P201

Wellbore Measurement Simulations for the Seismo-Electric Effect

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SUMMARY

In this paper we derive global reflection and transmission coefficients from the one-way operators to in a similar way as Kennett does, later we use them to simulate a vertical seismo-electric profile (VSEP) and an electro-kinetic well bore to well bore survey.

Introduction

In this paper we derive global reflection and transmission coefficients from the one-way operators to in a similar way as Kennett \cite{ken} does, later we use them to simulate a vertical seismo-electric profile (VSEP) and an electro-kinetic well bore to well bore survey.

1 One-way wavefield operators

We can describe an electro-kinetic survey by means of operators describing each of the phenomena taking place, such as excitation, propagation or reflection. In this section we describe the mentioned operators and how we move from two-way to one-way expressions. One-way wave equations describe the propagation of a certain wave (e.g. fast-P wave) across the medium either up or downgoing, while two-way wave equations describe the propagation of a certain field quantity (e.g. $E1$ field) up and downgoing.

1.2 Decomposition of wavefields

We have that the two-way wave equation for the seismo-electric coupling is

$$\frac{\partial \widehat{\mathbf{Q}}}{\partial x_3} = \widehat{\mathbf{A}}\widehat{\mathbf{Q}} + \widehat{\mathbf{D}} \qquad \textbf{(1)}$$

where the two-way wavefield represented by vector **Q** in equation (1) are

$$\tilde{\mathbf{Q}}_H = \left(-\tilde{\tau}_{23}^b, -\tilde{H}_1, \tilde{E}_2, \tilde{v}_2^s\right)^t \quad \text{and} \quad \tilde{\mathbf{Q}}_V = \left(\tilde{v}_3^s, w_{3,}, -\tilde{\tau}_{13}^b, \tilde{H}_2, \tilde{E}_1, -\tilde{\tau}_{33}^b, p, \tilde{v}_1^s\right)^t \qquad \textbf{(2)}$$

and **D** contains the two-way source vectors (Shaw 2006)

$$\mathbf{D}_\mathrm{H} = \left(f_2^b - \frac{\rho^f}{\rho^E} f_2^f, -J_2^e - \frac{p_1}{\mu_0} J_3^m - L f_2^f, J_1^m, 0 \right)^t \quad \text{and} \qquad \textbf{(3)}$$

$$\mathbf{D}_\mathrm{V} = \left(0, \frac{p_1}{\mu_0} f_1^f, f_1^b - \frac{\rho^f}{\rho^E} f_1^f, -J_1^e - L f_1^f, -J_2^m + \frac{p_1}{\varepsilon} J_3^e, f_3^b - \frac{\rho^f}{\rho^E} f_3^f, \frac{\rho^E}{\varepsilon} L J_3^e + f_3^f, 0 \right)^t \quad \textbf{(4)}$$

where the subscripts V and H stand for the coupling among fast-P, slow-P, vertical shear and TM electromagnetic waves, and horizontal shear and TE electromagnetic waves respectively. When the source is seismic we assume that the forces applied to the fluid and to the solid are equal, therefore $f_i^f = f_i^b$. The two-way vector **Q** can be decomposed in downgoing and upgoing one-way wavefields by using the transformation

$$\widehat{\mathbf{Q}} = \widehat{\mathbf{L}}\widehat{\mathbf{P}} \qquad \textbf{(5)}$$

where matrix **L** contains the eigenvectors of **A** and is the composition operator that converts the one-way wavefields into two-way wavefields. Expressions of the operator **L** can be found in (Pride and Haartsen 1996).

1.3 Reflection and transmission coefficients

The reflection and transmission coefficients were derived following the scheme from Ursin and the open pore boundary conditions (Deresiewicz and Skalak 1963). We consider an interface between a porous layer and a porous halfspace that simulates an interface between two layers right below the surface.

1.4 Wavefield extrapolators

Here we present the wavefield extrapolation operators. These operators describe the propagation of a wavefield through a medium, they are

$$w_m^{\pm} = e^{-j\omega q_m |z_r - z_0|} \qquad \textbf{(6)}$$

where m is the wavefield type (e.g. fast-P wave). We use the + sign in w+ when the wavefield is downgoing, i.e. when $z_r > z_0$ and the - sign in w when the wavefield is upgoing, i.e. when $z_r < z_0$.

1.5 Source decomposition operator

The relation between the two-way wavefields generated by the source and the up or downgoing one-way wavefields is given by the source decomposition operator. The one-way representation of the source function **S** is

$$\mathbf{S} = \mathbf{L}^{-1}\mathbf{D} \qquad \textbf{(7)}$$

where $\mathbf{L}^{-1}$ is the inverse of the composition operator **L**. The inverse of the composition operator decomposes the different two-way source wavefields into one-way up and downgoing source wavefields.

1.6 Receiver composition operator

The relation between the two-way wavefield recorded at the receivers and the one-way wavefields arriving there is given by the receiver composition operator, that combines all the up and downgoing one-way wavefields into the measurable two-way wavefields we are interested in. For example to compose the two-way wavefield E_1 from the one-way wavefields that arrive to the receivers (e.g. fast-P, vertical shear and electromagnetic TM waves). We can express equation (1.8) as

$$\begin{pmatrix} \mathbf{Q}_1 \\ \mathbf{Q}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{L}_1^+ & \mathbf{L}_1^- \\ \mathbf{L}_2^+ & \mathbf{L}_2^- \end{pmatrix} \begin{pmatrix} \mathbf{P}^+ \\ \mathbf{P}^- \end{pmatrix} \quad \mathbf{(9)}$$

where $\mathbf{Q}_2$ contains the two-way wavefields from **Q** that have been selected to be measured by the receivers. Let's assume a receiver at depth z_n where the up and downgoing wavefields $\mathbf{P}^-$ and $\mathbf{P}^+$ respectively arrive, then we can write the receiver composition operators as

$$\mathbf{C}_r^+ = \mathbf{L}_2^+ \text{ and } \mathbf{C}_r^- = \mathbf{L}_2^- \quad \mathbf{(10)}$$

where $\mathbf{C}_r^+$ and $\mathbf{C}_r^-$ are the receiver composition operators to convert the down and upgoing wavefields respectively into two-way wavefields.

2 The Reflectivity method

In the previous section we described the one-way operators needed to simulate a seismo-electric survey. In this section we used these operators to derive global reflection and transmission coefficients in a similar way as in (Kennett 1989), and later we use them to simulate a vertical seismo-electric profile (VSEP) and an electro-kinetic wellbore to wellbore survey.

2.1 Vertical Seismo-Electric Profile

In the Vertical Seismo-electric Profile we use electrodes along the well as receivers and a seismic source at the surface, or the other way around. Following the scheme from (Kennett 1989) we have the global coefficients for a generic stack of n layers. From those coefficients we can derive the wavefields arrive at each receiver, up and downgoing, denoted as

$$\mathbf{P}(z_m) = \mathbf{P}^+(z_m) + \mathbf{P}^-(z_m) \quad \mathbf{(11)}$$

where

$$\mathbf{P}^+(z_m) = (\mathbf{I} - \mathbf{R}^-(z_{m-1})\mathbf{R}^+(z_m))^{-1}\mathbf{T}^+(z_m) \quad \mathbf{(12)}$$

$$\mathbf{P}^-(z_m) = (\mathbf{I} - \mathbf{R}^+(z_m)\mathbf{R}^-(z_{m-1}))^{-1}\mathbf{R}^+(z_m)\mathbf{T}^+(z_m) \quad \mathbf{(13)}$$

where the coefficients $\mathbf{R}(z_m)$ and $\mathbf{T}(z_m)$ are the global coefficients from level z_m and they correspond to the complete stack of layers between the level z_m and the bottom of the multilayered medium for $\mathbf{R}^+(z_m)$ and $\mathbf{T}^+(z_m)$, or between the level z_m and the top for $\mathbf{R}^-(z_m)$ and $\mathbf{T}^-(z_m)$. We use the index m to denote the level from which we are calculating the coefficients.

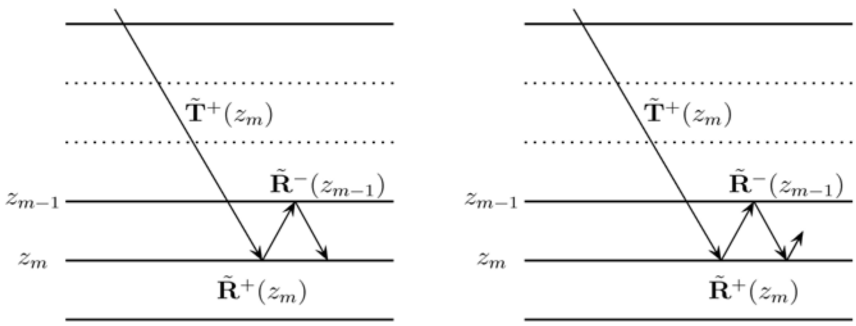

Figure 1: *Left and right: down and upgoing wavefields as in equations* (12) *and* (13)

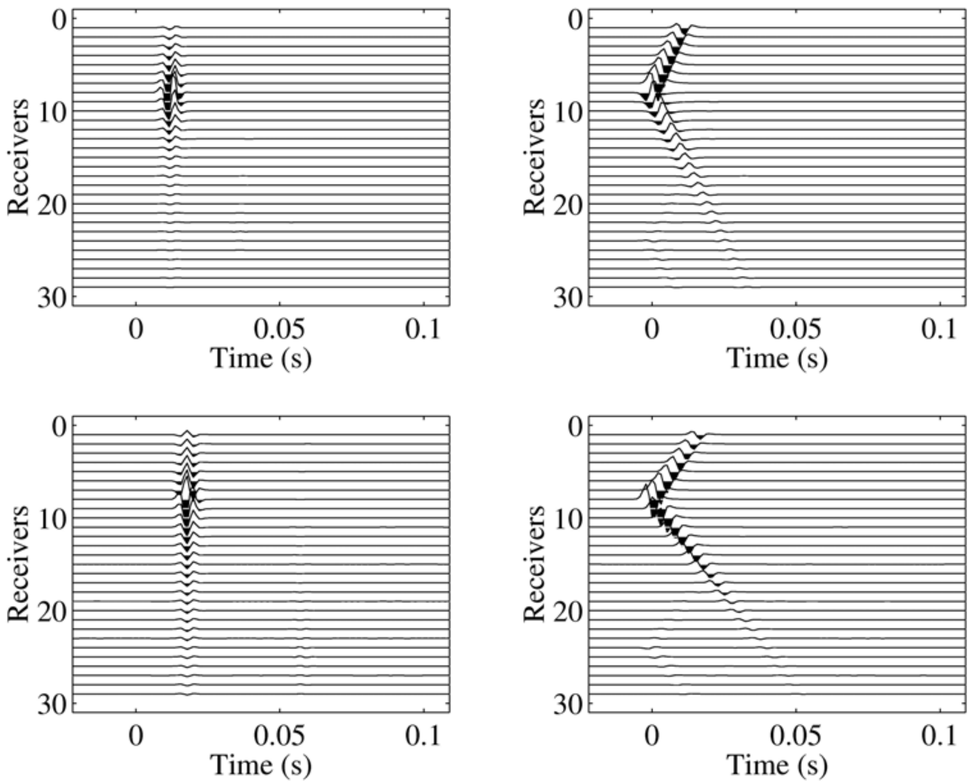

Figure 2: *Seismo-electric conversions in a VSEP model. Left: conversions from seismic(fast-P and shear) waves to electromagnetic TM wave. Right: conversions from electromagnetic TM wave to seismic(fast-P and shear) waves.*

In Figure 2 we can see the results of the VSEP model. On the left graphs we see the conversion from fast-P (above) and shear (below) waves to electromagnetic TM wave at an interface close to receiver 8. Note that since the velocity of the TM wave is close to the speed of light, the traces on the VSEP appear vertical. On the right graphs we see the conversion from TM waves to fast-P (above) and shear (below) waves.

2.2 Wellbore to wellbore model

The model we present for the wellbore to wellbore simulation is composed by two VSEP models interconnected in an iterative expression. For this we use two auxiliary media: medium U and medium L. In medium U we have all the layers that originally were above the source level plus a homogeneous porous halfspace below the source level z_s whose medium properties are those of the layer right below z_s. In medium L we have all the layers that originally were below z_s plus a homogeneous porous halfspace above it whose medium properties are those of the layer right above z_s. We apply the VSEP model to the mentioned setup iteratively, the first time the results of it are as those of two concatenated VSEP models, but on each step of the iteration we feed each medium's outgoing wavefields into the opposite medium. This way we ensure the continuity of all wavefields across the source level. The iterated VSEP simulation on medium U will model the upper half of the wellbore to wellbore simulation while the iterated VSEP simulation on medium L will model the lower half of it. Finally both wavefields are summed to yield the full wellbore to wellbore model. Applying the equations for the VSEP problem to these two media provide us with all the one-way wavefields at all the layers. From those we can extract the up and downgoing wavefields that propagate across z_s. These two wavefields are important because they serve as "source wavefields" for the opposite medium on the next iteration. After running the algorithm once we obtain $\mathbf{P}_1^{+,U}$ that will be propagated into medium L and $\mathbf{P}_1^{-,L}$ that will be propagated in medium U. All this is done inside the first iteration loop. For the second and following iterations we have that

$$\mathbf{P}_s^U(z_m) = \left(\mathbf{P}_{s-1}^{+,U}(z_m) + \mathbf{P}_{s-1}^{-,U}(z_m)\right)\mathbf{P}_{s-1}^{-,L}(z_s) \quad \textbf{(14)}$$

$$\mathbf{P}_s^L(z_m) = \left(\mathbf{P}_{s-1}^{+,L}(z_m) + \mathbf{P}_{s-1}^{-,L}(z_m)\right)\mathbf{P}_{s-1}^{-,U}(z_s) \quad \textbf{(15)}$$

where s is the iteration index. Finally we obtain the full one-way wavefield arriving to any receiver summing up equations (1.16) and (1.17)

$$\mathbf{P}_s(z_m) = \mathbf{P}_s^U(z_m) + \mathbf{P}_s^L(z_m) \quad \textbf{(18)}$$

In Figure 3 we see the results of the two-way wellbore to wellbore simulation in the (x1,x3,t) domain. The wellbore separation is 30 m and the interfaces present a porosity contrast at receiver 8 and a ion concentration contrast at receiver 25. Upper graphs: the receivers measure v_3 and v_1, and the source is an electric current in the x_1 direction Je^1 .Lower graphs: the receivers measure H_2 and E_1, and the source is a bulk and fluid force in the x_1 direction .

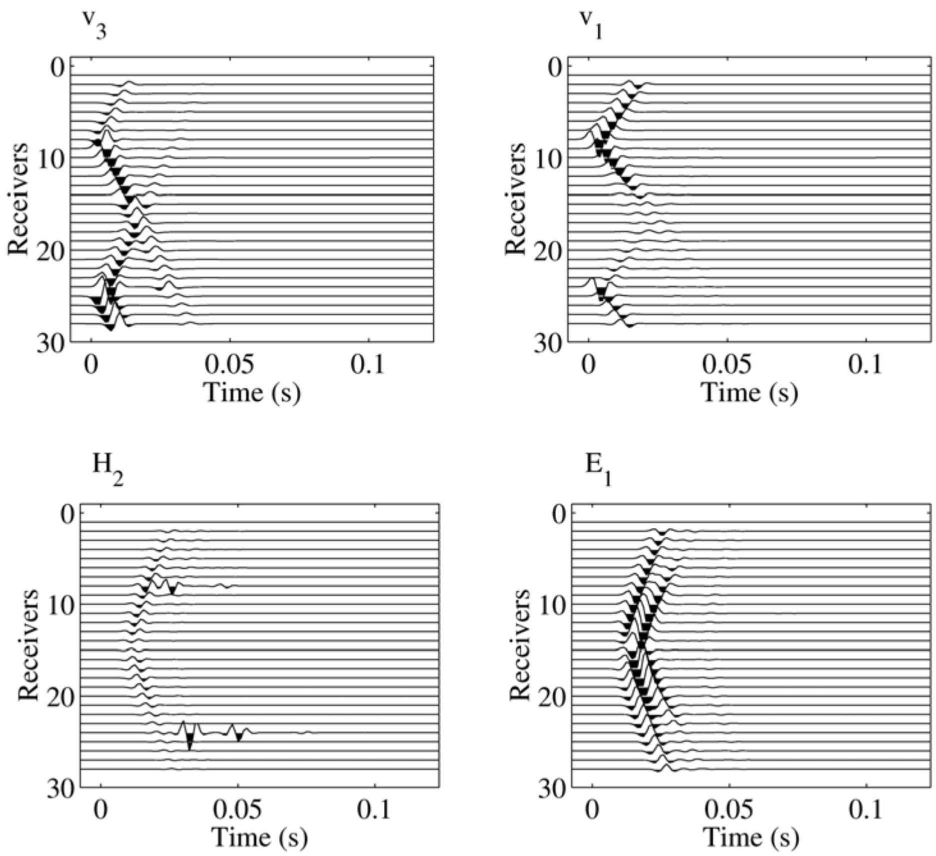

Figure 3: *Line source response for the two-way wellbore to wellbore simulation in the (x1,x3,t) domain.*

References

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