SUMMARY

[0015] According to an embodiment, there is a method for multiple attenuation in seismic data associated with a subsurface. The method includes receiving seismic data *D* for a plurality of shots and a plurality of receivers, where the seismic data *D* include multiples *M* associated with a free surface, where the seismic data *D* is in a space-time domain, obtaining a multiple generator, which is located within the subsurface and is responsible for generating the multiples *M*, calculating a source-side multiple model M_S based on the seismic data *D* and the multiple generator, estimating an image *r* of the multiple generator based on a multiple periodicity method applied to the seismic data *D*, calculating a receiver-side multiple model M_R by applying wavefield propagation to the seismic data *D* and the image *r*, generating demultiple data *DD* by subtracting from the seismic data *D* the source-side multiple model M_S and the receiver-side multiple model M_R, and generating a final image of a geological formation in the subsurface based on the demultiple data *DD*, wherein pure-source side multiples are attenuated from the seismic data to generate pure-source side attenuated multiples data, and the pure-source side attenuated multiples data is used in the multiple periodicity method.

[0016] According to another embodiment, there is a computing system for multiple attenuation in seismic data associated with a subsurface. The computing system includes an interface configured to receive seismic data *D* for a plurality of shots and a plurality of receivers, wherein the seismic data *D* include multiples *M* associated with a free surface, wherein the seismic data D is in a space-time domain, and a processor connected to the interface. The processor is configured to obtain a multiple generator, which is located within the subsurface and is responsible for generating the multiples *M*, calculate a source-side multiple model M_S based on

the seismic data D and the multiple generator, estimate an image r of the multiple generator based on a multiple periodicity method applied to the seismic data D, calculate a receiver-side multiple model M_R by applying wavefield propagation to the

seismic data *D* and the image *r*, generate demultiple data *DD* by subtracting from the seismic data *D* the source-side multiple model M_S and the receiver-side multiple model M_R, and generate a final image of a geological formation in the subsurface based on the demultiple data *DD*, wherein pure-source side multiples are attenuated from the seismic data to generate pure-source side attenuated multiples data, and the pure-source side attenuated multiples data is used in the multiple periodicity method.

[0017] According to yet another embodiment, there is a non-transitory computer readable medium including computer executable instructions, wherein the instructions, when executed by a processor, implement the method discussed above.

WHAT IS CLAIMED IS:

1. A method for multiple attenuation in seismic data associated with a subsurface, the method comprising:

receiving seismic data *D* for a plurality of shots and a plurality of receivers, wherein the seismic data *D* include multiples *M* associated with a free surface, wherein the seismic data *D* is in a space-time domain;

obtaining a multiple generator, which is located within the subsurface and is responsible for generating the multiples *M*;

calculating a source-side multiple model M_S based on the seismic data *D* and the multiple generator;

estimating an image *r* of the multiple generator based on a multiple periodicity method applied to the seismic data *D*;

calculating a receiver-side multiple model M_R by applying wavefield propagation to the seismic data *D* and the image *r*;

generating demultiple data *DD* by subtracting from the seismic data *D* the source-side multiple model M_S and the receiver-side multiple model M_R; and

generating a final image of a geological formation in the subsurface based on the demultiple data *DD,*

wherein pure-source side multiples are attenuated from the seismic data to generate pure-source side attenuated multiples data, and the pure-source side attenuated multiples data is used in the multiple periodicity method.

2. The method of Claim 1, wherein the source-side multiple model M_S is calculated in a receiver-domain.

3. The method of Claim 1, wherein the source-side multiple model M_S is based on estimating a Green's function of a multiple generator based on knowledge of a multiple generator depth, a velocity of sound in the subsurface, and source and receiver positions.

4. The method of any one of the preceding claims, wherein the receiver-side multiple model M_R is calculated in a shot-domain.

5. The method of any one of claims 1 to 3, wherein the receiver-side multiple model M_R includes multiples reflected from a plurality of multiple generators.

6. The method of any one of the preceding claims, wherein the step of calculating the image *r* further comprises:

applying a correlation or deconvolution between a forward-propagated and a reverse-propagated wavefield.

7. The method of any one of claim 1 to 5, wherein the step of calculating the image *r* further comprises:

applying a least squares migration.

8. The method of Claim 7, wherein the least squares migration involves a sparse inversion.

9. A computing system for multiple attenuation in seismic data associated with a subsurface, the computing system comprising:

an interface configured to receive seismic data *D* for a plurality of shots and a plurality of receivers, wherein the seismic data *D* include multiples *M* associated with a free surface, wherein the seismic data D is in a space-time domain; and

a processor connected to the interface and configured to,

obtain a multiple generator, which is located within the subsurface and is responsible for generating the multiples *M*;

calculate a source-side multiple model M_S based on the seismic data *D* and the multiple generator;

estimate an image *r* of the multiple generator based on a multiple periodicity method applied to the seismic data *D*;

calculate a receiver-side multiple model M_R by applying wavefield propagation to the seismic data *D* and the image *r*;

generate demultiple data *DD* by subtracting from the seismic data *D* the source-side multiple model M_S and the receiver-side multiple model M_R; and

generate a final image of a geological formation in the subsurface based on the demultiple data *DD,*

wherein pure-source side multiples are attenuated from the seismic data to generate pure-source side attenuated multiples data, and the pure-source side attenuated multiples data is used in the multiple periodicity method.

10. The system of Claim 9, wherein the source-side multiple model M_S is calculated in a receiver-domain.

11. The system of Claim 9, wherein the source-side multiple model M_S is based on estimating a Green's function of a multiple generator based on knowledge of a multiple generator depth, a velocity of sound in the subsurface, and source and receiver positions.

12. The system of any one of claims 9 to 11, wherein the receiver-side multiple model M_R is calculated in a shot-domain.

13. The system of any one of claims 9 to 11, wherein the receiver-side multiple model M_R includes multiples reflected from a plurality of multiple generators.

14. The system of any one of claims 9 to 13, wherein the processor is further configured to calculate the image *r* by applying a correlation or deconvolution between a forward-propagated and a reverse-propagated wavefield.

15. The system of any one of claims 9 to 13, wherein the processor is further configured to calculate the image *r* by applying a least squares migration.

16. The system of Claim 15, wherein the least squares migration involves a sparse inversion.

17. A non-transitory computer readable medium including computer executable instructions, wherein the instructions, when executed by a processor, implement a method for multiple attenuation in seismic data associated with a subsurface, the medium comprising instructions for:

receiving seismic data *D* for a plurality of shots and a plurality of receivers, wherein the seismic data *D* include multiples *M* associated with a free surface, wherein the seismic data D is in a space-time domain;

obtaining a multiple generator, which is located within the subsurface and is responsible for generating the multiples *M*;

calculating a source-side multiple model M_S based on the seismic data *D* and the multiple generator;

estimating an image *r* of the multiple generator based on a multiple periodicity method applied to the seismic data *D*;

calculating a receiver-side multiple model M_R by applying wavefield propagation to the seismic data *D* and the image *r*;

generating demultiple data *DD* by subtracting from the seismic data *D* the source-side multiple model M_S and the receiver-side multiple model M_R; and

generating a final image of a geological formation in the subsurface based on the demultiple data *DD,*

wherein pure-source side multiples are attenuated from the seismic data to generate pure-source side attenuated multiples data, and the pure-source side attenuated multiples data is used in the multiple periodicity method.

18. The medium of Claim 17, wherein the source-side multiple model M_S is calculated in a receiver-domain and the receiver-side multiple model M_R is calculated in a shot-domain.