PREPROCESSING IN *DISPLACEMENT SPACE* IN PREPARATION FOR ONSHORE SEISMIC PROCESSING: REMOVING GROUND ROLL AND GHOSTS WITHOUT DAMAGING THE REFLECTION DATA

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MOTIVATION

• Preprocessing
  ✓ is required for all land seismic data processing
Ground roll (Rayleigh wave)
Boustani et al., 13

Direct wave

Ground roll
(Rayleigh wave)
Ghosts exist in reflection.

Ground roll (Rayleigh wave) exist in reflection.

Direct wave

Boustani et al., 13
Ghosts exist in reflection

Preprocessing to separate these events from upgoing reflection

Boustani et al., 13

Direct wave

Ground roll (Rayleigh wave)
MOTIVATION

• Preprocessing
  ✓ is required for all land seismic data processing
  ✓ provides necessary prerequisite for Inverse Scattering Series (ISS) multiple removal, which is the most capable method available today and does not need any subsurface information
IMPACT OF DEGHOSTING ON ISS MULTIPLE REMOVAL

( Jinlong Yang, 14; P. Carvalho and A. Weglein, 92; Jingfeng Zhang, 05, 06, 07 )
IMPACT OF DEGHOSTING ON ISS MULTIPLE REMOVAL

Input data with ghosts

Multiple removal result

( Jinlong Yang, 14; P. Carvalho and A. Weglein, 92; Jingfeng Zhang, 05, 06, 07 )
IMPACT OF DEGHOSTING ON ISS MULTIPLE REMOVAL

Input data **without** ghosts

Multiple removal result

( Jinlong Yang, 14; P. Carvalho and A. Weglein, 92; Jingfeng Zhang, 05, 06, 07 )
DELIVERABLE OF THIS TALK

• For onshore seismic processing, with the energy source above the measurement surface, elastic Green’s theorem can arrange to remove all direct waves, the receiver ghosts and the ground roll at once.
OUTLINE

- THEORY
- NUMERICAL TESTS
- DISCUSSION AND SUMMARY
THEORY
GREEN’S THEOREM WAVE SEPARATION

\[ P = P_1 + P_2 \]
GREEN’S THEOREM WAVE SEPARATION

\[ P = P_1 + P_2 \]

\[ P_1 = \int (P \nabla' G_0 - G_0 \nabla' P) \cdot \hat{n} dS' \]

Reference medium

\( S_1 \)

\( S_2 \)

\( P_1 \)

\( P_2 \)

\( S' \)

(A. Weglein and B. Secrest, 90; A. Weglein, 02; J. Zhang, 05, 06, 07; J. Mayhan, 12, 13; L. Tang, 13)
ONSHORE: 2D EXPERIMENT

Source

\((F_x, F_z)\)

Receiver

\((u_x, u_z)\)

Air

Earth

F. S.
ONSHORE: 2D EXPERIMENT

Air

Earth

\((F_x, F_z)\)

\((u_x, u_z)\)

F. S.

M. S.

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ONSHORE: REFERENCE MEDIUM
ONSHORE: REFERENCE MEDIUM + 3 SOURCES + RECEIVERS

(sources)
ONSHORE: REFERENCE MEDIUM
ONSHORE: REFERENCE MEDIUM + SOURCES

✓ $S_1 + S_2$ generate direct wave

\[ (F_x, F_z) \]
ONSHORE: REFERENCE MEDIUM + SOURCES

✓ $S_1 + S_2$ generate ground roll

![Diagram showing the interaction between $S_1$, $S_2$, and the medium, with forces $F_x$, $F_z$, and the elastic medium.]

F. S.
M. S.
**ONSHORE: REFERENCE MEDIUM + SOURCES**

✓ $S_1 + S_2$ generate **ghosts**

![Diagram showing the interaction of sources $S_1$ and $S_2$ with a reference medium and air, generating (F_x, F_z).](image)
ONSHORE: REFERENCE MEDIUM + SOURCES

✓ $S_3$ generates up reflections
ONSHORE: REFERENCE MEDIUM + 3 SOURCES + RECEIVERS
ONSHORE: OBTAIN UP WAVE WHEN $\vec{r}$ IS ABOVE M.S.
ONGHORE: **UP WAVE PREDICTION**

2D:

$$
\bar{u}^{up}(\bar{r}, \bar{r}_s, \omega) = - \int_{m.s.} \left( \tilde{t}(\bar{r}', \bar{r}_s, \omega) \cdot G_0(\bar{r}', \bar{r}, \omega) - \bar{u}(\bar{r}', \bar{r}_s, \omega) \cdot \left( \hat{n} \cdot \Sigma_0(\bar{r}', \bar{r}, \omega) \right) \right) \cdot dS
$$

(Wegelein and Secrest, 1990)

\[ \bar{u} = (u_x, u_z) \] Total wave

\[ \tilde{t} = (t_x, t_z) \] Traction along the m.s.

\[ \bar{u}^{up} = (u_x^{up}, u_z^{up}) \] Up wave

\[ G_0 \] Green’s tensor in reference medium

\[ \Sigma_0 \] Stress tensor of Green’s function
ONSHORE: UP WAVE PREDICTION

2D:

\[ \vec{u}^{up}(\vec{r}, \vec{r}_s, \omega) = - \int_{m.s.} \left( \vec{t}(\vec{r}', \vec{r}_s, \omega) \cdot G_0(\vec{r}', \vec{r}, \omega) - \vec{u}(\vec{r}', \vec{r}_s, \omega) \cdot \left( \hat{n} \cdot \Sigma_0(\vec{r}', \vec{r}, \omega) \right) \right) \cdot dS \]

\[ \text{( Weglein and Secrest, 1990 )} \]

\[ \vec{u} = \left( \begin{array}{c} u_x \\ u_z \end{array} \right) \quad \text{Total wave} \]

\[ \vec{t} = \left( \begin{array}{c} t_x \\ t_z \end{array} \right) \quad \text{Traction along the m.s.} \]

\[ \vec{u}^{up} = \left( \begin{array}{c} u_x^{up} \\ u_z^{up} \end{array} \right) \quad \text{Up wave} \]

✓ Directional derivative of displacement is required to compute traction

✓ Triangle relationship among wavelet, displacement and traction can be used to determine traction \( (\text{A. Weglein & L. Amundsen, 2002}) \)
ONSHORE: UP WAVE PREDICTION

2D:

\[
\ddot{u}^{up}(\vec{r}, \vec{r}', \omega) = - \int_{m.s.} \left( \ddot{t}(\vec{r}', \vec{r}, \omega) \cdot G_0(\vec{r}', \vec{r}, \omega) - \ddot{u}(\vec{r}', \vec{r}, \omega) \cdot (\hat{n} \cdot \Sigma_0(\vec{r}', \vec{r}, \omega)) \right) \cdot dS
\]

( Weglein and Secrest, 1990 )

\[
\ddot{u} = \begin{pmatrix} u_x & u_z \end{pmatrix} \quad \text{Total wave}
\]

\[
\ddot{t} = \begin{pmatrix} t_x & t_z \end{pmatrix} \quad \text{Traction along the m.s.}
\]

\[
\ddot{u}^{up} = \begin{pmatrix} u_x^{up} & u_z^{up} \end{pmatrix} \quad \text{Up wave}
\]

\[
G_0 \quad \text{Green's tensor in reference medium}
\]

\[
\Sigma_0 \quad \text{Stress tensor of Green's function}
\]
NUMERICAL TESTS

✓ Onshore shot record with buried receivers
✓ Onshore shot record with on-surface receivers
ONSHORE MODEL WITH BURIED RECEIVERS

Layer | P Velocity (m/s) | S Velocity (m/s) | Density (kg/m³) |
--- | --- | --- | --- |
1 | 1800 | 1200 | 1500 |
2 | 4000 | 2500 | 1800 |
\( u_x \) TOTAL WAVE INPUT TO SEPARATION ALGORITHM

![Graph showing waves and time as a function of depth and offset](image)

- Time/s
- Offset/m
- Depth of receivers at 100 m

Values:
- \(-5\times10^{-12}\) to \(5\)
- \(-2000\) to \(2000\) Offset/m
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

Offset/m

Direct

Direct

Time/s

 Depth of receivers at 100 m

-2000 0 2000
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

![Graph showing wave input to separation algorithm.](image)

- Depth of receivers at 100 m
- Time/s
- Offset/m

Rayleigh

Depth of receivers at 100 m
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

Offset/m

Time/s

Depth of receivers at 100 m
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

![Graph showing depth of receivers at 100 m with offset and time axes.]

- $\text{Depth of receivers at 100 m}$
- $\text{Offset/m}$
- $\text{Time/s}$

Ghosts
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

Offset/m

Time/s

Depth of receivers at 100 m

Direct
Rayleigh
Ghosts

Up

-2000 0 2000
SEPARATED X COMPONENT OF UP WAVE
ANALYTIC X COMPONENT OF UP WAVE

Depth of receivers at 100 m
SPECTRUM COMPARISON

- Total wave
- Separated up wave
- Analytic up wave
ONSHPRE MODEL WITH ON-SURFACE RECEIVERS

Layer | P Velocity (m/s) | S Velocity (m/s) | Density (kg/m³) |
------|-----------------|-----------------|----------------|
1     | 1800            | 1200            | 1500           |
2     | 4000            | 2500            | 1800           |
$u_x$ TOTAL WAVE INPUT TO SEPARATION ALGORITHM

![Graph showing total wave input to separation algorithm with depth of receivers at 0 m, offset/m, and time/s axes.]
SEPARATED X COMPONENT OF UP WAVE

Depth of receivers at 0 m vs Offset/m

Time/s

Depth of receivers at 0 m

Offset/m

-2000 0 2000

Up

10^{-11}
ANALYTIC X COMPONENT OF UP WAVE
DISCUSSION AND SUMMARY
FOR DIFFERENT ONSHORE WAVE SEPARATION OBJECTIVES

✓ If obtaining the upgoing reflection is the only interest, elastic Green’s theorem can remove both ground roll and ghosts at once;

✓ If separated ground roll / ghosts are useful for other applications, elastic Green’s theorem can provide them separately.

• A companion talk in SPNA-EP: Coherent Noise Removal, room229, Wednesday, 10/21/2015 10:00 AM
SUMMARY

- Elastic Green’s theorem in the displacement space can
  - remove ground roll, without damaging reflection data;
  - remove ghosts from reflection data;
  - provide effective preparation for all onshore seismic processing;
  - provide a necessary prerequisite for onshore ISS multiple elimination.
Thank you