Controlled illumination by double focussing in the source domain

A.J. Berkhout [1]
Jan Thorbecke [2]

The CFP-method computes a virtual source in the subsurface by simulating a focal source array at the surface. The response of such a virtual source represents the CFP-gather. It is proposed to construct a distribution of virtual sources along a vertically oriented trajectory. By simulating a second focal array along this trajectory of virtual sources, a 'pencil beam' is created that illuminates the subsurface in a user-controlled way. The subsurface response of this double focal source array (DFS-array) equals a weighted sum of CFP-gathers.

14.1 Introduction

In the past (Berkhout, 1997; Thorbecke, 1997) it was shown that virtual sources can be simulated in the subsurface by simulating a focal source array at the surface. Figure 14.1 shows the principle.

Using the $\mathbf{WRW}$-model, we may write for the focal source array along the surface:

$$\mathbf{S}_j(z_0, z_m) = \mathbf{S}(z_0)\mathbf{F}_j(z_0, z_m) \tag{14.1a}$$

with

$$\mathbf{W}(z_m, z_0)\mathbf{S}(z_0)\mathbf{F}_j(z_0, z_m) = \mathbf{I}_j(z_m), \tag{14.1b}$$

[1] E-mail: A.J.Berkhout@tudelft.nl
[2] E-mail: J.W.Thorbecke@tudelft.nl

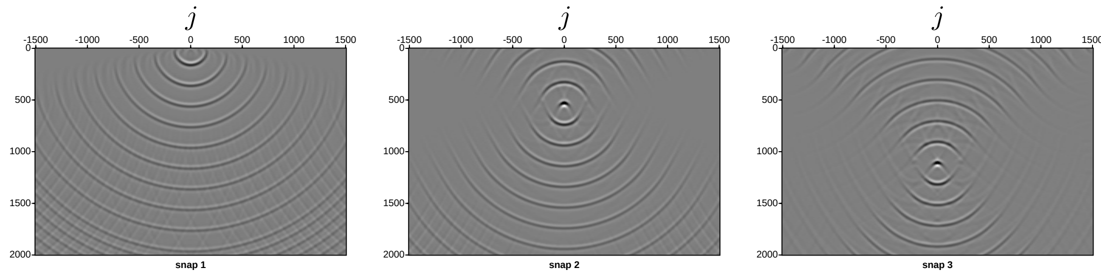

Fig. 14.1 *Generation of virtual sources in the subsurface by simulating focal source arrays at the surface.*

$\mathbf{F}_j(z_0, z_m)$ representing the focal operator for a virtual source at $(\boldsymbol{x}_j, z_m)$ and $\mathbf{I}_j(z_m)$ being the j'th column of unit matrix $\mathbf{I}(z_m)$. The response of this focal source array is given by the CFP-gather

$$\mathbf{P}_j(z_0, z_m) = \mathbf{P}(z_0, z_0)\mathbf{F}_j(z_0, z_m), \qquad (14.2)$$

$\mathbf{P}(z_0, z_0)$ representing the data matrix.

If m ranges from m_1 to m_2, a distribution of virtual sources is generated along the vertical trajectory at surface position j:

$$\mathbf{S}_j(z_m, z_m) = \mathbf{W}(z_m, z_0)\mathbf{S}(z_0)\mathbf{F}_j(z_0, z_m) \quad \text{for } m = m_1, m_1 + 1, \ldots m_2. \qquad (14.3a)$$

Figure 14.2 displays the delayed source signatures at the focal points for a homogeneous medium:

$$\mathbf{S}'_j(z_m, z_m) = \mathbf{S}_j(z_m, z_m)e^{-j\omega\tau_m} \quad \text{for } m = 1, 2, \ldots 24 \qquad (14.3b)$$

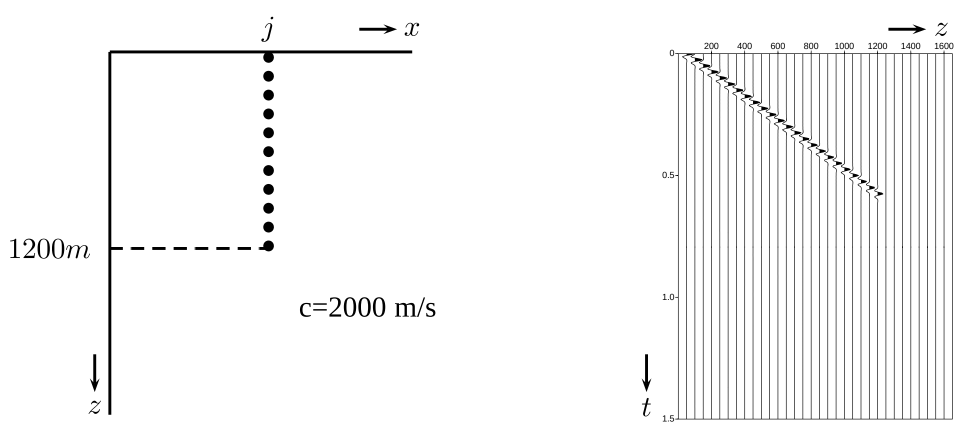

Fig. 14.2 *Distribution of virtual sources (left) with source signatures (right). The virtual sources are constructed by applying a focusing process to the sources at the surface, see equations (14.3a,b).*

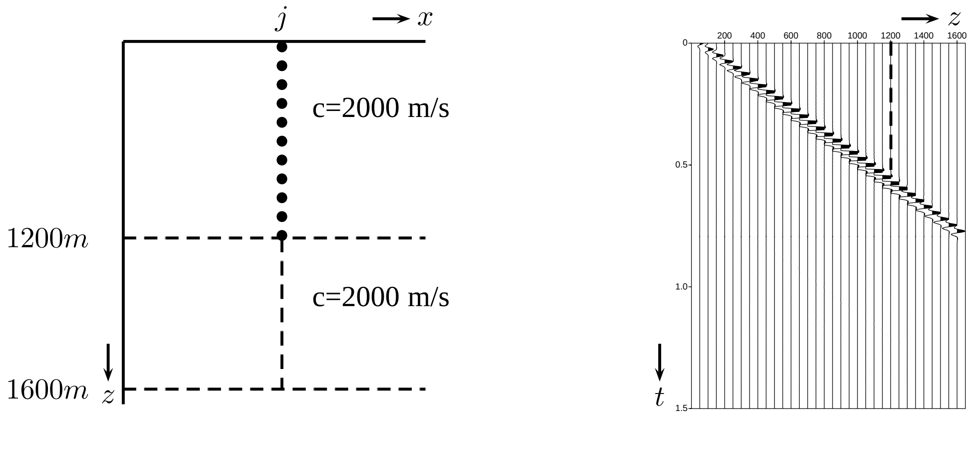

Fig. 14.3 *Source signatures of a vertical array upto 1200 m ($m = 1, 2, \ldots 24$), displayed along the vertical upto 1600 m.*

with $\Delta z = 50$ m. In equation (14.3b) τ_m is the traveltime along the trajectory between the depth levels z_0 and z_m. Note that τ_m can be found in focusing operator $\mathbf{F}$.

Let us introduce a second focusing step by simulating a focal source array along the vertical trajectory (z_{m_1}, z_{m_2}):

$$\mathbf{S}_j(z_{m_2}, z_{m_1}) = \sum_{m_1}^{m_2} \mathbf{S}_j(z_m, z_m) \tag{14.4a}$$

or for display purposes:

$$\mathbf{S}'_j(z_{m_2}, z_{m_1}) = \sum_{m_1}^{m_2} \mathbf{S}_j(z_m, z_m) e^{-j\omega\tau_{m_2}}. \tag{14.4b}$$

Equation (14.4b) simulates a source wavefield that is each time enhanced when it reaches the next source position in the vertical array. This is illustrated in Figure 14.3 for a homogeneous medium ($m = 1, \ldots, 24$). In terms of Figure 14.2, it means that the signatures in the $z - t$ plane are added in phase and positioned at the vertical traveltime. In Figure 14.4 the beam properties of this double-focussing array are shown. Note the increasing amplitude with depth.

Figure 14.5 shows the illumination properties of the DFS-array ($m_1 = 1, m_2 = 24$). Note the high amplitude at the centre of the source beam.

Figure 14.6a shows a simple example of a two reflector model. Note the effect of the velocity change at 800 m.

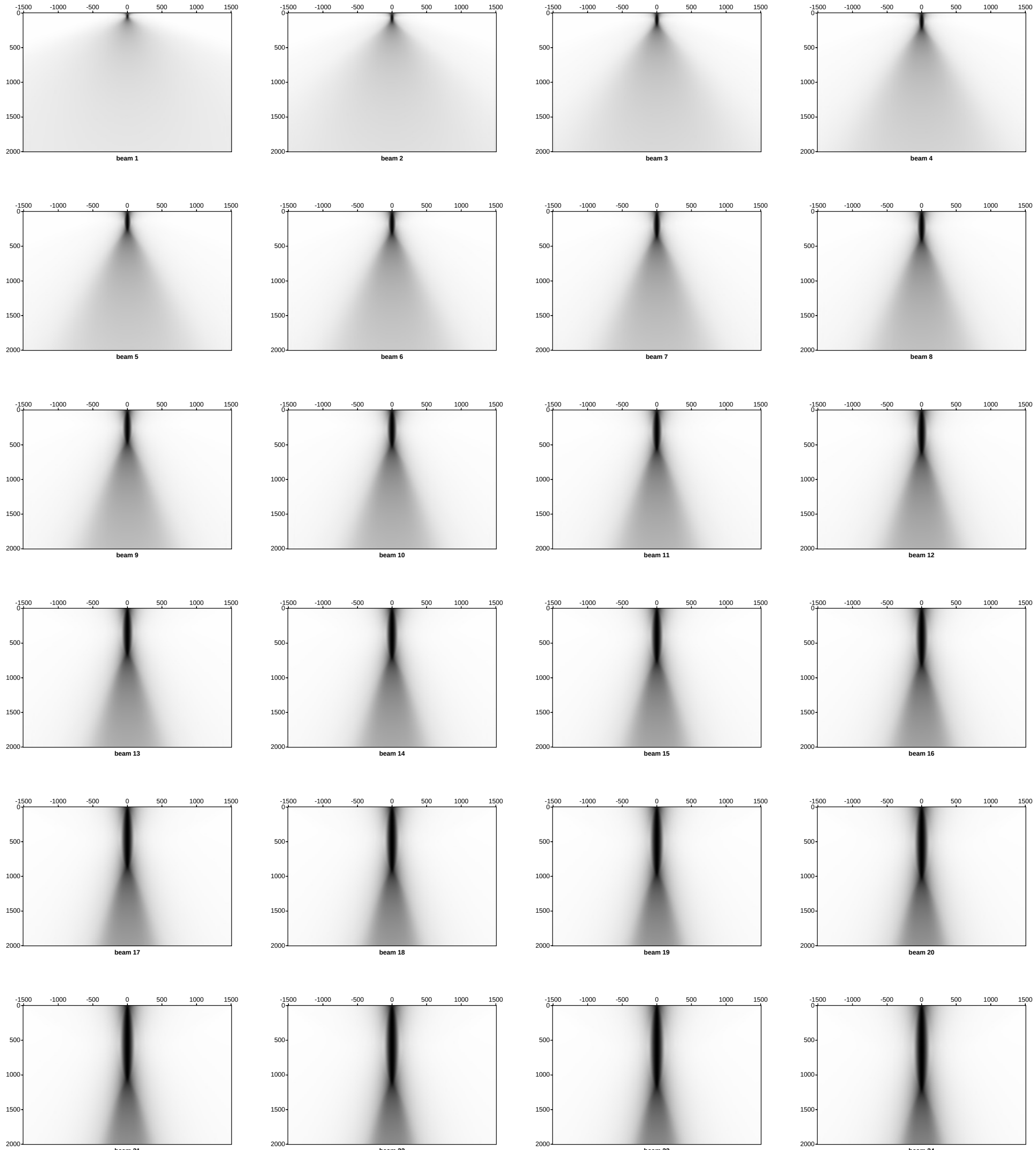

Fig. 14.4 *Illumination by double focussing (horizontal array of physical sources, vertical array of virtual sources). The vertical array consists of 24 virtual source points with a distance of 50m [50-1200] m. Starting from $z = 0$ every 50 m the wavefield of a virtual source is added in phase to the total wavefield. Note that the beams are displayed with different maximum values for each picture.*

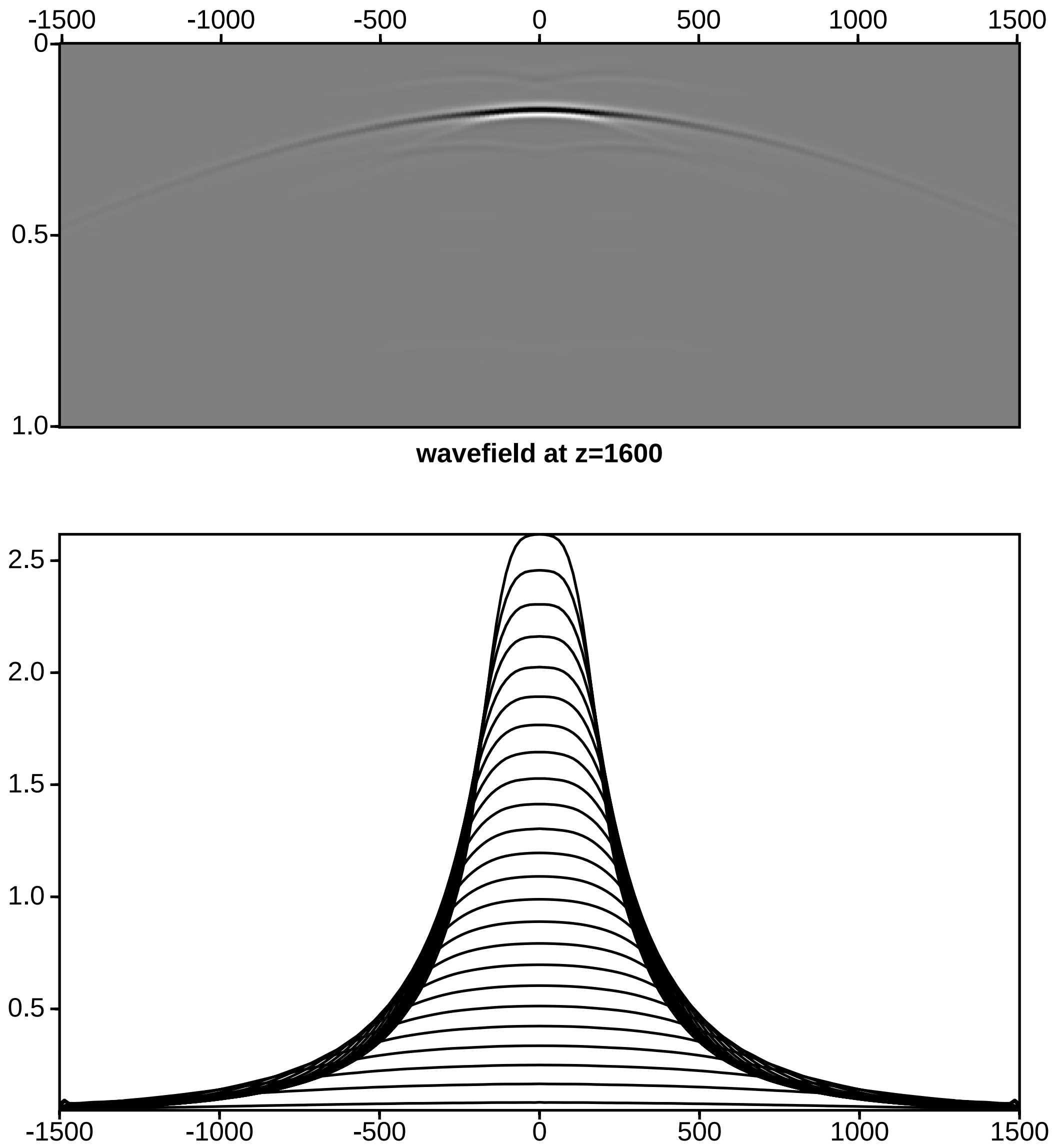

Fig. 14.5 *Source wavefield, obtained by double focussing ($m_1 = 1, m_2 = 24$), measured at depth level $z = 1600$ m (upper part). Amplitude cross-section through the beams of Figure 14.4, measured at depth level $z = 1600$ m (lower part).*

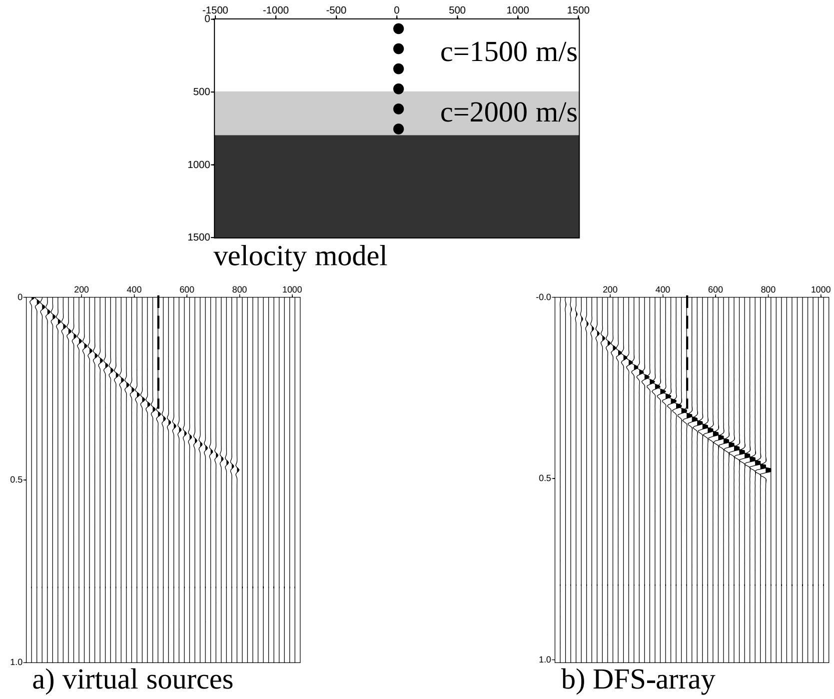

Fig. 14.6 *Source signatures in a two reflector model with the first reflector at 500 m and the second at 800 m depth. The vertical DFS-array consists of 80 virtual source points with a vertical distance of 10 m [0-800] m.*

14.2 Conclusion

By introducing double focussing in the source domain, horizontally as well as vertically, the illumination can be controlled in a user-oriented fashion.

The use of DFS-arrays may open a new way of looking at the migration process of sparse data in complex subsurfaces (both P and S). It may also offer a new opportunity to better utilize multipath illumination.

14.3 References

Berkhout, A. J., 1997, Pushing the limits of seismic imaging, part I: Prestack migration in terms of double dynamic focusing: Geophysics, **62**, 937–953.

Thorbecke, J. W., 1997, Common focus point technology: Ph.D. thesis, Delft University of Technology.