

Seismic Oceanography

A New Tool to Characterize Physical Oceanographic Structures and Processes

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Seismic Oceanography

A New Tool to Characterize Physical Oceanographic Structures and Processes

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APPENDIX IV

Seismic Oceanography Glossary

Due to the cross disciplinary nature of seismic oceanography, some effort has been made throughout the text to clarify terminology which might otherwise be ambiguous or confusing to those not initiated in either seismology or oceanography. To this end, I have included the following glossary of terms to serve as a quick reference guide to the uninitiated reader.

Acoustic impedance - The product of sound speed and density. Reflectivity (reflection coefficient) is related to changes in acoustic impedance for a seismic wave which meets an interface at normal incidence.

Air gun - An impulsive seismic source used mainly in marine seismic surveys. It injects a bubble of high pressure air into the water column. It's frequency content depends upon the volume of air in its compression chamber, the air pressure and water depth. Knowledge of the frequency content of the source allows stricter control of the characteristics of the source wavelet, which in turn provides better estimates of reflectivity.

Aliasing - Frequency ambiguity as a result of digital sampling where there are fewer than two samples per cycle. This causes a signal of a given frequency to yield the same sample values (and thus appear to be) as another frequency.

Amplitude - The maximum departure of a wave from the average value. The amplitude of a seismic wave at an interface is directly proportional to acoustic impedance contrasts (reflection coefficient), and thus to the physical properties of the reflecting media. In the case of water column reflections, it is indicative of variations in temperature and salinity across isopycnals. See Chapter 5.

Amplitude spectrum - A graphical display of the relationship of amplitude vs. frequency. Useful to determine the dominant frequency range of a given signal.

Autocorrelation - The correlation of a waveform with itself.

Automatic gain control (AGC) - A type of scaling used in seismic data processing in which the output amplitude is used for automatic control of the gain of the amplifier. AGC destroys the relative amplitude of seismic events, thus should be used with care when interpreting seismic data in terms of real intrinsic properties. See Chapter 5.

Band-pass filter - A digital operation which permits frequencies of certain specified ranges and attenuates frequencies outside that range.

Batchelor scale - Encompasses the smallest scales of fluctuations in a fluid scalar concentration that can exist before being dominated by molecular diffusion.

Beaufort wind scale - A numerical scale indicating a range of wind speeds from 0, equaling calm winds of less than 1 km/h to 12, or hurricane strength winds greater than 118 km/h.

Breaking wave - A wave whose amplitude reaches a certain critical height upon which wave energy is converted into turbulent kinetic energy. Wave breaking is a process that occurs in times usually comparable to the wave's characteristic period whereupon the wave loses energy and generates turbulent motions. Breaking waves are not just confined to surface waves, but have been observed in internal waves as well.

Coherence - The property of two wavetrains (several cycles of waves) being in-phase. Lateral coherence across a seismic section is an indication of a continuous interface with similar acoustic impedance contrasts.

Common midpoint method - The seismic acquisition method whereby each source is recorded at a redundant number of geophone locations and each geophone location records from several successive sources. This method is typical for most multi-channel seismic (MCS) reflection surveys since the inherent redundancy of source and receiver greatly increases the ratio of signal-to-noise. The common midpoint (CMP) is the point midway between source and receiver along a given ray path. The term common depth point (CDP) is also commonly used, however it is erroneous where reflecting interfaces dip.

Conductivity - The ability of a medium to conduct electricity. Conductivity is useful in physical oceanography as a measure of salinity. Thus, instruments such as the Conductivity Temperature Depth probe (CTD) measure conductivity to estimate salt content at a given depth.

Conductivity Temperature Depth (CTD) probe - An electronic device used in oceanography to continuously measure salinity (by measuring conductivity), temperature and depth (by measuring pressure) as the instrument is lowered from a stationary ship. The CTD also collects water samples at various depth and may have other instruments attached as well.

Coriolis effect - The apparent deflection of a body in motion with respect to the Earth's rotating frame of reference as seen by an observer on the Earth. In the northern hemisphere the effect of this is to deflect ocean circulation to the right, as in the case of the Mediterranean Undercurrent, which thus flows north following the continental shelf of Iberia.

Correlation - The degree of linear relationship between two traces, thus a measure of similarity between traces (wave forms). The frequency-domain analog is coherence.

Correlation length - The upper limit for scale invariance in heterogeneity. It is the distance from a point beyond which there is no further correlation of a physical property that is associated with that point. At lengths greater than the correlation length, physical properties vary randomly, as white noise.

Deconvolution - A digital signal processing algorithm designed to restore a wavelet to the shape it had prior to the linear filtering action of passing through a given medium.

Density driven current - A current that is primarily driven by gravitational forces, for example, the Mediterranean Outflow, which spills into the Gulf of Cadiz from the

Mediterranean Sea due to density (and therefore, weight) contrasts between the two water masses.

Diapycnal - Across lines of equal density. For example, vertical mixing of two adjacent water masses separated by large density contrasts across the isopycnal surface. Diapycnal mixing is inhibited by the isopycnal as a result of buoyancy forces.

Diffraction - The bending of wave energy around obstacles as explained by Huygens' principle, where energy is transmitted along a wave crest. Diffraction can be in the form of ocean waves circumventing a barrier (for example, a breakwater) or sound waves bending around a large acoustic impedance contrast. Diffraction is manifested in seismic data as 'diffraction hyperbole', which are ideally collapsed to their point source by the process of migration.

Dip - The term used to describe the inclination of an acoustic impedance boundary. In seismic oceanography, dips describe the inclination relative to the horizontal of undulating isopycnal surfaces.

Direct wave - The seismic wave which travels along the shortest path from source to receiver. Direct waves usually arrive at receivers first, but can be overtaken by deeper, thus faster, moving waves.

Double-diffusive convection - Convective motions that occur in a fluid where density contrasts are present. The most common example of double-diffusive convection is that of 'salt fingers', where heat and salt both diffuse at different rates (diffusion of heat being two orders of magnitude faster than the molecular diffusion of salt).

Dynamic range - The range of recording signal from lowest to highest amplitude (sound volume).

EBCDIC - A computer code used for character symbols and common as the header of a seismic trace. The acronym stands for: Extended binary coded decimal interchange.

Ensonification - To fill with sound.

Entrainment - When fluids of different densities pass each other, frictional forces between the water masses cause boundary mixing. This is seen in the Mediterranean Outflow Water in the Gulf of Cadiz, where, as it cascades down the continental slope, it entrains the surrounding North Atlantic water masses, thus incorporating its waters into the Outflow, thereby reducing its density and approaching neutral buoyancy.

Eulerian - The description of the motion of a body or fluid past a fixed point, as time passes.

Expendable Bathymetry Thermograph (XBT) - Disposable devices used to measure temperature variation as a function of pressure (depth). XBTs consist of a heavy weighted head encasing a thermocouple and a long coil of thin copper wire (approximately 2 km) which measures temperature and depth in real-time. XBTs are useful in seismic oceanography as independent measurements of thermohaline finestructure which can be correlated with acoustic impedance contrasts.

Expendable Conductivity Temperature Depth (XCTD) probe - Similar to the XBT, but also measures conductivity (salinity) as a function of depth.

f-k domain (frequency domain) - A representation of spatial data in terms of its frequency (f) and wavenumber (k) variables. Data are converted to the f-k domain by a 2D Fourier transform. Visualization of seismic data in the f-k domain is common and useful in data analysis because it allows certain filtering techniques to be performed, for example, filtering data on the basis of velocity (sound speed) and the removal of coherent noise trains.

Fourier transform - Set of equations which convert a time series function into its frequency domain representation or vice versa.

Fractal - Defined by its founder, the late Benoît Mandelbrot to be "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole", a property that is known as self-similarity. It describes shapes which are too difficult to be described by Euclidian geometry. Stochastic Heterogeneity Mapping (Chapter 2) operates on the basis of the von Kármán model, which describes a power law (or, fractal) process.

Fractal dimension - A statistical quantity which describes how completely a fractal fills space. The fractal dimension is generally not an integer and is directly related to the Euclidian dimension and the Hurst exponent.

Fresnel zone - The percentage of a reflector from which energy can arrive at a detector within one-half wavelength of its first reflected energy. The Fresnel zone describes the limit of horizontal resolution in seismic data and is dependent upon sound speed and frequency.

Gain - An increase or change in signal amplitude. Seismic data can be gained in various ways to aid in visualization and interpretation. However, it should be used with the caveat that it may destroy the relative amplitude variation of reflectors.

Garrett-Munk spectrum - Spectrum of frequency and both horizontal and vertical wavenumber which is used to describe the energy in the internal wave field.

Geometry - In reference to seismic data analysis, how the acquisition of a seismic survey is deployed in geographical coordinates. An accurate geometry description is paramount to proper processing and hence, interpretation of seismic data. Modern geometries are precisely created using global positioning systems.

Geophone - A detecting device used in seismic surveys which measures sound wave pressure. The first geophones consisted of a magnet moving within a coil of copper wire to induce a current which is a function of sound wave pressure, thus seismic amplitude.

Modern devices also measure amplitude as a function of induced voltage, but use more sensitive and robust piezoelectric materials.

Hurst number - A measure of surface roughness, or equivalently the richness of range of scales of a surface as described by a power law distribution. The Hurst number (ν) is directly related to the fractal dimension (D) and Euclidian dimension (E) through the relation, $D=E+1-\nu$. The Hurst number is the index of dependence and as such is a measure of the tendency of a time series to regress to a mean or cluster in a specific direction.

Hydrophone - A geophone specially designed for marine seismic surveys. It is embedded in the streamer.

Internal Waves - Gravity waves that oscillate within rather than on the surface of a fluid medium arising from perturbations to hydrostatic equilibrium. Internal waves in the ocean move more slowly (typically 1 m/s) than surface waves due to the smaller difference in density between the media.

Isopycnal - A surface of constant potential density of water. In the ocean, depth increases with depth. Varying degrees of temperature and salinity modify the density of water, thereby modifying the position of isopycnals.

Lagrangian - A description of dynamics where the observer follows an individual fluid parcel as it moves through space and time.

Least-squares fit - An analytical function which approximates a data set such that the sum of the squares of the distances the observed points to the curve is a minimum.

Lowered Acoustic Doppler Current Profiler (LADCP) - Device lowered from a ship which provides a measurement of the velocity of water currents across an entire water column using the Doppler effect.

Meddy - Mediterranean Eddy; a large lens of highly saline Mediterranean Water that forms in the Gulf of Cadiz vicinity. The thermohaline signature of meddies have been tracked as far west as the Caribbean Sea.

Mediterranean Outflow - The so-called 'tongue' of Mediterranean type water which overflows the continental shelf at the Strait of Gibraltar while mixing and equilibrating with surrounding Atlantic water.

Mediterranean Undercurrent - A portion Mediterranean Outflow water which travels as an undercurrent at depths between approximately 500-1500 m. It begins at the Strait of Gibraltar and moves west, then north along the coast of the Iberian peninsula, follows the continental shelf into the Bay of Biscay, and along the Porcupine Banks west of Ireland.

Mediterranean Water - Archetypal water of the Mediterranean Sea. It is present in sufficient quantities in the North Atlantic to be considered a major water mass. It is characterized by a high salinity and temperature profile.

Midpoint - In seismic data acquisition, the midpoint between source and receiver.

Migration - In seismic data processing, the mathematical inversion process of moving seismic traces to their true subsurface locations and collapsing diffraction hyperbolae. The need arises due to sound speed variations in the subsurface as well as dipping reflecting interfaces. In seismic oceanography, migration is generally considered not as necessary as in studies of the solid Earth because of the small sound speed variation and generally near-horizontal distribution of isopycnals.

Multiple - Seismic energy which has been reflected more than once. Multiples are considered noise on seismic records and are generally attenuated or muted to improve signal-to-noise ratio. Long-path multiples arrive as apparent separate events from wanted reflected energy. Short-path multiples arrive soon after the primary reflected event as so to add an apparent tail to the primary.

Noise - In seismic data analysis, any unwanted seismic signal. Noise may come in the form of random noise, such as background noise or other environmental effects, or it may be in the form of coherent noise such as multiples or the direct wave.

Normal Moveout - The variation of reflection arrival time due to increasing source-receiver distance (offset). This is manifest on a seismic shot record as a hyperbola. Velocity analysis is used to correct for normal moveout.

Ocean - In this text, the Ocean refers to the sum of the world's major oceans, their connected seas and straits as well as continental shelf waters and seas such as the Mediterranean, Black Sea and Baltic Sea.

Offset - In seismic data analysis parlance, the distance from source to receiver. Offset is an important parameter because it allows discrimination of how seismic wavelet characteristics change as a function of distance, for example, amplitude.

Phase - The angle or lead of a sine wave with respect to a reference, usually expressed in angular measure, it as an indicator of wavelet shape. Phase information carries the timing information of a seismogram. For example, a minimum phase wavelet is nominally front-loaded, that is the dominant amplitude distribution is near time zero.

Phase spectrum - A plot of phase-shift vs. frequency illustrating the characteristics of a wavetrain. A phase spectrum can be useful to create filters that may not 'see' amplitude variations but can discriminate on the basis of phase, thus allowing wavelet shaping.

Practical Salinity Unit (PSU) - The standard unit for salinity content in oceanography. It is a dimensionless variable, but is roughly equal to one thousand times the mass of dissolved salts per unit mass of seawater.

Prandtl number - The ratio of viscous diffusion rate to thermal diffusion rate. The Prandtl number in the ocean is approximately 7.

P-wave - A seismic wave in which the particle motion is in the direction of wave propagation. As opposed to an S-wave, where particle motion is orthogonal to the propagation direction. In seismic oceanography, we are only concerned with P-waves since S-waves require shear strength to propagate, which is not present in fluids.

Record length - The length of a seismic trace or set of seismic traces. Equivalently, the recording two-way time on a seismic section.

Reflectivity - The degree to which energy incident upon an acoustic impedance boundary is reflected as opposed to transmitted. Perfect reflection does not exist, thus specular reflectivity can be thought of as approaching perfect reflectivity from a smooth interface following the reflection law. In contrast, diffuse reflectivity may come from various angles and ray paths, be much weaker and difficult from which to extract useful physical information. Stochastic Heterogeneity Mapping (Chapter 2), for example, statistically analyzes the whole reflectivity field for any type of reflectivity.

Reflectivity coefficient - The ratio of amplitude of displacement of a reflected wave to an incident wave. Reflection coefficient is dependent upon the respective sound speeds and densities on either side of an acoustic impedance boundary.

Resolution - The degree to which two features can be separated. One of the principal advantages of seismic oceanography is the high level of horizontal resolution (approximately two orders of magnitude finer) relative to traditional oceanographic probes, dropped every 1 km or so. The horizontal resolution is determined by the closeness of seismic receivers and the Fresnel zone, which is in turn dependent upon frequency and sound speed.

Reynolds number (Re) - A dimensionless number expressed as the ratio of inertial forces to viscous forces, thus quantifying the relative importance of each for given flow conditions.

Root-mean square (RMS) - The square root of the average of the squares of a given measurement.

Salinity - A measure of the dissolved salt content in a body of water. Salinity is usually measured in Practical Salinity Units (PSU) which is the conductivity ratio of a sea water sample to a standard KCl solution. The PSU is approximately 1000 times the mass of dissolved salts per unit mass of seawater.

Salt fingers - Small structures that form in the ocean as a result of a mixing process that occurs when warm salty water overlies cold fresh water. Since diffusion of heat is approximately 100 times faster than the molecular diffusion of salt, as heat is gained or lost there are buoyancy changes which occur while the salt content remains more stable.

Sample rate - In digital signal processing, the rate at which a continuous analog time series function is sampled to create a digital time series. The shorter the sample rate, the more the digital signal approximates the true analog signal.

Second law of thermodynamics - The observation of irreversibility in nature where entropy (disorder) tends to increase with respect to time in a given isolated physical system.

Signal - That of a time series which contains valuable information about which it represents.

Spherical divergence - The decrease in wave strength as a function of distance from the source as a result of three-dimensional geometric spreading. The signal strength decreases inversely proportional to the square of the distance. For spreading along a surface, the equivalent term is cylindrical divergence, where signal strength decreases inversely proportional to the distance.

Stacking - A mathematical operation of summing together time series (seismic traces). The process results in a 'stack' which is a composite record of combining traces from

different records. Stacking is necessarily a filtering process because of wave shape differences among the traces being stacked.

Stacking velocity - The sound speed calculated from normal moveout corrections during 'velocity analysis'. The stacking velocity is the normal moveout correction needed to optimize a stacking response during common-midpoint stacking.

Static instability - The condition where a more-dense parcel of water overlies a less-dense parcel leading to convection.

Streamer - A cable filled with an array of hydrophones (geophones) that is towed behind a vessel. The streamer receives direct and reflected energy from the source.

S-wave - A body wave in which the particle motion is perpendicular to the direction of propagation. S-waves are not present in the ocean since fluids have no shear strength to allow propagation.

Temperature - The physical property of a substance or medium related to the average kinetic energy of its atoms or molecules. Temperature variations in the ocean have important effects for convection and circulation, among others.

Thermohaline finestructure - Temperature and salinity derived structure in the ocean. Variations in the temperature and salinity fields create density contrasts which are amenable to seismic reflection ensonification.

Thermohaline staircase - Oceanic layering where temperature and salinity decrease downward in a series of steps. So called because a plot of temperature and/or salinity as a function of depth resembles a familiar staircase.

Trace - In seismology, a digital time series which expresses the record of data from a seismic channel. Traces are composed of samples of amplitude (signal strength) along the function.

Turbulence - A fluid regime characterized by chaotic or stochastic changes in physical property and manifests itself by abrupt changes to velocity at small scales (1 mm to 1 cm). Turbulence causes the formation of eddies across a broad range of length scales and results in small scale mixing, leading to homogeneity in property contrasts. It promotes conditions in which viscous dissipation transfers kinetic energy into heat.

t-x domain (spatial domain) - representation of seismic data in units of time (t) and distance (x) (offset).

Variable density - In seismic data processing, a display method whereby the photographic density is proportional to signal amplitude.

Velocity - Throughout this text, velocity will refer to actual vectors such as current velocity. The term 'velocity' is ubiquitous in seismology to refer, erroneously, to sound speed (a scalar). I use the oceanographic convention 'sound speed' in most cases. Except for terms that would otherwise be ambiguous (eg. velocity analysis).

Velocity analysis - the modification of the position of traces by making sound speed adjustments on a common-midpoint gather to account for normal moveout. The 'velocity' used in velocity analysis is termed 'stacking velocity' and is effectively the normal moveout velocity, the velocity needed to correctly position hyperbolically moved out traces.

Velocity function - In seismic data processing, it is sound speed as a function of depth or two-way time.

von Kármán spectra - The von Kármán power spectra is described by statistical variance, a characteristic correlation length and a Hurst number. The correlation length represents the largest scale for which the scaling is described by a power law and the Hurst number is the exponent of the power law.

Wave equation - An equation which describes the spatial and time dependence of a disturbance which propagates as a wave.

Wavelength - the distance between successive similar points on a two adjacent cycles of a monochromatic wave. Monochromatic waves are effectively non-existent in practice, so in seismology one speaks of the dominant wavelength.

Wavelet - A seismic pulse consisting of a few cycles.

Wavenumber - the reciprocal of wavelength, or the number of waves per unit distance perpendicular to a wavefront.

Well log - A record of one or more physical measurements as a function of depth in a borehole. In oceanography, its analog is that of the oceanographic in situ probe, which may measure properties such as temperature, pressure or conductivity. These measurements can then be used to estimate depth, salinity and sound speed. The CTD (conductivity-temperature-depth) probe creates an approximately vertical profile, whereas expendable probes (such as the XBT or XCTD), since they are launched from a moving ship have a small component of velocity in the direction of the ship.

XBT - see Expendable Bathymetry Thermograph

XCTD - see Expendable Conductivity Temperature Depth

Zero-offset section - a composite seismic section composed of common midpoint traces, each being the sum of all traces having a common midpoint. With this method it is possible to create an approximation of the subsurface as if the sources and receivers were co-located, a procedure that is impossible in practice due to noise issues and other constraints.