



Seismic Attributes - from Interactive Interpretation to Machine Learning

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Geometric Attributes

Multispectral, Multioffset, and Multiazimuth Coherence

Multispectral, Multiazimuth, and Multioffset Coherence

After this webinar will be able to:

- 1. Display coherence computed from different spectral, azimuthal, or offset components against RGB or CMY color models, and
- 2. Combine multiple edge models using SOM, PNN, or other clustering algorithms.
- Although not available in commercial software, you will be able to see the advantage of:
 - 3. Improved edge illumination provided by different spectral, azimuthal, or offset components by stacking the covariance matrix of each component prior to computing coherence

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Alignment of uncorrelated reflectors across faults



Reflector alignment across faults varies with the spectrum



(Lyu et al., 2020)











RGB blending of coherence from different spectral bands (Tarim Basin, China)



RGB blending of coherence from different spectral bands (Tarim Basin, China) RGB-blended cohere Peak frequency RGB-blended cohere





Method 2. Combining more than three coherence volumes using SOM



Broadband coherence followed by Petrel's "ant-tracker"



(Dewett and Henza, 2016)

Combining more than three coherence volumes using SOM

Self-organizing map combination of coherence volumes computed at 5 frequencies, each of which were filtered using Petrel's ant-tracker



Improved fault connectivity (yellow arrows) and more reasonable fault dip (red rectangle) in the right image

(Dewett and Henza, 2016)

Broadband coherence followed by Petrel's "ant-tracker"







Vertical slice

(Dewett and Henza, 2016)

Time (s)

Combining more than three coherence volumes using SOM

Self-organizing map combination of coherence volumes computed at 5 frequencies, each of which were filtered using Petrel's ant-tracker







Vertical slice

Time (s)







3-coherence RGB blending flow chart



Multispectral coherence flow chart





Method 3. Computing multispectral coherence by stacking covariance matrices



Original broadband coherence

Noise attenuated broadband coherence

Maximum entropy multispectral coherence

Equally or exponentially spaced spectral voice components?



(Lyu et al., 2020)

Coherence using original broadband seismic data before structure-oriented filtering



Coherence using original broadband seismic data after principal component structure-oriented filtering



Multispectral coherence using equally spaced CWT voice components



Multispectral coherence using exponentially spaced CWT voice components



Multispectral coherence using exponentially spaced maximum entropy voice components



Coherence using original broadband seismic data before structure-oriented filtering



Access to multispectral capabilities in the AASPI program similarity3d

Multispectral:

- Energy ratio similarity
- Semblance (outer product) similarity
- Sobel filter similarity
- Amplitude gradients
- Amplitude Laplacian

🗙 aaspi_similarity3d GUI (Release Date: 27 Jan 2021)									_		\times
]] Eile											Help
similarity3d - Calculate 3d similarity family, energy, and amplitude gradient attributes											
Seismic input file	Seismic input filename (*.H): /ouhomes6/marf2925/projects/GSB_AAPG/d_mig_GSB_AAPG.H Browse										
Inline dip filename (*.H): homes6/marf2925/projects/GSB_AAPG/inline_dip_GSB_AAPG_0_broadband.H Browse											
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Suffix:	Ī	D									
Verbose output?											
Primary par	ameters A	nalysis window p	arameters	Filter bank definiti	on	Parallelization par	ameters				
Ormsby Filter Bank Definition Parameters											
Compute multi-spectral attribute volumes											
Output attribute volumes for each filter bank Output attributes for each filter bank											
f_low (cycles/s): 5											
f_high (cycles/s):											
Taper applied to filter banks (0-50%))											
Number of filter banks applied to the data:											
Construct linearly or exponentially spaced filter bank? Exponentially spaced filter banks											
Exponentially spaced filter banks											
Update the filter banks											
	f1	f2	f3	f4	1						
Filter Bank 1	2.25901	5	5	11.0668							
Filter Bank 2	5	11.0668	11.0668	24.4949							
Filter Bank 3	11.0668	24.4949	24.4949	54.2161							
Filter Bank 4	24.4949	54.2161	54.2161	120							
Broad Band Filt	2.25901	5	120	125							
	1.20001	5	120								
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(c) 2008-2021 AASPI for Linux - authors at Univ. Oklahoma, Univ. Alabama, Univ. Texas Permian Basin, Univ. Alaska, and SISMO | Execute similarity3d



Multispectral coherence illumination of faulting

Broadband coherence (Great South Basin, NZ)





(Marfurt, 2017)

t=1.24 s

Multispectral coherence (Great South Basin, NZ)





(Marfurt, 2017)

Broadband coherence (Great South Basin, NZ)





(Marfurt, 2017)

t=1.48 s

Multispectral coherence (Great South Basin, NZ)





(Marfurt, 2017)

t=1.48 s

5h-35

Broadband coherence (Great South Basin, NZ)





t=1.76 s

5h-36

Multispectral coherence (Great South Basin, NZ)





t=1.76 s

(Qi et al., 2017)

Broadband coherence (Polygonal faulting, Great South Basin, NZ)

3 trace by 3 trace by ±12 ms window




Multispectral coherence (Polygonal faulting, Great South Basin, NZ)

6 spectral bands 3 trace by 3 trace by ±12 ms window





Broadband coherence (British Columbia)

Horizon slice



Coherence High Low

Horizon slice + 68 ms

5h-40

Multispectral coherence (British Columbia)

Horizon slice





Horizon slice + 68 ms

Chopra and Marfurt, 2019)

Multispectral coherence imaging of channels

(Megamerge survey, Anadarko Basin, Oklahoma, USA)

RGB-blended spectral magnitude



Coherence from 10-15-25-30 Hz volume

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Coherence from 30-35-45-50 Hz volume



Coherence from 50-55-65-70 Hz volume



Coherence from 70-75-85-90 Hz volume



Coherence from 90-95-105-110 Hz volume



Coherence from 110-115-125-130 H volume



10000 ft



(Li et al., 2017)







Anomalies not in black are coherence anomalies seen only at specific spectral bands

10000 ft

Northeast British Columbia, Canada

3 km



Conventional (Broadband) Coherence

Multispectral Coherence









3 km



(Chopra and Marfurt, 2019)

Conventional (Broadband) Coherence

Multispectral Coherence



0.88 1.0 Coherence



3 km



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(Chopra and Marfurt, 2019)





Multispectral Coherence



0.88 Coherence

(Chopra and Marfurt, 2019)

1.0

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Coherence computed from different input components

Different spectral voices





Different offset limited volumes







Coherence computed from different input components

Different spectral voices











5h-59



Multiazimuth coherence



Coh

High

Low

Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.



Coh

High

Low

Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.



Coh

High

Low

Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.



Coh

High

Low

Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.

t=0.740 s



Coh

High

Low

Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.



Although one can identify faults (yellow arrows) and karst collapse features (green arrows), the images are quite noisy.

(Qi et al., 2017)

The differences include: the shape and size of karst features; the continuity of subtle faults; the level of incoherent noise.

High

Low

RGB blending of 3 azimuthal coherence volumes

RGB coherence



Azimuthal sectors: -15° to +15° 45° to 75° 105° to 135°



Anomalies are in CMY

Azimuthal anisotropy (AVAz attributes)



Poststack coherence





t=0.74s

Sum of azimuthally limited coherence







Multi-azimuth coherence



Coh

High

Low

t=0.74s

5h-71

Multi-azimuth coherence



t=0.74s

5h-72

Red Fork and STACK Plays, Oklahoma, US



Horizon Slice near STACK Play, Oklahoma, USA

> Conventional (Stacked azimuths) Coherence


Horizon Slice near STACK Play, Oklahoma, USA

Mulitazimuth Coherence



Red Fork Channels, Oklahoma, USA

Conventional (Stacked azimuths) Coherence



(Chopra and Marfurt, 2019)

4 km

Red Fork Channels, Oklahoma, USA

Multiazimuth Coherence



(Chopra and Marfurt, 2019)

4 km

Multioffset coherence

Multioffset coherence (STACK play, Oklahoma, US)





Offset: 6801 - 10,200 ft



(Chopra and Marfurt, 2019)



- Different spectral components, azimuthal components, and offset components often illuminate edges differently. For this reason, coherence computed from such components also illuminate edges differently
- RGB-blending provides a means of combining the information content of up to three separate components
- Summing the covariance matrix of each component provides an energy-weighted measure of the discontinuities
- Multispectral, multiazimuth, multioffset coherence based on the sum of the covariance matrices for each component allows one to display the edge information contained in more than three components.
- Computation cost increases linearly with the number of spectral components

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Arithmetic of broad-band energy ratio coherence

1. Compute the covariance matrix, C

$$C_{mn} = \sum_{k=-K}^{K} \left[u(t_k, x_m, y_m) u(t_k, x_n, y_n) + u^H(t_k, x_m, y_m) u^H(t_k, x_n, y_n) \right]$$

2. Compute eigenvectors of the covariance matrix, $\mathbf{v}^{(j)}$

$$C_{mn}v_n^{(j)} = \lambda^{(j)}v_n^{(j)}$$

3. Compute the KL-filtered data

$$u_{n}^{KL} = \sum_{j=1}^{J} \left[\sum_{m=1}^{N} \left(v_{m}^{(j)} u_{m} \right) v_{n}^{(j)} \right], J < N$$

4. Compute the energy ratio coherence

$$S = \frac{\sum_{n=1}^{N} (u_n^{KL})^2}{\sum_{n=1}^{N} (u_n)^2}$$

Arithmetic of multispectral energy-ratio coherence (L components)

1. Compute the *N* by *N* covariance matrix, *C*_{mn}

$$C_{mn} = \sum_{l=1}^{L} \sum_{k=-K}^{K} \left[u(t_k, f_l, x_m, y_m) u(t_k, f_l, x_n, y_n) + u^H(t_k, f_l, x_m, y_m) u^H(t_k, f_l, x_n, y_n) \right]$$

2. Compute first J eigenvectors of the covariance matrix, $v_n^{(j)}$

$$C_{mn}v_n^{(j)} = \lambda^{(j)}v_n^{(j)}$$

3. Compute the KL-filtered data

$$u_{nl}^{KL} = \sum_{j=1}^{J} \left[\sum_{m=1}^{N} \left(v_m^{(j)} u_{ml} \right) v_n^{(j)} \right], J = 1 \text{ or } 2$$

4. Compute the energy ratio coherence

$$s = \frac{\sum_{l=1}^{L} \sum_{n=1}^{N} (u_{nl}^{KL})^2}{\sum_{l=1}^{L} \sum_{n=1}^{N} (u_{nl})^2}$$



$$C_{stack} = \left(u_{1x} + u_{1y}\right)\left(u_{2x} + u_{2y}\right) = u_{1x}u_{2x} + u_{1x}u_{2y} + u_{1y}u_{2x} + u_{1y}u_{2y}$$

Rotentialuis

If there is a change in alignment, or a change in wavelet, the cross terms will provide decreased resolution

What might be the cause of the change in geologic definition? Arithmetic of 2-trace semblance for frequency components f_1 and f_2

$$N_{\text{multispectral}} = \frac{1}{4} \sum_{k=-K}^{+K} \left(u_{\text{L}k1} + u_{\text{R}k1} \right)^2 + \left(u_{\text{L}k2} + u_{\text{R}k2} \right)^2$$

$$N_{\text{broadband}} = \frac{1}{4} \sum_{k=-K}^{+K} \left[\left(u_{\text{L}k1} + u_{\text{L}k2} \right) + \left(u_{\text{R}k1} + u_{\text{R}k2} \right) \right]^2$$

$$N_{\text{broadband}} - N_{\text{multispectral}} = \frac{1}{2} \sum_{k=-K}^{+K} \left(u_{\text{L}k1} u_{\text{R}k2} + u_{\text{L}k2} u_{\text{R}k1} \right)$$
Potential correlation

ind

If there is a change in alignment, or a change in wavelet, the cross terms can provide increased correlation and hence a decreased coherence anomaly. Can such correlations also give rise to increased noise?

RGB blending of 3 coherence volumes using RGB results in CMY blending of low coherence anomalies



Computational effort

- 0.7 Gbyte data volume
- 2016 Dell laptop
- Use 7 of 8 processors

Output	Wall clock time (hours)
Broadband coherence volume only	0.216
Broadband and multispectral coherence volumes only (6 bands)	1.464
Broadband, multispectral, and 6 spectral coherence volumes	1.498

Comparison of multispectral coherence and CNN fault probability

Multispectral coherence



Artifacts in low coherence salt. Breaks in faults across some zones

Comparison of multispectral coherence and CNN fault probability

CNN fault probability



Spurious faults in salt More continuous faults across some zones Misinterpretation of MTD boundaries as faults