The Marchenko method and its application to time-lapse monitoring

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Introduction. Interbed multiples are more sensitive to time-lapse velocity changes than primaries. Therefore, they are, at least in theory, of great value for time-lapse monitoring. However, interbed multiples have relatively low amplitudes, are difficult to identify, and are often hidden behind primaries with higher amplitudes. This paper consists of two parts. In the first part we give a comprehensive overview of various versions of the Marchenko method. In the second part we discuss how a specific version of the Marchenko method can be used to recover interbed multiples from behind the stronger primaries and use them for monitoring subtle time-lapse changes in a target zone.

Overview of Marchenko methods. The key principle of the Marchenko method is that focusing functions, which properly account for interbed multiples, can be retrieved from reflection data at the surface and a smooth subsurface model. Once these focusing functions are known, Green's functions between the acquisition surface and a depth level in the subsurface can be obtained. These Green's functions can be used for redatuming by multidimensional deconvolution (MDD), followed by imaging. Alternatively, redatuming and imaging can be achieved by double focusing, i.e., by applying a second focusing function to the retrieved Green's functions. Whereas the MDD process removes all interbed multiples of the overburden, double focusing leaves some multiples untouched but it is a more stable process.

Instead of redatuming and imaging, the Marchenko method can also be used for multiple elimination, while keeping the sources and receivers at the surface. An advantage of this approach is that no subsurface model is needed. For a comprehensive overview of the different versions of the Marchenko method, see Wapenaar et al. (2021). For applications in large-scale 3D imaging problems, see Ravasi and Vasconcelos (2021).

Application of the Marchenko method in time-lapse monitoring. To apply the Marchenko method for time-lapse monitoring, we subdivide the subsurface in three regions: a target zone in which the time-lapse changes take place, an overburden and an underburden (van IJsseldijk and Wapenaar, 2021). We define two horizontal depth levels which separate these three regions; these depth levels do not need to coincide with interfaces.

Step 1: Using the Marchenko method, we retrieve Green's functions between the acquisition surface and the depth level above the target zone. Using MDD, we obtain the response of the target zone and the underburden, which can be extrapolated to the surface using the direct arrival of the Green's functions.

Step 2: Using the Marchenko method, we retrieve focusing functions between the acquisition surface and the depth level below the target zone. Using MDD, we are left with the response of the target zone only.

This two-step approach removes the responses of the overburden and underburden from the reflection data at the surface. This significantly improves the interpretability of the response of the target zone, including its interbed multiples. By applying this approach to baseline and monitor data, we obtain two isolated responses of the target zone, of which the primaries and interbed multiples can be used to infer the time-lapse changes in the target zone. This is illustrated with modelled time-lapse data in Figure 1.

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References

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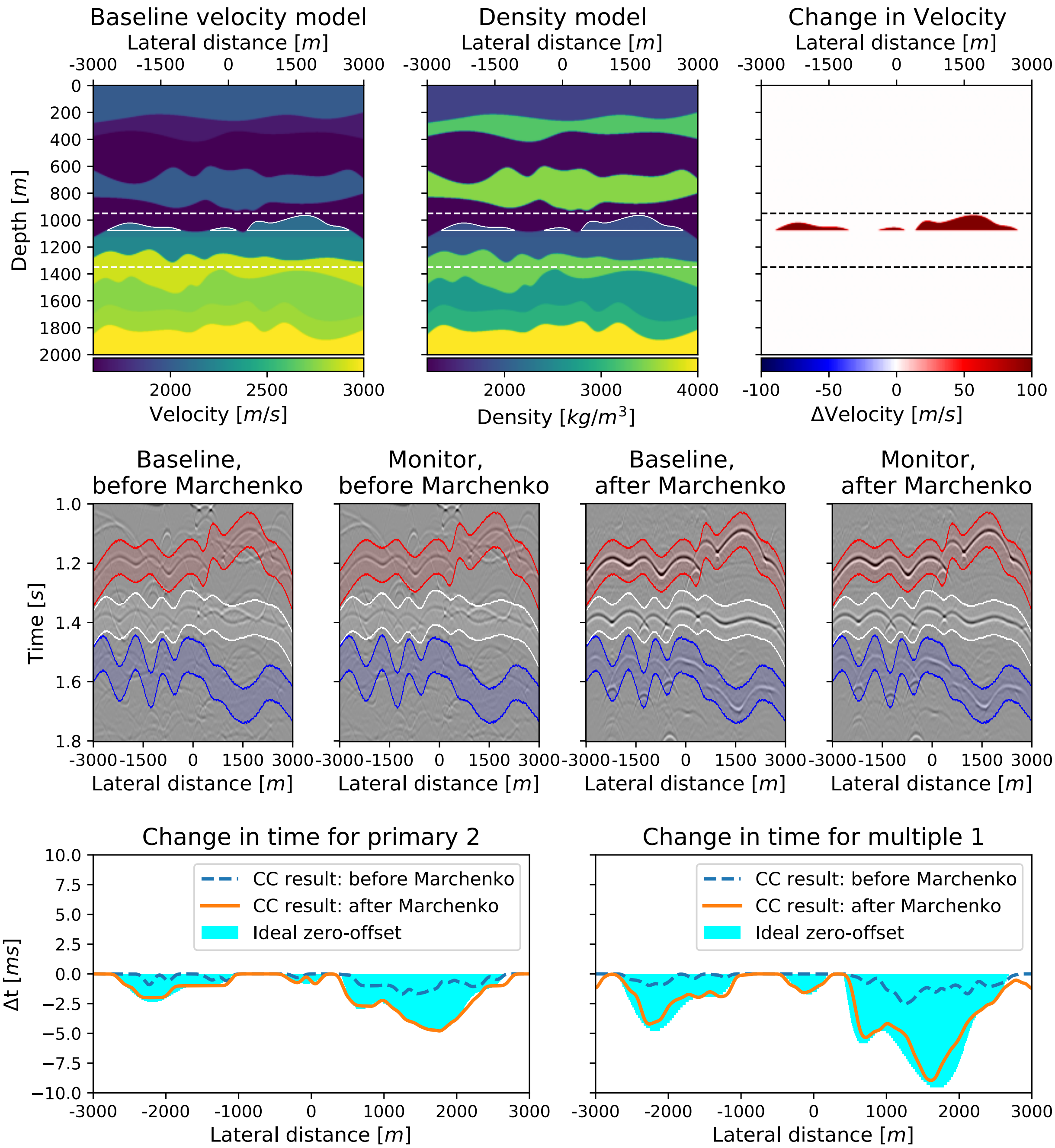

Figure 1. Example of time-lapse monitoring with the Marchenko method.
First row: baseline velocity and density models, and the time-lapse velocity change.
Second row: zero-offset responses of the target zone for the baseline and monitor state, before and after removal of the overburden and underburden response with the Marchenko method. Red and white windows: primaries from top and bottom of target layer. Blue window: multiple between top and bottom of target layer. Note that the responses after applying the Marchenko method are much cleaner.
Third row: time-lapse traveltime shifts obtained by cross-correlating the primaries in the white windows (left) and the multiples in the blue windows (right), before (blue dashed) and after (orange solid) removal of the overburden and underburden response with the Marchenko method. The light-blue area marks the correct time difference. The retrieved traveltime shifts after applying the Marchenko method are the most accurate. The traveltime shift obtained from the multiples is the most sensitive to the velocity change.