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GEO YPS Webinar Series: The Value of Multispectral Coherence

Questions

Name	Question	Answer
Haifa Salmi	How do you measure spectral voice? and how is it different from viewing spectral amplitude and phase separately?	The spectral voice is a fancy word for a bandpassed filtered version of the data. If you can bandpass filter the data in your interpretation software, simply choose three different filters and use the output as input to your coherence algorithm. Then plot the resulting coherence volumes against RGB or CMY. If you have the spectral magnitude, m(t,f) and the spectral phase ϕ(t,f), then the spectral voice d(t,f)=m(t,f)COS[ϕ(t,f)]. Remember that crosscorrelation is embedded in all coherence algorithms (even semblance it you expand the arithmetic). The voices have positive and negative values with a mean of 0.
Haifa Salmi	What would you say would be a good application of the synchrosqueezing transform in reservoir characterization? What would it be great at illuminating?	To me, synchrosqueezing adjusts the frequency resolution of what is otherwise a version of the continuous wavelet transform. By giving higher frequency and temporal resolution, synchrosqueezing should (from the papers I have read) provide greater detail in reservoir characterization. However, I do not believe that you can take the synchrosqueezed components and reconstruct the original data (Please correct me if I am wrong and point me to a reference to show how this is done). Also, the temporal sparcity of synchrosqueezed events my give rise to equally temporally sparse coherenec anomalies. For this reason, I do not believe synchrosqueezing "voices" can be used as in put to multispectral coherence analysis. If you have access to such an algorithm, please try it and let me know what you find.
Haifa Salmi	can you measure spectral voice for all the transforms (e.g. synchrosqueezing)? or just CWT?	I know you can compute spectral voices for the CWT, matching pursuit, and maximum entropy (also called constrained least-squares spectral analysis) algorithms. When added, these voices accurately reconstruct the original data. As in the response to the previous question, most of the papers I've read on synchrosqueezing use it to increase resolution for interpretation, not a transform pair for filtering. As an additional observation, the spectral probe algorithm developed by Dengliang Gao that crosscorrelates sines and cosines at different frequencies with the original data and normalized to generated output that ranges between -1 and +1. Theses images can be put into a coherence algorithm, with the understanding that because of the normalization each frequency component has equal importance. If you read Gao's 2013 paper (Wavelet spectral probe for seismic structure interpretation and fracture characterization: A workflow with case studies, Geophysics, vol 78, p O57-O67) you will see that faults at difference frequencies are easy to see by the lateral change in phase. This change in phase is what coherence measures. Finally, voices constructed by simple bandpass filters using the STFT will generate good coherence images but may not add up to reconstruct the data unless you somehow normalize and orthogonalize the results.
Aleksei Gritsenko	It true that Structure-oriented filtering can produce fault likelihood attribute as side-product?	In general, this is not true. Several edge-preserving structure-oriented filtering algorithms use coherence-family attributes as an input where the filter is NOT applied if the coherence indicates a sufficiently strong discontinuity. For example, Hoecker and Fehmers (2002, Fast structural interpretation with structure-oriented filtering: The Leading Edge, vol 21, p 238-243) used chaos to flag discontinuities. In our work, we use coherence for the same purpose. The work by Wu and Hale (Automatically interpreting all faults, unconformities, and horizons from 3D seismic images: Interpretation, 4, T227-T237) uses reflector dip estimates and continuity to detect faults, but their primary purpose in this work is to predict faults and generate a mesh of horizons rather than smooth the data in any way. I know that the Landmark software has implemented many of these latter features, and while it might make sense to put smoothing into the same package, in general they are different processes with different objectives.
Akinmuda Olusegun	Thanks for that wonderful presentation. My question goes thus: What are the limitations of spectral decomposition?	Spectral decomposition subdivides the input seismic amplitude data into different bandlimited frequency components. Some algorithms (CWT, matching pursuit, CLSSA) are reversible, allowing one to reconstruct the original data. Other algorithms (STFT, spectral probe, synchrosqueezing, Wigner,...) are not reversible. All algorithms are limited by the bandwidth of the input volume. For example, if the input data were acquired by a vibrator sweeping from 10-80 Hz, you can construct frequency components centered around 10, 20, 30,...,80 Hz, but cannot construct frequency components around 5 or 120 Hz. This latter process is called bandwidth extension, and is built around the assumptions of a specific subsurface model, commonly that of either sparse spikes (discrete jumps in impedance) or sparse dipoles (discrete layers). Bandwidth extension does not currently work on data whose underlying impedance increase or decrease smoothly with depth.
Akinmuda Olusegun	What approach do you use in extracting your frequency and how can a seismic interpreter identify the dominant frequency from seismic data	The most common means to identify the dominant frequency at a particular depth is to measure the peak-to-peak or trough-to-trough distance of a seismic reflection event. This measure of the dominant period, T, is the inverse of the dominant frequency, f. Thus, if the peak-to-peak distance is 40 ms (0.040 s), then the dominant frequency f=(1.0/0.040s) =25 Hz. Most interpretation workstation software allows an interpreter to draw a box around an area of interest and then use Fourier transforms to define the spectrum.

Hala Alwagdani	I'm sold on multispectral coherence. But what are the limitations of this method ?	The primary limitation is cost. In general, if the cost of a coherence computation is x, then the cost of coherence computations for each spectral component is also x, such that the cost goes up linearly with the number of desired components. If you choose not to output the individual components but only output the multispectral estimate computing by summing the individual covariance matrices, the cost is slightly less than linear. You will also find some data volumes (particular those with a high signal-to-noise ratio) where their are few improvements in but little detriment to the coherence results. Also, for dipping faults, you may see some lateral smearing of the coherence anomaly, which at present, I attribute to the compounding the stair-step artifacts for each component (Lin, T., and K. J. Marfurt, 2017, What causes those annoying stair step artifacts on coherence volumes?: AAPG Explorer Geophysical Corner, March, Article 37830). In this case, the faults are also more continuous and amenable to subsequent sharpening using Petrel's ant tracker (Pedersen, S. I., T. Randen, L. Sonneland, and O. Steen, 2002, Automatic 3D Fault interpretation by artificial ants: 64th Meeting, EAGE Expanded Abstracts, G037) or simple oriented Laplacian filters (Qi, J, G. Machado, and K. Marfurt, 2017, A workflow to skeletonize faults and stratigraphic features: Geophysics, O57-O70).
Rogerio Santos	Kurt, why do you believe the conventional coherence is not able to detect multiazimuth heterogeneities at once?	Most of the wide azimuth surveys that I have access to were acquired on land for shale resource plays. In these plays, the shale reservoir is permeated by microcracks oriented in all directions. Those microcracks oriented perpendicular to the minimum stress (almost always horizontal stress. SHmin) are preferentially open while those perpendicular to the maximum horizontal stress (SHmax) are closed. The result is that P-waves traveling across the (fluid-filled) open cracks will be slower, whereas those travelling across the closed cracks will be faster, giving rise to velocity "azimuthal" (or horizontal transverse) anisotropy. Because of cost constraints, few of these surveys undergo careful prestack HTI migration. Rather, by using a simple isotropic velocity model, the discontinuities are migrated to slightly different locations for each azimuthally limited set of traces. Although all discontinuities may be imaged, stacking these traces results in a blurred image. I tried to show this anisotropy in slides 70 and 71, where black anomalies in slide 70 indicate that the discontinuities are aligned by the three different azimuths, whereas polychromatic anomalies indicate the discontinuities are not aligned. I believe such misalignment can provide improved velocities. Gabriel Perez started this work (Perez, G., and K. J. Marfurt, 2008, New azimuthal binning for improved delineation of faults and fractures: Geophysics, 73, S7-S15; Perez, G., and K. J. Marfurt, 2008, Warping prestack imaged data to improve stack quality and resolution: Geophysics, 73, P1-P7) but data access and the computational burden proved too much for us in the university environment. For some reason, stacking the covariance matrices generated for each azimuthally-limited volume is less sensitive to this misalignment. I attempt to explain (OK, I conjecture!) what is happening is slides 87 and 88.
Diana Duran	What software do you use to perform the work presented in this webinar?	All of the examples here were generated using the AASPI software developed over the past 13 years by the Attribute-Assisted Seismic Processing and Interpretation consortium (http://mcee.ou.edu/aaspi/) . Many, but not all of the capabilities can be obtained using commercial software. Our goal is to be "always emulated, never duplicated". (I stole that motto from of my daughter's high school marching band).
Mohamed Abdulla	Hello Kurt, great lecture. Is this available as open code?	For reasons of supporting hungry students, it is not open code. That's how we feed them! We supply the software and source code to our sponsors, which runs over multiple processors using MPI in both Windows and Linux environments. I can provide you (or anyone) with an 3-month evaluation license if you wish - just email me at kmarfurt@ou.edu. All algorithmic details are published theses, dissertations, and publications that you can find on our website (http://mcee.ou.edu/aaspi/). Further algorithmic details can be found under the documentation tab. Feel free to start typing!
David Dietz	Should you use a smaller vertical window when computing spectral coherence than for broadband coherence?	Hmmm. You ask the correct question, and no, we've never evaluated that. For others, let me repharse the question to be "for a given computational budget, which algorithm gives me the best bang for the dollar?". For example, most folks will agree that given an accurate velocity/depth model that reverse time migration is better than Kirchhoff migration. However, for the same $1,000,000 I can image up to 80 Hz using Kirchhoff migration but only 25 Hz using reverse time migration. Then you need to ask, is it more important to have higher resolution of the relatively flat reservoirs at the tops of structures or to have better positioning of the steeply dipping flanks of the reservoirs? To address the question asked - the cost of the covariance matrix increases and the vertical resolution decreases with the vertical height of the analysis window. Does the improvement in the signal-to-noise ratio allow us to improve the vertical resolution, reducing the mixing of stratigraphic discontinuities at different levels?
Aleksei Gritsenko	Should you use a smaller vertical window when computing spectral coherence than for broadband coherence?	Aha! This is the same question as above! To be honest, I don't know because I never thought of it. So thanks. This is something we (and you) need to investigate.
Denny Sulistiono	What is the impact of coherence noise (multiple) in seismic to spectral decomposition? how to differential signal and noise?	Coherence and all seismic attributes, including prestack inversion for impedances suffer from coherent noise. Although steeply dipping coherent noise cutting across gently dipping reflectors can be reduced by structure-oriented filtering, subparallel multiples cannot. Machine learning will also confound multiples with primaries in facies classification. All is not hopeless. For example, Bob Hardage (2009, Frequencies are fault finding factors: Looking low aids data interpretation: AAPG Explorer, 30, no 9, 34) found that for his Permian Basin data volume that the signal at the reservoir depth was confined to 25 Hz and lower. This signal was overprinted by broadband (10-80 Hz) multiples reverberating in the shallow section. A simple low-pass filter provided significantly improved the fault images at depth. This workflow implies that you, the interpreter, need to examine the spectrum of your signal and your noise and determine which parts of the spectrum provide the best signal-to-noise ratio.

Tahir Chaudhry	I know data conditioning may be depending on the acquired data quality. however, if you have any rule of thumb to pre-condition data for MC	We found that the order of data conditioning operators makes a difference (Ha, T. N., K. J. Marfurt, B. C. Wallet, and B. Hutchinson, 2019, Pitfalls and implementation of data conditioning, attribute analysis, and self-organizing maps to 2D data: Application to the Exmouth Plateau, North Carnarvon Basin, Australia : Interpretation, 7, SG23-SG42). if your faults are non vertical, sharpening them adds an abrupt change that cuts across a vertical trace, thereby introducing high frequency components that are not in the original data. For data that have already been migrated and stacked, I would first spectrally balance the data and then follow with one or two passes of edge-preserving structure oriented filtering. Remember that steeply dipping migration artifacts (migration operator aliasing) will exhibit low APPARENT frequencies. Therefore, choose parameters that avoid enhancing such noise when you spectrally balance.
Rogerio Santos	Thanks Kurt. One more question: how to handle multiazimuth noises generated by events responsible by apparent attenuation?	1) there will be different types of noise at different azimuths, where ground roll can leak into the geophone and source array response. Clearly, you could apply structure-oriented filtering to each azimuthally-limited volume separately or generalize to work on 4D or 5D volumes as we did in a paper by Zhang et al. (Zhang, B., T, Lin, S. Guo, O. E. Davogustto, and K. J. Marfurt, 2016, Noise suppression of time-migrated gathers using prestack structure-oriented filtering: Interpretation, 4, SG19-SG-29). 2) Many folks, such as Heloise Lynn (2004, The Winds of Change: Anisotropic Rocks...their Preferred Direction of Fluid Flow and their Associated Seismic Signatures: SEG Fall 2004 Distinguished Lecturer) feel that such azimuthally dependent attenuation is important signal rather than noise. The attenuation may be due to P-waves being more sensitive to fluid filled fractures oriented perpendicular to the ray path. The attenuation may also be due to geometric scattering from regularly spaced fractures. I interpret the findings by Cho to this latter phenomenon, which I tried to demonstrate when I pulled out a compact disc that all grandfathers have handy and rotated it in the light to illustrate the diffraction grating effect (Cho, D., B. Goodway, M. Perez, A. Iverson, and G. F Margrave, 2013, 4D attenuation analysis for permeability estimates in hydraulically induced fractures: CSEG Recorder, no. 1, 38, https://csegrecorder.com/articles/view/4d-attenuation-analysis-for-permeability-estimates)