source is activated, the source generates a seismic (e.g., sound wave) signal that travels downward through the Earth, is reflected, and, upon its return, is recorded using one or more receivers disposed on or above the subsurface region of the Earth. The seismic data recorded by the receivers may then be used to create an image or profile of the corresponding subsurface region.

[0005] Over time, as hydrocarbons are being extracted from the subsurface region of the Earth, the location, saturation, and other characteristics of the hydrocarbon reservoir and (e.g., overburden) within the subsurface region may change. As such, it may be useful to determine how the image or map of the subsurface region changes over time, such that the operations related to extracting the hydrocarbons may be modified to more efficiently extract the hydrocarbons from the subsurface region of the Earth.

SUMMARY

[0006] A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

[0006a] According to a first aspect of the present invention, there is provided a method for determining a displacement seismic image between a first seismic image and a second seismic image, including: receiving, via a processor, the first seismic image and the second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth; generating, via the processor, a first scaled image based on the first seismic image and a second scaled image based on the second seismic image; obtaining, via the processor, a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement

volume; determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images; generating, via the processor, a third seismic image by applying the displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image; and determining, via the processor, an image of a difference volume between the first seismic image and the third seismic image for display on a display or other tangible element, wherein the image represents how production of hydrocarbons in the subsurface region of the Earth has affected the subsurface region of the Earth.

[0006b] According to a second aspect of the present invention, there is provided a non-transitory computer-readable medium, including computer-executable instructions configured to cause a processor to: receive a first seismic image and a second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth; determine an displacement volume between the first seismic image and the second seismic image using an optical flow algorithm; iteratively refine the displacement volume between the first seismic image and the second seismic image based on the optical flow algorithm, wherein the iteratively refining comprises continuously comparing the first seismic image and a warped second image produced by applying the displacement volume to the second seismic image and updating the displacement volume; and generate a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image.

[0006c] According to a third aspect of the present invention, there is provided a method for drilling into a subsurface region of the Earth, including: analyzing a displacement volume between a first seismic image and a second seismic image associated with the subsurface region; and performing one or more drilling operations or one or more production operations into the subsurface region based on an analysis of a displacement seismic image, wherein the displacement seismic image is determined by: receiving, via a processor, the first seismic image and the second seismic image; generating, via the processor, a first scaled image based on the

first seismic image and a second scaled image based on the second seismic image; obtaining, via the processor, a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement volume; determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images; iteratively refining, via the processor, the displacement volume between the first and second images based on an optical flow algorithm; generating, via the processor, a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image; and determining, via the processor, the image of the difference volume based on the first seismic image and the third seismic image.

[0006d] According to a fourth aspect of the present invention, there is provided a method for determining a displacement seismic image between a first seismic image and a second seismic image, including: receiving, via a processor, the first seismic image and the second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth; generating, via the processor, a first scaled image based on the first seismic image and a second scaled image based on the second seismic image; obtaining, via the processor, a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement volume; determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images; generating, via the processor, a third seismic image by applying the displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the

first seismic image; and determining, via the processor, an image of a difference volume between the first seismic image and the third seismic image for display on a display or other tangible element, wherein the image represents how production of hydrocarbons in the subsurface region of the Earth has affected the subsurface region of the Earth.

[0006e] According to a fifth aspect of the present invention, there is provided a non-transitory computer-readable medium, including computer-executable instructions configured to cause a processor to: receive a first seismic image and a second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth; determine an displacement volume between the first seismic image and the second seismic image using an optical flow algorithm; iteratively refine the displacement volume between the first seismic image and the second seismic image based on the optical flow algorithm, wherein the iteratively refining comprises continuously comparing the first seismic image and a warped second image produced by applying the displacement volume to the second seismic image and updating the displacement volume; and generate a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image.

[0007] Seismic data processing, such as seismic data registration, may involve determining a multi-dimensional displacement volume (which may be a shift solution indicative of position differences between corresponding events in two seismic images or datasets). Generally, the two seismic images may be acquired at two different times, but it should be noted that the seismic data registration techniques may also be performed

CLAIMS

1. A method for determining a displacement seismic image between a first seismic image and a second seismic image, comprising:

receiving, via a processor, the first seismic image and the second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth;

generating, via the processor, a first scaled image based on the first seismic image and a second scaled image based on the second seismic image;

obtaining, via the processor, a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement volume;

determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images;

generating, via the processor, a third seismic image by applying the displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image; and

determining, via the processor, an image of a difference volume between the first seismic image and the third seismic image for display on a display or other tangible element, wherein the image represents how production of hydrocarbons in the subsurface region of the Earth has affected the subsurface region of the Earth.

2. The method of claim 1, comprising iteratively refining, via the processor, the scaled displacement volume between the first scaled image and the second scaled image based on an optical flow algorithm.

3. The method of claim 2, wherein the optical flow algorithm is configured to determine a pattern of motion between the first scaled image and the second scaled image.

4. The method of claim 2 wherein the optical flow algorithm comprises a Horn-Schunck algorithm or a Lucas-Kanade algorithm.

5. The method of claim 2, wherein iteratively refining the scaled displacement volume comprises:

applying, via the processor, the scaled displacement volume to the second scaled image thereby generating a third scaled image;

determining, via the processor, a second scaled displacement volume between the first scaled image and the third scaled image using an optical flow algorithm;

updating, via the processor, the scaled displacement volume based on the second scaled multi-dimensional displacement volume; and

assigning the updated scaled displacement volume as the scaled displacement volume.

6. The method of claim 2, wherein iteratively refining the scaled displacement volume comprises:

(a) receiving, via the processor, a number of iterations M;

(b) applying, via the processor, the scaled displacement volume to the second scaled image thereby generating a third scaled image;

(c) determining, via the processor, a second scaled displacement volume between the first scaled image and the third scaled image using an optical flow algorithm;

(d) updating, via the processor, the scaled displacement volume by adding to itself the second scaled displacement volume;

(e) iteratively repeating blocks (b), (c) and (d) M-1 times using a respective second scaled displacement volume and a respective third scaled image, thereby determining an M-number scaled displacement volume; and

(f) assigning the M-number scaled displacement volume as the scaled displacement volume.

7. The method of claim 1, wherein the first scaled image is determined from the first seismic image based on a Gaussian pyramid, where the first scaled image comprises a smaller-size and lower-resolution compared to the first seismic image or the first scaled image comprises an identical size and resolution to the first seismic image.

8. The method of claim 1, wherein obtaining the scaled displacement volume comprises:

determining, via the processor, a first scaled displacement volume at a current scale based on a second scaled displacement volume at a previous scale with respect to the first and second scaled images at a previous scale and the scaling function between the current scale and the previous scale, if the previous scale exists; and

determining, via the processor, a second scaled displacement volume at the current scale using the first scaled image and the second scaled image at the current scale based on an optical flow algorithm, if the previous scale does not exist.

9. The method of claim 1, comprising displaying, via the processor, the image of the displacement volume on the display or the other tangible element.

10. The method of claim 1, comprising:

determining, via the processor, a number of scales L;

generating, via the processor, a first plurality of scaled images of number L based on the first seismic image and the number of scales L and a second plurality of scaled images of number L based on the second seismic image and the number of scales L using a Gaussian pyramid;

for each of the number of scales L:

if a current scale is not equal to the number of scales L, determining, via the processor, a respective scaled displacement volume at a current scale based on the respective previous scaled displacement volume at a previous scale and a respective scaling function between the current scale and the previous scale;

if the current scale is equal to the number of scales L, determining, via the processor, the respective scaled displacement volume at the current scale using the respective first scaled image of the first plurality of scaled images and the

respective second scaled image of the second plurality of scaled images at the current scale based on an optical flow algorithm;

iteratively refining, via the processor, the respective scaled displacement volume at the current scale between the respective first scaled image of the first plurality of scaled images and the respective second scaled image of the second plurality of scaled images at the current scale; and

assigning, via the processor, the iteratively refined displacement volume at the current scale as the displacement volume.

11. A non-transitory computer-readable medium, comprising computer-executable instructions configured to cause a processor to:

receive a first seismic image and a second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region of the Earth;

determine an displacement volume between the first seismic image and the second seismic image using an optical flow algorithm;

iteratively refine the displacement volume between the first seismic image and the second seismic image based on the optical flow algorithm, wherein the iteratively refining comprises continuously comparing the first seismic image and a warped second image produced by applying the displacement volume to the second seismic image and updating the displacement volume; and

generate a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image.

12. The non-transitory computer-readable medium of claim 11, wherein the computer-executable instructions are configured to cause the processor to:

(a) generate a plurality of first scaled images of number L based on the first seismic image and a number of scales L;

(b) generate a plurality of second scaled images of number L based on the second seismic image and the number of scales L;

(c) determine an L-level scaled multi-dimensional displacement volume associated with a scale L between a first L-level scaled image of the plurality of first scaled images and a second L-level scaled image of the plurality of second scaled images using an optical flow algorithm;

(d) iteratively refine the L-level scaled multi-dimensional displacement volume associated with the scale L between the first L-level scaled image and the second L-level scaled image;

(e) determine an (L-1)-level scaled multi-dimensional displacement volume based on the L-level scaled multi-dimensional displacement volume and a scaling function between the first L-level scaled image and an (L-1)-level scaled image of the plurality of first scaled images;

(f) iteratively refine the (L-1)-level scaled multi-dimensional displacement volume associated with the scale L-1 between the first (L-1)-level scaled image and the second (L-1)-level scaled image;

(g) repeating blocks (e) and (f) for each of a remaining number of scales L-2 using the respective levels L and L-1, thereby generating a 1-level displacement volume associated with the first seismic image and the second seismic image; and

(h) assigning the 1-level displacement volume as the iteratively refined displacement volume.

13. The non-transitory computer-readable medium of claim 12, wherein the displacement volume at every scale comprises a scalar or a multi-dimensional vector per voxel.

14. The non-transitory computer-readable medium of claim 11, wherein the number of scales L is received via user input.

15. The non-transitory computer-readable medium of claim 11, wherein the computer-executable instructions cause the processor to predict how the production of hydrocarbons in the subsurface region of the Earth will affect the subsurface region of the Earth over a second period of time based on the iteratively refined displacement volume.

16. The non-transitory computer-readable medium of claim 12, wherein the displacement volume associated with each scale of the number of scales L is determined using an iterative refinement approach that quantifies one or more changes between each respective scaled image of the plurality of first scaled images and each respective scaled image of the plurality of second scaled images.

17. A method for drilling into a subsurface region of the Earth, comprising:

analyzing a displacement volume between a first seismic image and a second seismic image associated with the subsurface region; and

performing one or more drilling operations or one or more production operations into the subsurface region based on an analysis of a displacement seismic image, wherein the displacement seismic image is determined by:

receiving, via a processor, the first seismic image and the second seismic image;

generating, via the processor, a first scaled image based on the first seismic image and a second scaled image based on the second seismic image;

obtaining, via the processor, a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement volume;

determining, via the processor, a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images;

iteratively refining, via the processor, the displacement volume between the first and second images based on an optical flow algorithm;

generating, via the processor, a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image; and

determining, via the processor, the image of the difference volume based on the first seismic image and the third seismic image.

18. The method of claim 17, wherein the first seismic image is associated with a first set of seismic data acquired by a set of seismic receivers during a marine seismic survey or a land seismic survey.

19. The method of claim 18, wherein the second seismic image is associated with a second set of seismic data acquired by the set of seismic receivers at a time after the first set of seismic data was acquired.

20. The method of claim 17, wherein the first seismic image is associated with a first set of seismic data acquired by a first set of seismic receivers of a seismic survey, and wherein the second seismic image is associated with a second set of seismic data acquired by a second set of seismic receivers of the seismic survey.

21. A method (90) for determining a displacement seismic image between a first seismic image and a second seismic image, comprising:

receiving (92), via a processor (64), the first seismic image and the second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region (26) of the Earth;

generating (96), via the processor (64), a first scaled image based on the first seismic image and a second scaled image based on the second seismic image;

obtaining (98), via the processor (64), a scaled displacement volume between the first scaled seismic image and the second scaled image, wherein obtaining the scaled displacement volume comprises refining the scaled displacement volume by continuously comparing the first scaled image and a warped second scaled image produced by applying the scaled displacement volume to the second scaled image and updating the scaled displacement volume;

determining (99), via the processor (64), a displacement volume based on the scaled displacement volume and a scaling function used to generate the first and second scaled images based on the first and second seismic images;

generating (104), via the processor (64), a third seismic image by applying the displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image; and

determining (106), via the processor (64), an image of a difference volume between the first seismic image and the third seismic image for display on a display or other tangible element, wherein the image represents how production of hydrocarbons in the subsurface region (26) of the Earth has affected the subsurface region of the Earth.

22. The method of claim 21, comprising iteratively refining, via the processor (64), the scaled displacement volume between the first scaled image and the second scaled image based on an optical flow algorithm.

23. The method of claim 22, wherein the optical flow algorithm is configured to determine a pattern of motion between the first scaled image and the second scaled image.

24. The method of claim 22 wherein the optical flow algorithm comprises a Horn-Schunck algorithm or a Lucas-Kanade algorithm.

25. The method of claim 22, wherein iteratively refining the scaled displacement volume comprises:

applying, via the processor (64), the scaled displacement volume to the second scaled image thereby generating a third scaled image;

determining, via the processor (64), a second scaled displacement volume between the first scaled image and the third scaled image using an optical flow algorithm;

updating, via the processor (64), the scaled displacement volume based on the second scaled multi-dimensional displacement volume; and

assigning the updated scaled displacement volume as the scaled displacement volume.

26. The method of claim 22, wherein iteratively refining the scaled displacement volume comprises:

(a) receiving, via the processor (64), a number of iterations *M*;

(b) applying, via the processor (64), the scaled displacement volume to the second scaled image thereby generating a third scaled image;

(c) determining, via the processor (64), a second scaled displacement volume between the first scaled image and the third scaled image using an optical flow algorithm;

(d) updating, via the processor (64), the scaled displacement volume by adding to itself the second scaled displacement volume;

(e) iteratively repeating blocks (b), (c) and (d) *M*-1 times using a respective second scaled displacement volume and a respective third scaled image, thereby determining an M-number scaled displacement volume; and

(f) assigning the M-number scaled displacement volume as the scaled displacement volume.

27. The method of claim 21, wherein the first scaled image is determined from the first seismic image based on a Gaussian pyramid, where the first scaled image comprises a smaller-size and lower-resolution compared to the first seismic image or the first scaled image comprises an identical size and resolution to the first seismic image.

28. The method of claim 21, wherein obtaining the scaled displacement volume comprises:

determining, via the processor (64), a first scaled displacement volume at a current scale based on a second scaled displacement volume at a previous scale with respect to the first and second scaled images at a previous scale and the scaling function between the current scale and the previous scale, if the previous scale exists; and

determining, via the processor (64), a second scaled displacement volume at the current scale using the first scaled image and the second scaled image at the current scale based on an optical flow algorithm, if the previous scale does not exist.

29. The method of claim 21, comprising:

determining, via the processor (64), a number of scales L;

generating, via the processor (64), a first plurality of scaled images of number L based on the first seismic image and the number of scales L and a second plurality of scaled images of number L based on the second seismic image and the number of scales L using a Gaussian pyramid;

for each of the number of scales L:

if a current scale is not equal to the number of scales L, determining, via the processor (64), a respective scaled displacement volume at a current scale based on the respective previous scaled displacement volume at a previous scale and a respective scaling function between the current scale and the previous scale;

if the current scale is equal to the number of scales L, determining, via the processor (64), the respective scaled displacement volume at the current scale using the respective first scaled image of the first plurality of scaled images and the respective second scaled image of the second plurality of scaled images at the current scale based on an optical flow algorithm;

iteratively refining, via the processor (64), the respective scaled displacement volume at the current scale between the respective first scaled image of the first plurality of scaled images and the respective second scaled image of the second plurality of scaled images at the current scale; and

assigning, via the processor (64), the iteratively refined displacement volume at the current scale as the displacement volume.

30. A non-transitory computer-readable medium (66), comprising computer-executable instructions configured to cause a processor (64) to:

receive (92) a first seismic image and a second seismic image, wherein the first seismic image and the second seismic image are representative of one or more geological formations within a subsurface region (26) of the Earth;

determine (98) an displacement volume between the first seismic image and the second seismic image using an optical flow algorithm;

iteratively (99) refine the displacement volume between the first seismic image and the second seismic image based on the optical flow algorithm, wherein the iteratively

refining comprises continuously comparing the first seismic image and a warped second image produced by applying the displacement volume to the second seismic image and updating the displacement volume; and

generate (104) a third seismic image by applying the iteratively refined displacement volume to the second seismic image, wherein one or more seismic events depicted in the third seismic image are aligned with one or more seismic events depicted in the first seismic image.

31. The non-transitory computer-readable medium (66) of claim 30, wherein the computer-executable instructions are configured to cause the processor (64) to:

(a) generate a plurality of first scaled images of number L based on the first seismic image and a number of scales L;

(b) generate a plurality of second scaled images of number L based on the second seismic image and the number of scales L;

(c) determine an L-level scaled multi-dimensional displacement volume associated with a scale L between a first L-level scaled image of the plurality of first scaled images and a second L-level scaled image of the plurality of second scaled images using an optical flow algorithm;

(d) iteratively refine the L-level scaled multi-dimensional displacement volume associated with the scale L between the first L-level scaled image and the second L-level scaled image;

(e) determine an (L-1)-level scaled multi-dimensional displacement volume based on the L-level scaled multi-dimensional displacement volume and a scaling function between the first L-level scaled image and an (L-1)-level scaled image of the plurality of first scaled images;

(f) iteratively refine the (L-1)-level scaled multi-dimensional displacement volume associated with the scale L-1 between the first (L-1)-level scaled image and the second (L-1)-level scaled image;

(g) repeating blocks (e) and (f) for each of a remaining number of scales L-2 using the respective levels L and L-1, thereby generating a 1-level displacement volume associated with the first seismic image and the second seismic image; and

(h) assigning the 1-level displacement volume as the iteratively refined displacement volume.

32. The non-transitory computer-readable medium (66) of claim 30, wherein the displacement volume at every scale comprises a scalar or a multi-dimensional vector per voxel.

33. The non-transitory computer-readable medium (66) of claim 30, wherein the number of scales L is received via user input.

34. The non-transitory computer-readable medium (66) of claim 30, wherein the computer-executable instructions cause the processor (64) to predict how the production of hydrocarbons in the subsurface region of the Earth will affect the subsurface region of the Earth over a second period of time based on the iteratively refined displacement volume.

35. The non-transitory computer-readable medium (66) of claim 31, wherein the displacement volume associated with each scale of the number of scales L is determined using an iterative refinement approach that quantifies one or more changes between each respective scaled image of the plurality of first scaled images and each respective scaled image of the plurality of second scaled images.