SEI 04 Scattering of seismic waves by the bathymetry of the trench off Mexico seen in MASE data by applying the Hough transform

SEI 04.1 Overview
The Middle American Seismic Experiment (MASE) is an inter-disciplinary project target to image the subduction of the Cocos plate beneath North America by interconnecting seismic sensor using wireless technologies developed at CENS. The Middle American region raises several questions about the formation of volcanic arcs, water release from the subducting slab and tectonic consequences of this process. The main goal of this experiment is to improve our knowledge on subduction zones by obtaining a high resolution map of the slab, crust and upper mantle. Previous studies in this area were limited by the sparse instrumentation and low resolution velocity models. Nevertheless, data obtained from the MASE experiment has led to new questions about the influence of the topography in the wave propagation and how changes in the propagation medium can be induced excite a particular interface and generate secondary fields.

Signal processing of the seismic records revealed a strong excitation of scattered waves by the trench caused by the incidence of body waves from teleseismic events. The Pacific trench of Mexico is a submerged structure (Figure 1) located about 30 km from the coast and at a depth of 5km below the sea level. The trench also marks the surface expression of the contact zone between the dense oceanic crust and the lighter continental crust. Our project focuses primarily in analyzing the interaction between the trench and seismic waves coming from events in the Southern Hemisphere. This phenomenon is known in physics as scattering, and occurs when waves encounter obstacles whose size is comparable to their wavelength.

We are approaching this problem from a pattern recognition point of view. Using image processing techniques such as the Hough Transform; we were able to identify, track and isolate the scattered field produced by the trench.

SEI 04.2 Approach
As mentioned in the previous section, the basic condition for scattering is the size of the wavelength. For teleseismic events (distance > 10,000km), the wavelength of the incident body waves when it reaches the Pacific trench of Mexico ranges between 60-100km, comparable to the structure formed by the trench, the continental crust and the subducting slab. A necessary condition for detecting this signal is sufficient strength of the generating wave. We analyzed events with magnitude larger than 7.0 to obtain a sufficient signal to noise ratio. Finally we assume that both the incident and the scattered wavefront appear as linear traces in the seismic record.

Detection of scattered fields faces several obstacles. First of all, the generating field usually overlaps the scattered field, especially for large events (Mw>7.0) that have a long time function. Another difficulty is the conversion amplitude. The amplitude of the scattered field usually does not exceed the amplitude of the incident field. This makes the signal difficult to detect under noisy environments. Finally, due to failure in the communication system of the stations, bad weather conditions (flooding) and/or urban noise some records could not be either retrieved or used. However, representing the seismograms as color images and applying image processing techniques turns out to be an efficient way to overcome all these difficulties.

SEI 04.3 System Description and Experiments
The Middle American Seismic Experiment is a joint international project that involved CENS/UCLA, Caltech and the National Autonomous University of Mexico. This high density network was installed in 2005 and pulled out in 2007 providing two years of high resolution data of the area. The array consisted of 100 broadband seismic stations extended for almost 550km from the city of Acapulco towards the North, to the city of Tempoal only 80km away from
the coast of the Gulf of Mexico. 50 of these stations functioned as standalone stations requiring manual data retrieving at monthly basis. The remaining 50 stations, managed by CENS/UCLA, collected data and broadcasted wirelessly at daily basis to a central computer in Mexico City, for its later retransmission through a regular internet connection to the central database in Caltech, Pasadena. Linear layout (perpendicular to the trench), high spatial density (every 5km) and high sensitivity equipment (Guralp CMG-3T with a sampling rate of 100Hz) of this network resulted in one of the most advance portable arrays around the globe.

We analyze data from this array for seven events with magnitude larger than 7.0 shown in Table 1. Data from individual stations were combined into a single matrix using a regular grid in time and space. Representation of the data as a matrix made the visualization easier and the use of image processing techniques possible. Missing data was estimated by interpolating records from neighboring stations to obtain a continuous representation. We started the processing of the image by first equalizing the seismic records. Afterwards, we apply an edge detector to mark possible phases in the record. Finally, we look for linear patterns in the edge map using the Hough Transform. This transformation can be briefly described as a map in the parameter space of all possible lines than can be traced through a specific point in space. Once every point in the edge map is associated with a family of lines in the parameter space, we inspect the areas where the density of curves is higher and consequently represents a pair of parameters corresponding to a line marking the arrival of either the incident or scattered field. We constrained the

Table 1 Detection of the scattered field was successfully achieved for seven events at teleseismic distances > 10,000km during the time of the experiment. Table shows their location magnitude and time of the event.
solutions by assuming that the scattered phases travel at a surface wave speed (between 3-4 km/s), this process allows us to discriminate between scattered body waves and scattered surface waves from the trench. The Hough transform turned out to be an efficient tool to detect scattered signals from the trench despite the noisy environment and the missing data.

Once the scattered field has been detected, it is now possible to formulate new hypotheses about the possible mechanism that determine this phenomenon. So far, we have shown that the scattered field branches off from incident low frequency body waves when the body waves from teleseismic events cross the trench. The velocity of the scattered field propagating through the array suggests that part of the energy from the incident body waves is converted into surface waves. However, how this process occurs and what factors determine the conversion is still an open question and will be explored in future work.

**SEI 04.4 Accomplishments**

Despite of the overlapping of the scattered field by the incident body waves, and the low signal to noise ratio that seemed to make the scattered field, in many of the cases, virtually invisible. We successfully identified scattered phases for seven events due to interaction of body waves and the Pacific trench of Mexico. Fig. 3, shows the location of these events. We identify some of the ingredients needed to induce scattering at the trench: (1) Distance from the array; for all cases a minimum distance of 10,000km is required in order to bias the spectrum of the incident field towards long wavelengths comparable to the size of the trench and the subduction zone; (2) Magnitude; only events with Mw>7.0 caused a field strong enough to be detectable by the network; (3) incident angle; all events analyzed shown an oblique incidence to the trench. This condition is constrained by the distribution of earthquakes during the time of the experiment. Further investigation is required to confirm or rule out this constraint.

This result is critically important for studies imaging the crust and upper mantle. When the MASE network was installed in 2005, the main goal was to obtain a high resolution image of the subducting slab beneath Mexico. However, parasitic signals such as scattered phases from the trench might lead to erroneous interpretation of the results. Correcting, modeling and detecting of the scattered field provides a new application of the network from its original target. Understanding scattered fields at topographic scales is important not only for removing an undesired signal from the seismic records, but also might shed light into the factors that can cause site effect resonance and amplification.

**SEI 04.5 Future Directions**

Results obtained by applying the Hough Transform to the synthetic seismograms revealed a new tool to identify phases through the MASE array. Three major directions of research are now needed it. (1) Apply this technique to other events at different wavelength intervals to seek for other possible scatters such as volcanic arcs, mountain ranges, basins, etc. (2) to develop a more general technique to track and detect non linear phases such as the Radon transform. The major disadvantage of this technique is that it is only applicable to phases with a linear move-out which is only valid when very long structures such as a trench cause radiation of the scattered wavefield. For smaller structures this may not be the case. Therefore a more general technique is need it. (3) Modeling. To prove the identification of the scattered wavefield requires a mathematical model that explains the physics behind this effect. Several techniques such as the spectral element method, the indirect boundary element method or finite frequency analysis can be used to solve the wave equation for different geometries and media. Understanding the effect produced by heterogeneities in the medium and/or irregularities in the topography will provide a better picture of site effects and more accurate hazard maps.