

Summer Intern Program, 2021



David Fuentes



Bill Menke



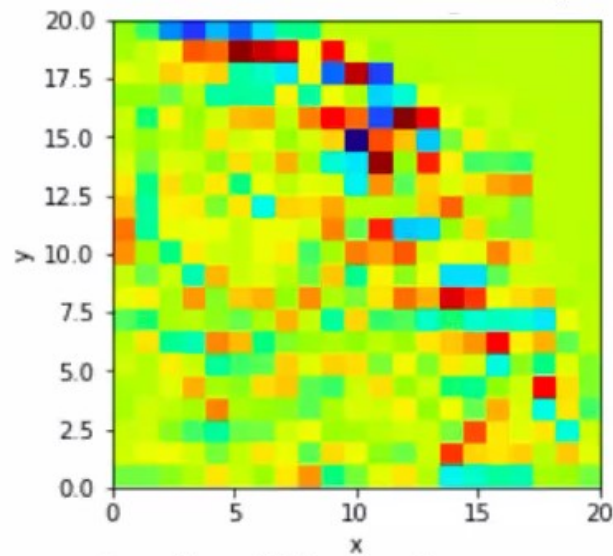
Charlotte Rhoads

Does Supplementing Travel Time Data with Amplitude Data improve Geo-tomographic Determinations of Earth Structure?

Charlotte Rhoads¹, Dr. William Menke²

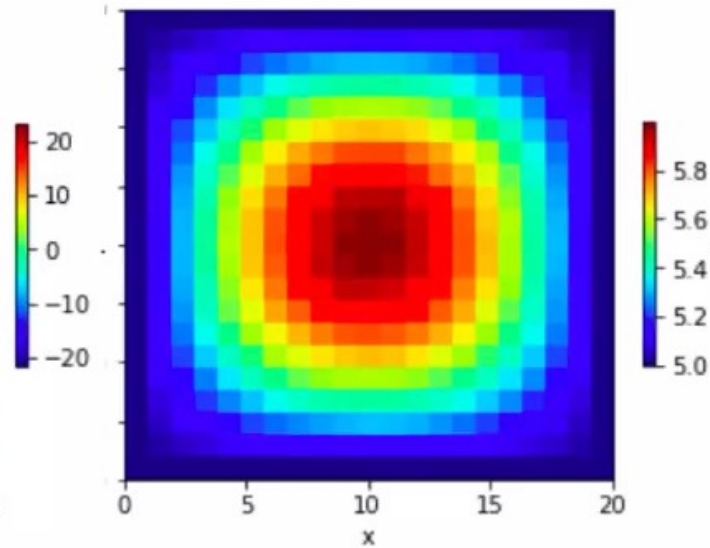
¹Vassar College, ²Lamont-Doherty Earth Observatory of Columbia University

Travel Time Data Only



Data from 20 Earthquakes

Travel Time + Amplitude Data



Data from 20 Earthquakes

Yes, the addition of amplitude data can substantially improve Earth images in a broad range of studies.



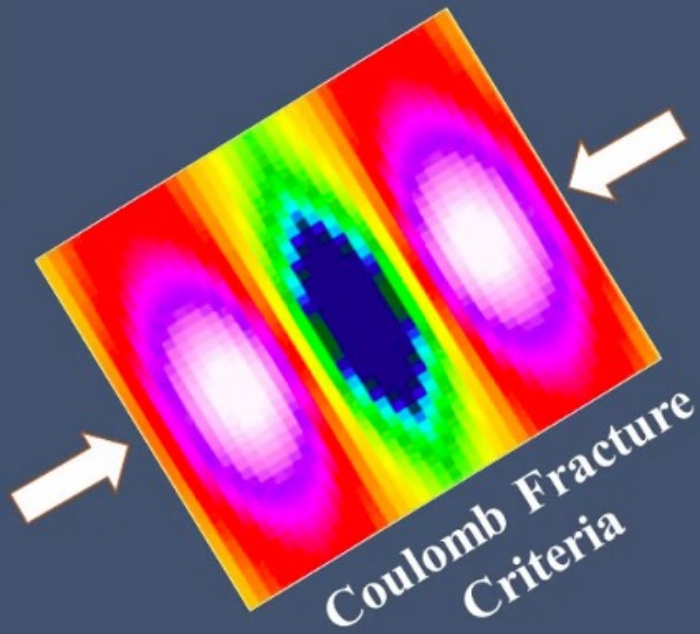
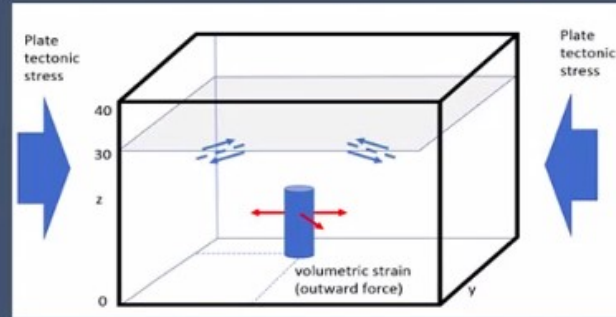
Charlotte Rhoads

Recording

Can Earthquakes be Induced by Thermal Expansion or Chemical Expansion Affecting Stress in the Earth?

David Fuentes¹, Dr. William Menke²
¹City College, ²LDEO

Earth Model



Yes, it is possible.



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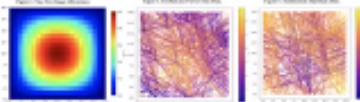
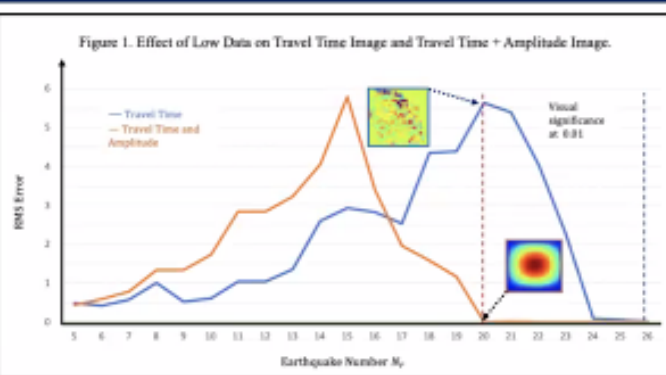
Columbia University
Lamont-Doherty Earth Observatory

1. Abstract

- Previously, geo-tomographic imaging of mantle convection has mostly relied on P and S wave travel times. However, errors in travel time measurements can lead to poor images.
- In this study, a new geo-tomographic method is explored that improves the image quality by expanding the observations to include P and S wave amplitudes.
- It is found that the combination of travel time and amplitude observations leads to an image that is less sensitive to the presence of noise, especially when the ray paths are sparse.
- The imaging technique requires observations along fewer rays to achieve a high-quality image.
- The new method suggests that the addition of amplitude data can substantially improve Earth images in a broad range of studies.

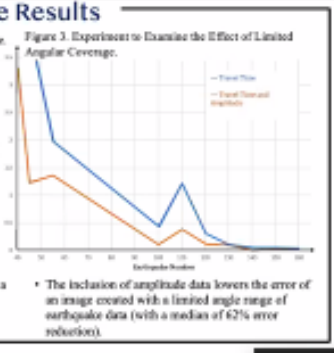
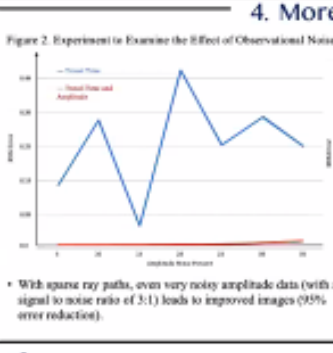
2. Methods

- A numerical model is coded with Python in a Jupyter Notebook that implements the geo-tomographic technique of imaging with seismic wave information.
- The quantity being imaged is slowness (the reciprocal of wave speed). Travel time is related to the slowness along the ray and amplitude to the second derivative of slowness along the ray (Menke, 2021).
- A true test image is created using a known function of slowness.
- We invert the method of cubic interpolation described by Keys (1981) in order to relate measurements at points along a ray to properties of the slowness grid.
- An image is then estimated using designed least squares from the combined data sets and is compared to one estimated from travel time data, only.
- Experiments are simulated to quantify the improvement of the technique when travel time and amplitude data are randomly synthesized for each trial.
- Image quality is assessed by calculating the RMS between the true and estimated images.

3. Results

- The threshold of consistently perfect images is when 0.01 mean RMS error is reached.
- The image quality of both techniques first worsen as more data is entered because with each little information for the interpolation method, details are being placed randomly in the final image.
- The travel time + amplitude image reaches a critical point in which the RMS error trend rapidly decreases much earlier than the travel time image.
- The travel time + amplitude image needs data from 20 earthquakes whereas the travel time image needs 25 earthquakes to reach the significant RMS error value.
- This is a 40% reduction in the number of rays required to make a high-quality image.



5. Analysis

- With the new geo-tomographic method, less data is needed to achieve a high-quality image.
- The inclusion of noisy amplitude data still significantly improves image quality.
- Amplitude data, in addition to travel time data, produces a lower error with limited coverage of ray paths in the study area.
- In summary, the addition of amplitude data can substantially improve Earth images.

References

- Keys, R. (1981). Cubic convolution interpolation for digital image processing. IEEE Transactions on Acoustics, Speech, and Signal Processing 29, 1153-1160.
- Menke, W. 2021. Sensitivity Kernel for Ray Amplitude for Initially Straight Rays. Research Note 239, www.ldeo.columbia.edu/~wmenke/research_notes/menke_research_note239.pdf (last accessed August 3, 2021).

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 This work was supported by the Lamont-Doherty Earth Observatory.



Choose a different breakout room

Can earthquakes be induced by thermal expansion or chemical expansion affecting stress in the earth?

David Fuentes¹, Dr. William Menke²

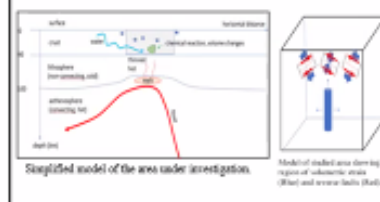
¹City College, ²Columbia University

LDEO

Columbia University
Lamont-Doherty
Earth Observatory

1. Abstract

- The CFC is used to assess whether or not earthquakes occurring in the shallow crust of New England might have a relationship to the Northern Appalachian Anomaly (NAA).
- We hypothesize that lower crustal volume changes are produced by chemical alteration.
- A suite of different shapes are simulated using a 3D finite difference method finding that the strongest effect is predicted for a chimney-shaped altered region.
- The overall effect of the chemical alteration is to lead to pattern of seismicity that is spatially very heterogeneous and that shares some similarity with the actual pattern of seismicity observed in New England.

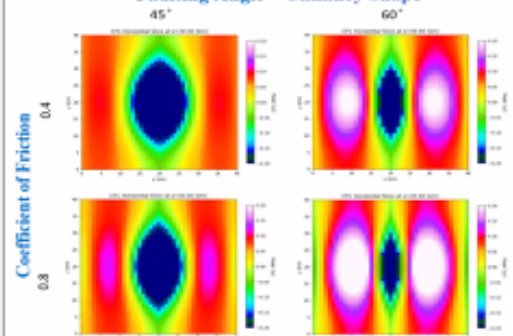


2. Methods

- Worked with the finite difference method.
- Simulated stress in the Earth and predicted if earthquakes were favored.
- The model used was a 40°40°40 km cube.
- The source of stress was a region of 1% of volumetric expansion, simulating a chemical reaction.
- The Coulomb Friction Criteria (CFC) was used to determine whether stress changes favored or suppressed earthquakes.

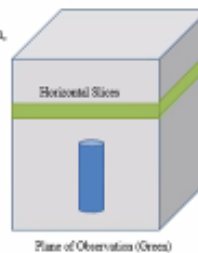
3. Results

Faulting Angle – Chimney Shape



This figure shows the results that corresponds to the chimney shape, which obtained a higher positive value in the Coulomb Friction Criteria (CFC) compared to the spherical and pancake shape.

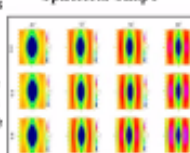
- Three different volumetric strain shapes were simulated: spherical, pancake and chimney.
- Depending on the angle and coefficient of friction, it was determined whether reverse failure was favored.
- The combinations and angles and coefficient of friction that occurred in the chimney shape were the most positive CFC favoring the reverse fault.
- It was also found that a zone located right above the volumetric stress resulted in no reverse faults and therefore earthquakes did not occur.



4. Effects of other Shapes

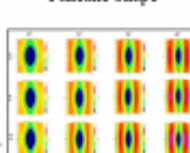
- In the other two shapes that were simulated, it was observed that the spherical shape favored reverse failure more than the pancake shape, but less than the chimney shape.

Spherical Shape



- At the highest angle degree (60°) and highest coefficient of friction (0.8), both the spherical and pancake shape had the minimal reverse faulting in comparisons to the chimney shape. (as seen in the lower right-hand corner of both images)

Pancake Shape



5. Summary of Results

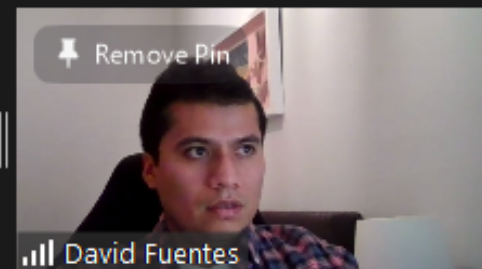
- The chemical reaction causes the earthquakes to not occur right above the reaction, regardless of the coefficient of friction and the fault angle.
- Combinations of angle of faulting and coefficient of friction enhance earthquakes at edges (CFC = 0.3 Mpa).
- The chimney shape is the volumetric strain that is most likely to favor the faulting and cause an earthquake.
- It is possible, but not proven that the NAA is caused by chemical alteration above its upwelling.

References

- Levin, V., Long, M.D., Skryzala, P., Li, Y. and López, I., 2018. Seismic evidence for a recently formed mantle upwelling beneath New England, *Geology*, 46, 87–90. doi: 10.1130/G38641.1
- Menke, W., Skryzala, P., Levin, V., Harper, T., Durbakova, F. and Dong, T., 2016. The Northern Appalachian Anomaly: A modern asthenospheric upwelling, *Geophysical Research Letters*, 43, 10,173–10,176. doi:10.1002/2016GL070918

Acknowledgments

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Mute



Stop Video



Participants 2



Chat



Share Screen



Breakout Rooms



Reactions

Leave Room