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Design of Surface Wave Radars for Tsunami Predictions

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Abstract: Tsunamis are ever-present threat to lives and property along the coasts of most of the world's oceans that cause considerable destruction and kills people. As the Sumatra tsunami of 26 December 2004 revealed the fact that we must be more proactive in developing ways to reduce their impact on our global society. This paper provides an overview of the technique the surface wave radars for the detection of tsunami. Basic radar block diagram and radar range equation and its effect on sea surface are also discussed. Overviews of the signals and their characteristics have done. This overview is then used to develop guidelines for advancing the science of forecasting. High-frequency (HF) surface wave radars can also provide a unique capability to detect targets far beyond the conventional microwave radar coverage. This capability also could contribute to the development and improvement of Tsunami Early Warning Systems. This paper concludes that surface wave radar systems can be used to detect tsunamis well before their arrival at a coastline. We should create a world that can coexist with the tsunami hazard.

Keywords: Remote sensing; OTH Radar; DART Systems; Surface Wave radar; HF surface radar.

I. INTRODUCTION

An incoming tsunami can be anticipated in many ways that includes both direct human recognition of cues such as earthquake shaking and an initial recession of the sea as well as to the technological warnings based on environmental sensors and data processing. The U.S. tsunami warning centers (TWCs) paying specific attention to the infrastructure of the earth and ocean observation networks and mainly to the data processing and tsunami modelling that occur at the TWCs. All initial tsunami warnings are based mainly on the rapid detection and characterization of seismic activity. Since there exists a fundamental difference in nature between the solid earth in which an earthquake takes place and the fluid ocean where tsunami gravity waves propagate, the majority of earthquakes occurring on a daily basis mostly do not trigger appreciable or even measurable tsunamis. But, some smaller earthquakes could trigger submarine landslides that can result in local tsunamis. Normally need a large event (magnitude will be greater than 7.0) to generate a damaging tsunami in the near-field and a great earthquake (magnitude greater than 8.0) to generate a tsunami in the far-field. However, the generation of a tsunami is affected not only by the magnitude of an earthquake, but also by the material conditions at the source, such as source focal geometry, source depth of earthquake, and water depth above the fault-rupture area. Although estimating the size of a tsunami is basically depends on the magnitude of an earthquake, that has severe limitations, the initial warning from a seismically generated tsunami is still based on the interpretation of the parent earthquake because of several reasons:

- Mostly tsunamis are excited (or initiated) by earthquakes;
- Basic earthquake waves are very easy to detect, and its instrumentation is available, plentiful, and accessible in near-real time ;
- More over seismic waves travel faster than tsunamis by a factor of 10 to 50, thereby allowing an earthquake that provides an immediate natural warning for people who feel it while it leaves time for instrumental seismology to give official warnings for coasts that is near and far from the tsunami source; and Once earthquakes have been studied, and their sources are reasonably well understood.

Even though most tsunamis result from earthquakes, some are triggered by either landslides or volcanic eruptions. Technological warning of a tsunami that has been generated without a detectable earthquake will likely need the detection of the tsunami waves themselves by water-level gauges. A natural disaster like tsunami cannot be stopped, but early warning can reduce the damage caused by it. Tsunami detectors can be placed in the sea about 50 km in the shore. The detectors will record any disturbances and transmit it to the land. But these detectors will identify the tsunamis closer to the sea. Nowadays satellite technology has made it easy the detection process. Now the technology has improved a lot to enable early

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warning systems to avoid the hazards minimum. Surface waves can be used for the detection of tsunami. It can work as an OTH Radars which can conduct to and from a reasonable distance. A surface wave travels along the surface of the earth by virtue of inducing currents in the earth. Tsunami can be measured from the surface wave current that are produced by the friction between the wind and the water as the wind blows across the ocean. Some of the wind energy is transferred to the water which produces waves across the surface of the ocean and some of the energy is transferred into surface currents. When current run in to a continent, it must turn right or left to form boundary currents. Surface currents cover over 70percent of the earth that includes the Atlantic Ocean, Indian Ocean, Pacific Ocean and the Arctic Ocean.

II. GROUND WAVE PROPAGATION

The energy radiated from a transmitting antenna reaches the receiver side over any of many propagation paths. One of the propagation methods is sky wave propagation or ionospheric propagation in which the waves are arrived at the receiver after reflection or scattering in the ionosphere. The waves that are reflected or scattered in the troposphere are termed as space waves. Energy propagated over other paths near the earth's surface is considered to be Ground wave. Ground waves consist of space waves as well as surface waves. The space wave is made up of direct wave which is the signal that travels directly from transmitter to receiver, and the ground reflected wave, which is the signal which is obtained at the receiver after reflection from the surface of the earth. It also includes the portion of the energy received as a result of diffraction around the earth's surface and refraction in the upper atmosphere. During surface energy communication the energy is abstracted from the surface wave to supply losses in the ground. If the antennas are placed in the line of sight then there will be a direct wave as well as a reflected signal. Direct signal is not affected by its locality.

But at the same time it is reflected by a number of objects including the earth's surface as well as any hills or large buildings that may be present. In addition to this there is a surface wave that tends to follow the curvature of the earth and makes the coverage area beyond the horizon. The sum of all these components together called as ground waves. Beyond the horizon, the direct and reflected waves are blocked by the curvature of the earth and the signal is made up of the diffracted surface wave. It is for this reason that surface wave is commonly called as ground wave propagation.

A. Surface Waves

Surface waves can be applied to many fields since it have many interesting properties. The main consideration is its increased range due to the surface waves bound nature and signal convertness. Moreover surface waves are non-radiating so that could be considered for convert systems. Another property is the terrain following that is the ability of the electromagnetic wave to follow the topology of the earth. Due to the surface wave being bound to the interface, it should follow the terrain. By utilizing a surface wave based system, one could ensure more signal power is transmitted to the desired location, following the terrain. This results in the capability of non-line of sight communication. But the major drawback of terrain following will be the sharpness of angle around which a surface wave can still remain bound to the interface. Because of that some loss through radiation will occur. However, this will not cause excessive loss as most of the topologies are relatively small compared to the wavelength. Lower frequencies (between 30 and 3,000 kHz) is having the property of following the curvature of the earth. These radio waves propagate by interacting with the semi-conductive surface of the earth. The surface wave "clings" to the surface and thus it follows the curvature of the earth and hence the name. In this type of waves Vertical polarization is usually used to alleviate short circuiting the electric field through the conductivity of the ground. Ground waves are usually attenuated rapidly as they follow the earth's surface because ground is not a perfect electrical conductor. Since the Attenuation is proportional to the frequency and this will make this mode mainly useful for LF and VLF frequencies. Nowadays LF and VLF are mostly used as time signals, and for military communications, especially one-way transmissions to ships and submarines. Radio broadcasting using surface wave propagation uses the higher portion of the LF range in Middle East countries. Early commercial and professional radio services relied exclusively on long wave, low frequencies as well as ground-wave propagation. Amateur and experimental transmitters were restricted to the higher (HF) frequencies to prevent interference with these services. The advantages of HF for commercial and military purposes became apparent by the discovery of the other propagation modes possible at medium wave and short wave frequencies. Surface waves are nothing but seismic waves that occurs at or near the surface of the earth. These waves have high wavelengths and larger amplitudes . So more suitable for tsunami signal detection. These waves are generated by explosions or earth quakes and they can travel multiple times if the disturbance is large enough. These type of waves travels slowly but can cause a large amount of damage. The lower the frequency the better the waves penetrate the sea water. So low frequency surface wave radars can be used for the detection. A surface wave can be mechanical or electromagnetic. Some of the characteristics of surface waves are due to the imperfectly conducting earth. The range depends upon the following four factors. i.e. Frequency, Polarization, Location and Ground Conductivity. And the surface waves dies more quickly as the frequency increases:

$$\text{Range km} = \frac{200}{f\ (MHz)}$$

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III.RADAR BLOCK DIAGRAM

The basic principle behind radar is sound-wave reflection. For example if you shout in the direction of a sound-reflecting object you will hear an echo. We can estimate the distance and general direction of the object if we know the speed of sound in air. And the time required for an echo to return can be converted to distance if the speed of sound is known. For that the radar uses electromagnetic energy pulses. The radio-frequency energy is transmitted to and reflected from the reflecting object. The reflected energy portion(echo) returns to the radar set. Radar sets use this echo to find the direction and distance of the reflecting object.

The following figure describes the operating principle of a primary radar set. The radar antenna is used to illuminate the target with a microwave signal, and the reflected signal called as echo is picked up by a receiving device. The radar block diagram involves a powerful transmitter and a highly sensitive receiver.All targets can produce a diffuse reflection because it is reflected in a wide number of directions. The reflected signal is also named as Back scattering since it is in the opposite direction to the incident rays.

Radar signals can be displayed either on the traditional plan position indicator (PPI) or any other more advanced radar display systems. A PPI has a rotating vector at the origin that indicates the pointing direction of the antenna and hence shows the bearing of targets.

- **Transmitter**

The radar transmitter produces the modulated short duration high-power radiofrequency pulses of energy that are into space by the antenna.

- **Duplexer**

The function of duplexer is to alternately switch the antenna between the transmitter and receiver. This switching is needed otherwise the high-power pulses of the transmitter would destroy the receiver suppose if the energy were allowed to enter the receiver.

- **Receiver**

The function of receiver is to amplify and demodulate the received RF-signals and it gives the video signals as output.

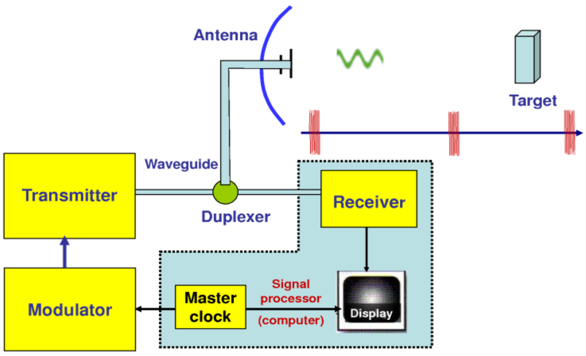
- **Radar Antenna**

The Antenna transfers the transmitter energy to signals in space in accordance with the required distribution and efficiency needed. This process should apply in an identical way on reception in order to get the signal back.

- **Indicator**

The indicator should appear to the observer as a continuous, easily understandable as well as a graphic picture of the relative position of radar target. The radar screen displays the produced signal from the echo. The longer the pulses were delayed by the runtime, the further away will be it displayed. The deflection direction on this screen will be the same as the direction in which the antenna is currently pointing.

Simplified Radar Block Diagram



A. The Radar Range Equation

In Radar theory one of the simpler equations is the radar range equation. The radar range equation relates the transmit power, that is nothing but the wave propagation up to the receiving of the echo-signals. The radar equation gives the ower P_E returning to the receiving antenna and depending on the transmitted power P_S, the range R, and the reflecting characteristics of the target. At known sensibility of the radar receiver the radar equation determines theoretically the maximum range. Furthermore one can assess the performance of the radar set with the radar range equation. One form of the basic radar range equation is

$$SNR = \frac{P_S}{P_N} = \frac{P_T G_T G_R \lambda^2 \sigma}{(4\pi)^3 R^4 k T_0 B F_n L}$$

Where

- SNR is termed the signal-to-noise ratio and has the units of watts/watt, or w/w.
- P_S is the signal power at some point in the radar receiver – usually at the output of the matched filter or the signal processor. It has the units of watts (w).
- P_N is the noise power at the same point that P_S is specified and has the units of watts.
- P_T is termed the peak transmit power and is the average power when the radar is transmitting a signal. P_T can be specified at the output of the transmitter or at some other point like the output of the antenna feed. It has the units of watts
- G_T is the power gain of the transmit antenna and has the units of w/w.
- G_R is the power gain of the receive antenna and has the units of w/w. Usually, $G_T = G_R$ for monostatic radars.
- λ is the radar wavelength (see (21) of the Radar Basics section) and had the units of meters (m).
- σ is the target radar cross-section or RCS and has the units of square meters or m^2.

- R is the range from the radar to the target and has the units of meters.
- k is Boltzman's constant and is equal to $1.38\times10^{23}\ \text{w}/(\text{Hz}\ ^{\circ}\text{K})$.
- T_0 denotes room temperature in Kelvins $(^{\circ}\text{K})$. We take $T_0 = 293\ ^{\circ}\text{K}$ and usually use the approximation $kT_0 = 4\times10^{-21}\ \text{w/Hz}$.
- B is the effective noise bandwidth of the radar and has the units of Hz.
- F_n is the radar noise figure and is dimensionless, or has the units of w/w.

B. Ground Wave Attenuation Factor

When we deals with ground wave propagation the effect of surface roughness should take in to consideration since it cause additional losses. The roughness can be represented by the measuarable, directional wave-height spectrum. The ground wave attenuation factor increases with wind speed due to an increase in sea surface roughness.

Also for a given wind speed, the added loss increases with frequency since the modified surface impedance increases. And the most important challenging task in the sea water measurement is the interpretation of the signal returned by the sea surface. The return varies with changes in frequency, radar system and mode of operation for any given set of ocean conditions. These complications can be avoided by the better understanding of the interaction processes occurring in the scattering of radio waves from the ocean surface. But the ocean surface is not deterministic in nature. The phase of the normalized surface impedance also affects the attenuation factor.

C. Surface Wave Currents

Tsunamis are long gravity waves and, like tides, have the capability of triggering internal waves under given oceanographic conditions. Even though internal waves appear as radar cross section variations of the ocean surface, it is worth reminding that the generating mechanism and the spatial scale of these features are completely different from tsunami shadows. All these features are ocean surface physical features, and might be detectable by satellite borne sensors (SAR, satellite altimeters, scatter meters and radiometers). Indeed, a number of mechanisms (either known or unknown) might contribute to tsunami-induced radar cross section modulations and chances are that these effects are strong enough to be used as principles of detection by future tsunami warning systems. This involves not only detection but also an estimate of the tsunami magnitude. Ultimately, a stationary sensor has the possibility to learn normal patterns and detection and/or magnitude estimation can be achieved by comparing pre- and post-quake patterns.

IV. TSUNAMI PREDICTION METHODS

The main detection schemes include the following:

- Deep-Ocean Assessment and Reporting Of Tsunamis (DART systems)
- Buoy-Bottom Pressure Recorder System(BPR)
- Satellite Detection System
- Global Earth Observation Systems of systems(GEOSS)
- Using Surface wave radars (Radio Method): That can be done either using low frequency surface wave radars or High frequency surface wave radars.

RADIO METHODS: SURFACE WAVE RADARS

Surface waves are the most obvious phenomena that is almost constantly present on the surface of any water basin such as seas, oceans etc. The most important cause of surface waves are the wind. The most effective means to predict major tsunamis is to predict major earthquakes. However this ambitious objective to say the least, and despite the research of many decades of earth scientists this remains a grand challenge problem, on which major progress will take much time. The question remains, however, as to find credible aspects of tsunami prediction on which mathematicians can contribute. It seems to me that there are many important open questions in the modelling of (1) tsunami wave generation in the event of a major earthquake, (2) wave propagation across the Open Ocean, and (3) wave impact upon the coastlines affected by the event. Indeed the design of tsunami early warning systems or some of its components involves mathematical modeling of solutions of the partial differential equations describing ocean wave dynamics, and computer simulation of solutions which, if they are to be an effective warning, must be performed in faster than real time. It is also an important problem to be able to clarify the character of tsunami waves, in particular those features of the waves as they impact on coastal areas which can affect tsunami safety codes in engineering and architecture. In light of the events of the 2004 tsunami in South Asia, there has been an increasing concern about future tsunami threats, and with it, growing interest in tsunami detection and prevention systems. Part of my task was to research existing tsunami detection systems, consider their effectiveness and feasibility and also to theorize new systems and ways of improving existing ones. Majority of Radars used by Air force, Airport authorities including weather Radars are LOS systems. These radars may not be used in prediction of arrival of Tsunami. Special type of radar called "Surface Wave Radars" Which may have to be operated in VLF/LF bands may do the job. Even HF radars propagating through Ionospheric layers may be helpful in the prediction of Tsunami. It is learned that Indian Navy is using a Radio transmitter at about 10 KHz to contact submarines and surface vessels in and around Indian Ocean Region-Arabian Sea and Bay of Bengal section. The transmitter is located at Tirunelveli. If this transmitter is employed as a surface wave Radar the

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"Return" from the sea will be "Strong" during Tsunami and it should be possible to predict the incoming Tsunami quite before its arrival at the shore and prevent destruction and damage at the shores. Existing tsunami watch systems are based on computer modeling programs that warn against the possibility of earthquake-generated tsunami impacts, and attempt to predict their strength and location. Before the tsunami occurred, there was the naturally occurring circulation pattern, dominated by tides, wind-driven flows, and the strong Western Boundary current called the Gulf Stream. All of these current contributors are added in, on top of the tsunami pattern. Finding the tsunami pattern within the obscuring background is facilitated by capitalizing on two factors:

• The background currents don't change very much over time periods of 1 – 2 hours, while the tsunami currents change a lot over that time. Therefore we calculate continuously an average background flow and subtract it from the latest incoming radial pattern.

• Devise an algorithm that looks for onshore vectors that are nearly constant within strips parallel to the bathymetry contours, but are allowed to vary with distance from shore[7].

A surface wave can follow the contours of the Earth due to the process of diffraction, .The wave tends to curve or bend around the object as long as when a surface wave meets an object and the dimensions of the object do not exceed its wavelength. But weakening or attenuation of the wave takes place as long as it moves away from the transmitting antenna since the induced voltage takes energy away from the surface wave. The amount of induced voltage must be reduced in order to reduce the attenuation. This can be done by using vertically polarized waves that minimize the extent to which the electric field of the wave is in contact with the Earth. And the electric field of the wave is parallel with the surface of the Earth and it will be in contact with it as long as a surface wave is horizontally polarized. Then the wave is said to be completely attenuated within a short distance from the transmitting site. But when the surface wave is vertically polarized, that wave becomes out of the Earth's surface. So we can say that vertical polarization is superior to horizontal polarization for surface wave propagation.

Another major factor that affects in the attenuation of surface waves is its frequency. The higher frequency wave will have shorter wavelength. These high frequencies, with their shorter wavelengths, are usually absorbed by the Earth at points relatively close to the transmitting site. More rapidly the surface wave will be absorbed, or attenuated, by the Earth as long as the frequency of a surface wave is increased. So the surface wave is impractical for long distance transmissions usually where the frequencies are above 2 megahertz. But as long as the frequency of a surface wave is low enough to have a very long wavelength, the Earth looks like very small, and diffraction is enough for propagation well beyond the horizon. So by lowering the transmitting frequency into the very low frequency range and using very high-powered transmitters, we can propagate the surface wave at great distances. The major application area involves the Navy's extremely high-powered very low frequency transmitters that are actually capable of transmitting surface wave signals around the Earth and so they can provide coverage to naval units operating anywhere at sea. This idea can be extended for the prediction of tsunami [8].

Two remote sensors namely direct sensors that observe some relevant parameter of the wave system as well as indirect sensors that observe the surface waves via the interaction with some other physical processes are used. The radar transceivers may be coherent or non-coherent. Coherent Radars measures Doppler as well as amplitude modulation and so contains more information about the sea surface properties. The radar transmitter waveform contains modulated or pulsed radar that can resolve echoes from different ranges. In radar remote sensing we are measuring the characteristics of the sea surface by means of electromagnetic waves without disturbing the sea surface. The electromagnetic waves that are transmitted by the radar antenna are scattered back from the sea surface. That wave will be modulated in amplitude and phase or frequency by the interaction with the sea surface in motion. This modulation basically carries information about the characteristics of sea –surface that is surface waves and currents. Oceanographic data can be extracted from the back scattered signals by signal processing techniques. Surface waves may be measured by a large no of techniques and a lot of instruments are commercially available.

The high frequency (HF) surface wave radar could also contribute to the improvement of Tsunami Early Warning Systems. The HF radar, which is based on surface wave propagation along salty water, uses the frequency band of 3-30 MHz to provide a large coverage that could extend to more than 200 Kilometers in range. These maximum range values are of high interest for many applications including ship detection, tracking, and guidance, as well as search and rescue, distribution of pollutants, fishery and oceanographic research. These radar systems recently became an operational tool in costal monitoring worldwide. No one can afford to wait for a major tsunami in order to have relevant data sets for analyses. Hence we must use simulations for continuing optimization efforts, as well as for examining new processing, pattern-recognition, and decision-making algorithms. This will ensure the best, most relevant outcomes.

Radar Remote Sensing of ocean surface waves may in general be defined as measuring characteristics of the sea surface by means of electromagnetic waves so that the sea surface is itself not disturbed. The electro-magnetic waves transmitted by the radar antenna are scattered back from the sea surface, modulated in amplitude and phase or frequency by the interaction with the sea surface in

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motion. This modulation carries information about sea-surface characteristics, surface waves and currents. Oceanographic data is extracted from the backscatter signal by sophisticated signal processing and data analysis.

V. RESULTS & CONCLUSION

Tsunami forecasts should provide site- and event-specific information about tsunamis well before the first wave arrives at a threatened community. The only information forecasted at present is the tsunami arrival time based on indirect seismic information about the source. Real-Time Tsunami Forecasting of all critical tsunami parameters (amplitudes, inundation distances, current velocities, etc.) are done based on direct tsunami observations. There are many technical obstacles of achieving this. Accuracy, speed, and robustness are the three important factors. In this paper we attempt to consolidate the important milestones in the development of tsunami signal detection by reviewing the major works done so far. Tsunamis are originated by relative movement of the 'tectonic plates' or the segments of the earth's crest under the sea. In common terms 'an earthquake' at the bottom of the ocean causes Tsunami. Today there is no full proof 'Tsunami detection' system operational in any part of the world. Most reliable detection is claimed with the help of buoys which are equipped with water velocity sensors and data transmitting electronics. However their capability is limited to the local area. Therefore very large numbers of such buoys would be required to cover a large ocean area. The sea state monitoring radars have a potential of detecting Tsunamis from a distance of about 300 to 400Km. This capability makes these radars a promising option for the 'Tsunami disaster warning system'. It is important to understand the oceanic current patterns during Tsunami. Relative tectonic plate movement initiates a burst or wave of surface current which is 50 to 200 Km wide. In other words the wave becomes very high at the coasts where the sea is shallow. These wavelength give enhanced 'Bragg scattered' radar echoes in the HF range. The period of tsunami waves is invariant over changes in bathymetry and is in the range 2 to 30 minutes. High frequency (HF) coastal ocean radar is well conditioned to observe the surface current bursts at the edge of the continental shelf and give a warning of 40 minutes to 2 hours when the shelf is 50 to 200 km wide. The capability of the radar to detect Tsunami is translated to the capability of resolving the sea echoes in terms of Range or the distance and Doppler or the velocity of the target. Thus the surface wave radar could contribute to the improvement of Tsunami Early Warning Systems. If a well functioning and efficient warning system is in work, warning and escape are probably the best way to prevent loss of life due to geohazards. Care must be taken in interpreting coastal sea level data, as the signal may only represent the local response rather than offshore tsunami wave characteristics, hence the requirement and implementation of far deeper ocean tsunameters in recent years.

REFERENCES

[1] Bernard, E.N. (1991): Assessment of Project THRUST: Past, present, future. Special Issue on Tsunami Hazard (E.N. Bernard, ed.), Nat. Hazards, 4(2,3), 285–292.
[2] Zielinski, Adam and Saxena, Narendra. Tsunami Detectability Using Open-Ocean Bottom Pressure Fluctuations. IEEE Journal of Oceanic Engineering. Vol OE-8, No.4, pg 272, 1983.
[3] Eble, M.C., and F.I. González (1991): Deepocean bottom pressure measurements in th northeast Pacific. J. Atmos. Ocean. Tech., 8(2),221–233.
[4] González, F.I., E.N. Bernard (1988): Deepocean tsunami and seismic wave observations:Three recent gulf of Alaska events. Presented at U.S. Japan Earthquake Prediction Seminar, 11-15 Sept. 1988, Morro Bay, CA, USA.
[5] Wallendorf, Louise. Solutions to Coastal Disasters 2008 Tsunamis. American Society of Civil Engineers. 2008. Page 146.
[6] Yamazaki, F., Matsuoka, M., Warnitchai, P., Polngam, S., Ghosh, S. Tsunami Reconnaissance Survey in Thailand Using Satellite Images and GPS. AJG. 2005.
[7] T. Buffard, T. Gallou¨et, and J. M. H´erard. A naive Godunov scheme to solve the shallow water equations. CR Acad. Sci. Paris., 1(326):885–890, 1998.
[8] Looking at the Sea, Physical Features of the Ocean. http://www.mos.org/oceans/planet/features.html. The Museum of Science, 1998