Marchenko redatuming: A novel approach to scaling factor estimation

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Marchenko redatuming is a method by which the Green's functions inside of a medium are calculated iteratively, using the surface reflection response (R) and an estimate of the direct wave from the surface to the desired location. Both the medium and the recorded data have to fulfill certain requirements at this point. One of them is that the direct wave has to be removed from the surface reflection response R, and the remaining reflection data deconvolved with the source wavelet. The data then has to be normalized by the surface source strength. In case the absolute value of the surface source strength is unknown, the deconvolved reflection data can be corrected by multiplication with a scalar scaling factor *b*.
To find a suitable scaling factor, a data driven scheme has been proposed where the L_2 norm of the redatumed upgoing Green's function is minimized with respect to its first estimate. This works if there are no strong reflectors below the redatuming point. We propose an alternative approach which makes use of the partial temporal antisymmetry of wavefields used to iteratively calculate the total Green's function at the redatuming point.

Approach proposed by Brackenhoff (2016) and van der Neut et al. (2015)

Brackenhoff (2016) and van der Neut et al. (2015) propose to minimize the ratio of the sum of the amplitudes squared of the redatumed upgoing Green's function after *k* iterations over that of its first estimate. The wavefields are calculated using *b***R** for varying values of *b*:

$$j_I(b) = \frac{\sum_x \sum_t \mathbf{G_k^-}^2(\mathbf{x}, t, b)}{\sum_x \sum_t \mathbf{G_0^-}^2(\mathbf{x}, t, b)}$$

We use a 1D subsurface model developed by Brackenhoff (2016), which was designed such that their scheme diverges at z = 2200 m. We build a layered 2D model from their density model and constant velocity model (v_P = 2500 m/s). To mitigate effects caused by the finite model geometry, we make our model 12 km wide and use data from the central part (Fig.1).

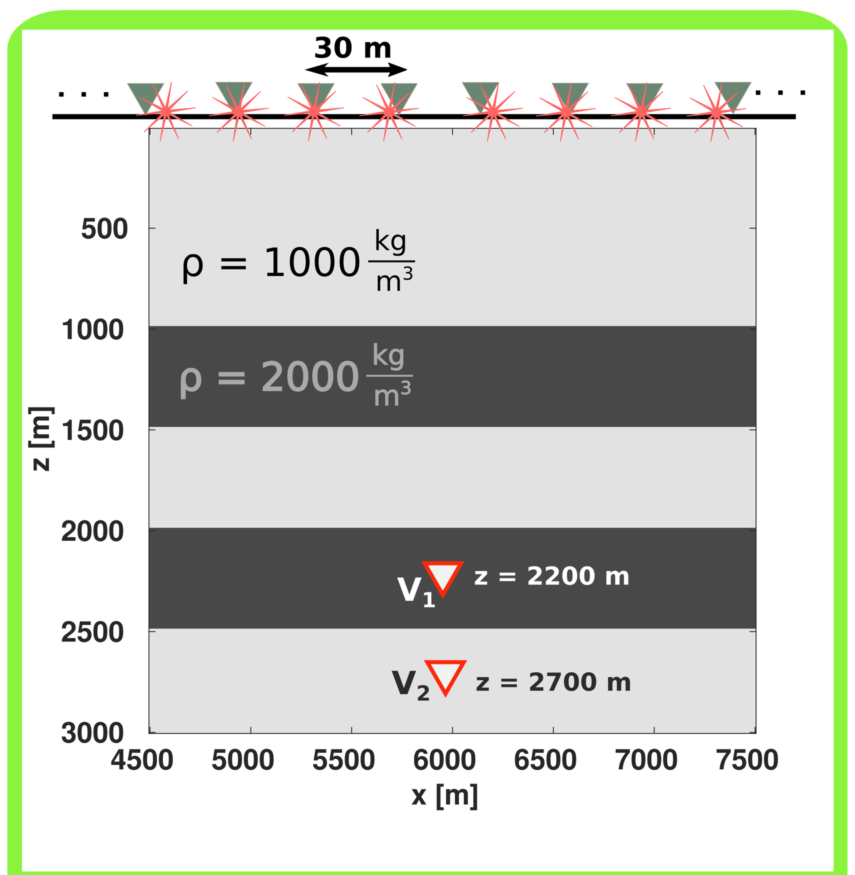

Figure 1: 2D density model. *Green triangles* - physical receivers, *red stars* - physical sources, *red and white triangles* - virtual receivers V_1 and V_2.

Broggini et al. (2014) present a set of equations linking the Green's function observed at an arbitrary virtual receiver location x_{VR} inside of a medium to the reflection response recorded at the top of the medium. They show that the sum of the Green's function at x_{VR} and its time reverse can be written as a sum of auxiliary wavefields: G(x,t) + G(x,-t) = p(x,t) + p(x,-t).

$$p_k(\mathbf{x}, t) = p_k^+(\mathbf{x}, t) + p_k^-(\mathbf{x}, t)$$

p(x,t) is decomposed into an upgoing (-) and a downgoing (+) part, which are calculated iteratively.

$$p_k^+(\mathbf{x}, t) = p_0^+(\mathbf{x}, t) - w(\mathbf{x}, t) p_{k-1}^-(\mathbf{x}, -t)$$

$$p_k^-(\mathbf{x}_R, t) = \int_{-\infty}^{\infty} \left[R(\mathbf{x}_R, \mathbf{x}, t) * p_k^+(\mathbf{x}, t) \right]_{z=0} \mathrm{d}x$$

$$w(x,t) = \begin{cases} 1 & t < |t_d| \\ 0 & t \geq |t_d| \end{cases}$$

p(x,t) is symmetric in time for $t \geq |t_d|$ and antisymmetric for $t < |t_d|$.

t_d is the arrival time of the direct wave from the surface to x_{VR}, plus a small time shift to accommodate the wavelet.

p_0^+ is an estimate of the direct wave from the surface to the desired virtual receiver position x_{VR}.

As the scheme converges, the fit of p(x,t) and p(x,-t) in the time window defined by w(x,t) increases such that

$$E_k = \sum_x \sum_t w(\mathbf{x}, t) \left(p_k(\mathbf{x}, t) + p_k(\mathbf{x}, -t) \right)^2 \longrightarrow 0$$

We use this property to find a scaling factor *b* which minimizes the ratio of E_k over its initial value:

$$j(b) = \frac{E_k(b)}{E_1(b)}$$

We use a golden section search (Press et al., 2007) to bracket the minimum of this function.

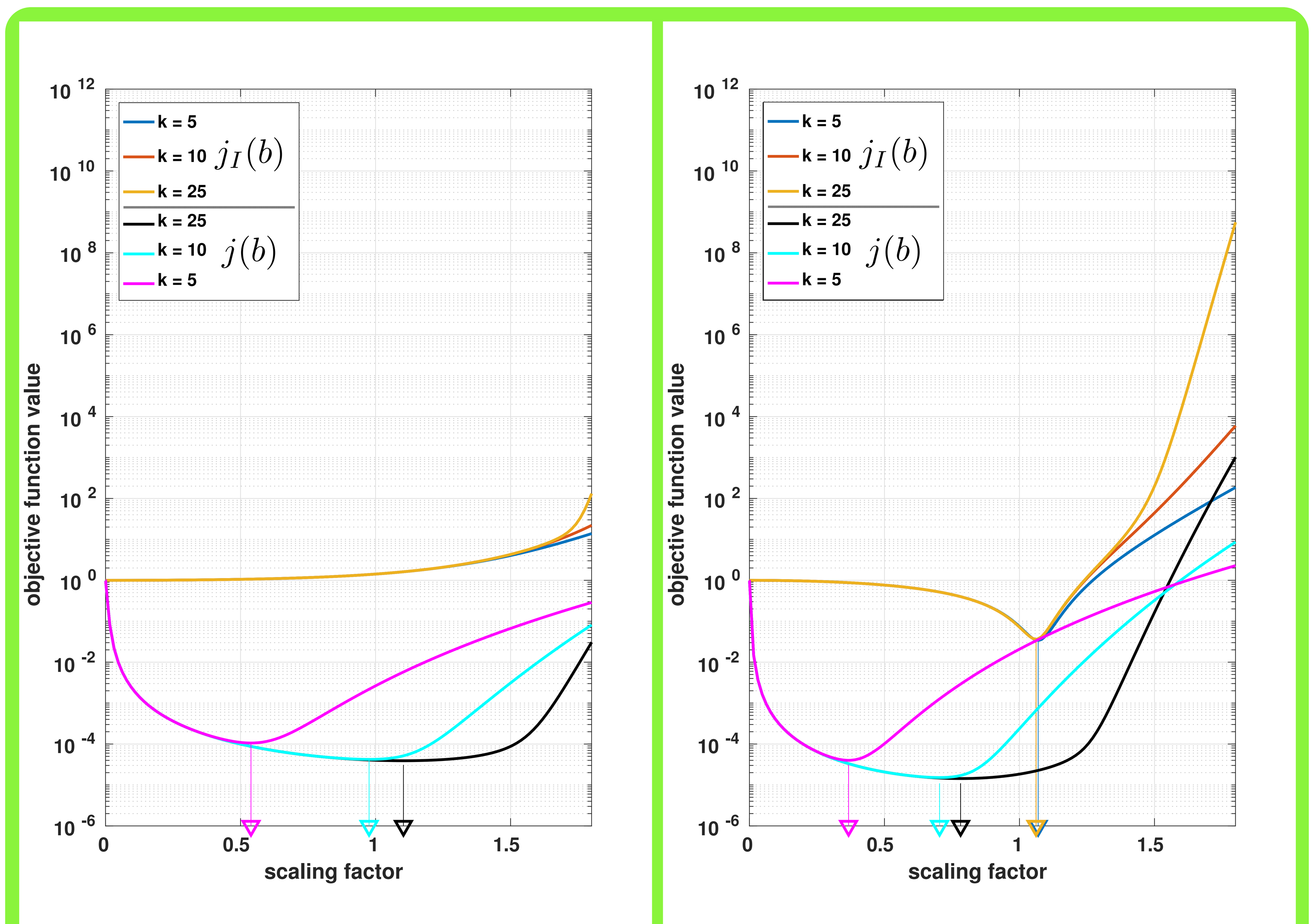

Figure 2: Trend of the two objective functions and optimum values found after a given number of iterations *k*. *Left*: V_1, *right*: V_2

We find that our method converges to a value close to the true scaling factor *b* at the upper virtual receiver position. At the lower virtual receiver position (z = 2700 m) the scheme converges at a value which is too low (Fig.2). The minimum of our scheme seems to depend on the number of iterations used, as does the minimum of the other scheme in more complex models.

These results seem to indicate that our scheme performs less well if no strong reflectors are present below the redatuming point. However, it also appears to be more robust if there are reflections from below which cause the other method to fail. This is a scenario which can easily present itself in practical applications. Further investigation will determine to what extent our scheme can be beneficial in such situations.

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