3D passive wavefield imaging using the energy norm

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Microseismicity

- enhanced oil recovery
- fracture characterization
- underground CO₂ storage
Microseismic monitoring

borehole

surface
Passive imaging
Wavefield extrapolation

\[ t_0 \text{ is unknown, therefore } l(x) \text{ involves } \sum_t \]

5 issues to be addressed: A B C D E
Passive wavefield imaging: acoustic

1. separate P-S events: $P(x_r, t)$ and $S(x_r, t)$
2. acoustic backpropagations: $P(x, t)$ and $S(x, t)$
3. imaging condition: $\sum_t P S$

(Witten & Shragge, 2015)

A: does not account for source radiation
Passive wavefield imaging: elastic

1. multicomponent data:
   \( U(x_r, t) \)

2. elastic backpropagation:
   \( U(x, t) \)

3. imaging condition:
   \( \sum_t P \| S \| \)
   (Artman et. al., 2009)

B: produces nodal planes
C: expensive PS decomposition in anisotropic media
PS imaging condition

$$\sum_{t} P S = I_{PS}(x)$$
\[ \sum_{t} P\left( x + \lambda, t \right) S\left( x - \lambda, t \right) = l(x, \lambda) \]
Energy imaging condition

\[ I_{EN}(x) = \sum_{t} \left[ \rho \dot{U} \cdot \dot{U} - (\overline{c \nabla U}) : \nabla U \right] \]

\[ \text{kinetic} \quad \text{potential} \]

\[ D : \text{complementary extended imaging condition} \]
Energy imaging condition

for a single wave-mode (P or S) event

\[ \rho u_i u_i - u_i u_k c_{ijkl} p_j p_l = 0 \]

Christoffel eq.

- \( u_i \) : polarization vector component
- \( p_j \) : slowness vector component
Energy imaging condition

\[
\left[ \rho u_i u_i - u_i u_k c_{ijkl} p_j p_l \right] = 0
\]

Christoffel eq.

same \( u \) and \( p \):

\[\text{PP and SS}\]

different \( u \) and \( p \):

\[\text{PS}\]

\( E \) : enhances correlation of distinct wave modes
\[ [\Delta V_P, \Delta V_S] = [0, 0] \]
\[ [\Delta V_P, \Delta V_S] = [-8\%, +8\%] \]
overthrust model

receivers (field dataset)
\( \tau_{xx} = -2 \)

\( \tau_{yy} = 1 \)

\( \tau_{zz} = 1 \)
Summary

3D energy passive imaging condition (EPIC)

A: handles source radiation patterns
B: no nodal planes
C: no wave-mode decomposition (anisotropy)
D: complementary behavior in extended domain
E: enhances distinct modes, nullifies identical ones