), the '+\)' signs (shown as red in the original) denote a compression while '-' (blue in the original) is rarefaction wave. (b) shows a later phase of the tsunami from a simulation attributed to A. Piatanesi and available for some time on Novisibirsk Tsunami website.
The slip did not happen instantaneously but took place in two phases over a period of several minutes: Seismographic and acoustic data indicate that the first phase involved a rupture about 400km (250 mi) long and 100 kilometres (60 mi) wide, located 30km (19 mi) beneath the seabed—the largest rupture ever known to have been caused by an earthquake. The rupture proceeded at a speed of about 2.8km per second (1.7 miles per second) (10,000 km/h or 6,200 mph), beginning off the coast of Aceh and proceeding north-westerly over a period of about 100 seconds. A pause of about another 100 seconds took place before the rupture continued northwards towards the Andaman and Nicobar Islands. However, the northern rupture occurred more slowly than in the south, at about 2.1 km/s (1.3 mi/s) (7,500 km/h or 4,700 mph), continuing north for another five minutes to a plate boundary where the fault type changes from subduction to strike-slip.

The two linked line sources mentioned above can be seen quite clearly in the picture on the left in figure 8(a).

<table>
<thead>
<tr>
<th>Source of excitation</th>
<th>Intensity/distance relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>point</td>
<td>( \frac{1}{d^2} )</td>
</tr>
<tr>
<td>infinite line</td>
<td>( \frac{1}{d^1} )</td>
</tr>
<tr>
<td>infinite plane</td>
<td>( \frac{1}{d^0} )</td>
</tr>
</tbody>
</table>

### 4.5 Range dependence of signal intensity

Now, there is another aspect of these subduction induced tsunamis that may have been overlooked. They all occur at or near points where the continental shelf drops very suddenly.
Everything up to now has concentrated on vertical shift leading to wave generation, but if there is lateral displacement of the continental shelf then this is equivalent to a planar source whose intensity does not fall off with distance. The three situations are summarised in table II and if this is accepted then it does explain much about how the intensity in a tsunami is maintained over great distances.

5. Discussion

Before starting the discussion it is worthwhile revisiting the initiation of a tsunami in the light of the fact that the energy might be generated by lateral movement. In figure 9(a) we see a slump such as occurred in the Laurentian Gap in 1929. As it moved eastward it would have created a compressional wave in front of it, but would have left a trough in its wake, which is consistent with the observation of a significant sea withdrawal before the arrival of a crest.

Figure 9: (a) Slump creates a compressional wave in front and leaves a trough behind. (b) landmass rises as it moves relative the ocean floor plate. (c) ocean floor plate moves under the landmass without significant rise of the landmass
Two different cases of subduction are shown in figure 9(b) and (c). If in addition to a leftward movement in (b) there is a rising of the landmass, then the shallow region will also exhibit a rarefaction and thereby sea withdrawal. Reports from Banda Aceh and an inspection of figure 8(a) suggests that this is what might have happened in the east-moving tsunami following the Indonesian earthquake of 2004. The many video sequences from the March 2011 Japanese tsunami suggest that there was no prior run-out, that the first arrival was a trough and it is possible that the mechanism is more like that shown in figure 9(c). This is shown greater detail in figure 10. Movement of land relative to the ocean is equivalent to the arrival of a compressional wave at a rigid vertical boundary which is reflected back at all point except near the surface where an equation analogous to (7) will apply and this determines the fraction of the wave that continues towards the land and the fraction this is reflected, rather in the manner of the Yagi array shown in figure 7(b).

![Figure 10: Reflection of megathrust-induced wave at the ocean/landmass interface with transmission along the continental shelf.](image)

If we now return to equation (8), $V_g = c\sqrt{1 - \left(\frac{\lambda}{\lambda_c}\right)^2}$ we will make one assumption namely that the dome of water overlying a wave is proportional to the energy contained in the wave. If this
can be accepted then we can proceed to see how this influences the velocity in the cases considered. Equation (7) can be restated as

\[ \rho = \frac{1 - \varepsilon}{1 + \varepsilon} \quad \text{where} \quad \varepsilon = \frac{Z}{Z_T} \tag{9} \]

which is identical to the expression for the ratio of the reflected amplitude to the incident amplitude given by Mofjeld et al [6]. Their expression for ratio of the transmitted amplitude to the incident amplitude is \( \tau = \frac{2}{1 + \varepsilon} \) and they define \( \varepsilon = \frac{d_s}{d_o} \) where \( d_s \) is the depth of the shelf and \( d_o \) is the ocean depth. They also define the relative reflected and transmitted energy fluxes on a step escarpment as

\[ \frac{F_T}{F_i} = \frac{4\varepsilon}{(1 + \varepsilon)^2} \quad \text{and} \quad \frac{F_R}{F_i} = \frac{(1 - \varepsilon)^2}{(1 + \varepsilon)^2} \tag{10} \]

Thus an energetic wave travelling through deep ocean will be moving within a water dome which ensures that the local value of \( \lambda_C/4 \) is greater than the depth of the ocean by an amount which allows the tsunami to propagate at the observed speed.

The ratio of the Richter scales for the Indonesian and Japanese tsunamis gives \( \frac{10^9}{10^{8.9}} = 1.259 \)

The ratio of the deep ocean velocities of these two tsunamis gives \( \frac{1133}{900} = 1.259 \)

which agreement, given the uncertainties, is quite extraordinary.

So, finally, let us compare the transmitted energies when these were reflected at the escarpments of their respective subduction locations. From *GoogleEarth* we can find that
\[ \varepsilon_{\text{sl}} = \sqrt{\frac{500}{4000}} = 0.35355 \] at first contact with the Sri Lanka continental shelf

\[ \varepsilon_{\text{Jap}} = \sqrt{\frac{1700}{6000}} = 0.5323 \] at the continental shelf near the epicenter

Using Eqn (10) we obtain the following energy flux transmission coefficients

77.19% of the incident energy was transmitted landwards in the case of Sri Lanka

90.68% of the incident energy was transmitted landwards in the case of Japan which would account for the very significant destructive power of that tsunami.

Figure 11: The mirror-like reflectors of the Japanese continental shelf as a vehicle for 'beaming' the 11 March 2011 tsunami across the Pacific Ocean
6. Conclusions

It has been shown that concepts based on electromagnetics and their extension to acoustics can lead to new insights into tsunami propagation. A comparison of point-source excitation, finite line-source excitation and finite plane-source excitation has been used to show how a wave, supported between ocean surface and ocean floor can be 'guided' over long distances with little attenuation or dispersion. It is suggested that the interface between a landmass and the ocean is indeed a planar source and this accounts for the tsunamigenesis properties of subduction earthquakes. The Japanese earthquake could have been even more deadly because of the geometry of the faults in that area. The source plane is bounded by two reflectors which will help focus the beam (see figure 11). Fortunately there was nothing in close proximity to its line of fire.

It is noted that the ratio of the Richter scales for the 11March 2011 and 26 December 2004 earthquakes give a value which is remarkably similar to the ratio of the deep ocean velocities of the associated tsunamis

The conjecture concerning the presence or absence of significant sea withdrawal before the onslaught holds that if in the tsunami we have the arrival of crest before trough then this will be relatively small or absent. If trough arrives before crest then it could be substantial. Which arrives first will depend on the location of the target in relation to the lateral displacement of the place
The concept of 'stripping' of multi-node waves and the transfer of energy to the lower modes as a tsunami approaches a littoral region could be considered as another aspect of the deformation of waves on slopes [7]. As the amplitude increases and the wave slows down over-fall will occur which could account for the Chinese word for a tsunami HaiXiao (海啸) whose literal translation is 'sea-hiss'.
7. References


