model		
Use of a large time step in a time domain simulator	Discretization errors	Vary the time step interval

The above list is not exhaustive. The list includes examples only of approximations that reduce computation time. Sometimes it is advantageous to trade inaccuracy in one area to gain more accuracy in another. An example of such an accuracy tradeoff type of approximation is to use less accurate absorbing boundary conditions in the forward modeling in order to make the gradient computations more accurate. Absorbing boundary conditions are needed to solve the differential equation(s) governing the wave propagation, e.g. the anisotropic visco-elastic wave propagation equation (or some approximation thereof) in the case of seismic data, or Maxwell's equations in the case of electromagnetic data. In general, an accuracy tradeoff involves sacrificing accuracy in one aspect of the method in return for increased accuracy in another aspect.

Test Example 1 – Encoded Objective Function

[0040] Figures 2-5 represent a synthetic example of performing inversion using an approximation to the objective function in which the seismic sources in the measured data are encoded then summed; see U.S. Application Publication No. 2010-0018718 by Jerome Krebs et al. This approximation speeds up the inversion, because the encoded objective function can be evaluated using one run of the simulation software rather than running it once for each source as is the case for conventional inversion. Figure 2 is a self-explanatory flow chart that focuses Fig. 1 on this particular embodiment, with step **210** showing the encoding approximation.

[0041] The geophysical properties model in this example is just a model of the acoustic wave velocity. Figure 3 shows the base velocity model, i.e., the "unknown" model that will be inverted for and which was used to generate the data to be inverted~~).~~ for this example. The shading indicates the velocity at each depth and lateral location, as indicated by the "color" bar to the right. Figure 4 shows the inversion resulting from application of this invention as summarized by the flow chart in Fig. 2. In this example the sources are encoded

[0049] The geophysical properties model in this example is just a model of the acoustic wave velocity. Figure 11 is the base velocity model (the model that will be inverted for and which was used to generate the data to be inverted) for this example. The shading indicates the velocity at each depth. Figure 12 is the inversion resulting from application of this invention as summarized by the flow chart in Fig. 10. In this example, in step **1060**, a subset of the measured data is randomly selected as inversion iteration increases. This results in a different subset of the data being used in each iteration cycle. Figure 12 shows a good match to the base model shown in Fig. 11 using ten percent of the measured data.

[0050] Figure 13 shows the results of applying the inversion method outlined in the flowchart in Fig. 6, but eliminating the inventive, artifact-reducing step **1060**. It may be noted that the inversion in Fig. 13 has artificial footprints at deeper parts below 2000 meters and short wavelength noises in the overall inverted model, whereas ~~this~~these footprint noises are mitigated in the inversion using the ~~presnt~~present inventive method (Fig. 12), and the short wavelength noises are invisible.

[0051] It should be understood that the flow charts of Figs. 2, 6 and 10 represent examples of specific embodiments of the invention that is described more generally in Fig. 1.

[0052] The foregoing patent application is directed to particular embodiments of the present invention for the purpose of illustrating it. It will be apparent, however, to one skilled in the art, that many modifications and variations to the embodiments described herein are possible. All such modifications and variations are intended to be within the scope of the present invention, as defined in the appended claims. Persons skilled in the art will readily recognize that in practical applications of the invention, at least some of the steps in the present inventive method (typically steps **140-160**, and often generating the model in **120**) are performed on a computer, i.e. the invention is computer implemented. In such cases, the resulting updated physical properties model of the subsurface may either be downloaded or saved to computer storage.

References

1. Tarantola, A., "Inversion of seismic reflection data in the acoustic approximation," *Geophysics* **49**, 1259-1266 (1984).

CLAIMS

1. A method for reducing artifacts in a subsurface physical property model caused by an approximation, other than source encoding, in an iterative, computerized geophysical data inversion process, said method comprising varying the approximation as the iterations progress.

2. The method of claim 1, wherein said method comprises:

(a) assuming a physical properties model of a subsurface region, said model providing values of at least one physical property at locations throughout the subsurface region;

(b) selecting an iterative data inversion process having a step wherein a calculation is made of an update to the physical properties model that makes it more consistent with measured geophysical data acquired from the subsurface region;

(c) making in said calculation an approximation that either speeds up the selected iterative inversion process other than by source encoding, or that works an accuracy tradeoff;

(d) executing, using a computer, one cycle of the selected iterative inversion process with said approximation and using the physical properties model;

(e) executing, using the computer, a next iterative inversion cycle, wherein a selection is made to either change some aspect of the approximation or not to change it;

(f) repeating (e) as necessary, changing the approximation in some or all of the iteration cycles, until a final iteration wherein a selected convergence criterion is met or another stopping condition is reached; and

(g) downloading the updated physical properties model from the final iteration or saving it to computer storage.

3. The method of claim 2, wherein one or more artifact types are identified in an updated subsurface physical property model as being caused by the approximation.

4. The method of claim 3, wherein the aspect of the approximation that is changed in some or all iteration cycles is selected for having an effect on artifacts of the one or more identified artifact types.

5. The method of claim 4, wherein said effect is such that artifacts from one approximation do not add constructively with artifacts from another iteration cycle that uses an approximation with a changed aspect.

6. The method of claim 2, wherein the approximation is to select a subset of the measured geophysical data for inputting to the iterative inversion process, and the changed aspect is a different selected subset.

7. The method of claim 6, wherein each different subset is selected randomly.

8. The method of claim 1, wherein the approximation is imperfect absorbing boundaries in simulation of synthetic data in the iterative inversion process.

9. The method of claim 1, wherein the approximation is reflecting boundaries in simulation of synthetic data in the iterative inversion process.

10. The method of claim 1, wherein the approximation is random boundary conditions in simulation of synthetic data in the iterative inversion process.

11. The method of claim 1, wherein the approximation is spatial variation of grid cell size in a finite difference simulator in the iterative inversion process.

12. The method of claim 1, wherein the approximation is spatial variation in a simulation operator's accuracy in the iterative inversion process.

13. The method of claim 1, wherein the approximation is use of a grid cell size in simulation of synthetic data in the iterative inversion process, wherein the grid cell size is too coarse to accurately represent variations in the model.

14. The method of claim 1, wherein the approximation is use of a large time step in a time domain simulator in the iterative inversion process, where "large" is determined relative to other time steps used.

15. The method of claim 1, wherein the iterative, computerized, geophysical data inversion process includes computing gradients of a cost function, and the approximation involves using less accurate absorbing boundary conditions in order to make the gradient computations more accurate.

CLAIMS

1. A method for reducing artifacts in an inverted subsurface physical property model caused by an approximation, other than source encoding, in an iterative geophysical data inversion process, wherein the model is updated at the end of each iteration cycle, said method comprising:

identifying an approximation, other than the source encoding, made in the course of:

(i) processing or selecting measured data to invert, or

(ii) parameterization of the model, or

(iii) simulation of synthetic data to compare to measured data; and

reducing the artifact by varying the approximation in consecutive iteration cycles such as to cause the artifact in the updates to add incoherently in leading to a final model as the inversion progresses from one iteration to a next wherein the inversion is performed using a computer.

2. The method of claim 1, wherein the iterative data inversion process comprises:

(a) selecting measured data to invert;

(b) processing the selected data as needed;

(c) selecting a physical properties model of a subsurface region, said model providing values of at least one physical property at locations throughout the subsurface region;

(d) selecting a computational grid, and using it and the selected physical properties model to generate synthetic data corresponding to the selected data from (b);

(e) comparing the synthetic data to the measured data from (b) and generating an update to the physical properties model that makes it more consistent with the measured; and

(f) repeating (a)-(e), selecting the updated model from the previous iteration as the selected model in (c) until a final iteration wherein a selected convergence criterion is met or another stopping condition is reached.

3. The method of claim 2, wherein one or more artifact types are identified in an updated subsurface physical property model as being caused by the approximation.

4. The method of claim 3, wherein varying the approximation comprises changing an aspect of the approximation and the aspect of the approximation that is changed is selected for having an effect on artifacts of the one or more identified artifact types.

5. The method of claim 4, wherein said effect is such that artifacts from one approximation do not add constructively with artifacts from another iteration cycle that uses an approximation with a changed aspect.

6. The method of claim 1, wherein the artifact is footprints of source position in the inverted model, and approximation is to select a subset of the measured geophysical data for inputting to the iterative inversion process, and varying the approximation is selecting a different subset.

7. The method of claim 6, wherein each different subset is selected randomly.

8. The method of claim 1, wherein the artifact is inaccuracy at edges of the inverted model caused by artificial reflections from the edges, and the approximation is imperfect absorbing boundaries in simulation of synthetic data in the iterative inversion process, and the variation of the approximation is to vary thickness of an absorbing boundary layer.

9. The method of claim 1, wherein the artifact is inaccuracy at edges of the inverted model caused by artificial reflections from the edges, and the approximation is using a

type of reflecting boundary condition in simulation of synthetic data in the iterative inversion process, and the variation of the approximation is using a different type of reflecting boundary condition.

10. The method of claim 1, wherein the artifact is inaccuracy at edges of the inverted model caused by artificial reflections from the edges, and the approximation is random boundary conditions in simulation of synthetic data in the iterative inversion process, and the variation of the approximation is varying distribution of the random boundary.

11. The method of claim 1, wherein the approximation is spatial variation of grid cell size in a finite difference simulator in the iterative inversion process, and the artifact is errors at boundaries between changes in grid cell size caused by artificial reflections from those boundaries, and the variation of the approximation is varying location of a boundary separating regions with different grid cell sizes.

12. The method of claim 1, wherein the approximation is spatial variation in simulator accuracy in the iterative inversion process, and the artifact is errors at boundaries between changes in simulator accuracy caused by artificial reflections from those boundaries, and the variation of the approximation is varying location of a boundary separating regions with different simulator accuracies.

13. The method of claim 1, wherein the artifact is spatial discretization errors, and the approximation is use of a grid cell size in simulation of synthetic data in the iterative inversion process, wherein the grid cell size is too coarse to accurately represent variations in the model, and the variation of the approximation is varying the grid cell size or origin of the grid.

14. The method of claim 1, wherein the artifact is discretization errors, and the approximation is use of discrete time steps in a time domain simulator in the iterative

inversion process, and the variation of the approximation is to use in one iteration a time step larger than time steps used in other iterations.

15. The method of claim 1, wherein the iterative geophysical data inversion process includes forward modeling of synthetic data and computing gradients of a cost function, and the approximation is using absorbing boundary conditions in the forward modeling, and the variation of the approximation is using less accurate absorbing boundary conditions in the forward modeling, thereby trading forward modeling accuracy for more accurate gradient computations.

16. The method of claim 1, wherein the approximation speeds up the iterative inversion process or works an accuracy trade-off.