Sub Bottom Profiling Chirp Signal Processing

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Summary

Acoustical(infrasonics,sonics,ultrasonics) techniques are employed for geophysical prospecting.Sub-bottom profilers(SBP) are acoustic systems traditionally used to image sediment layers and rocks beneath the seabed, providing information about sediment thicknesses and stratigraphy. Seismic Unix (Chirp,boomer) is employed for SBP signal processing. The application of wavelet transform to high resolution marine acoustics signal and its use in the estimation of attenuation of acoustic wave energy for signals reflected from seabed reflectors. Horizon Picking on Subbottom Profiles using multiresolution analysis using the wavelet transform is used for the mapping of sediment layers on subbottom profiles. The Hilbert transform(chirp signal) is used to extract instantaneous frequency information from Chirp seismic, which is used to derive attenuation information for selected individual stratigraphic layers imaged by the sub-bottom profiler. Methods for extracting the Quaternary facies by the Hilbert Huang transformation (HHT) based on acoustic data recorded by the SBP. The aforementioned transformation allows a study of nonlinear and/or non-stationary phenomena. A good example of this type of problem is the propagation and reflection of acoustic waves in water and the geological formations occurring beneath the surface of the seabed, as well as their scattering on objects at the bottom. High resolution seismic stratigraphy using SBP and seismoacoustic tomography are useful for sub ocean bottom imaging and marine sedimentary depositional system study (turbidites-channels ,contourites- potential hydrocarbon system, sand injectites). Chirp systems operate around a central frequency that is swept electronically across a range of frequencies (i.e. a chirp.) between 3kHz to 40kHz and can improve resolution in suitable near-seabed sediments. In contrast to simple echosounders that use acoustic energy reflected off the bottom to measure the depth, subbottom profilers provide a record of acoustic energy reflected by layers beneath the seafloor. Sub-bottom profiler processing, presentation and interpretation for wreck sites,Submerged landscapes survey design – Sub-Bottom Profiler(3D chirp system).,Sub-bottom profiler processing, presentation and interpretation for submerged landscapes palaeo-channels. - 3D (combined with bathymetric data). Segmentation and classification of shallow subbottom acoustic images using image processing and neural networks-Subbottom profiler, Image processing, segmentation, textural analysis, SOM, neural networks, classification,Image Processing- Grey Level co occurrence Matrix (GLCM) are found to be very useful in identification of subbottom structure and extraction of textural features. Image segmentation-Image segmentation is the process used in identification of the boundaries of different sediment strata /structure and isolation of an image corresponding to structural feature. Texture Analysis-Texture analysis has been extensively used to classify remotely sensed images. The SOM Self-Organizing Maps is able to detect the inherent features of the problem, also known as Self-organizing feature maps (SOFM), learn to classify input vectors according to how they are grouped in the input space. SBP is employed for ocean floor mapping-UNESCO(Ocean Decade 2021-2030) Seabed2030, legal continental shelf, ISBA-deepsea mining-metallic nodules, dredging-placer deposits, ,ports, docks,drydock,harbour,shipping industry, submarine mass transport,deepwater hydrocarbon resources, sand injectites,geobody, Submarine landslide, geotechnical,etc.

Theory / Method / Workflow

Generally , the chirp signal takes the following path or steps: it is generated by the transducer, it reflects back off of some object, it is received by the transducers, it is digitized and processed, and it is written to some storage medium and displayed.The gain, or signal power, may be adjusted at the transducer during send and receive stage, usually just prior to display. All signal amplitudes are adjusted by the same amount. The gain adjustment during processing may vary with two-way travel time, and usually start from a selected water bottom time (i.e., they are hung from the seafloor). Time varying gain (TVG) is inadequate when the water bottom can not be picked, so automatic gain control may be an option.Chirp signal is same as vibroseis sweep signal.The first sweep signal processing step is to deconvolve, correlate or match filter the transmitted signal with the received signal. This way , the long out going sweep signal is compressed and the resulting signal is similar to the conventional signal. The correlation step is best fit to the manufacturer's recording device, since it requires knowledge of the exact out going signal. The marine sub bottom profiler is different from the land vibroseis system in that vibroseis sweeps are much lower in the frequency(often less than 100 hertz), while the marine chirp systems are more than several kilo hertz. The marine chirp systems use additional signal processing techniques to lower the frequency content so that the signals can be displayed the particular manner the seismic user is accustomed to seeing them The next processing step is to divide the correlated signal(the correlate) into two parts. The first part is untouched and second one is phase shifted by 90 degree. The phase shifted signal is called the Hilbert transform, or quadrature. The untouched signal and the Hilbert transform are the merged into a new single signal to form the analytic, or complex signal. Non-Stationary statistical Geophysical Seismic Signal Processing (GSSP) is of paramount importance for imaging underground geological structures and is being used all over the world to search for petroleum deposits and to probe the deeper portions of the earth. Hilbert Transform can be made fashionable for seismic signal processing with a view to precise subsurface imaging. The Hilbert transform preserves the orthogonality, local smoothness , and connection (coefficients) of a scaling function (wavelet) basis. In other words the Hilbert transform of a wavelet is a wavelet.To describe a signal simultaneously in time and in frequency is to consider its instantaneous frequency.The signal and its Hilbert Transform are orthogonal. This is because by rotating the signal 90° we have now made it orthogonal to the original signal, that being the definition of orthogonality The signal and its Hilbert Transform have identical energy because phase shift do not change the energy of the signal only amplitude changes can do that. Hilbert transform not only helps us relate the real and imaginary components but it is also used to create a special class of causal signals called analytic which are especially important in simulation. The sweetness factor is defined as the quotient of instantaneous amplitude to instantaneous frequency of a seismic trace which are determined by Hilbert Transform. HT limitation is that it does not provide physically meaningful results in situations where the seismic trace contains events that overlap in time but have different frequencies.Such cases are frequently encountered in exploration seismology. This limitation is rectified by S-Transformation. MATLAB Signal Processing Toolbox(Hilbert Transform) is employed for seismic data analysis.The complex modulus(square root of the sum of squares of the real and imaginary) of each sample is formed from from the analytic signal and becomes the envelope, or instantaneous amplitude. The envelope contains only positive numbers, and no longer has any phase information, but it is much lower in frequency and can be displayed as the geoscientist is accustomed to. The envelope is the same length and has the same sample interval as the correlate

Reflection Loss; image interference and frequency effects; attenuation by a layer of bubbles; noise generation at higher frequencies due to surface weather; backscattering and surface reverberation. It is also common practice to use the term 'reflection coefficient' to express the amount of acoustic energy reflected from a surface or boundary between two media. This coefficient depends upon the grazing angle and the difference in the acoustic impedance between the two media. A reflection loss is then defined as 10 log (reflection coefficient). This reflection loss is referred to as surface loss when describing the reflection of sound from the sea surface, or as bottom loss when describing the reflection of sound from the sea floor. Subbottom acoustic profiler provides acoustic imaging of the subbottom structure of the upper sediment layers of the seabed and it is commonly used in geological and offshore geo-engineering applications. Delineation of the subbottom structure from a noisy acoustic data and classification of the sediment strata is challenging with the conventional signal processing techniques. Due to increase in attenuation of acoustic energy at high frequencies, the depth of penetration into the bottom ranges from a few tens of meters to a few hundred meters depending on the type of sediments. The data are very use full in offshore geotechnical, geo-engineering and geological applications, in resolving the upper layers sediment structures, studies on dynamics of sedimentation, compaction, and qualitative information on physical/acoustic properties of sediments, neotectonic activity, and shallow basement configuration.

Reflection Loss And Sub-Bottom Profiling With Ambient Noise-Measurements of ambient noise directionality on a vertical array (VLA) can already be converted into bottom reflection loss as a function of angle and frequency using a recently developed technique **(GAIN = GeoAcoustic Inversion of Noise).**The technique is extended by converting the reflection loss at each location into an impulse response as a function of travel time and angle. A minimum phase representation of the complex reflection coefficient is reconstructed by spectral factorization prior to Fourier transformation. The method is applicable to any bottom loss measurement and requires the reflection coefficient to be known over a range of frequencies and the grazing angle in question to be above critical. The evolution of the impulse response as the VLA drifts horizontally can then be plotted as a subbottom profile referenced to the seabed/water interface **(SUPRA-GAIN = SUb-bottom PRofiling using Ambient noise).**

Sub bottom profilers offer digital output in addition to a real-time display of the envelope data. The digital output is often formatted similar to the SEG-Y standard. The SEG-Y file may contain one of the following signals: the raw uncorrelated signal, the correlated signal, the analytic signal, the envelope signal or the envelope with time variable gain(TVG). the raw uncorrelated signal requires significant further processing and should be left for the expert signal processor.The correlate is required when advanced seismic processing is conducted that requires the phase of the signal to be present(e.g., seismic migration). The correlated signal should be converted to the envelope and TVG applied before display.The analytic, or complex , signal must be converted back into a real signal(the correlate) before it can be used in most seismic processes, since it has the signal phase. The analytic signal must be converted to the envelope and TVG applied before it can be displayed.The envelope signal is ready for TVG and display, but it should not be used in advanced seismic processes that require the phase of the signal. Automatic gain control (AGC) and TVG are operators that attempt to mitigate the decrease in amplitude of the signal as it propagates away from the source owing to geometric spreading and attenuation of the pulse caused by the water column and the sub-surface sediments. AGC algorithms set the maximum amplitude within a specified time window to a preset value. The time window is automatically moved down the time section, equalizing the amplitudes to the preset value for each new section. The result is that the amplitude range of the seismic trace is approximately the same throughout the entire section. However, it is important to note that applying AGC destroys the relative amplitude information that may be required to undertake quantitative analysis of the acoustic properties of individual reflectors.TVG, by comparison, applies an exponential gain operator to every seismic trace. Consequently, each trace is amplified down the time section by a regularly increasing factor instead of by a variable amount tied to a moving window.This long chirp pulse is compressed by cross-correlating the signal with a replica of the transmitted acoustic pulse, resulting in a much shorter 'Klauder' wavelet and maximising the output signal-to-noise ratio (SNR). Typical frequency ranges are 1.5kHz–7.5kHz and 1.5kHz–12.5kHz, but could be anywhere between 400Hz and 24kHz. Depending on the frequency used, vertical resolution of 10cm to 40cm can be achieved and penetration varies from 3m in coarse sands to >100m in fine-grained sediments. A major advantage of the chirp system is that the emitted pulse shape is well known and highly repeatable, aiding post-acquisitional processing and enabling quantitative sediment/object characterisation. The chirp system can be deployed either hull-mounted, surface-towed or deep-towed. The receiver (hydrophone) arrays can either be mounted on the tow vehicle or towed behind the chirp system.

Sub-bottom profiler processing, presentation and interpretation: **Band-pass filtering** is the most com-mon operation in high-frequency seismic processing. It is used to remove frequencies outside the bandwidth of the input pulse. These unwanted frequencies are typically associated with acoustic noise from the instrument, boat or other marine sources (including cetaceans). The success-ful application of these filters depends on knowledge of the frequency content of the data. This can either be assumed from the frequency content of the outgoing pulse (as determined from the system configuration; or, ideally, from being able to analyse the frequency content of the actual data. The latter can be important because attenuation of the pulse as it passes through sediment/archaeological materials typically results in a downward shift of the dominant frequency and a narrowing of the bandwidth owing to a preferential removal of the higher-frequency components. The application of band-pass filters is particularly important for boomer systems that in raw format are frequently associated with low-frequency noise (tens of Hz), which swamps the actual data. Automatic gain control (AGC) and time variable gain (TVG) are operators that attempt to mitigate the decrease in amplitude of the signal as it propagates away from the source owing to geometric spreading and attenuation of the pulse caused by the water column and the sub-surface sediments. AGC algorithms set the maximum amplitude within a specified time window to a preset value. The time window is automatically moved down the time section, equalizing the amplitudes to the preset value for each new section. The result is that the amplitude range of the seismic trace is approximately the same throughout the entire section. However, it is important to note that applying AGC destroys the relative amplitude information that may be required to undertake quantitative analysis of the acoustic properties of individual reflectors.TVG, by comparison, applies an exponential gain operator to every seismic trace. Consequently, each trace is amplified down the time section by a regularly increasing factor instead of by a variable amount tied to a moving window.

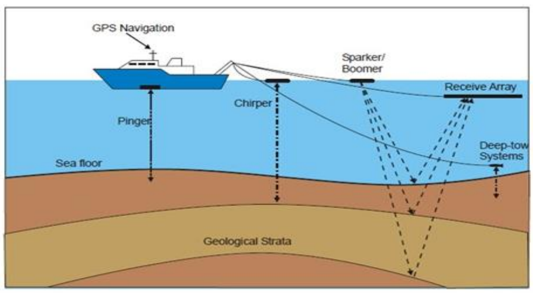
Stacking in the context of 2D sub-bottom profiling is a simple process of averaging a number of adjacent traces in order to smooth the along-track section.. Stacking can be particularly useful to enhance the continuity of reflectors and to deal with small breaks in the data. **Instantaneous amplitude/reflection strength** is an operator that is commonly applied to chirp data for image enhancement. Effectively this operator rectifies the data so that all amplitudes are positive, and ap-plies an envelope to the data to smooth the time section and enhance interpretability. As with AGC the destruction of the original properties of the acoustic pulse, in this case any polarity information, negates any potential quantitative analysis of the data at a later stage.

Deconvolution In addition to these fairly common processing steps it is possible to enhance sub-bottom data further through a filtering operator such as deconvolution. Deconvolution is particularly good at compensating for inherent changes in the acoustic properties of the signal: lengthening of the wave, shift in dominant frequency and reverberation effects (common in shallow water) as it passes through the sub-surface. There are several approaches to deconvolution, some of which rely on creating algorithms based on the source signature (and therefore are theoretically best suited for use with sources that output well constrained pulses, such as the chirp systems); others create predictive filters based on the acquired data.**Gold deconvolution** to obtain Earth's sparse-spike reflectivity series, The method uses a recursive approach and requires the source waveform to be known, which is termed as Deterministic Gold deconvolution. The method is effective in areas where small-scale bright spots exist and it can also be used to locate thin reservoirs. Since the method produces better results for the Deterministic Gold deconvolution case, it can be used for the deterministic deconvolution of the data sets with known source waveforms such as land Vibroseis records and marine Chirp system.

Migration is another currently under-used processing step. It attempts to reconstruct a seismic section so that reflection events are repositioned to their correct surface locations, at a corrected two-way travel time. This process is necessary because although a standard sub-bottom profile trace presents each reflection point as though it is located directly beneath the mid-point between the transducer and the hydrophone, in reality this is not the case unless the reflector is horizontal. If the reflector is dipping along the survey line the actual reflection point is displaced in an up-dip direction, while if there is dip across the survey line the reflection point is displaced out of the plane of the section. Migration also improves the horizontal resolution of the data by focusing energy that is otherwise spread over an area of the bed by the pattern of the acoustic pulse.Deconvolution after migration increases 20% resolution of subsurface imaging. **Correction of seabed layer thickness in processing subbottom profile data-**The subbottom profiler can be divided into two types according to the combination of transducers and hydrophones: integration type and separation type. To the subbottom profiler of separation type, because the acoustic signal are not a vertical path to go, but an oblique path, and the incidence angle and reflection angle is not zero, and it can only be treated as a system of self-excited and self-receiving in very deep water; When in shallow water, the incidence angle and reflection angle are very large and the profiler cannot be treated as a system of self- excited and self-receiving any more. In this case, the travel time interpreted from the profile is much larger than the case of vertical launch and vertical receive so that the distortion of shallow layer will be caused and to be corrected the layer thickness.When acquiring and processing the subbottom profile data, to determine the sound velocity of seabed sediments is a key problem.

Water depth compensation to deep water seismic data:. For deep water exploration, sea- bottom morphology has greater impact than the shallow marine one on the seismic reflectors in the zone of interest. Hence suitable correction for the varying water depth is required, more so, if the signature of interest is situated near or beneath a rapidly changing sea bottom. The most suitable solution lies in pre-stack depth migration. Some correction has to be applied to compensate for the distortions in travel time caused by the irregular sea-bottom topography. this has been termed as **Water Bottom Compensation.Multiple removal** to suppress the multiple reflections of the seabed and strong sub-surface reflectors that are common in shallow water, high-resolution sub-bottom data

Hilbert Huang Transform(HHT)- The available methods for signal processing ,understanding,behaviour are either for linear but nonstationary, or nonlinear but stationary and statistically deterministic processes. Hilbert–Huang transform HHT method is potentially viable for nonlinear and nonstationary data analysis, especially for time-frequency-energy representations. The HHT is employed to describe nonlinear distorted waves in detail, along with the variations of these signals that naturally occur in nonstationary processes. The natural physical processes are mostly nonlinear nonstationary and stochastic processes. The Hilbert-Huang transform (HHT) is an empirically based data-analysis method. Its basis of expansion is adaptive, so that it can produce physically meaningful representations of data from nonlinear and non-stationary processes. The HHT is based on a decomposition of the analyzed signal into individual mono-component signals, called as intrinsic mode functions (IMFs), first introduced by Huang et al. From these IMFs, by means of the Hilbert transform, the instantaneous frequency of the signal is obtained. This enables the presentation of the decomposed ultrasonic signal as a distribution of energy or amplitude in the time–frequency plane. For defective and defect free zones these distributions are different. The essential feature of the HHT is that the time–frequency decomposition is adaptive and therefore it is not limited by the time–frequency uncertainty relation, which is characteristic to the Fourier or wavelet analysis.The Hilbert-Huang transform (HHT) is an empirically based data-analysis method. Its basis of expansion is adaptive, so that it can produce physically meaningful representations of data from nonlinear and non-stationary processes. The HHT consists of two parts: Empirical Mode Decomposition (EMD) and Hilbert spectral analysis (HSA). HHT process comprises two main steps. First, Intrinsic Mode Functions (IMFs) are extracted from the signal itself based on Empirical Mode Decomposition (EMD). Second, the Hilbert transform is applied to each IMF component. Subsequently, the instantaneous frequency can be calculated and the energy distribution of the signal is obtained in the time-frequency plane it is based on an adaptive basis; the frequency is derived by differentiation rather than convolution; therefore, it is not limited by the uncertainty principle; it is applicable to nonlinear and nonstationary data and presents the results in time-frequency-energy space for feature extraction. The empirical mode decomposition method (the sifting process) the empirical mode decomposition method is necessary to deal with data from nonstationary and nonlinear processes.Sifting is the central signal separation process of the HHT algorithm.Huang's sifting process separates the highest-frequency component embedded in a multicomponent signal from all the lower-frequency components. The remaining lower-frequency components to gether make up the signal trend. “the HHT- separation technique “empirical mode decomposition,” and the individual component signals “intrinsic mode functions.”Ensemble Empirical Mode Decomposition (EEMD), CEEMDAN (Complete EEMD with Adaptive Noise) IMF sets can suffer from mode mixing and lack of uniqueness. Mode mixing consists of a single IMF containing signals of different time scales, or one signal scale residing on multiple IMFs (Huang and Wu, 2008). This can result in frequency aliasing in which IMFs transition from one scale to another. The EEMD is a noise-assisted data analysis method designed to counteract this problem. It repeatedly adds uniform white noise to the signal, performs EMD, and averages the IMFs of each trial together (Wu and Huang, 2009). As the number of trials increases, the average of noise-perturbed copies of a signal approach the true signal. The EEMD method greatly reduces mode mixing and thus represents a significant improvement over EMD (Huang and Wu, 2008). Because each EMD trial is independent, Hilbert-Huang Transform and Its Application to Texture Analysis- EMD for two dimension data-Bidimensional Empirical Mode Deposition (BEMD).HHT and wavelet transform is employed for precise subsurface imaging and thin bed analysis.. The empirical mode decomposition and the Hilbert spectrum for nonlinear and non-stationary time series analysis ,Empirical mode decomposition as a filter bank ,Application of Hilbert–Huang transform based instantaneous frequency to seismic reflection data ,Empirical mode decomposition based instantaneous frequency and seismic thin-bed analysis, Empirical mode decomposition based time-frequency attributes, Random and coherent noise attenuation by empirical mode decomposition,etc.



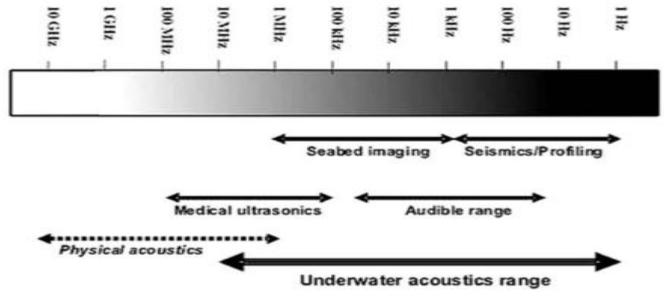


Figure1(left). Deployment of various shallow-water sub-bottom profiling systems. After Stoker et al. (1997).Figure2(right) : comparison of frequencies typically used in under water acoustics with other domain of acoustics

Results, Observations, Conclusions

SBP chirp signal processing –HHT is applied for ocean floor subsurface imaging. SEISMICUNIX, MATLAB, PYTHON, R are employed for SBP data analysis. HHT is very efficient for chirp signals [vibroseis,subbottom profiler,etc.] processing.SBP play a pivotal role for ocean floor mapping-UNESCO(Ocean Decade 2021-2030) Seabed2030, legal continental shelf, ISBA-deepsea mining-metallic nodules, dredging-placer deposits, ,ports, docks,drydock,harbour, submarine mass transport,deepwater hydrocarbon resources, sand injectites,geobody, Submarine landslide, geotechnical,etc.

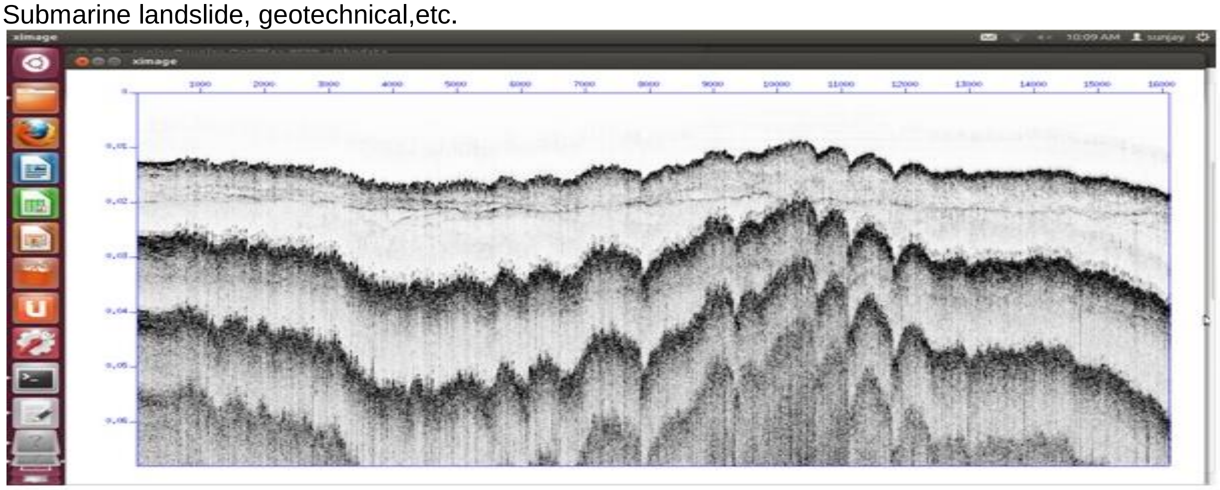


Figure3: SBP Data Processing SEISMICUNIX

Novel/Additive Information

Intergovernmental Oceanographic Commission of UNESCO ,Forum for Future Ocean Floor Mapping General Bathymetric Chart of Oceans (GEBCO) , International Hydrographic Organization (IHO), International Maritime Organization(IMO), International

Seabed Authority(Enterprise deep sea mining), United Nations Convention On The Law Of The Sea- Limits of the Continental Shelf ,Exclusive Economic Zone (EEZ) joint devevelopment area, /Coastal nations jurisdiction, Mining Law-deep sea mining(metallic nodules) law. The Role of Submarine Landslides in the Law of the Sea:Article 76 of the United Nations Convention on the Law of the Sea Recognizing that submarine mass movement is a slope process that also influences the shape of the continental margin, several nations have successfully argued that the downslope termination of mass transport deposits assist in distinguishing the continental slope from the rise and abyssal plain. The Commission on the Limits of the Continental Shelf have now made recommendations for a number of coastal States with rift margins, transform margins and subduction margins where the extents of surficial mass transport deposits were used to help delineate the base of slope zone within which the foot of the continental slope is chosen.The Commission on the Limits of the Continental Shelf (CLCS); the body that reviews extended continental shelf submissions under the UN Convention on the Law of the Sea, in its guidelines and decisions to date, has encouraged coastal States to use scientific arguments in defining the elements of a continental margin and thereby delimit its outer edges. One of the critical metrics in this process is establishment of the “foot of the continental slope” (FoS) and submarine landslides can assist in identifying this metric. A nautical mile is defined as the distance of 1 minute of latitude and is equivalent to 1.15 statute (land) miles or 1.85 kilometers, Exclusive Economic Zone (EEZ)/**Coastal nations jurisdiction.** The treaty established a uniform 12-mile (19-kilometer) territorial sea and a 200-nautical-mile (370-kilometer) **exclusive economic zone (EEZ)** from all land (including islands) within a nation. If the continental shelf (defined geologically) exceeds the 200-mile EEZ, the EEZ is extended to 350 nautical miles (648 kilometers) from shore.

Acknowledgements

I am thankful to geophysical data providers for research work
I have login/password approved by www.ig.utexas.edu/sdc for seismic data.
I downloaded chirp signal data by received link after request to SDC
Academic Seismic Portal at UTIG - Institute for Geophysics, University of Texas at Austin
UTIG Subbottom Profiling research group
Seismic Unix ,www.seismicunix.com , www.cwp.mines.edu/cwpcodes
Seismic Unix Scripts Chirp /Boomer https://pubs.usgs.gov/of/2001/of01-165/HTML/SEISUNIX.HTM
https://pubs.usgs.gov/ds/259/html/software.html, https://pubs.usgs.gov/ds/0972/ Digital Chirp Subbottom Profile Data

CNSOPB Data Management Centre ,www.cnsopbdmc.ca, (I have login/password)
Canada-Nova Scotia Offshore Petroleum Board

[CCNSOPB-Deepwater Hydrocarbon-submarine mass transport IGCP Projects]

Antarctic Seismic Data Library System (SDLS) – OGS **sdls**.ogs.trieste.it (I have login/password)
my participation and affiliation with IGCP PROJECT S4SLIDE

I am grateful to the project leaders of IGCP,432,619,511,IGCP 585,IGCP640 S4SLIDE

S4SLIDE Significance of Modern and Ancient Submarine Slope LandSLIDEs

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https://cran.r-project.org/web/packages/hht/index.html , **EMD code:** http://perso.ens-lyon.fr/patrick.flandrin/emd.html

HHT-based Identification codes: http://hitech.technion.ac.il/feldman/

LIBEEMD: A program package for performing the Ensemble Empirical Mode

Decomposition,CEEMDAN (Complete EEMD with Adaptive Noise) https://bitbucket.org/luukko/libeemd , https://github.com/helske/Rlibeemd ,http://cran.r-project.org/web/packages/Rlibeemd/index.html

An R interface for libeemd C library for ensemble empirical mode decomposition (EEMD) and its complete variant (CEEMDAN).

http://github.com/scikit-signal/pytftb , Python toolbox for the Hilbert-Huang transform , Python http://pyeemd.readthedocs.org/.

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