UNIVERSITY of HOUSTON

M-OSRP
Misson - Oriented Seismic Research Program
Solve The Right Problem

# A NEW PERSPECTIVE ON REMOVING AND USING MULTIPLES: THEY HAVE THE SAME EXACT GOAL, IMAGING PRIMARIES: RECENT ADVANCES IN MULTIPLE REMOVAL A KEY-NOTE ADDRESS FOR THE SEG/KOC WORKSHOP DEC. 3-5, 2019 IN KUWAIT

*Arthur Weglein*

*December 3-5, 2019*

*2019 SEG/KOC Workshop: Seismic  Multiples - the Challenges and the Way Forward*

*Kuwait City, Kuwait*

**2019 SEG | KOC Workshop: Seismic Multiples - The Challenges and the Way Forward**

# Primaries and multiples --- a new perspective

- Removal and usage of multiples are not adversarial. In fact they are after the same single exact goal, that is, to image primaries: both recorded primaries and unrecorded primaries. There are circumstances where a recorded multiple can be used to find an approximate image of an unrecorded subevent primary of the recorded multiple.

*Arthur B. Weglein*, (2016), "Multiples: Signal or noise?," *GEOPHYSICS* 81: V283-V302.
http://mosrp.uh.edu/content/07-news/key-note-address-at-the-seg-koc-workshop-dec-3-5-2019/mime-attachment.pdf

- There are two types of primaries and multiples: those that are recorded and those that are not recorded. Recorded data consists of recorded primaries and recorded multiples.
- To understand the role of primaries and multiples in seismic processing.
- Migration and migration-inversion are the methods used to locate structure and to perform amplitude analysis.
- Wave theory methods for migration have two ingredients: a wave propagation model and an imaging principle.
- All current migration methods make high frequency approximation in either the imaging principle and/or the wave propagation model.

# Wave Theory Seismic Migration

- Migration methods that use wave theory for seismic imaging have two components: (1) a wave propagation model, and (2) an imaging condition.

- All current migration methods make high frequency approximations in either the imaging primaries and/or the propagation model.

*Yanglei Zou, Qiang Fu, and Arthur Weglein*, (2017),
"A wedge resolution comparison between RTM and the first migration method that is equally effective at all frequencies at the target: Tests and analysis with both conventional and broadband data," *SEG Technical Program Expanded Abstracts* : 4468-4472.

# Three imaging principles

- For one way propagating waves, Jon Claerbout (1971) described three imaging principles
  - (1) the exploding reflector
  - (2) time and space coincidence of up and down going waves, and
  - (3) predicting a source and receiver experiment at a coincident-source-and-receiver subsurface point, and asking for time equals zero

## Imaging Conditions and High Frequency Assumptions

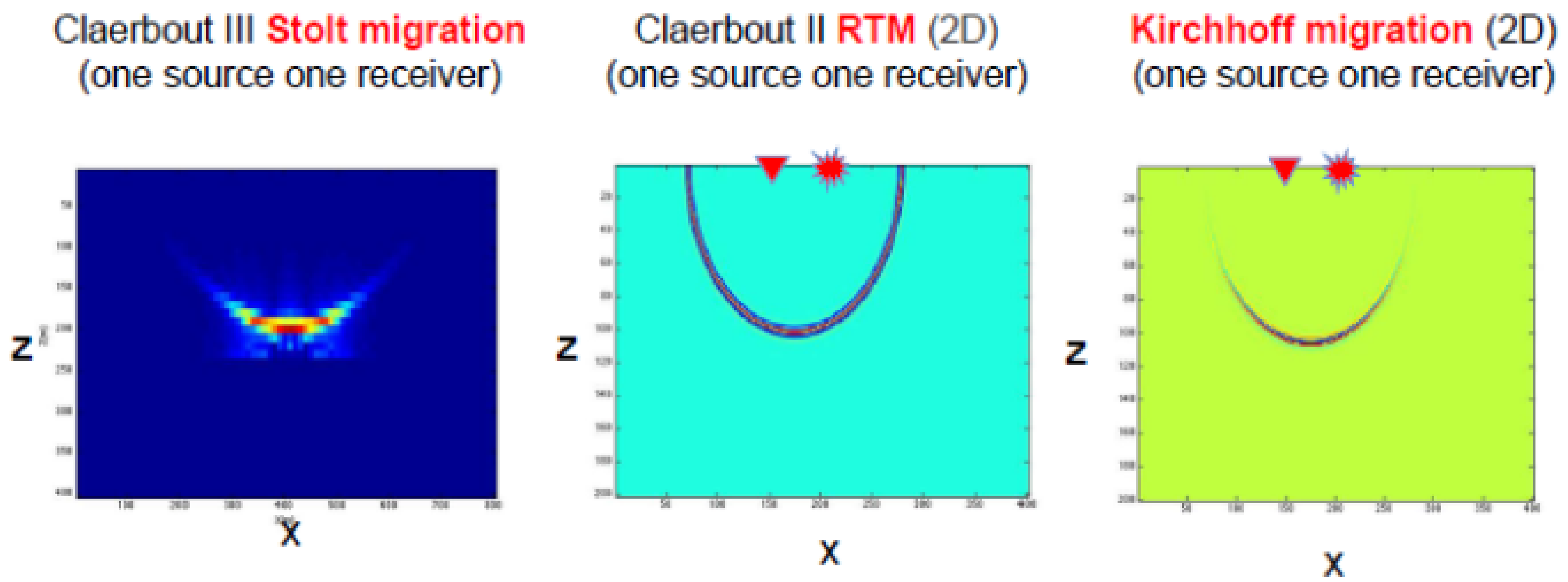


Figure 1: Left: No high frequency assumption, Center: High frequency assumption, Right: High frequency approximation from a stationary phase approximation.

- The most physically complete and accommodating imaging principle is what we call Stolt Claerbout III or Stolt CIII migration.

- M-OSRP has recently extended that imaging principle and migration method to
  - (1) accommodate discontinuous velocity models, and
  - (2) to avoid high frequency one-way wave asymptotic approximations in smooth velocity models. The latter is the only migration method that is able to input primaries and multiples and for a continuous or discontinuous velocity model is equally effective at all frequencies.

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# New from M-OSRP

## Stolt CIII migration for heterogeneous media for layers and continuous media without making a high frequency approximation in either the imaging principle or the propagation model

$$P = \int_{S_s} \left[ \frac{\partial {G_0}^{DN}}{\partial z_s} \int_{S_g} \left\{ \frac{\partial {G_0}^{DN}}{\partial z_g} P + \frac{\partial P}{\partial z_g} {G_0}^{DN} \right\} dS_g + {G_0}^{DN} \frac{\partial}{\partial z_s} \int_{S_g} \left\{ \frac{\partial {G_0}^{DN}}{\partial z_g} P + \frac{\partial P}{\partial z_g} {G_0}^{DN} \right\} dS_g \right] dS_s$$

Green's theorem for two way waves with measurements on upper surface
For details, see Weglein et al. (2011a,b) and F. Liu and Weglein (2014)

New SCIII migration beneath a single reflector with a discontinuous velocity model (please, e.g., imagine migrating through top salt). The new M-OSRP Claerbout III (Stolt extended) migration for 2 way wave propagation (for heterogeneous media)

- The example with $\frac{c_0}{c_1}$ velocity
- The image both above and beneath the reflector


Qiang Fu et al

Light color – image from above
Dark color – image from below

•No “rabbit ears”
•Consistent image along the reflector

# An initial study to quantify the resolution difference between an industry leading-edge migration, RTM, and the first migration method that is equally effective at all frequencies at the target

*Qiang Fu, Yanglei Zou, and Arthur B. Weglein, M-OSRP/Physics Dept./University of Houston*

## SUMMARY

There is an industry-wide interest in acquiring lower-frequency seismic data. There are industry reports that (1) when comparing the new and more expensively acquired broad-band lower-frequency data with conventional recorded data, taken over a same region, these two data sets have the expected difference in frequency spectrum and appearance, but (2) they often provide less than the hoped for difference in structural improvement or added benefit for amplitude analysis at the target and reservoir. There are two objectives of this paper: (1) to demonstrate that all current migration and migration-inversion methods (the methods that take recorded data and determine structure and perform amplitude analysis, respectively) make high-frequency asymptotic assumptions and consequently, in the process of migration, they lose or discount the information in the newly-acquired lowest-frequency components in the broad-band data, and (2) to address that problem, with the first migration method that will be equally effective at all frequencies at the target and reservoir, and that will allow the broad-band lower-frequency data to provide greater structural resolution improvement and enhanced amplitude analysis. In this paper, we begin to quantify the difference and the impact on resolution. We provide the first direct comparison of structural resolution differences with data with and without low frequencies, using the same homogeneous velocity model, comparing the current leading edge RTM (Claerbout II imaging principle) and the Stolt extended Claerbout III imaging principle. The new imaging method is able to benefit from broadband data for structural resolution improvement to a much greater extent than the current best industry standard migration. The differences in resolution benefit derived from the Stolt extended Claerbout III migration will be greater when both imaging principle and wave propagation model are included than we report here for only the imaging principle differences.

## INTRODUCTION

Migration methods that use wave theory for seismic imaging have two components: (1) a wave-propagation model and (2) an imaging condition. We examine each of these two components with focus on the specific topic of this paper: the frequency fidelity of migration algorithms. That analysis leads to a new and first migration that is equally effective at all frequencies at the target and/or the reservoir. Weglein (2016) provides a detailed development of this new migration method.

For the imaging principle component, a good start is Jon Claerbout's 1971 landmark contribution (Claerbout, 1971) which lists three imaging principles. The first is the exploding-reflector model for stacked or zero-offset data, which we call Claerbout imaging principle I (CI). The second is time-space coincidence of upgoing and downgoing waves, which we call Claerbout imaging principle II (CII). Waves propagate down from the source, are incident on the reflector, and the reflector generates a reflected upgoing wave. According to RTM (CII), the reflector exists at the location in space where the wave that is downward propagating from the source and the wave propagates up from the reflector are at the same place and time. The third is Claerbout imaging principle III (Stolt extended CIII), which starts with surface source and receiver data and predicts what a source and receiver would record inside the earth. Stolt extended CIII then arranges the predicted source and receiver to be coincident and asks for $t = 0$. If the predicted coincident source and receiver experiment at depth is proximal to a reflector one gets a non-zero result at time equals zero.

CII and Stolt extended CIII are of central industry interest today, since we currently process pre-stacked data. RTM (CII)and Stolt extended CIII will produce different results for a separated source and receiver located in a homogeneous half space above a single horizontal reflector. That difference forms a central and key message of this paper.

CII can be expressed in the form

$$I(\vec{x}) = \sum_{\vec{x}_s}\sum_{\omega} S'(\vec{x}_s,\vec{x},\omega)R(\vec{x}_s,\vec{x},\omega), \quad (1)$$

where $R$ is the reflection data (for a shot record), run backwards, and $S'$ is the complex conjugate of the source wavefield.

A realization of Stolt extended CIII is Stolt FK migration (Stolt, 1978)

$$\begin{aligned} M^{stolt}(x,z) = &\frac{1}{(2\pi)^3}\iiint d\omega dx_g dx_s dk_{sx} \\ &\times \exp(-i(k_{sz}z + k_{sx}(x-x_s))) \\ &\times \int dk_{gx}\exp(-i(k_{gz}z + k_{gx}(x-x_s))) \\ &\times \int dt\,\exp(i\omega t)D(x_g,x_s,t). \end{aligned} \quad (2)$$

The weighted sum of recorded data, summed over receivers, basically predicts the receiver experiment at depth, for a source on the surface. The sum over sources predicts the source in the subsurface. Then the predicted source and receiver experiment is output for a coincident source and receiver, and at time equals zero; it defines a Stolt extended CIII image. Each step (integral) in this Stolt-Fourier form of Stolt extended CIII has a specific physically interpretable purpose towards the Stolt extended CIII image.

## RTM IS A HIGH-FREQUENCY APPROXIMATION

Today all migration methods assume a high-frequency approximation in a wave-propagation model or an imaging condition or both. How does one know if a migration method has made

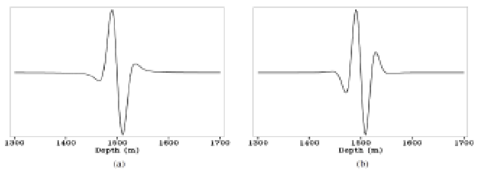



Figure 8: The wiggle comparison of (zoomed in) imaging results for both input wavelet by Claerbout III imaging principle. (a) from input data with low frequencies; (b) from input data without low frequencies. We can measure the normalized amplitudes of the first side lobe for both input data. And it turns out the normalized amplitudes of the first side lobes reduced 57% ( from 0.33 to 0.14) if we have low frequencies in the input datas.

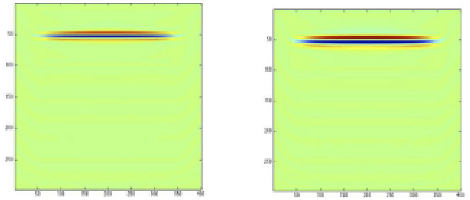


Figure 9: Claerbout II imaging result. (a) for the original data; (b) for the data without low frequency

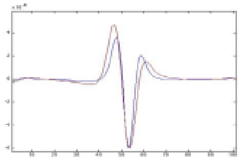


Figure 10: a wiggle comparison of the two images (one trace)

and 8 show the comparison of (zoomed in) imaging results for both input wavelets by Stolt extende CIII imaging principle. In figure 8, we can measure the normalized amplitudes of the first side lobe for both input data. And it turns out the normalized amplitudes of the first side lobes are reduced 57% ( from 0.33 to 0.14) if we have low frequencies in the input data. Figures 9 and 10 show the comparison of imaging results for both input wavelets by RTM (CII) imaging principle. In figure 10, the normalized amplitudes of the side lobes are reduced only 21% by including low frequencies, which is much smaller reduction comparing to the Stolt extende CIII results. The fact that RTM (CII) is less able to reduce side lobes with additional low frequency data indicates and quantifies how RTM (CII) is a high frequency approximation and how that property leads to less resolved reflector compared to a Stolt extended CIII migration. We expect that resolution difference will be significantly greater when the high frequency one-way implementation for heterogeneous medium used in RTM (CII), is compared with the two-way at every point propagation in our new Stolt extended CIII for heterogeneous medium (equation 4).

## CONCLUSION

Here we produced the first direct comparison of structural resolution differences with data with and without low frequencies, using the same homogeneous velocity model, comparing the current leading edge RTM (Claerbout II imaging principle) and the Stolt extended CIII migration. There are two factors that contribute to these differences: (1) is the imaging condition itself and (2) the wave propagation model. In current leading-edge migration methods both the imaging condition and the wave propagation model are each separately making high frequency approximations. In the new imaging method from M-OSRP both the imaging condition and method of implementation are equally effective at all frequencies at the target and reservoir (Weglein et al. (2016)). When broadband data is collected over the same area as a conventional band width data, and migrated with the same velocity and algorithm, the data has a different spectrum and shape, but the images at the target and amplitude analysis often show less than the hoped for difference compared to the conventional bandwidth data. There are side lobes in the structural image due to the missing low frequencies. With the new imaging method (Stolt extended CIII for heterogeneous media) and including low frequencies in the input data the side lobes reduced 57% (from 0.33 to 0.14) whereas the conventional leading edge RTM (CII) only reduced the side lobes by 21% (from 0.78 to .62). The new imaging method is able to benefit from broadband data for structural resolution improvement to a much greater extent than the current best industry standard. These tests will continue and will include analysis and comparisons for amplitude analysis. This comparison only tested differences in structural resolution due to the one factor, the imaging condition and focused on a single reflector. Part II of this two part paper, will examine resolution differences for a wedge. The next planned tests will include the wave propagation model for a smooth velocity model. The differences in resolution derived from the new imaging method will be greater when both imaging principle and wave propagation model are included than we report here for only the imaging principle differences.

## ACKNOWLEDGMENTS

We would like to thank Dr. Jim Mayhan for his suggestions and help for editing this paper. We are grateful to all M-OSRP sponsors for encouragement and support in this research. We would like to thank all our coworkers for their help in reviewing this paper and valuable discussions.

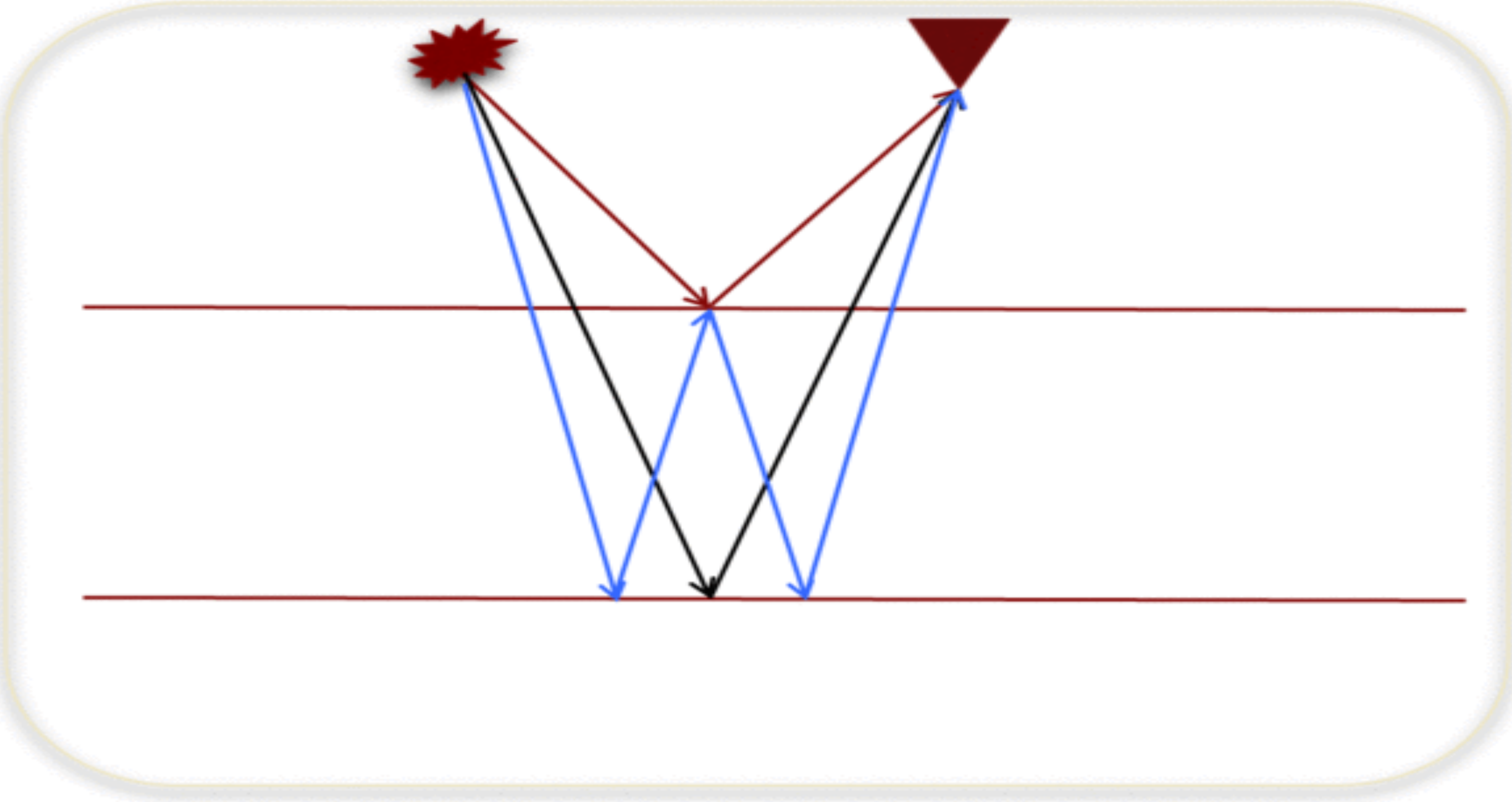
1. Given an accurate discontinuous velocity model above a reflector, free surface and internal multiples will provide neither benefit nor harm in migration and migration-inversion and need not be removed

2. For a smooth velocity model above a reflector, multiples will produce false images and hence must be removed prior to migration.
    - the industry standard smooth migration velocity model drives the need to remove free surface and internal multiples
    - the distinct inverse scattering series algorithms for removing free surface and internal multiples are the only methods that do not require subsurface information

*http://www.mosrp.uh.edu/news/key-note-address-at-the-seg-koc-workshop-dec-3-5-2019*

# New Stolt CIII migrating through layers

Case 1: two primaries and an internal multiples



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- **Only primaries** are migrated
- **Two types of primaries**
  1. Recorded primaries
  2. Unrecorded primaries

- Multiples can be used at times to provide an approximate image of an unrecorded primary

- In the evolution of seismic processing, methods have been developed to attempt to address issues caused by less that the necessary data
  - 2D data collection plus asymptotics for a 3D earth
  - Single component on-shore acquisition
  - Single cable methods to do wave separating and deghosting

- Eventually, there is no option but to advance the acquisition and provide the required data.

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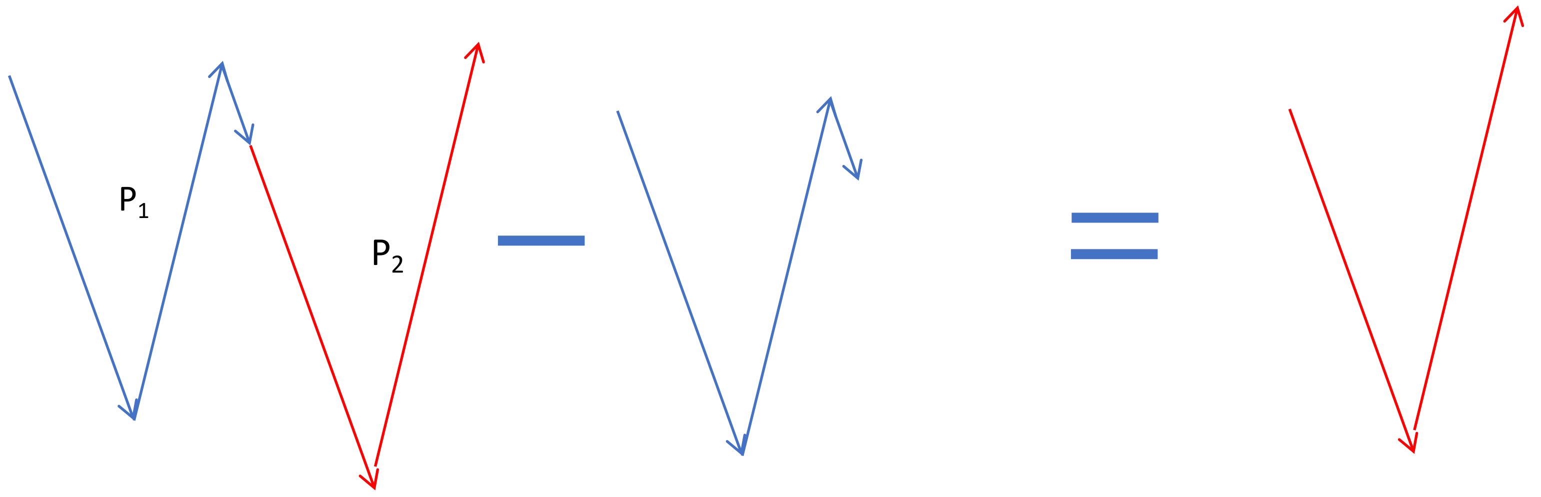
**Hence, with an accurate discontinuous velocity model, only recorded primaries contribute to migration and inversion, and only primaries are signal**. For a smooth velocity model, it is possible to correctly locate primaries in depth, but all multiples (if not removed) will result in artifacts and spurious images.

For smooth velocities, multiples produce false images and must be removed in any migration of primaries and multiples.

- What if we have a incomplete recording of primaries, i.e., some primaries are recorded and some are not.

# Seeking an approximate image of an unrecorded primary that is a subevent of a recorded multiple

- <u>Usage of a recorded multiple</u>




Decompose the composite

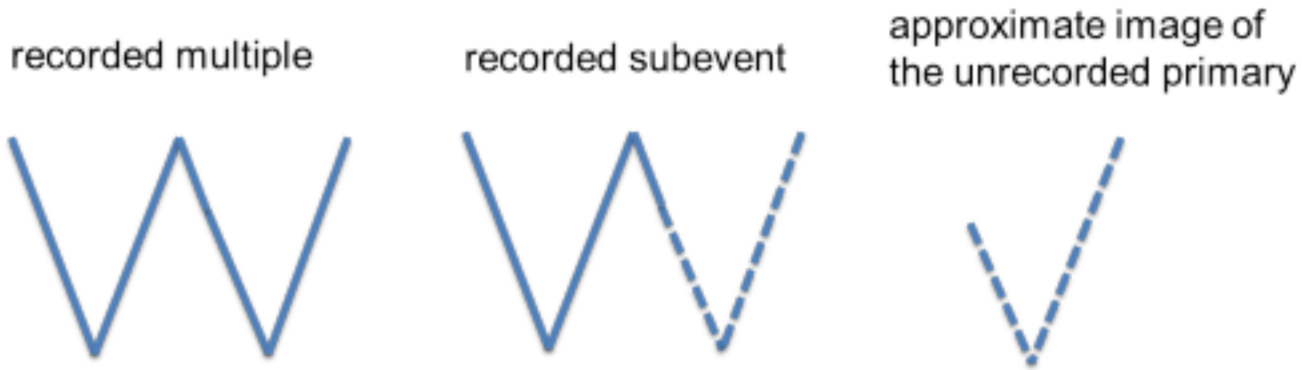
$M$ — Recorded

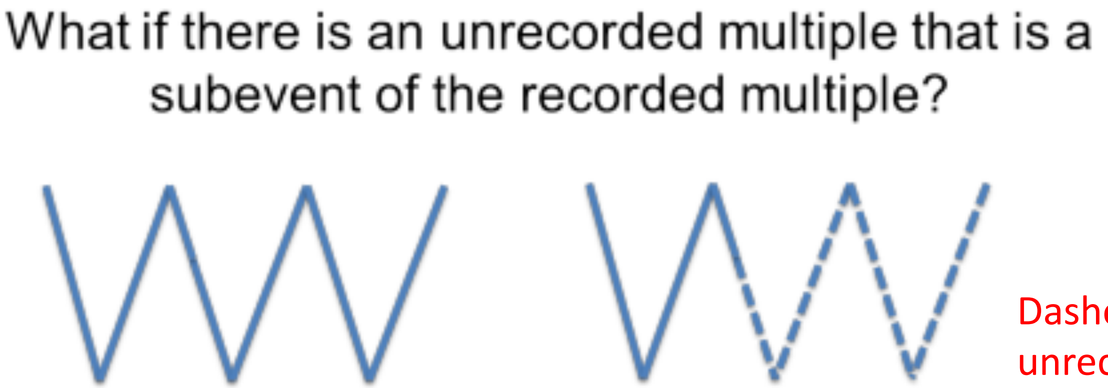
$P_1$ — Recorded

$P_2$ — Image of $P_2$ is approximated from M and $P_1$

To find an approximate image of unrecorded primary $P_2$

# What if the unrecorded subevent of the multiple is not a primary?




Dashed event is an unrecorded multiple

Using a recorded multiple to find an approximate image of an unrecorded primary of the multiple: illustrates the need to remove unrecorded multiples. A solid line ( ) is a recorded event, and a dashed line ( ) connotes an unrecorded event.

# The unrecorded multiple subevent will produce an imaging artifact

What if there is an unrecorded multiple that is a subevent of the recorded multiple?

Dashed event is an unrecorded multiple

- Therefore to image recorded primaries, recorded multiples must be removed and to find an approximate image of an unrecorded primaries, unrecorded multiples must be removed.

- A multiple is only useful if it has a recorded subevent that corresponds to an unrecorded primary.

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- To predict a recorded multiple requires recording <u>all</u> the subevents of the multiple. The use of multiples assumes a subevent of the multiple has <u>not</u> been recorded.

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- To predict a recorded multiple requires recording all the subevents of the multiple. The use of multiples assumes a subevent of the multiple has not been recorded.

- To use a multiple, we need to be able to predict a multiple.

- If a multiple is predictable it has no use. If a multiple is useful it cannot be predicted.

- Treating the entire data set of primaries and multiples as though they were unpredictable multiples is the origin of a problem called ‘cross-talk’. All primaries and all predictable multiples will cause artifacts, when seeking to use an unpredictable multiple.

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- To predict a recorded multiple requires recording all the subevents of the multiple. The use of multiples assumes a subevent of the multiple has not been recorded.

- We often hear that multiples are needed to improve upon the illumination provided by primaries.

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- To predict a recorded multiple requires recording <u>all</u> the subevents of the multiple. The use of multiples assumes a subevent of the multiple has <u>not</u> been recorded.

- We often hear that multiples are needed to improve upon the illumination provided by primaries.

- A response begins with paraphrasing a famous quote by Jon Claerbout ‘waves (and primaries) in the subsurface are ubiquitous, they go everywhere, and they have no illumination issues’

- However, methods that are used to process and image recorded data can make asymptotic or ray theory like assumptions --- and these methods result in illumination issues (Kirchhoff migration, and all RTM methods, including LSRTM are ray theory and high frequency approximation based.)

- And hence migration methods (like e.g., RTM and LSRTM) generate and create resolution and illumination issues that discount and diminish the information in recorded seismic data.

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- And hence migration methods (like e.g., RTM and LSRTM) generate and create resolution and illumination issues that discount and diminish the information in recorded seismic data.

- Multiple removal is as permanent as the inability to find an accurate discontinuous velocity model. Multiple usage provides something less than what a corresponding recorded primary can deliver with SCIII. Missing data fixes always diminish as acquisition becomes more complete.

- Only recorded primaries can provide SCIII imaging benefits. Multiple removal is a permanent and multiple usage is transient. In the near term, we encourage progress and advance on both.

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- Only recorded primaries can provide SCIII imaging benefits. Multiple removal is a permanent and multiple usage is transient. In the near term, we encourage progress and advance on both.

- SCIII migration requires recorded primaries and has advantages for resolution, amplitude analysis and illumination compared to RTM and Kirchhoff.

# Multiple removal: an update

- In the history of the seismic processing as methods for imaging and multiple removal became more capable, they had a commensurate increase in the need for subsurface information
- That evolution ran into a problem as the industry trend to deep water and a more complex geologic on-shore and off-shore plays made that requirement difficult or impossible to satisfy.
- The Inverse Scattering Series (ISS) communicates that all processing objectives can be achieved directly and <u>without subsurface information</u>
- Isolated ISS task-specific subseries were developed
  - Free-surface multiple elimination
  - Internal multiple attenuation/elimination
  - Q compensation without knowing Q
  - Depth imaging
  - Inversion (parameter estimation)

- More effective prediction is required when multiples interfere with or are proximal to other events
    - ISS free-surface multiple elimination rather than SRME
    - ISS internal multiple elimination

# ISS free-surface multiple elimination (Carvalho and Weglein, 1991, Weglein et al 1997,2003)

$$D'(k_g, k_s, \omega) = \sum_{n=1}^{\infty} D_n{}'(k_g, k_s, \omega)$$

$$D_n'(k_g, k_s, \omega) = \frac{1}{2\pi A(\omega)} \int dk \, e^{iq(z_g+z_s)} D_1'(k_g, k, \omega)(2iq) D_{n-1}{}'(k, k_s, \omega)$$

$$\text{n} = 2,3,4, \ldots$$

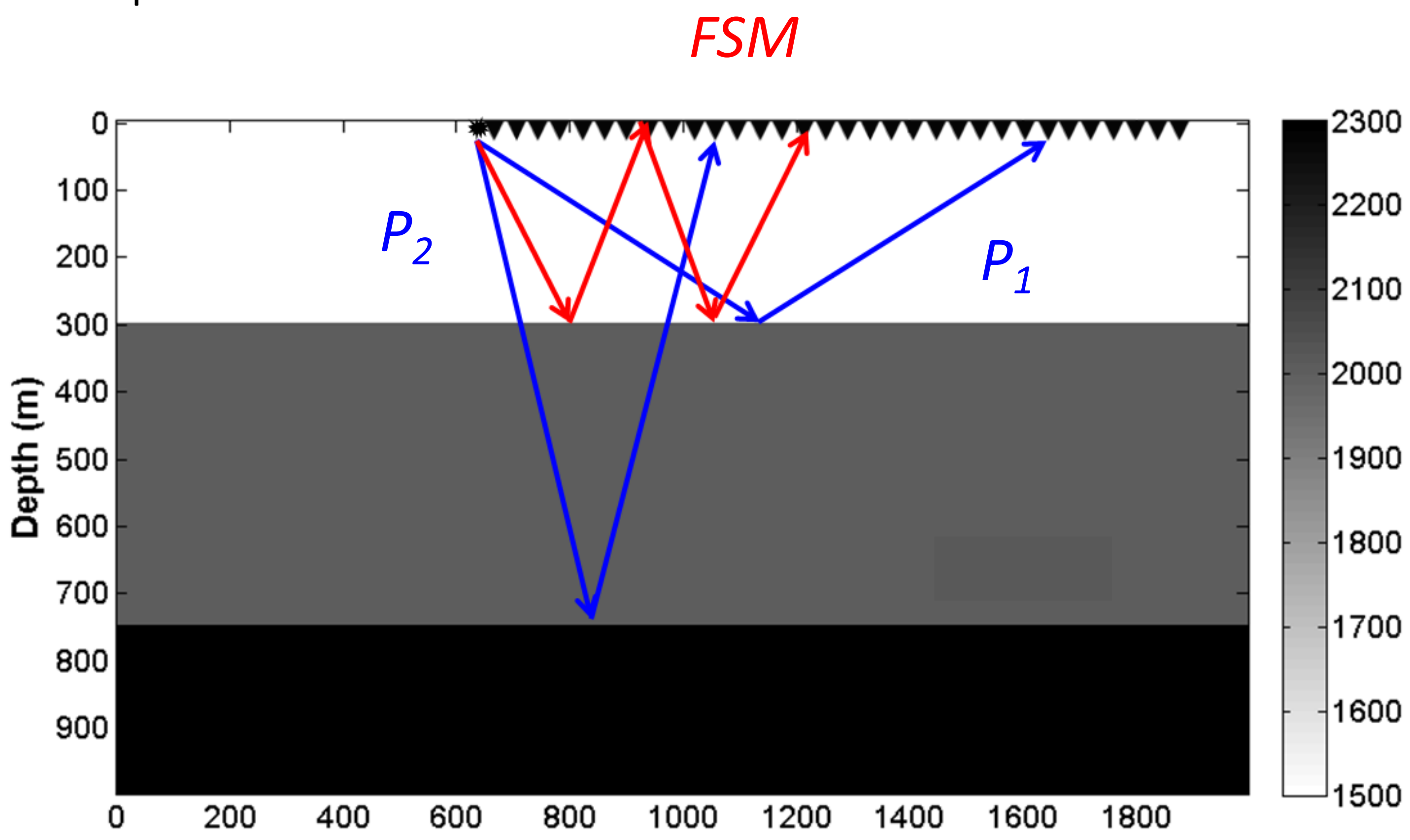
- The input $D_1{}'(k_g, k_s, \omega)$, in a 2D case, which are the Fourier transform of the deghosted prestack data, and with the direct wave removed.
- The output $D'(k_g, k_s, \omega)$ are free-surface multiple eliminated data.

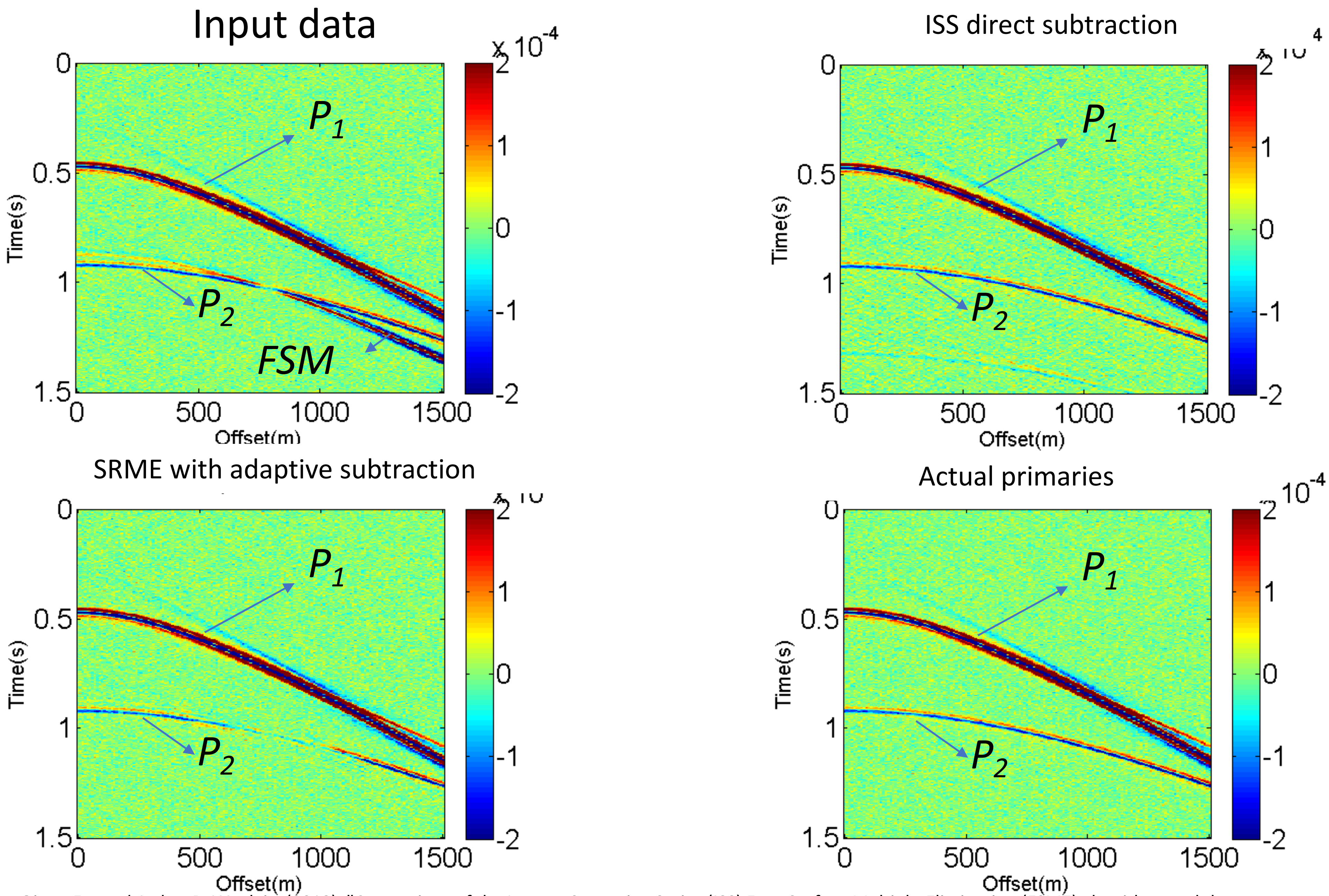
# SRME (Berkhout, 1985; Verschuur, 1991)

$$M(x_g, x_s, \omega) = \int D'_1(x_g, x, \omega)D'_1(x, x_s, \omega)$$

Conclusion: SRME can be an effective choice for isolated FS multiples. For proximal or interfering free−surface multiples, ISS FS elimination (that doesn't rely on an energy minimization adaptive subtraction) can be the more effective and appropriate choice.

Model used to generate the test data for the comparison between the ISS Free-surface multiple elimination and SRME






$P_1$: *first primary*

$P_2$: *second primary*

*FSM: free surface multiple*

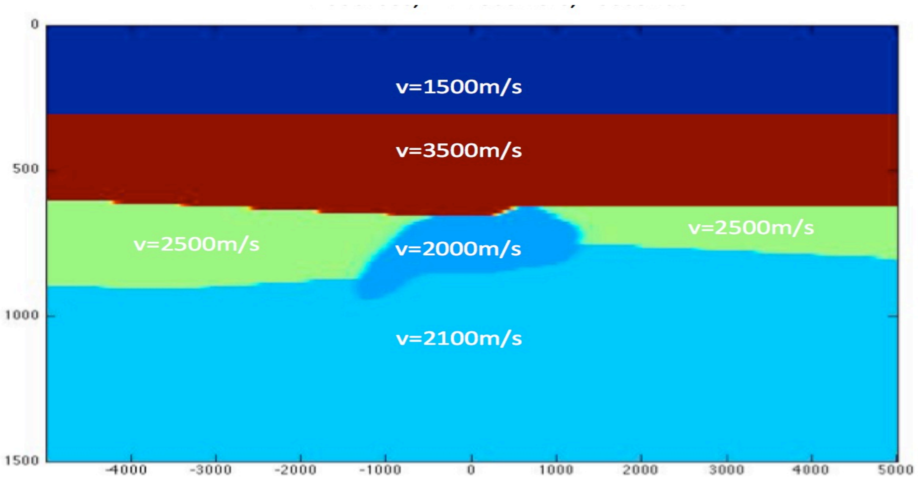
*Chao Ma, Qiang Fu, and Arthur B. Weglein,* (2019), "Comparison of the Inverse Scattering Series (ISS) Free-Surface Multiple-Elimination (FSME) algorithm, and the industry-standard SRME: Defining the circumstances where each method is the appropriate tool-box choice," *GEOPHYSICS*

# A sampling of the documented impact of the ISS internal multiple attenuation algorithm from M-OSRP

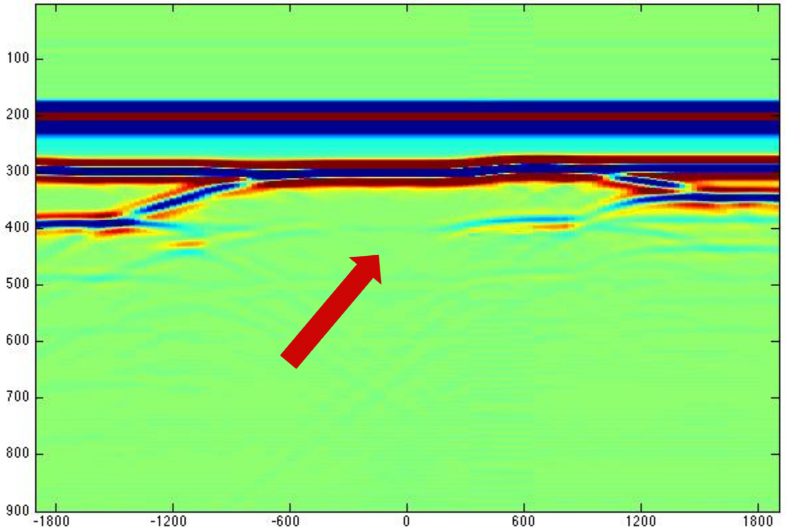
- Service companies
    - Dragoset,2013 (Schlumberger)
    - Frederico Xavier de Melo et al.,2013 (Schlumberger)
    - Griffiths et al., 2013 (CGG)
    - Hegge et al.,2013(PGS)
    - Hung and Wang, 2014 (CGG)
    - Wu et al, 2019, Espinoza et al, 2019 (Schlumberger)
- Oil companies
    - Matson et al., 2000 (ARCO) first marine field data test
    - Yi Luo et al., 2010 (Aramco) first on-shore field data test
    - Qiang Fu et al., 2010 (Aramco/UH )
    - Degang Jin et al., 2013 (CNPC)
    - Ferreira et al., 2013(Petrobras)
    - Goodway (Apache) and Mackidd (Encana), 2013
    - Kelamis et al.,2013 (Aramco)

# Multi-Dimensional ISS internal multiple elimination (numerical test )

model



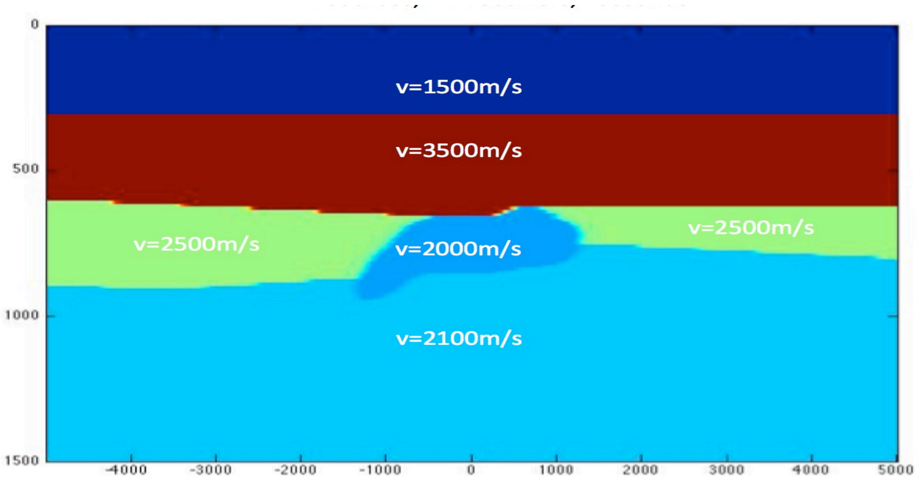

after internal multiple attenuation
+ energy minimization adaptive subtraction
(0-offset traces)



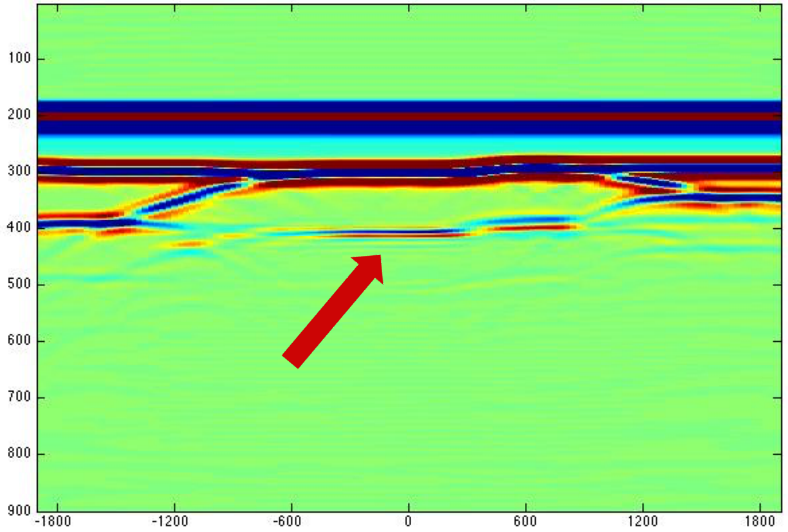

**For the case of an interfering internal multiple and base salt primary, the ISS internal multiple attenuation + adaptive damage the base salt primary**
(*Yanglei Zou, Chao Ma and A. Weglein*, 2019, SEG Abstract, 4525-4529)

# Multi-Dimensional ISS internal multiple elimination (numerical test )

model




**after internal multiple elimination (0-offset traces)**



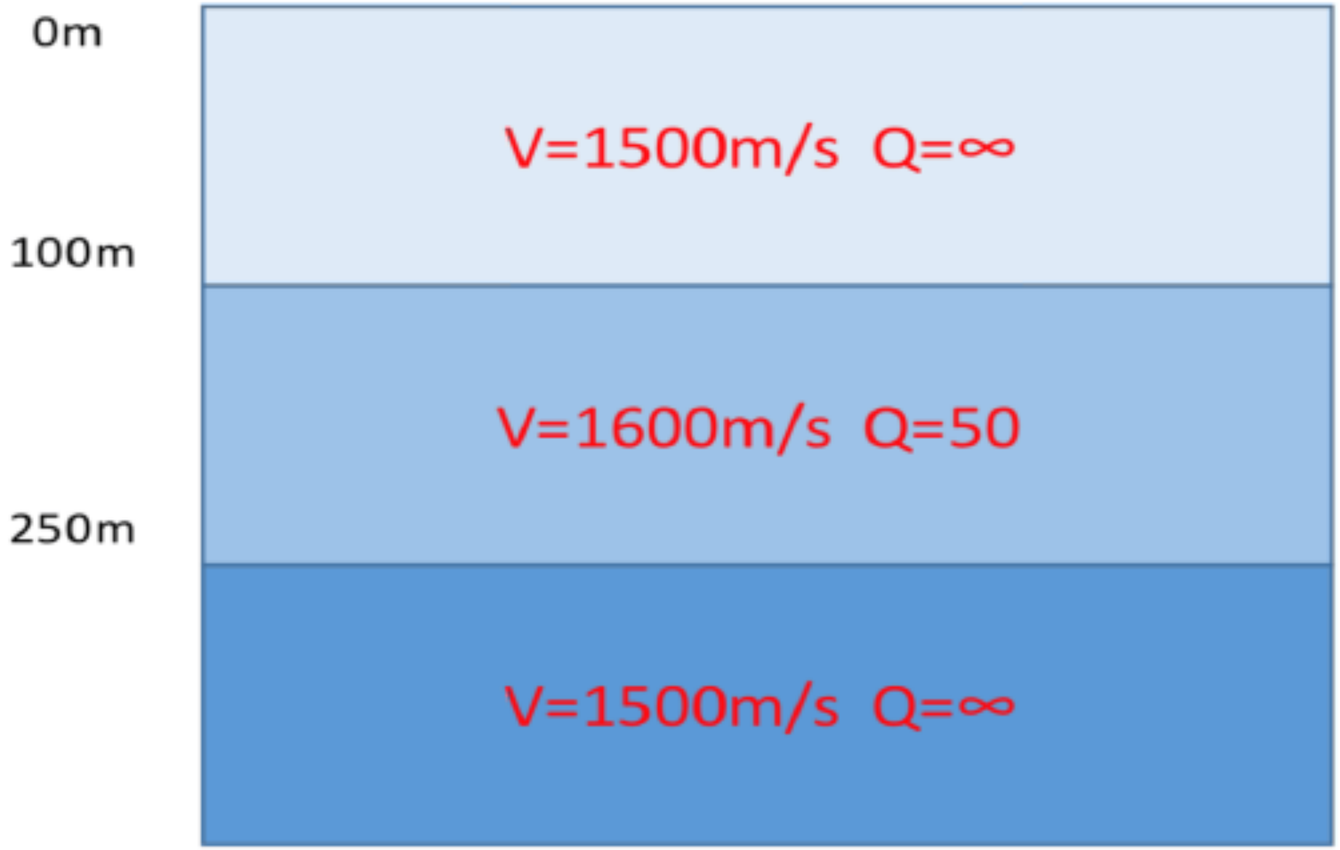

**For the case of an interfering internal multiple and base salt primary, the ISS internal multiple elimination without damaging the interfering base salt primary**

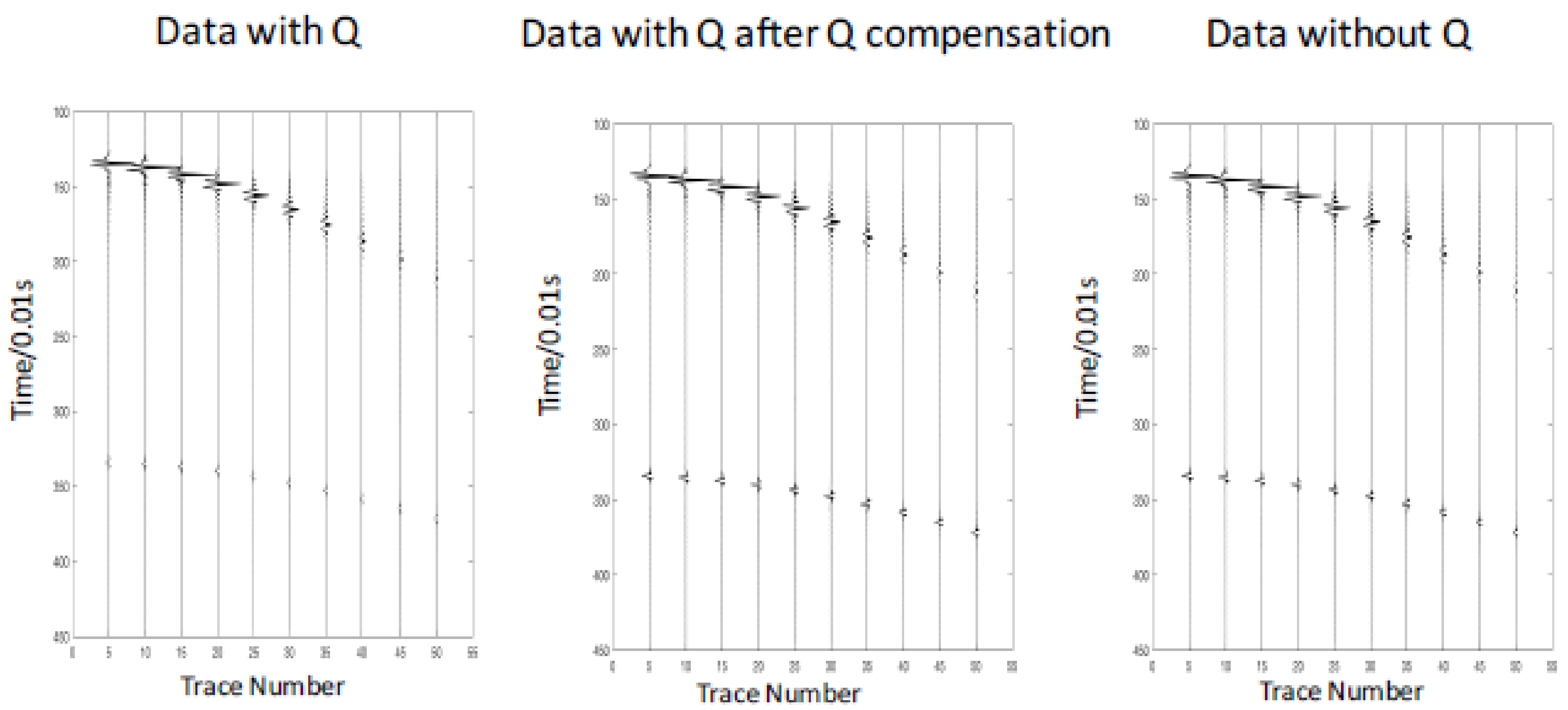
(*Yanglei Zou, Chao Ma and A. Weglein*, 2019, SEG Abstract, 4525-4529)

# ISS Q compensation without knowing or estimating Q

(Zou and Weglein, JSE, Dec. 2018)

## Two-reflector model for Q compensation without Q






Left: Data generated by the model with Q. Middle: The data (with Q) after ISS Q compensation without Q
Right: Data generated by the same model but without Q.

Yanglei Zou and Arthur Weglein 2018

# Conclusions

- Removing and using multiples have the same exact goal: imaging primaries (recorded and unrecorded primaries, respectively).
- As long as imaging methods use a smooth velocity model, multiples will cause artifacts and must be removed --- hence, for recorded primaries, recorded multiples must be removed, and for unrecorded primaries, unrecorded multiples must be removed.
- Even if a recorded multiple is useful, it must be removed before imaging recorded primaries.
- For multiple removal, only the methods derived from the ISS can predict the precise time and amplitude of all free-surface multiples and internal multiples, directly and without subsurface information.
- We suggest that if one is serious about removing internal multiples, that use of the ISS FSME is indicated, to assure that primaries and internal multiples enter the ISS IME for eliminating internal multiples.
- The ISS internal multiple elimination algorithm adds a new and more capable toolbox option for removing an internal multiple under the circumstances where the internal multiple can interfere or be proximal to other events (e.g., primaries) without damaging the primary.

# Conclusions

- This new tool-box option is called for in many off-shore and on-shore plays (e.g., the Middle East, the North Sea, offshore Brazil and Australia, and the Permian Basin).

- A recent development from M-OSRP provides all pre-processing and processing objectives without needing subsurface and near-surface information to be provided, estimated or determined. This overcomes a major current obstacle for on-shore processing and conventional and unconventional plays.

# Conclusions

- An added note for the **2019 SEG/KOC Workshop: Challenges and a Way Forward**
- We recognize that there are always open issues and challenges — and we encourage and welcome new ideas, concepts and methods that have the potential to address them —
- But we strongly recommend that research begins by defining carefully  what is the shortcoming of the current tool box of methods and the collective and individual capability that the research program is seeking to address.  And what open issues and challenges are being addressed , what new capability and relevant added value will be contributed to the toolbox if the research program is successful, and what E&P circumstances will be accommodated that are now beyond our tool box range and scope
- What specifically is the response to the latter relevant added value and tool box contribution beyond current options, for example, in the Marchenko and Interferometry research activities and programs.
- Providing that perspective and information would help the SEG community understand the relevant added value that these approaches seek to provide, and we would all appreciate and benefit from that clarity and understanding.

Seismic Imaging and Inversion: Application of Direct Non-linear Inverse Theory

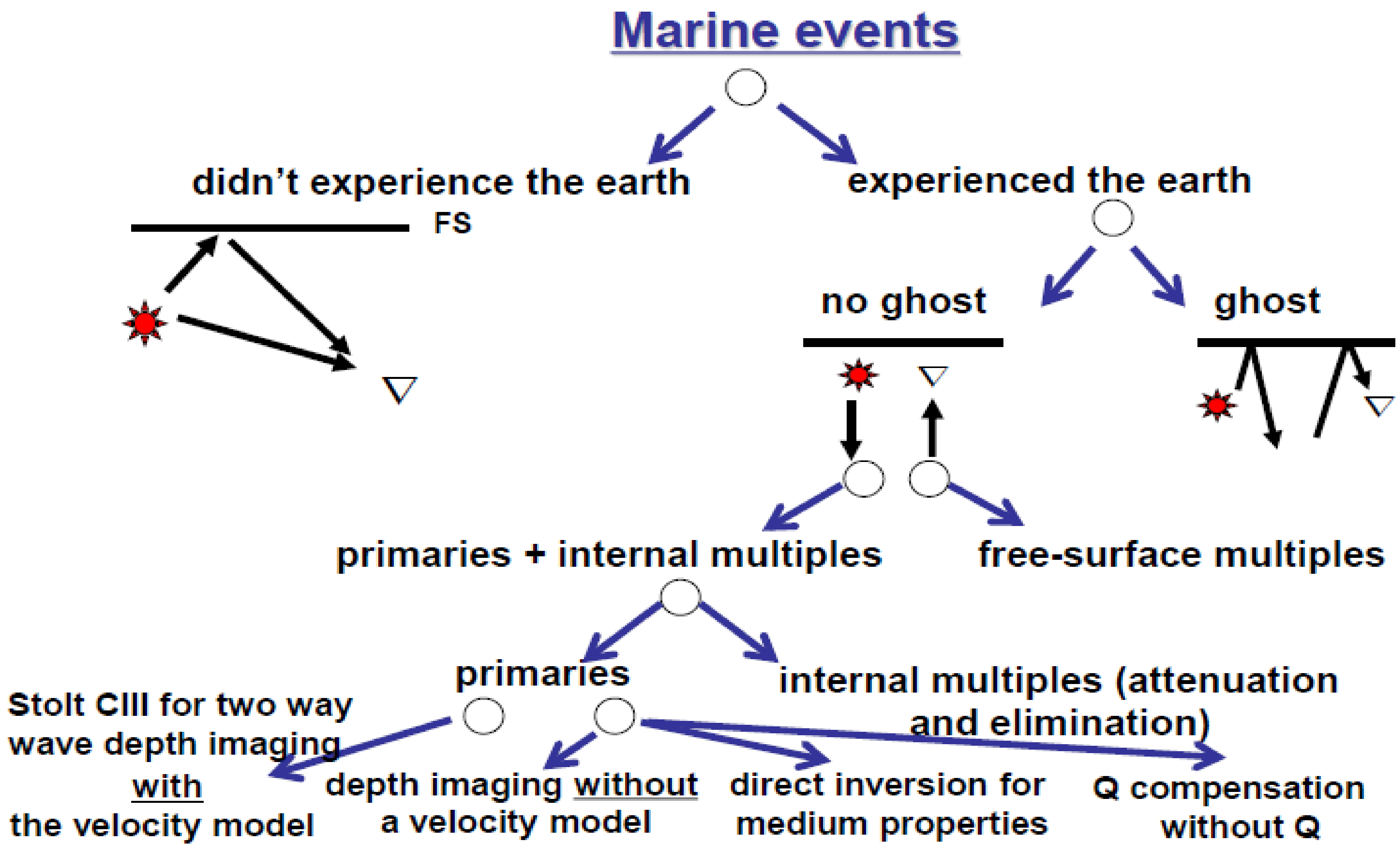



Figure 1: The road map for "Seismic Imaging and Inversion: Application of Direct Nonlinear Theory"

# M-OSRP goals, projects and deliverables

- http://mosrp.uh.edu/news/m-osrp-arthur-b-weglein-2019-2020
- http://mosrp.uh.edu/news/papers-and-presentations-documenting-m-osrp-goals-focus-plans-delivery-and-impact
- http://mosrp.uh.edu/news/m-osrp-strategy-and-plan-for-continued-high-impact-seismic-development-and-delivery-11-27-18
- http://arthurbenjaminweglein.com
- https://drive.google.com/file/d/13Nv0MDJKDjxPYsQdBQ95stC3

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