SEG|KOC Workshop on Advances in Land & Shallow Marine Multiple Attenuation and Imaging, scheduled on 28-30 November 2023 in Kuwait City, Kuwait.

A Keynote Address: Recent Advances and Open Issues in Multiple Attenuation and Imaging, including Land and Shallow Marine

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Multiple attenuation and imaging and inversion remain the central objectives of marine and onshore seismic processing. While there has been progress, many major hurdles and serious and daunting challenges remain. This Abstract will first describe the current state of multiple removal and imaging, and the open issues and challenges to all marine and onshore seismic processing. We then focus on specific prioritized obstacles to effectiveness for land and shallow water. Lastly new embryonic concepts, and methods that can begin to address these multiple removal and imaging and inversion challenges will be suggested and described.

Part I

Multiples must be removed in all seismic processing methods, that is in all direct and indirect seismic processing methods. The former, the direct methods include all classic wave equation migration methods (that require an adequate velocity model) and the inverse scattering isolated task subseries for depth imaging (that do not need to know, estimate or to determine a velocity model). Indirect methods, including all model matching methods like AVO and FWI- require all multiples to be removed either initially or at some point within the process.

We start with a history of conventional linear seismic migration- with the current (new) and most capable migration method defined in terms of its ability to image without artifacts in a discontinuous medium from above or beneath a reflector, and to automatically accommodate a specular(flat) or curved and pinch-out diffractive reflector, and to avoid intrinsic high frequency approximations in both the imaging principle and propagation components of the migration method, with one single unchanged imaging and inversion algorithm. We label that most capable imaging method Stolt-Claerbout III migration-inversion (SCIII) for heterogeneous and discontinuous medium. RTM doesn't satisfy any one of those properties and characteristic - let alone all of them. RTM and Kirchhoff have serious imaging, resolution, illumination and inversion issues compared to SCIII. Another important fact is that if one used a Stolt-Claerbout III migration with an accurate discontinuous velocity model, then multiples would not cause any problems, and would not need to be removed However, if you use a smooth velocity to migrate data from a discontinuous medium, every multiple will produce a false image, and every multiple must be removed. Since our most capable velocity analysis methods today can at best produce a smooth velocity, all multiples must be removed before migration.

Of course, the latter conclusion about velocity analysis includes FWI where a smooth velocity is the stretch goal today. The removal of multiples and the use of multiples have the same exact goal: the imaging of primaries, recorded and unrecorded primaries, respectively. Nobody is migrating multiples-the phrase 'migrating multiples' has no meaning. However, at times a recorded multiple can be used to find an approximate image of an unrecorded primary subevent of the recorded multiple. To predict a multiple, you need to have recorded all of its subevents; hence, if you can predict a multiple its useless. If you cannot predict a multiple, because you have not recorded all its subevents, then it might be useful. Hence, predicted multiples are useless, and useful multiples cannot be predicted. What if the unrecorded subevent of the recorded multiple, is not an unrecorded primary- but an unrecorded multiple. That unrecorded multiple will be treated as an unrecorded primary and will result in an artifact. Since we are confined to a smooth migration velocity, recorded multiples must be removed to image recorded primaries, and unrecorded multiples must be removed to find an approximate image of an unrecorded primary.   Therefore methods (like FWI) that at best produce a smooth velocity model-result in all multiples needing to be removed.

What is the current toolbox of multiple removal capability? The published paper (please see the link below) Feb. 2022, JSE, co-authored with John Etgen of BP and Fred Melo and Jing Wu of Schlumberger provides a timely overview and describes when each option within the multiple removal toolbox might be the well-informed cost-effective choice- along with open issues and challenges.

One of several conclusions of that recent overview paper (cited above)is that the most effective method for removing internal multiples is the inverse scattering internal multiple eliminator(ISS IME).(Yanglei Zou et al, (2019) There are three properties that only this internal multiple (ISS IME) method possesses:(1) it predicts the exact amplitude and phase of the internal multiple at all offsets ;(2) there is no subsurface information known, estimated or determined, no interpreter intervention, and (3) it is one unchanged algorithm for every earth model type;(4) it has a water speed Stolt-Claerbout III migration, and unlike Kirchhoff and RTM it can automatically accommodate multiple generators that are planar curved, and point scatterer diffractive pinch outs; (5) there is no need for an adaptive step since it predicts the exact phase and amplitude of the internal multiple at every offset- and (6)the key lower higher lower relationship is correct and in vertical time, not total time (the latter is erroneous (and deleterious)and called upon in Marchenko methods). The criteria behind energy minimization adaptive subtraction can fail with interfering or proximal events.

No other multiple removal method (e.g., Radon, Jakubowitz, or Marchenko) satisfies one let alone all these beneficial properties- and that explains why ISS IME is currently the most effective internal multiple removal method.
The inverse scattering internal multiple attenuator (ISS IMA) predicts the exact time and approximate amplitude of all internal multiples- and hence ISS IMA often calls upon an adaptive step to remove the internal multiple.
The inverse scattering free surface eliminator (ISS FSME) and the inverse scattering internal multiple eliminator (ISS IME) are the most effective methods for removing free surface and internal multiples, respectively. See e.g., Chao Ma et al 2018 for a direct comparison between ISS FSME and SRME, and Chao Ma et al (2020) for a comparison of internal multiple methods.

There is sometimes a serious confusion and serious misunderstanding about the properties of the forward scattering series (a modeling method) and the inverse scattering series. The former, the forward scattering series, as a modeling method requires the specification of the earth model type, and the exact properties of the subsurface for that model type. On the other hand, the inverse scattering series and every term within that series is directly computable in terms of the recorded seismic data and a constant reference (water) speed – and hence all isolated task subseries of the ISS share that property. Furthermore, Weglein et al (2003) prove that the distinct isolated task subseries of the ISS for free surface and internal multiple removal, are totally independent of the type of earth model (no line of code is changed for acoustic, elastic, anisotropic, heterogeneous, inelastic…models). Unfortunately, there is literature e.g., ten Kroode (2002) that mistakenly seek to 'derive' 'something like' the ISS isolated task subseries for internal multiple attenuation by looking at the forward series. That fundamental misunderstanding about the different properties and function of the forward and inverse series, and the origin of the ISS internal multiple attenuator, leads to incorrect conclusions, that would be valid if the distinct ISS isolated task subseries were modeling methods-which they aren't.

The ISS methods are often the well-informed cost-effective choice under the most complicated and daunting circumstances, with rapidly varying multiple generators (and for interfering and proximal events). Further detail and analysis can be found in the video presentations and publications in the links below.

Part II

What are the open issues for land and shallow water multiple removal? What are some of the approaches that could address these open issues on multiple removal and imaging and inversion?

Onshore challenges begin with the complex ill-defined near surface issues where identifying the model type and medium properties are a major obstacle and largely unsolved problem. A new embryonic seismic processing method has been developed that removes the need for near surface and subsurface information to be known, estimated, or determined (Weglein, 2023) . Early tests are encouraging. Jing Wu et al (2015) present a new way to separately predict ground roll and reflection data without filtering and harming either one.

Among major shallow water issues, is the fact that the nearest phone to the source can be in the postcritical regime. That is a major impediment to multiple removal methods that depend on recorded subevents. A note in the 2001 MOSRP Annual Report by Mrinal Sen, Paul Stoffa (UTIG)and A. Weglein(M-OSRP) present a method for predicting precritical data from postcritical data.

In the links below please find: What is the suggestion for starting and pursuing a research plan.

Why direct inverse methods play a fundamentally important role in defining the goals of a relevant research program that seeks added value in target identification and successful drilling. A direct inverse method assures that you have solved the problem you set out to solve, but equally if not more important it communicates whether the problem you are interested in solving is the relevant real problem you need to be solving. If a direct inverse method doesn't increase the drill success rate, the problem that you are solving is not the problem that you need to be solving. With an indirect model matching method like FWI, if you don't improve the drill success rate- you don't know if you are solving the wrong problem, or whether your indirect method is the issue, or both. Defining and solving the right problem is the key and essential first step in a research program and project.

http://mosrp.uh.edu/news/fundamentally-new-perspective-insight-and-understanding-on-seismic-multiples

In the link below please find two publications, referred to in the above text and published in February 2022 in JSE- the first details why multiples must be removed in all seismic processing methods, and the second is an overview of the toolbox of methods that remove multiples, and their assumptions and prerequisites- and a guide to when each method might the well-informed cost-effective choice. http://www.mosrp.uh.edu/news/two-papers-to-appear-in-jse-in-february-2022

In the link below, please find a video of the Keynote Address from the September 1, 2022, post SEG Convention/Conference Workshop on "FWI/FWM and New Imaging Concepts and Capability".

http://mosrp.uh.edu/news/a-b-weglein-the-keynote-address-2022-seg-workshop-fwi-and-new-imaging-capability There are many serious open issues within the seismic multiple toolbox. In our view the purpose of research is to start with identifying the collective toolbox shortcomings and to develop methods that seek to fill that gap.

We point out that it's important to distinguish between methods and people, and their properties- algorithms do not have egos, ambition, and they never exaggerate capability or market themselves. No method ever claimed it was the final and ultimate solution- and no method is, or ever will be.

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