UNIVERSITY OF CALGARY

CREWES

LSPSM / inversion for pre- and poststack time lapse studies

2012 CREWES
Sponsors' Meeting

Naser Yousefzadeh*, John Bancroft

Outline

I. Review on Least Squares PreStack Kirchhoff Migration (LSPSM)

II. Review on time lapse seismic/ challenges

III. Separate inversion

- Final section
- Prestack data

IV. Joint inversion

1. Multiple Image Joint Inversion
2. Image Difference Joint Inversion

V. Summary

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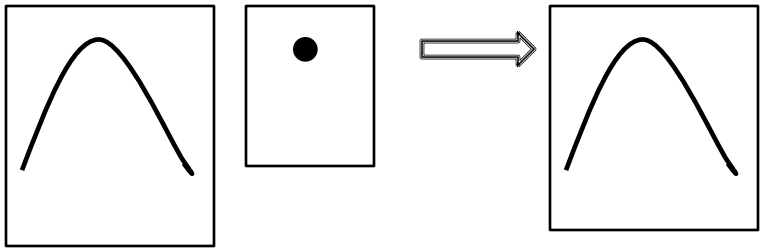
Kirchhoff Modeling/Migration

- **Modeling:** $Gm = d$



G **: Kirchhoff forward operator,**

m **: Reflectivity,**

d **: Real data.**

Kirchhoff Modeling/Migration

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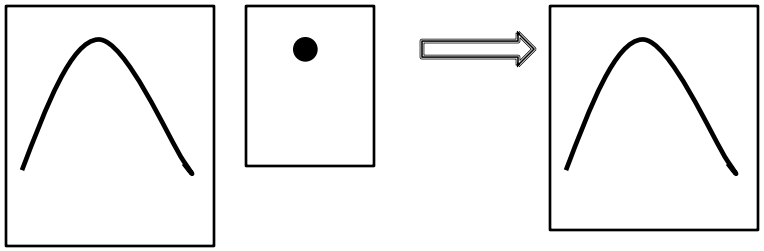
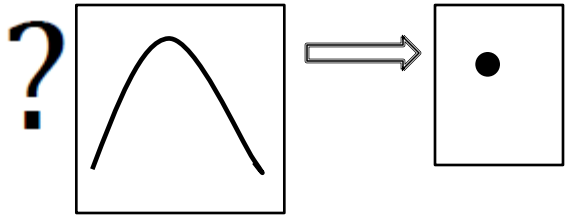


- **Inversion:** $G^{-1}d = m$



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Kirchhoff Modeling/Migration

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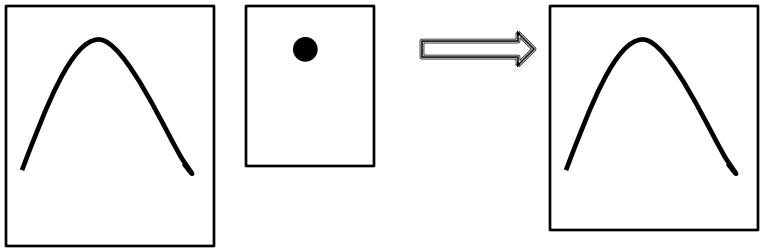

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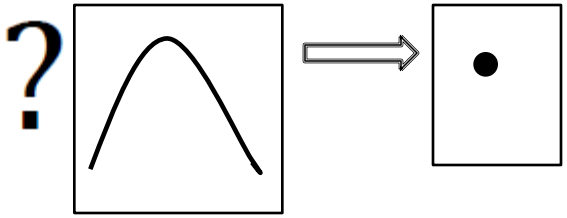
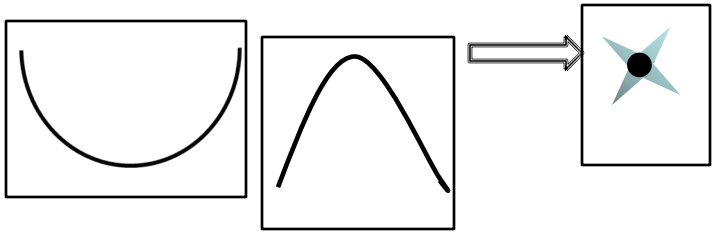


- **Migration:** $G^{T}d = \hat{m}$



G **: Kirchhoff forward operator,**

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LSPSM, how?

$$\boldsymbol{Gm} = \boldsymbol{d}$$ **(Modeling)**

$$\boldsymbol{G^T G\, m} = \boldsymbol{G^T d}$$

$$\boldsymbol{m} = (\boldsymbol{G^T G})^{-1} \boldsymbol{G^T d}$$ **(LSPSM)**

LSPSM, how?

$$\boldsymbol{Gm} = \boldsymbol{d}$$ **(Modeling)**

$$\boldsymbol{G^T G\, m} = \boldsymbol{G^T d}$$

$$\boldsymbol{m} = (\boldsymbol{G^T G})^{-1} \boldsymbol{G^T d}$$ **(LSPSM)**

- **Minimizing a general cost function:**

$$J(\boldsymbol{m}) = \underbrace{\|\boldsymbol{Gm} - \boldsymbol{d}\|^2}_{\text{Misfit term}} + \mu^2\, \mathcal{R}(\boldsymbol{m})$$

$\mathcal{R}$: Regularization term,

μ : Trade-off parameter

LSPSM, how?

$$\boldsymbol{G}\boldsymbol{m} = \boldsymbol{d}$$

$$\boldsymbol{G}^T\boldsymbol{G}\,\boldsymbol{m} = \boldsymbol{G}^T\boldsymbol{d}$$

$$\boldsymbol{m} = (\boldsymbol{G}^T\boldsymbol{G})^{-1}\boldsymbol{G}^T\boldsymbol{d}$$

Simplest solution: Damped LSM:

$$\boldsymbol{m}_{DLS} = (\boldsymbol{G}^T\boldsymbol{G} + \mu^2\boldsymbol{I})^{-1}\boldsymbol{G}^T\boldsymbol{d}$$

Nemeth et. al. (1999 ,2000) and Duquet et. al. (2000).

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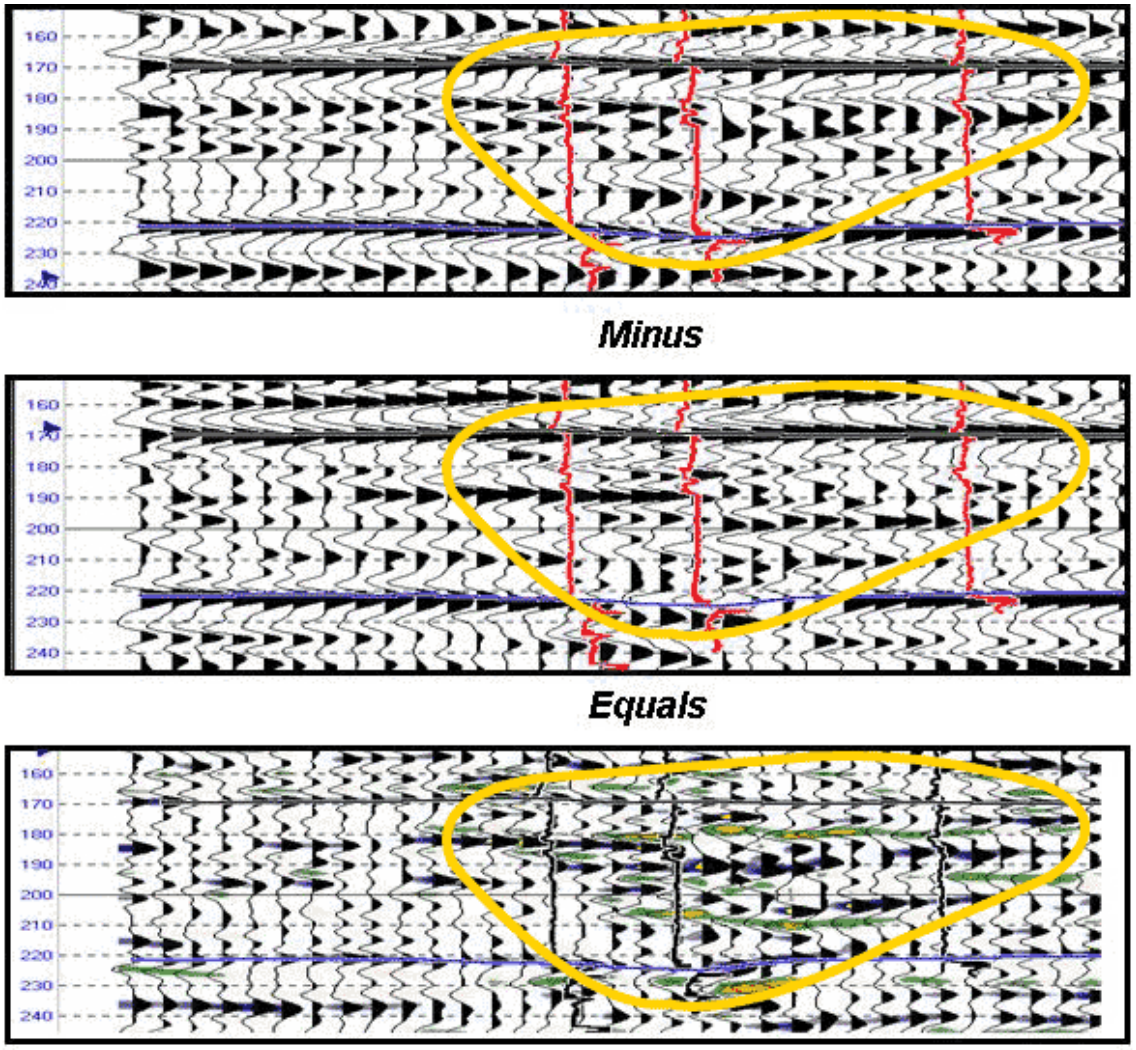
Time lapse seismic

- **Time lapse study of seismic data includes recording and analysing a secondary seismic survey after a period of time in order to detect the subtle changes in the physical properties of the hydrocarbon reservoirs.**

- **These changes can be due to changes in the fluid (oil, gas, water, steam, etc) saturation.**

Time lapse seismic terminology

- **Baseline survey**
- **Monitor survey**
- **Time lapse image**



http://www.accurategeotech.com/rss/time-lapse.html

Time lapse seismic challenges

- All acquisition geometries, instruments, environmental noises, near surface effects, and processing flows must be equivalent,
- Then differences in the migration images will be due to changes in the physical properties of the reservoir rocks/ fluids.

- Different acquisition geometries produce different patterns of the acquisition footprints.
- Resulting time lapse image may show the difference in artifacts, not changes in the model parameters.

Time lapse seismic challenges

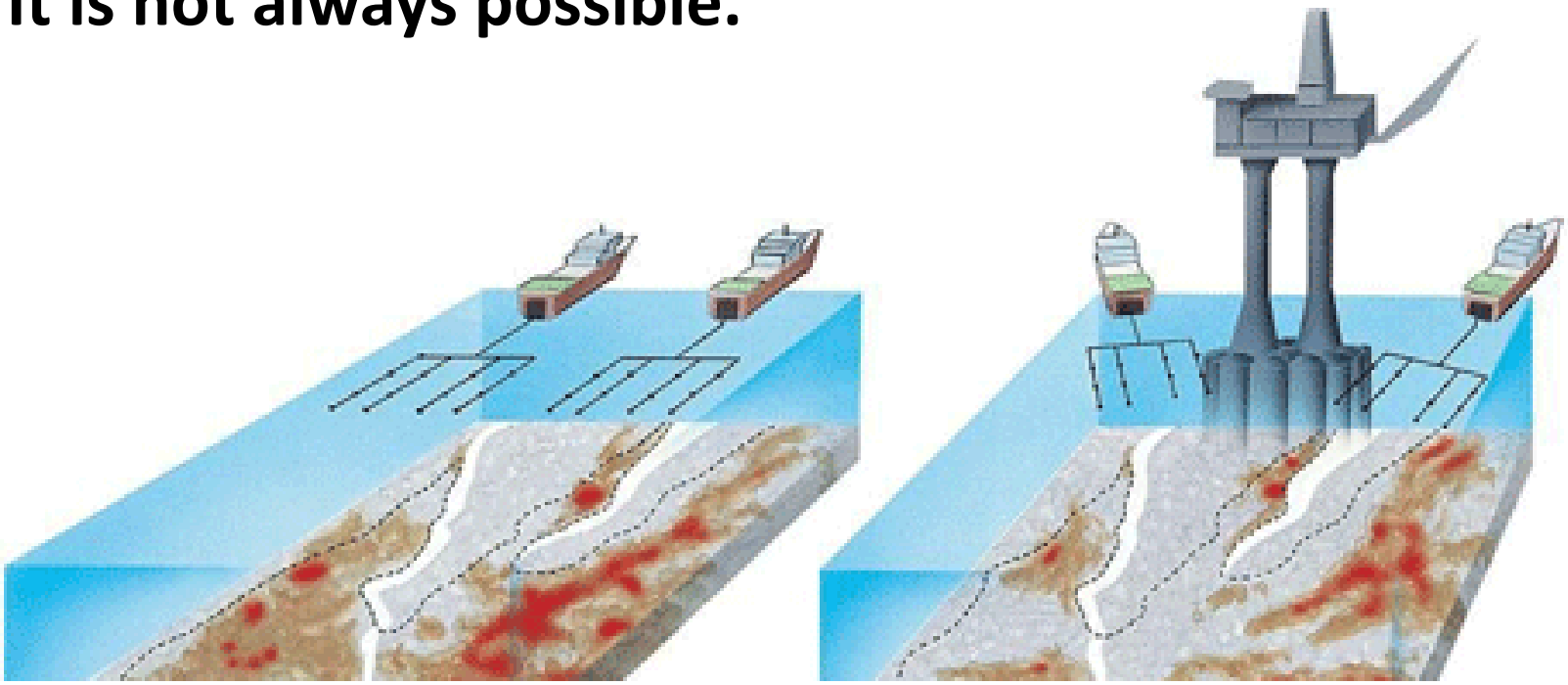
- **Repeating same geometry for baseline and monitor surveys is not always feasible:**
  - **New construction in land (& marine)**
  - **Marine streamers have feathering.**

- **OBC in marine , Cemented receivers in land:**
  - **effect of losing receivers by time.**

Time lapse seismic challenges

May use solid streamers, Q technology (Western Geophysical).

It is not always possible.



Baseline **Monitor**

www.Statoil.com

LSPSM/inversion of time lapse data

We are reducing the effects of different acquisition geometries

by

LSPSM/inversion of time lapse data

III. **Separate LSPSM/inversion of baseline and monitor surveys data.**

or

IV. **Joint LSPSM/inversion of baseline and monitor surveys data.**

LSPSM/inversion of time lapse data

III. **Separate LSPSM/inversion of baseline and monitor surveys data is used to**

1) **Remove the effect of having different acquisition geometries**
2) **Remove the effect of losing receivers in OBC**
3) **Increase the resolution of time lapse image**

LSPSM/inversion of time lapse data

III. **Separate LSPSM/inversion of baseline and monitor surveys data is used to**

1) **Remove the effect of having different acquisition geometries**
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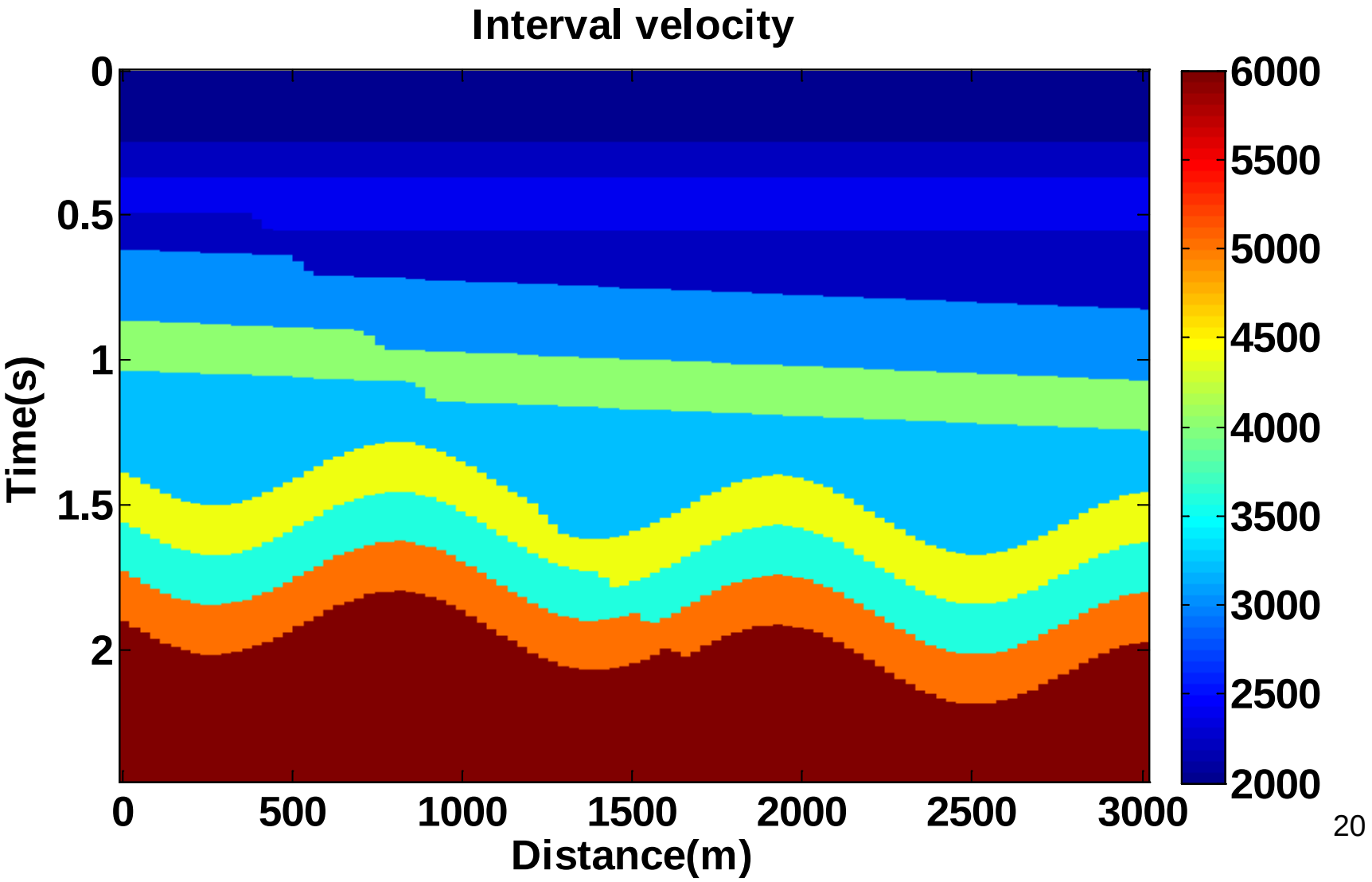
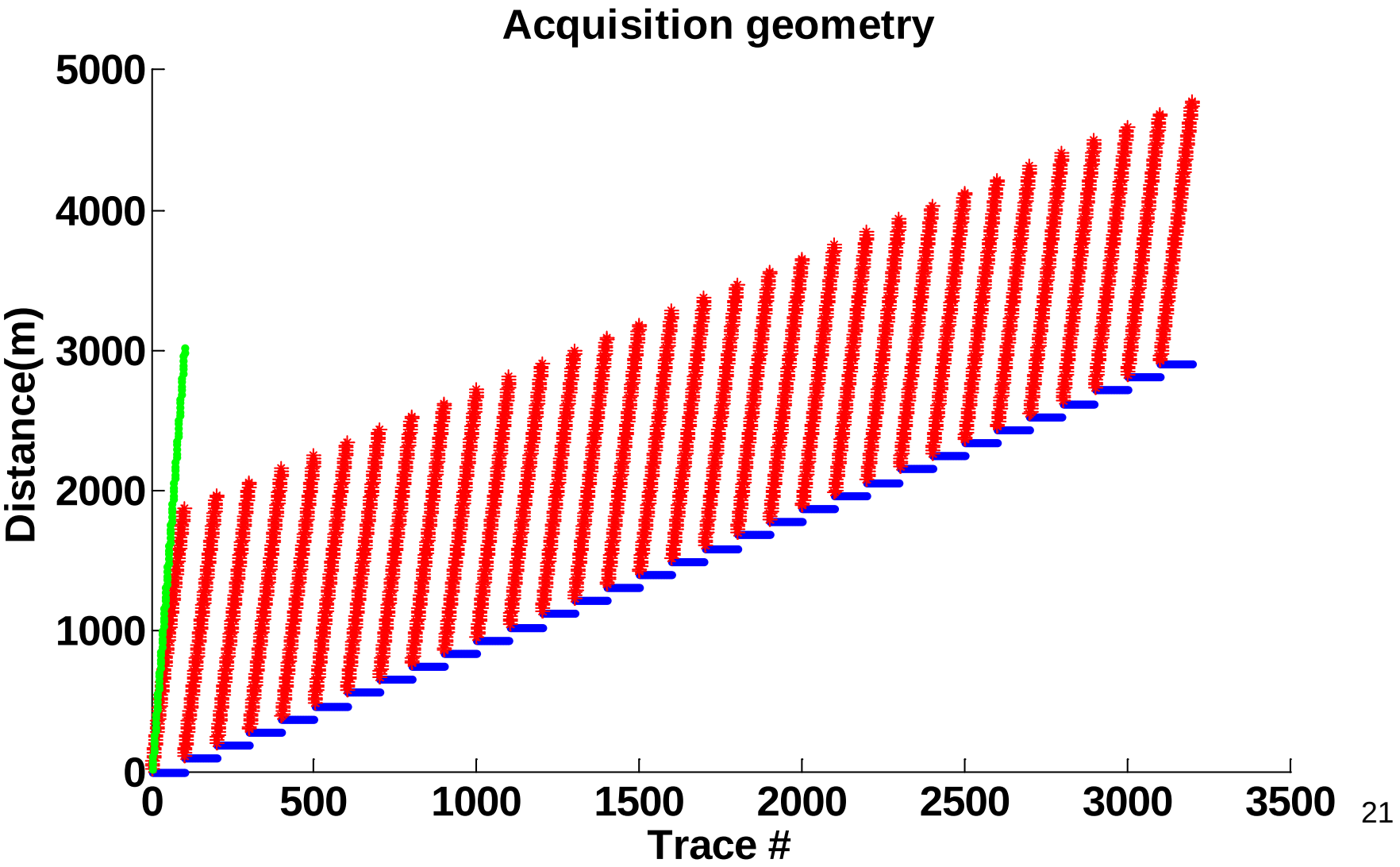
Velocity model



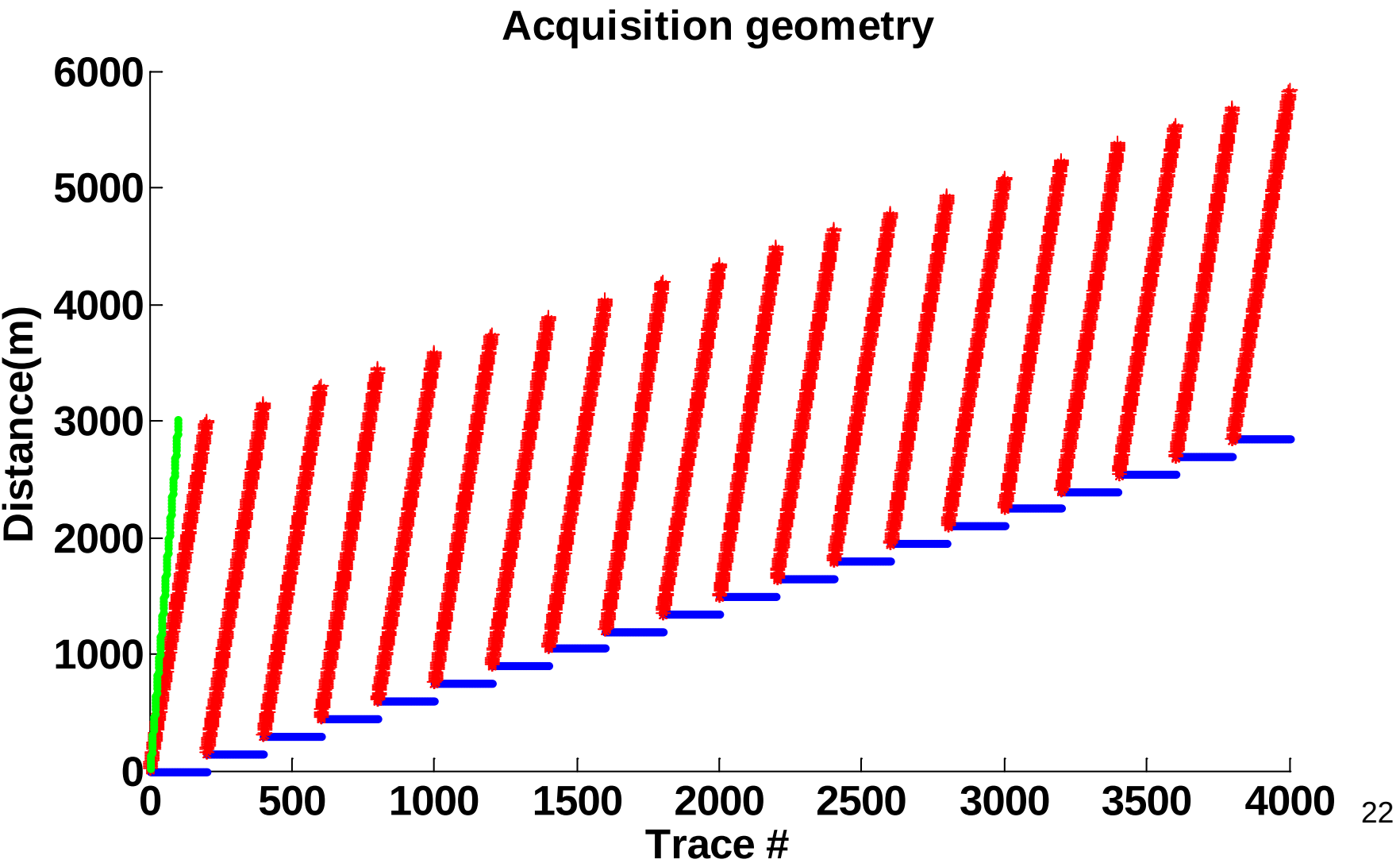
Baseline Survey

32 S, 100R/S, SI=100m, RI=18m



Monitor Survey

20S, 200R/S, SI=150m, RI=15m

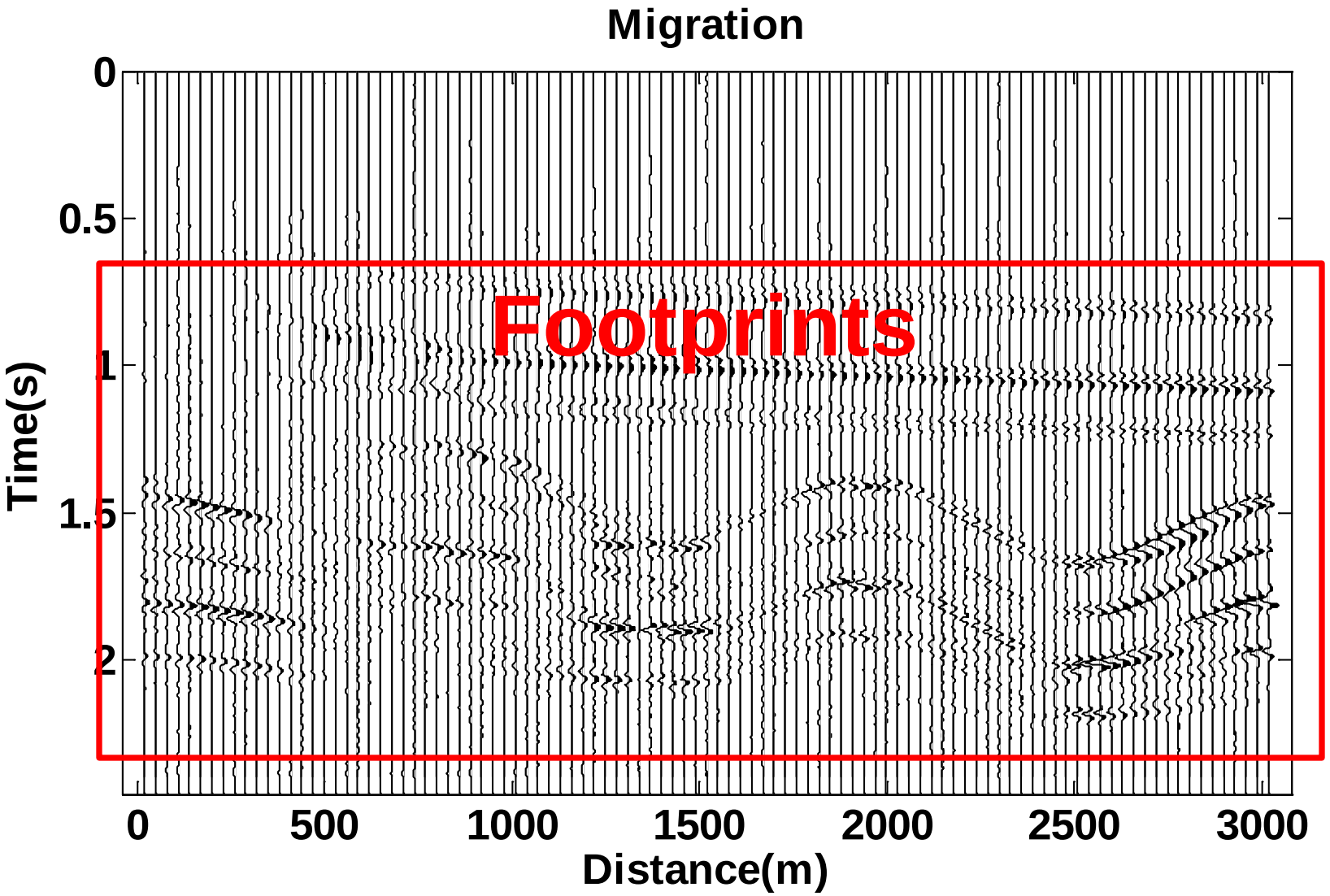


Time lapse seismic challenges

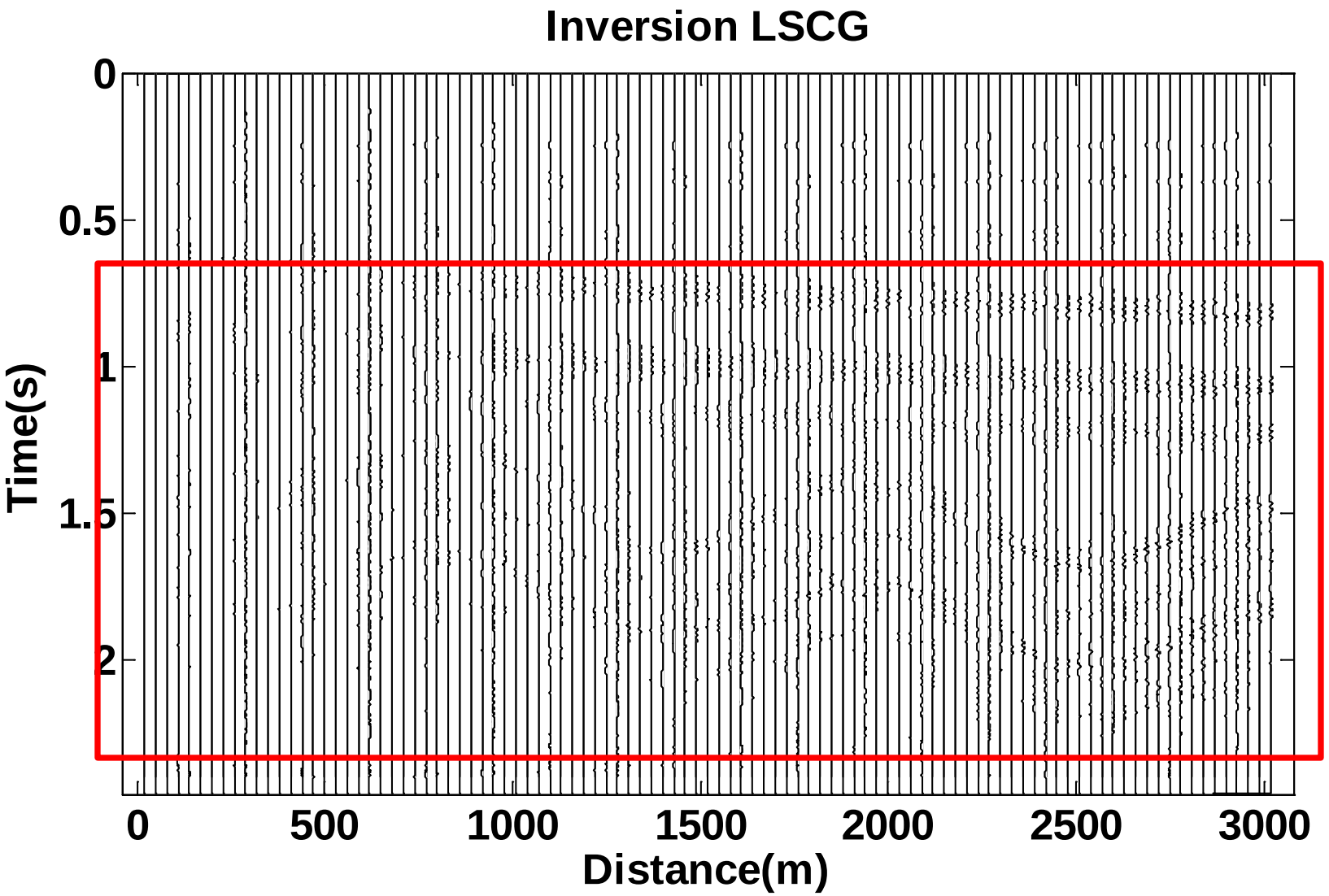
- **Both surveys are dense and regular,**

BUT

Migration time lapse

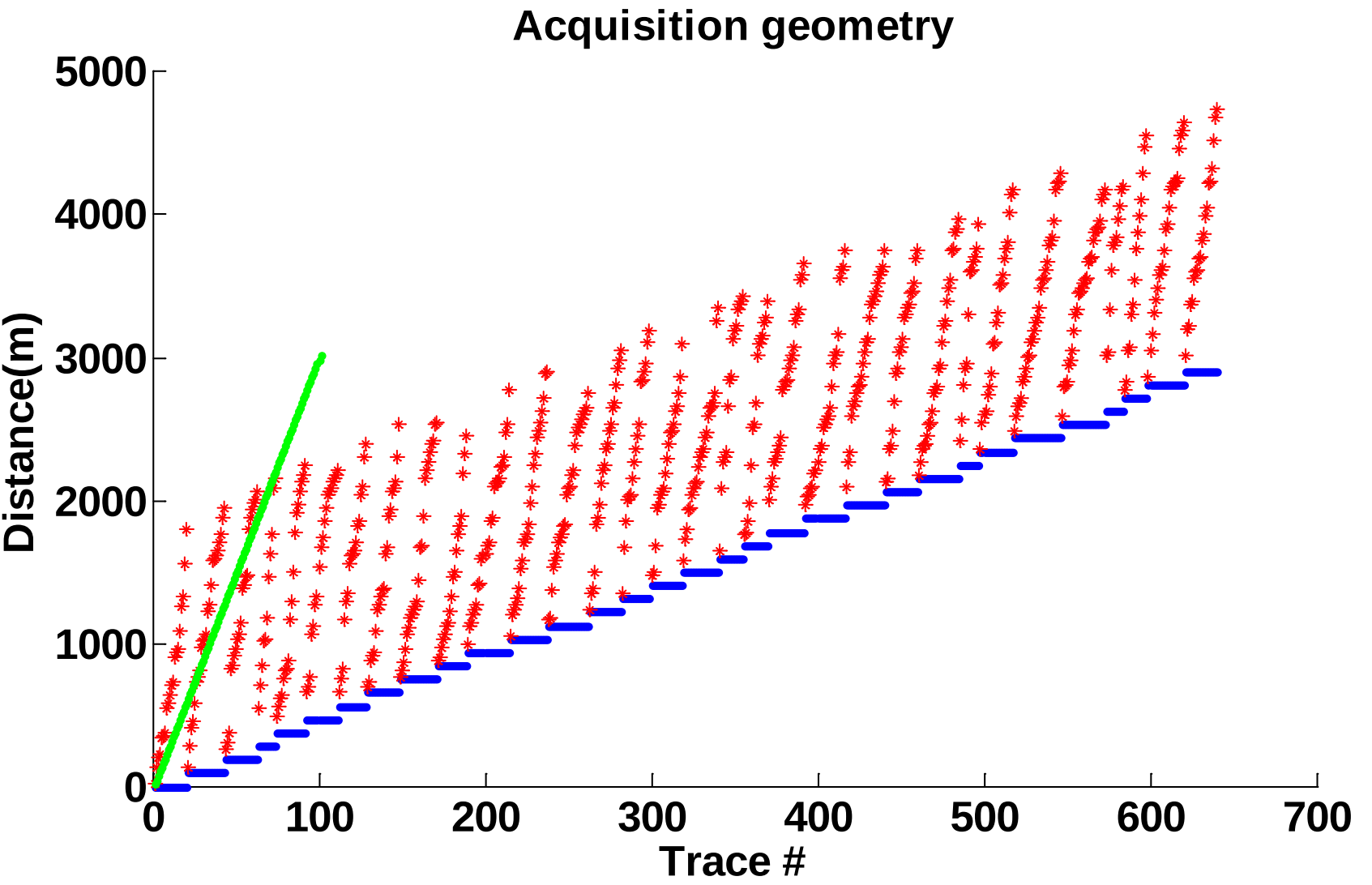


LSPSM time lapse



Baseline Survey

32S, 100R/S, SI=100m, RI=18m, 80% decimation



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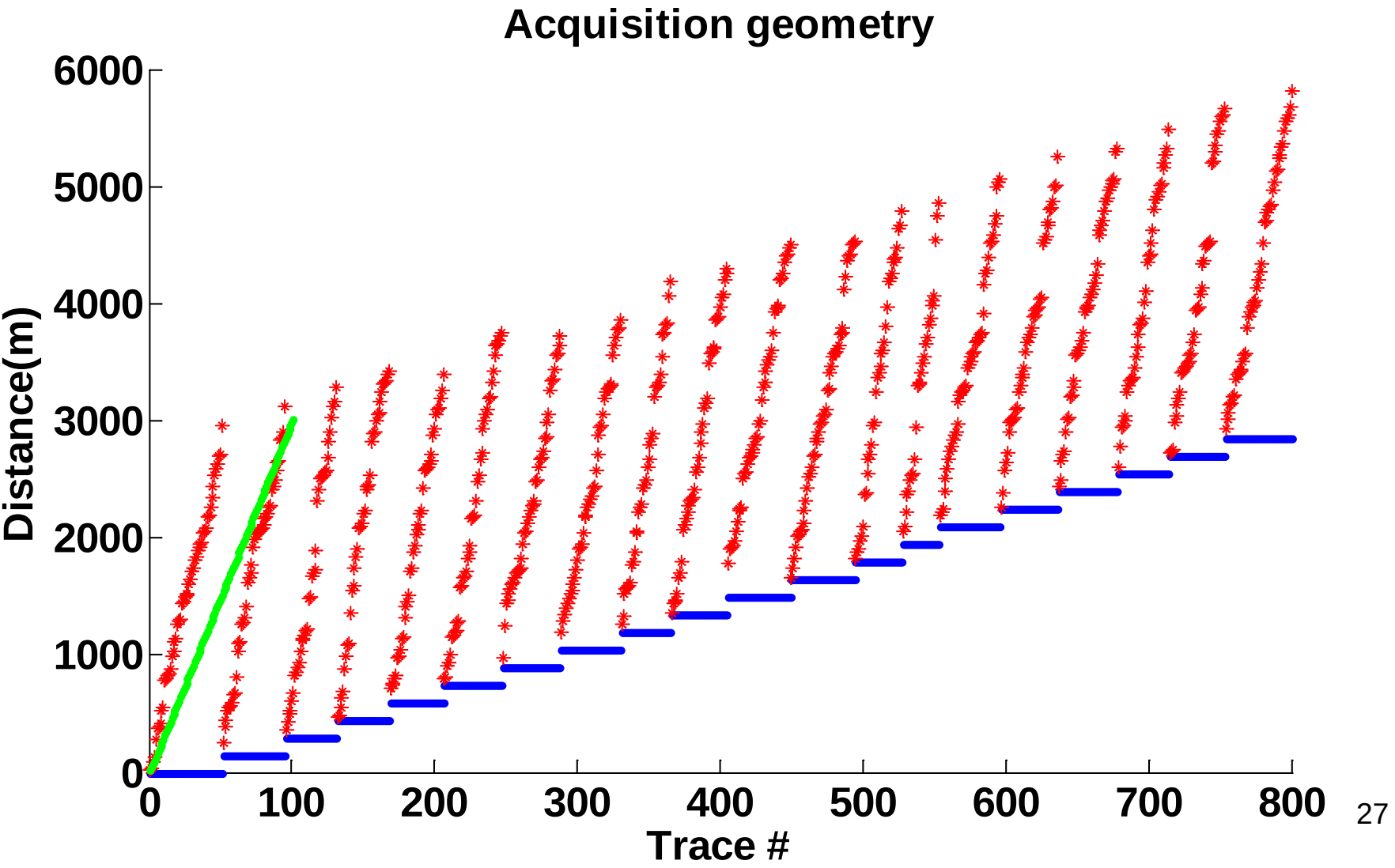
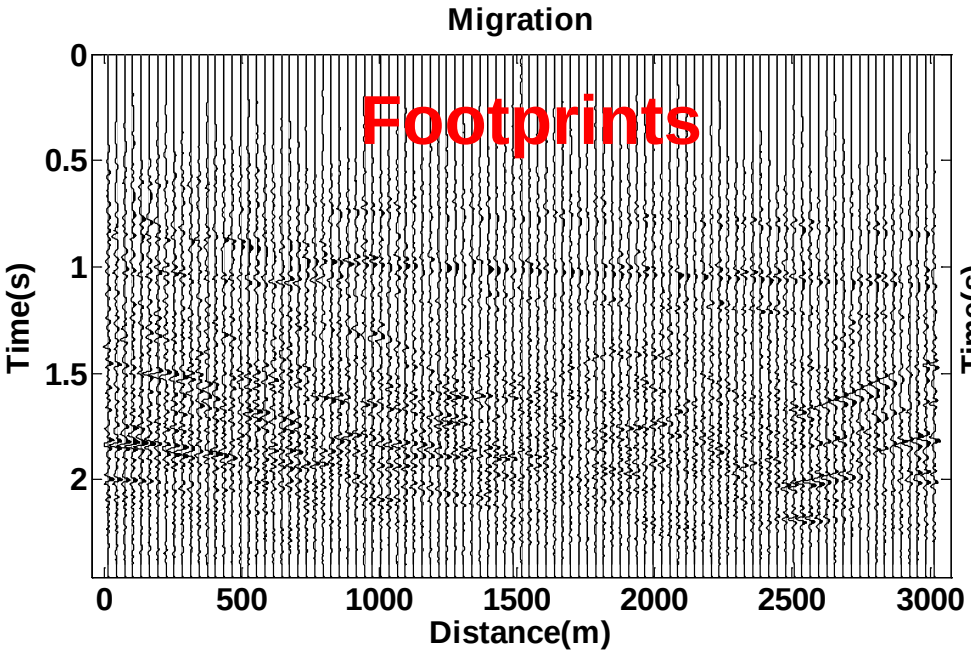
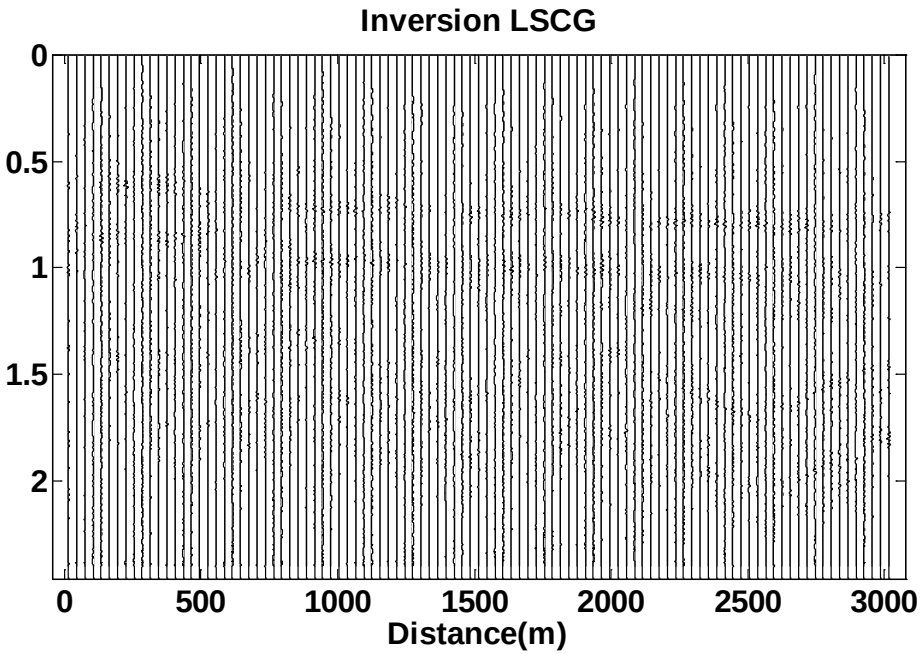


Time lapse images

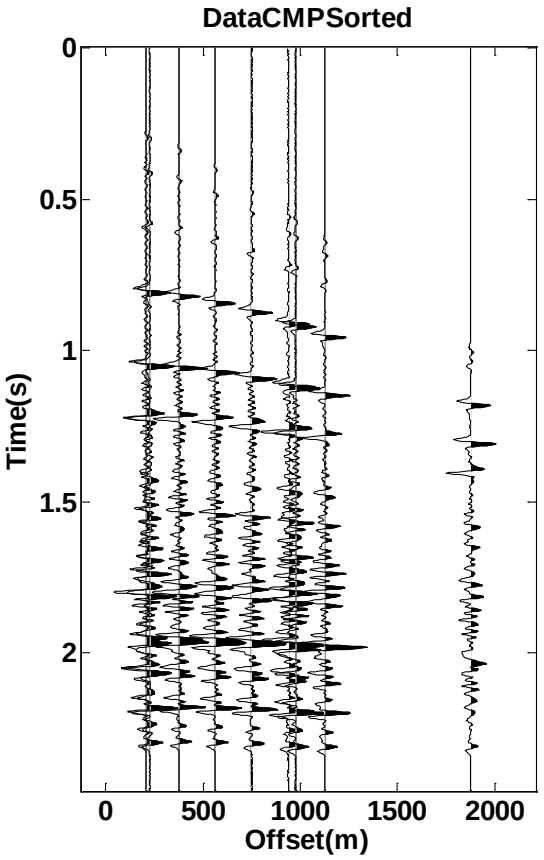


Migration

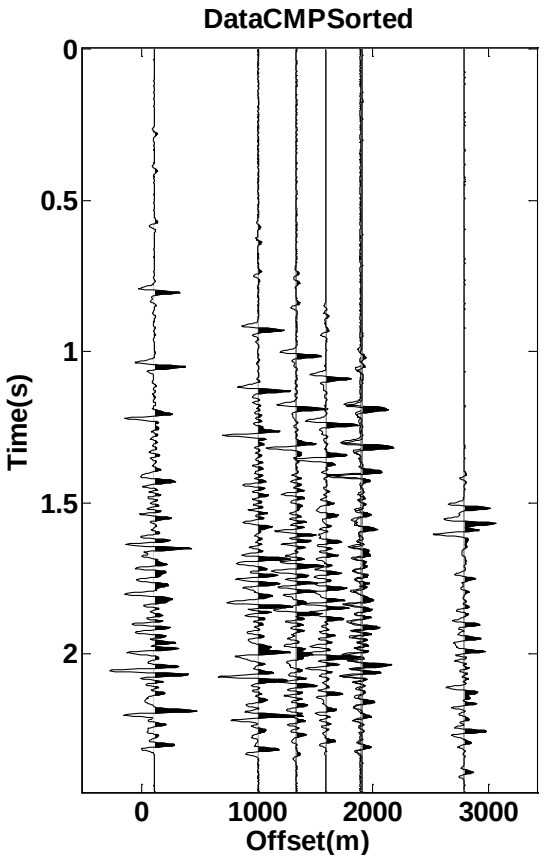


LSPSM

Prestack time lapse, Decimated data

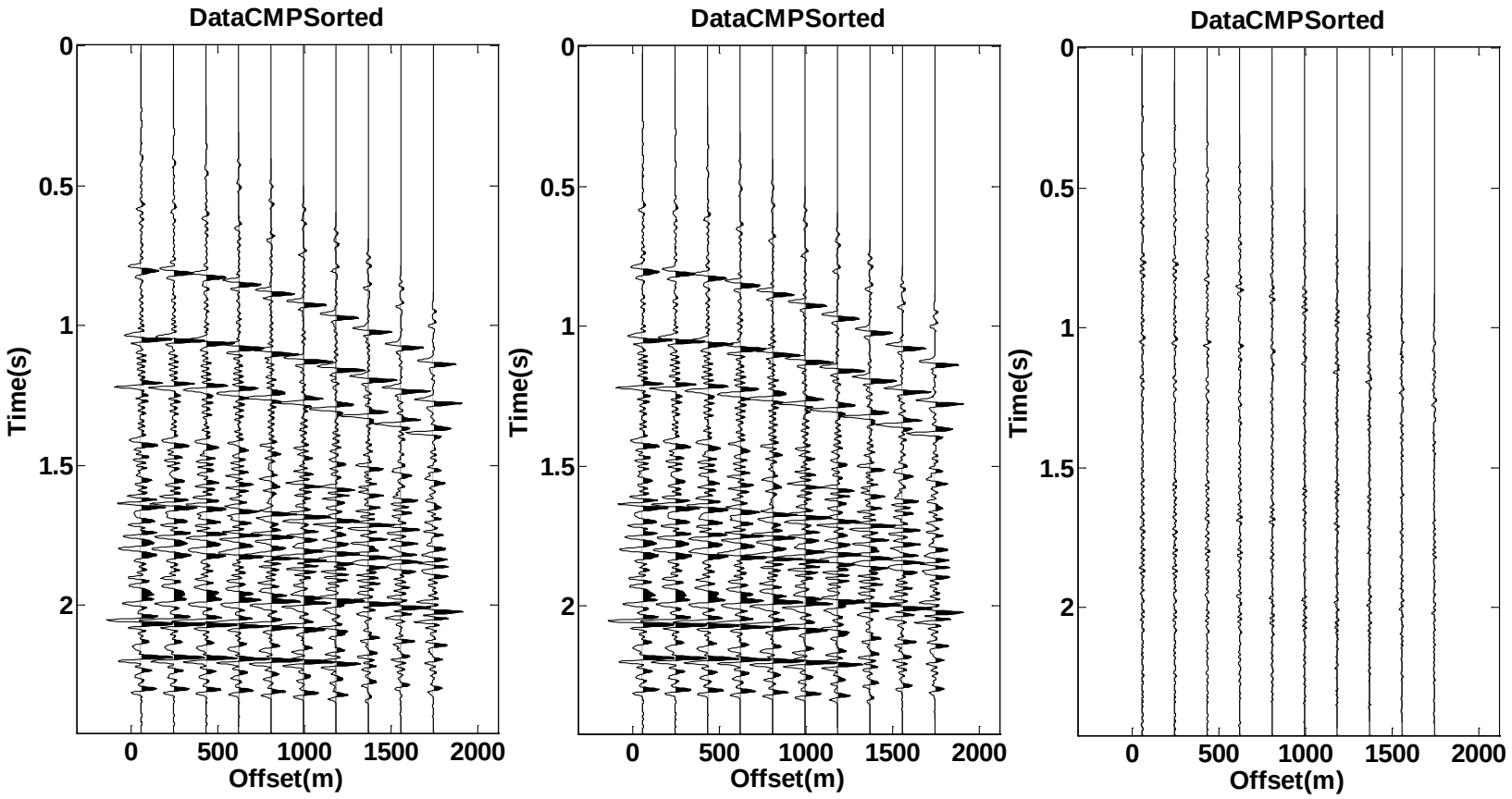


Baseline



Monitor

Prestack time lapse, Reconstructed Data



Baseline **Monitor** **Difference**

LSPSM/inversion of time lapse data

III. **Separate LSPSM/inversion of baseline and monitor surveys data is used to**

1) Remove the effect of having different acquisition geometries
2) **Remove the effect of losing receivers in OBC**
3) Increase the resolution of time lapse image

Baseline Survey

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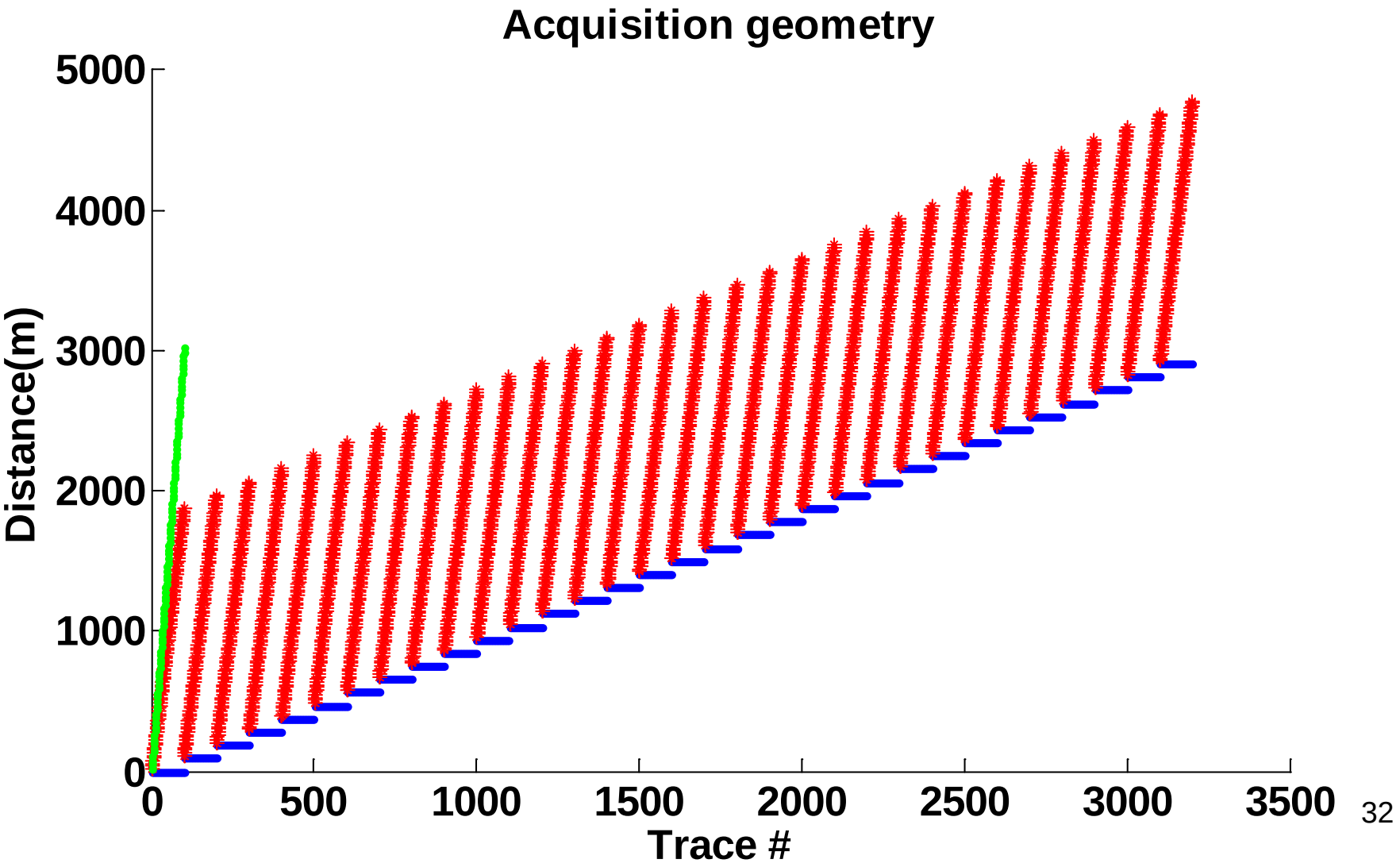
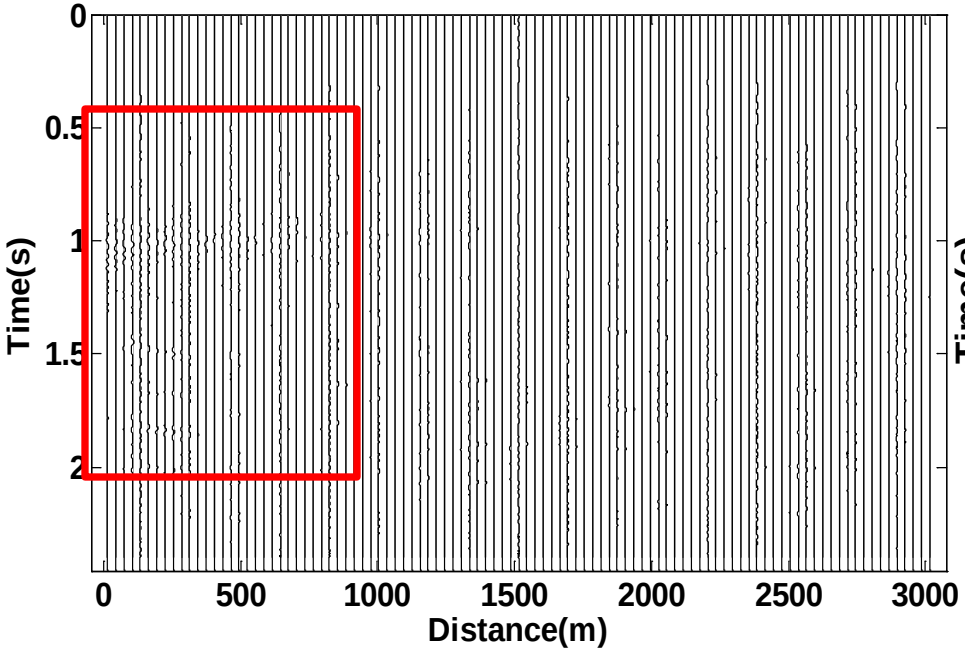


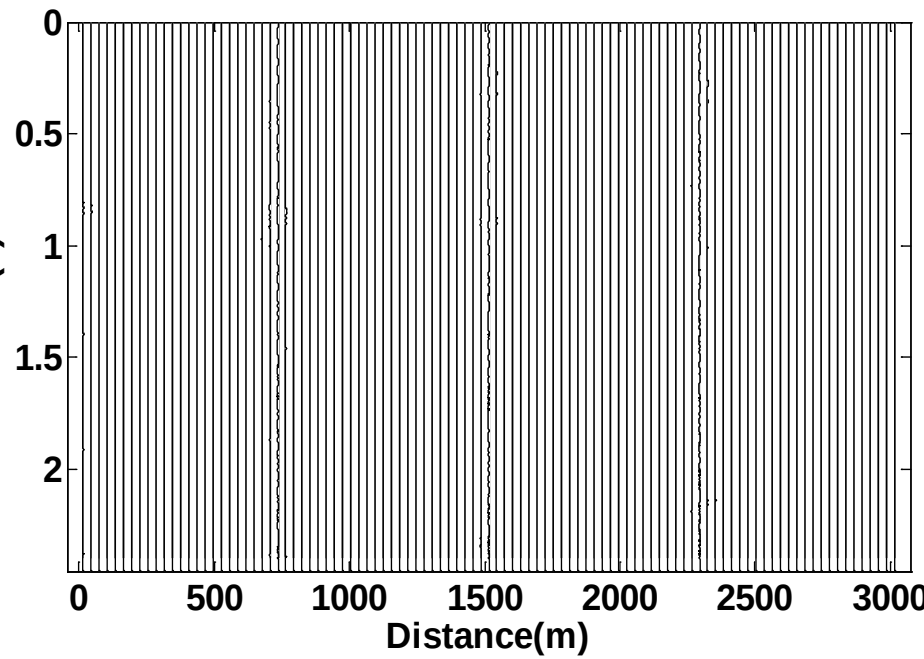
Time lapse, effect of loosing receivers

Losing 50% of data

Migration



LSPSM

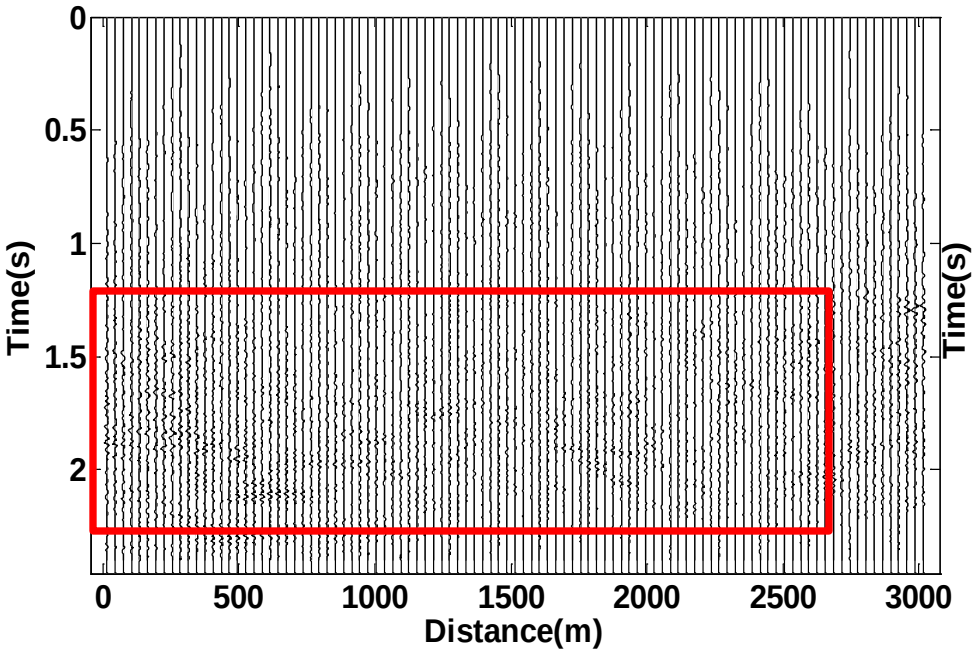


Footprints

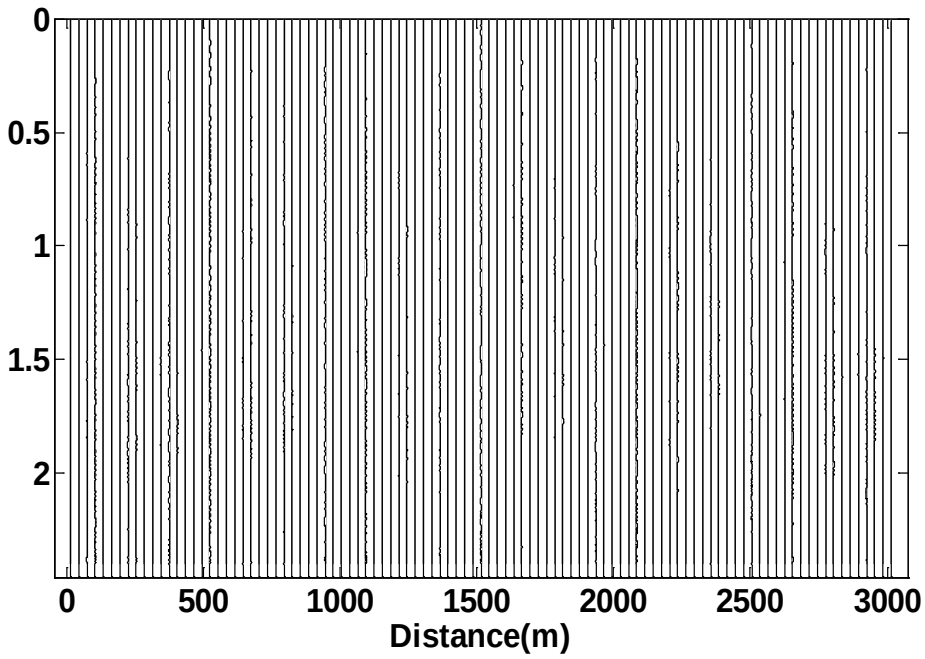
Time lapse, effect of loosing receivers

30% of data

Migration



LSPSM

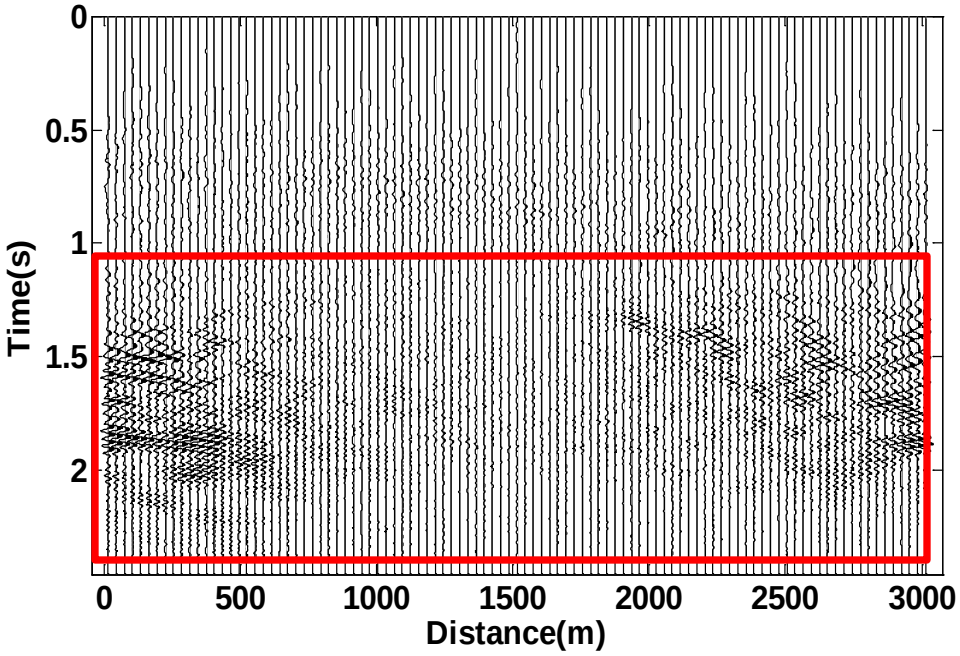


Footprints

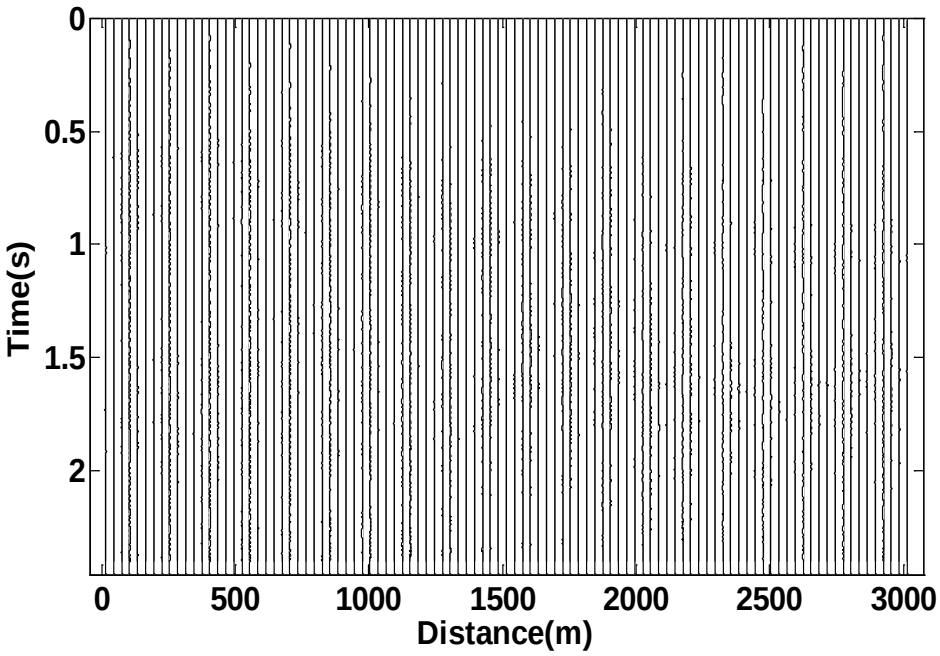
Time lapse, effect of loosing receivers

20% of data

Migration



LSPSM

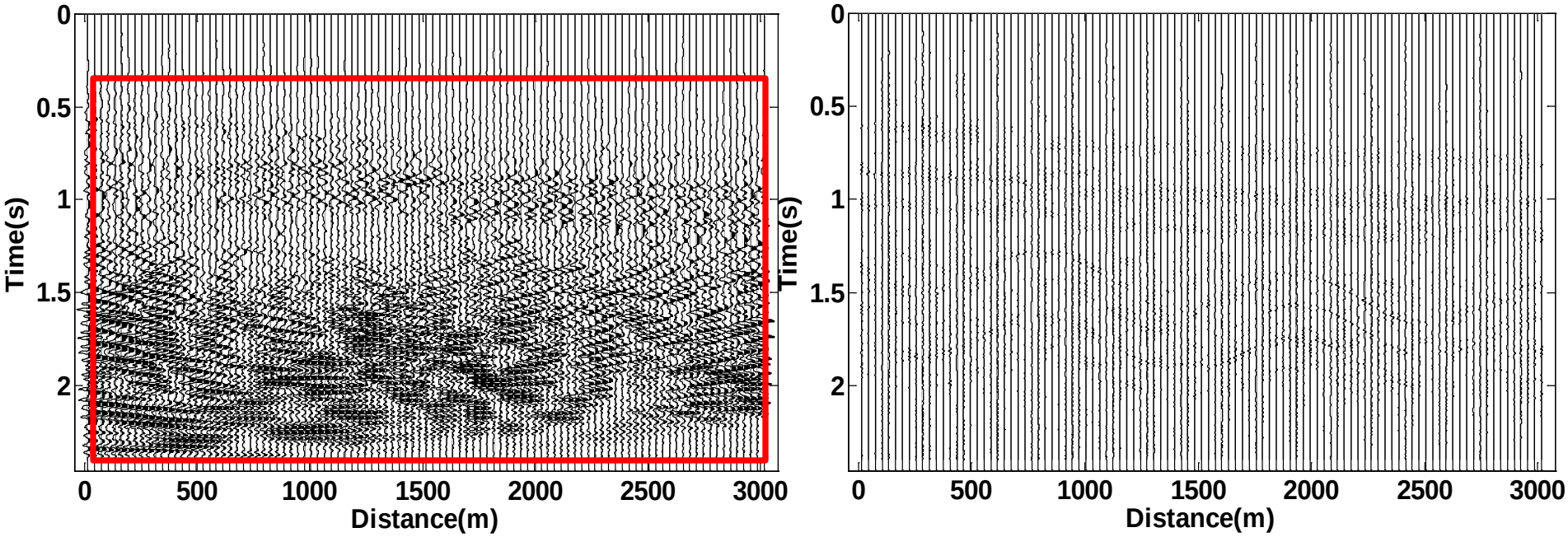


Footprints

Time lapse, effect of loosing receivers

10% of data

Migration **LSPSM**

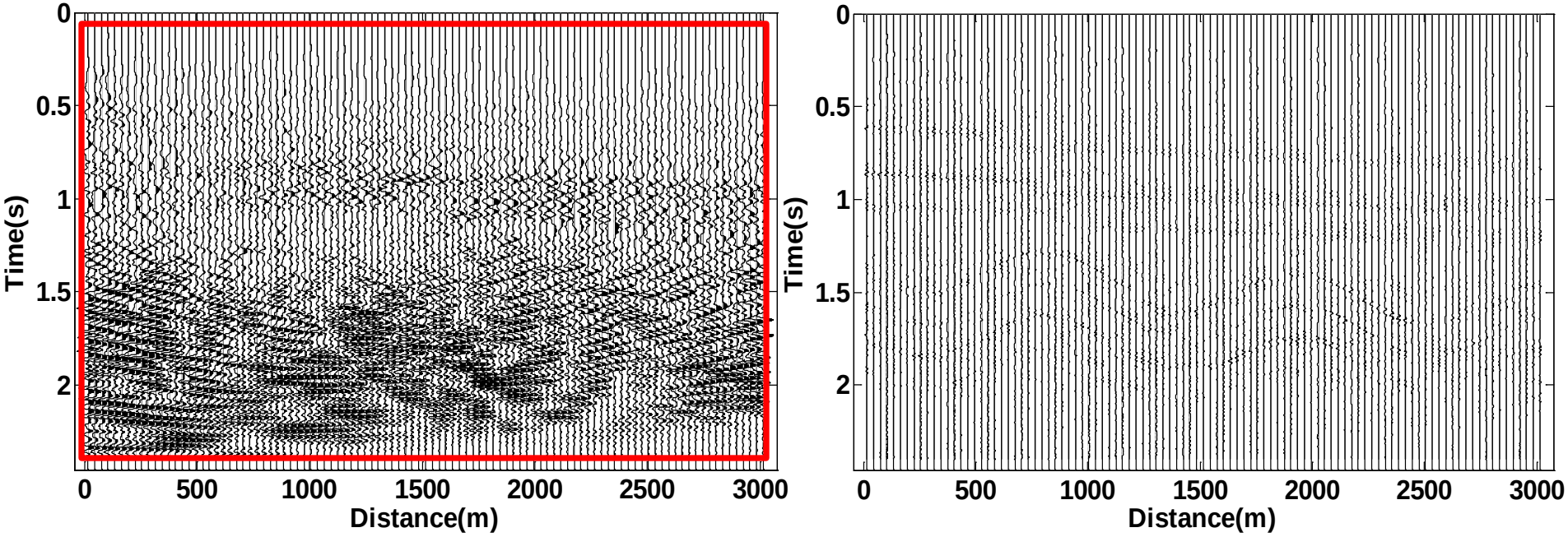


Footprints

Time lapse, effect of loosing receivers

5% of data

Migration **LSPSM**



Footprints

LSPSM/inversion of time lapse data

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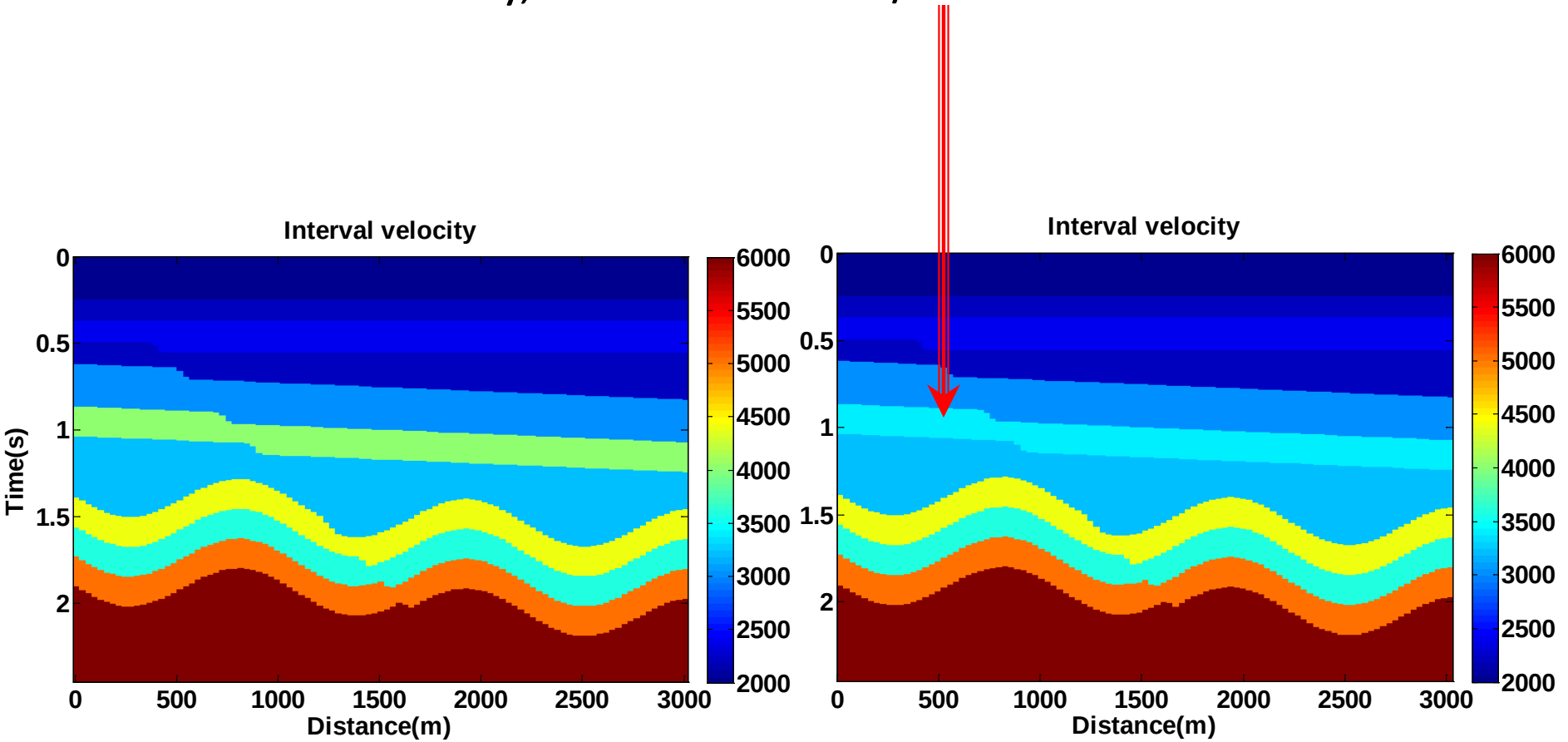
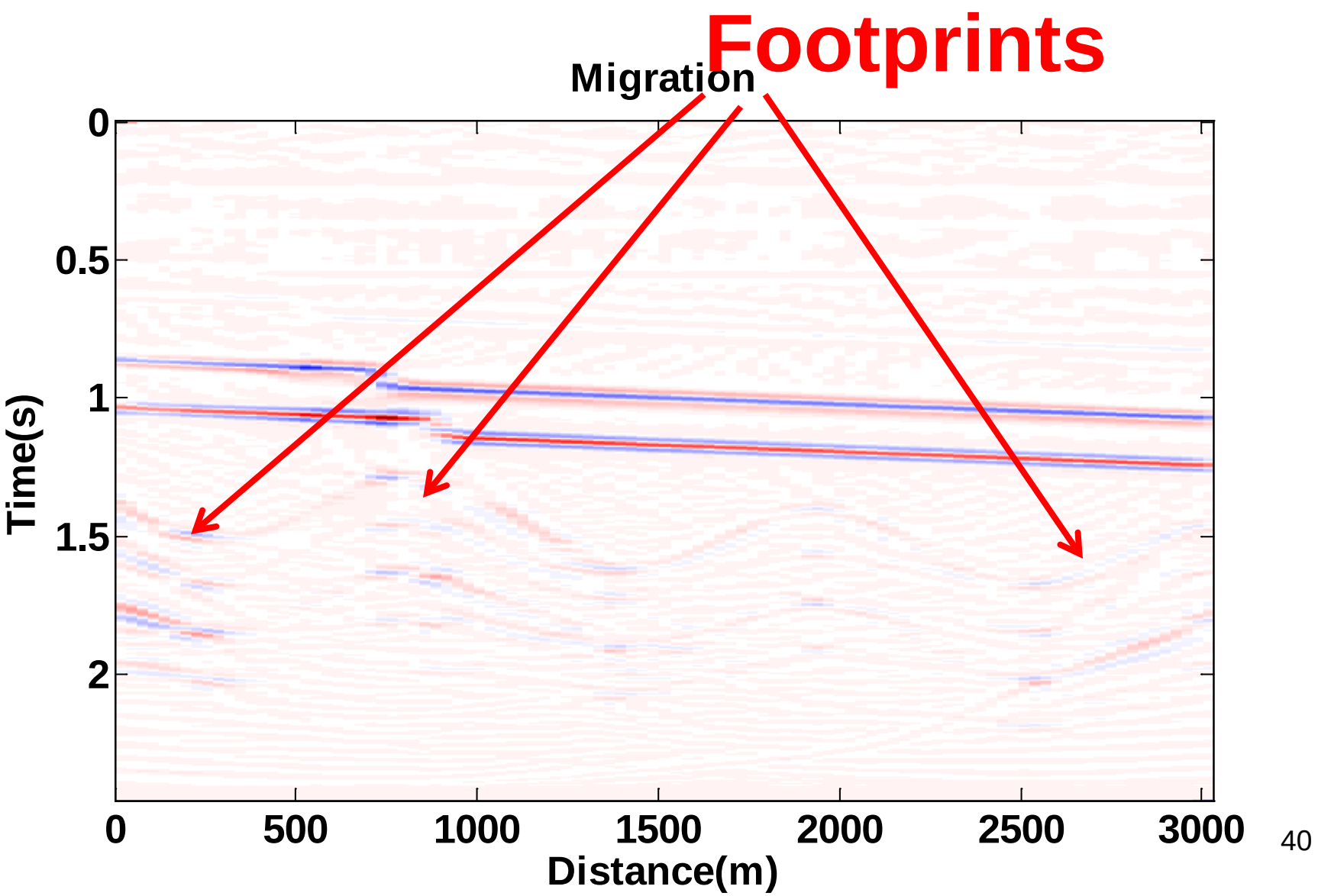
Change in velocity model

15% less velocity, 4000 >> 3400 m/s

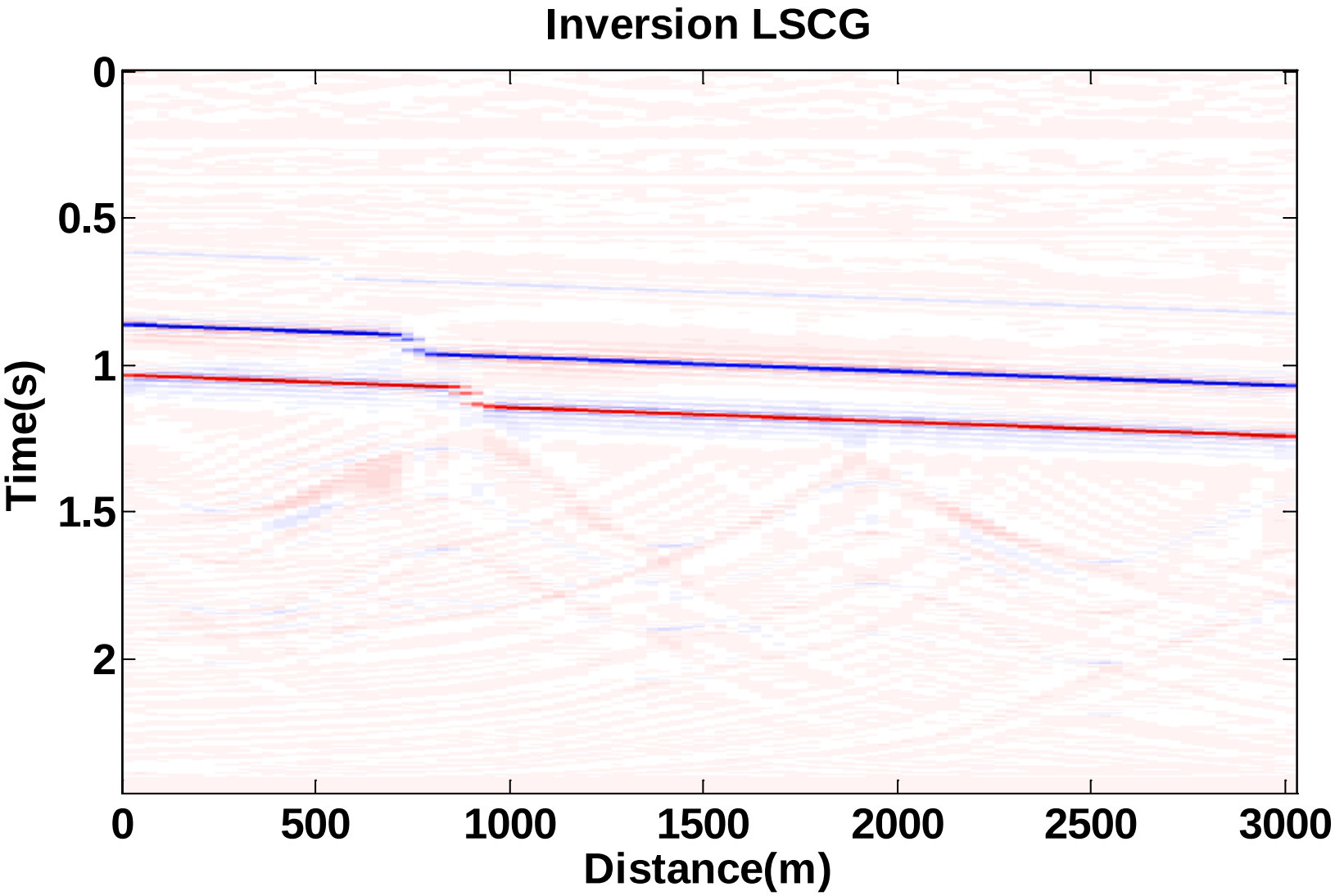


Baseline **Monitor**

Migration time lapse



LSPSM time lapse



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2. **Image Difference Joint Inversion (IDJI)**

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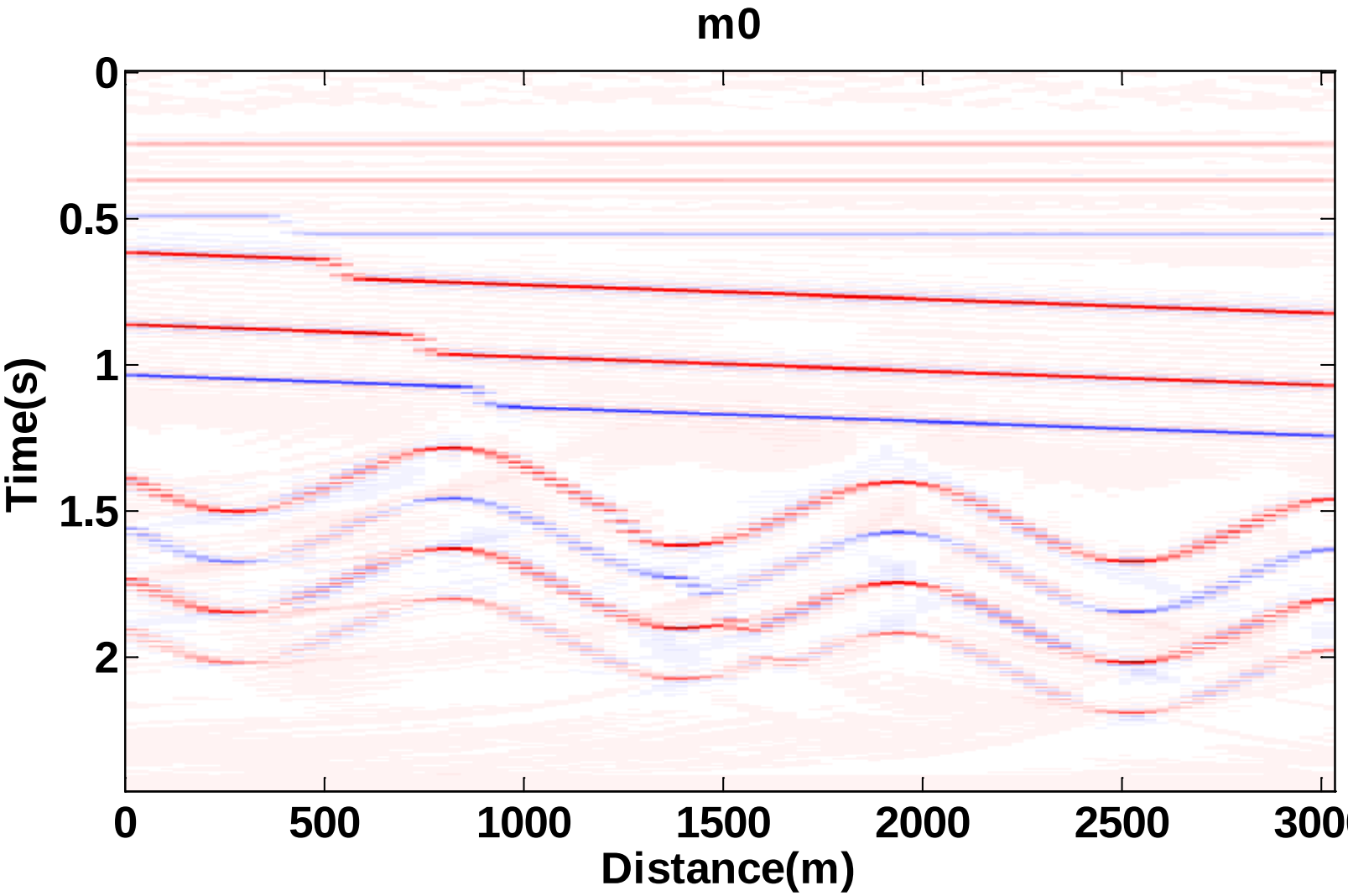
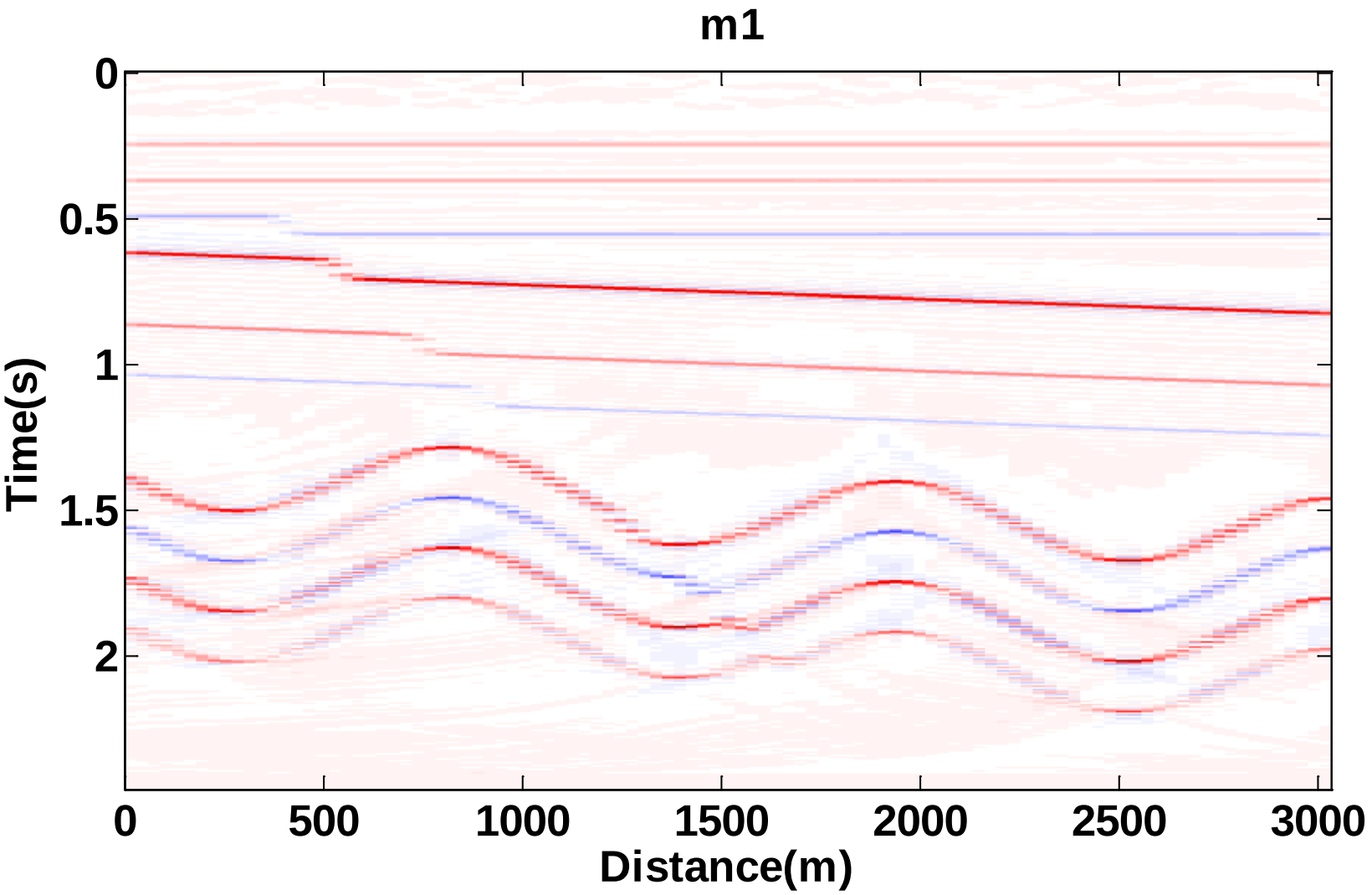
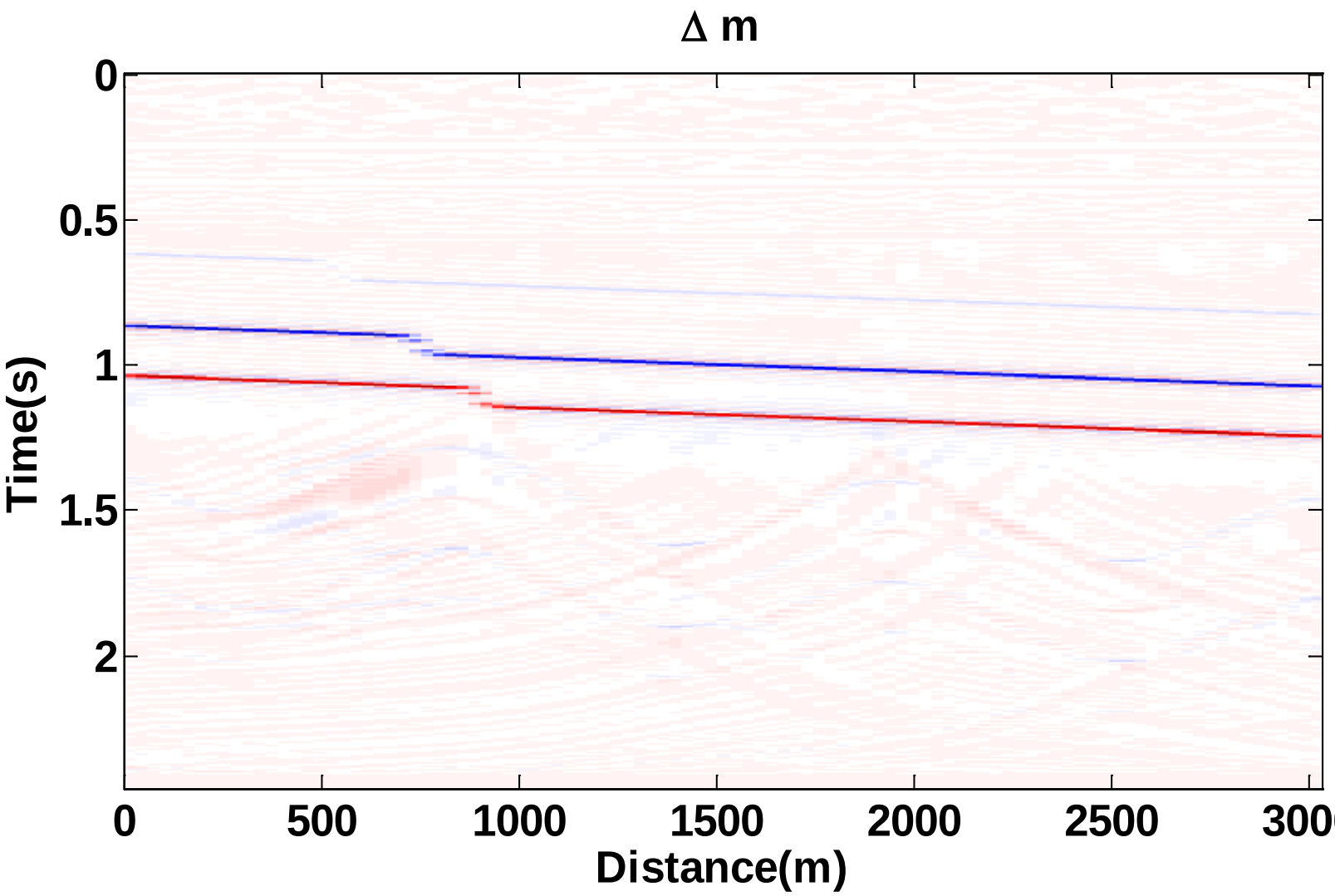
Joint inversion for baseline & monitor (MIJI)



Joint inversion for baseline & monitor (MIJI)



Joint inversion for baseline & monitor (MIJI)



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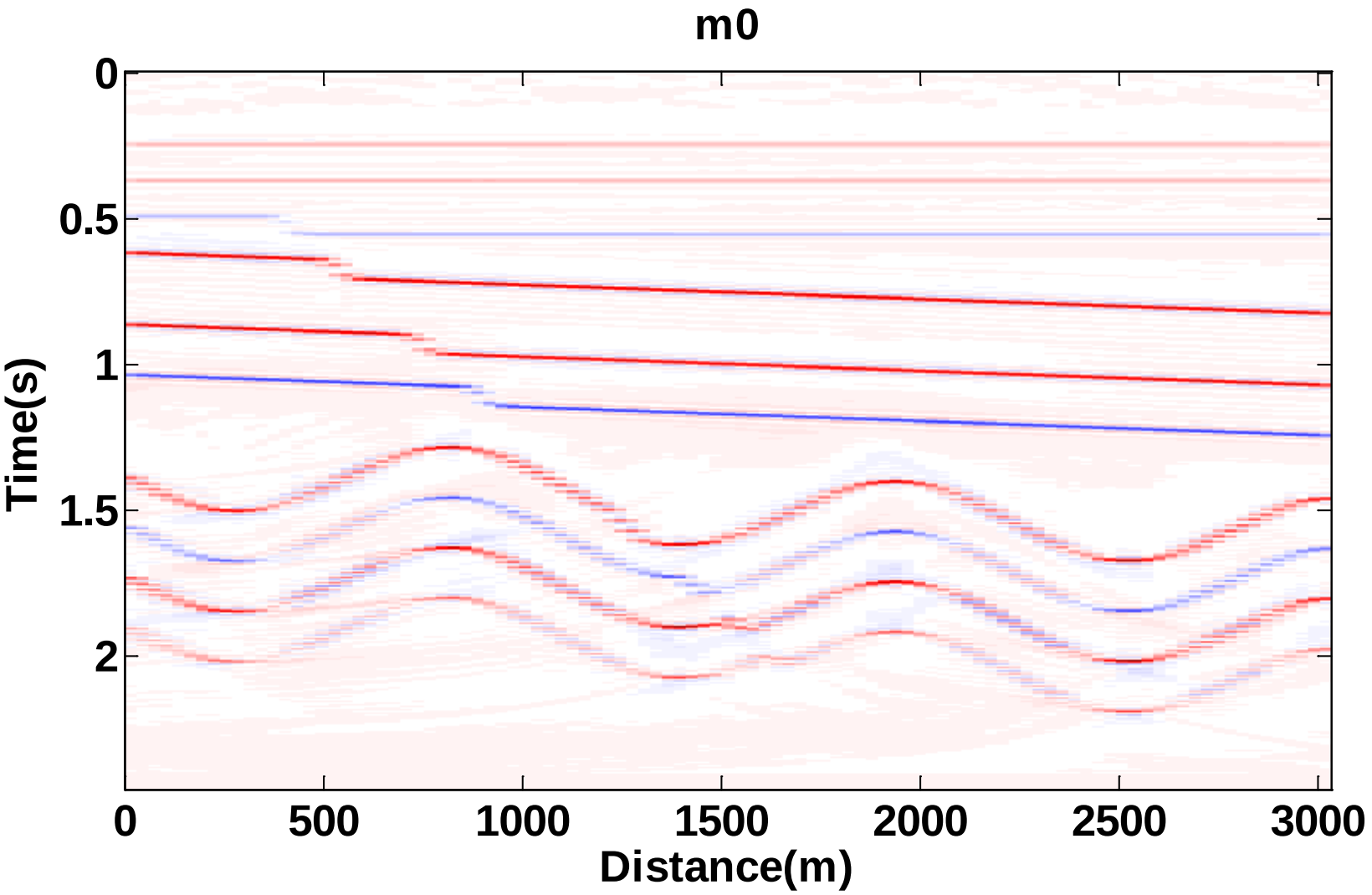
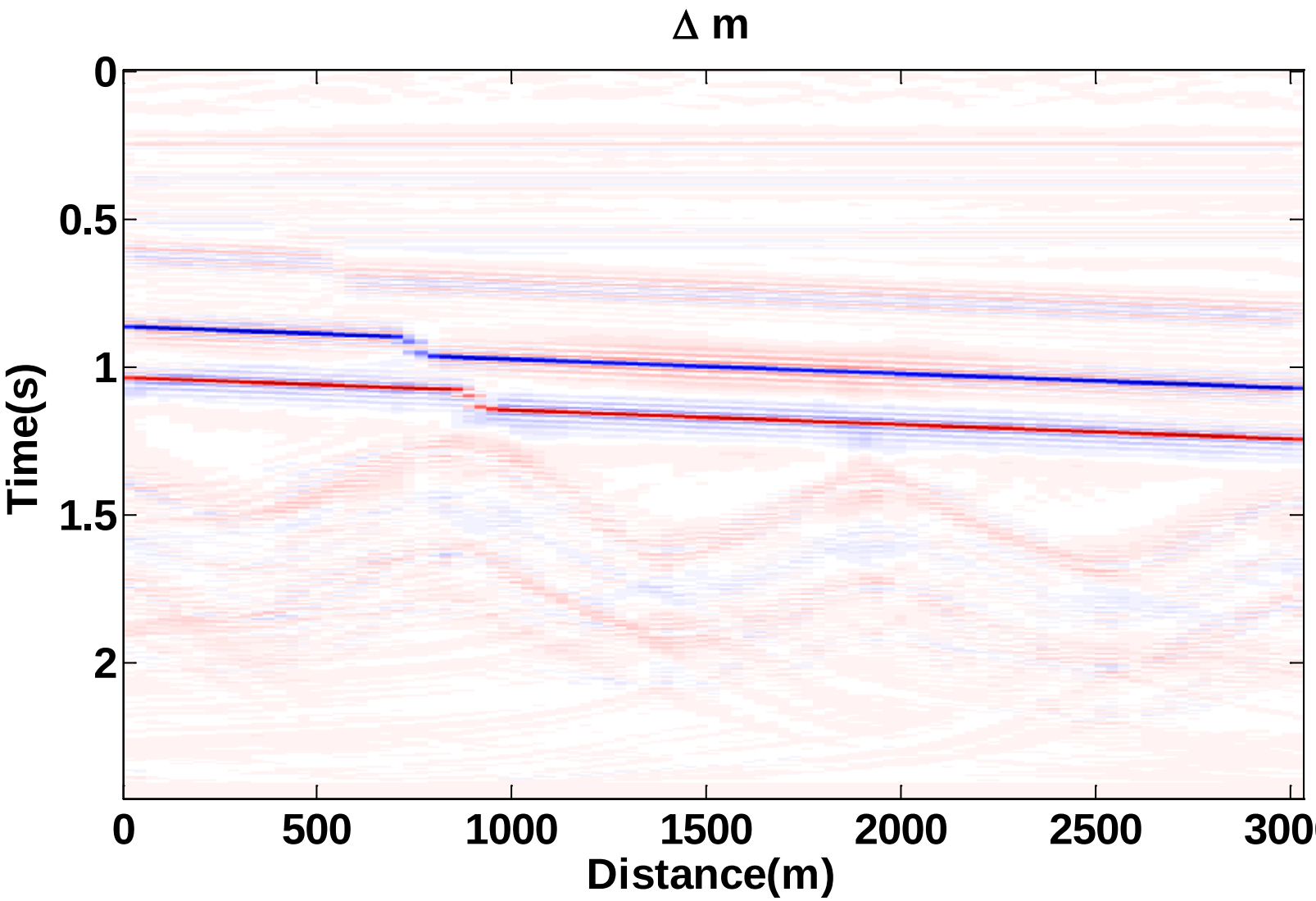
Joint inversion for baseline & difference (IDJI)



Joint inversion for baseline & difference (IDJI)



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Summary

- **Difference in acquisition geometries leaves different artifacts at the baseline and monitor migration images.**
- **Separate LSPSM/inversion of both datasets removes these artifacts.**
- **and produces comparable data for prestack time lapse studies.**

Summary

- **Joint inversion of both datasets produces a high resolution time lapse image.**
- **Best result achieved with the Multiple Image Joint Inversion (MIJI).**
- **Each iteration in LSCG to solve MIJI or IDJI costs 4 times more than a conventional migration of baseline data.**
- **Method is easily extendable for the joint inversion of baseline survey and multiple monitor surveys.**

Summary

- **It is possible to add regularization terms:**
  highlighting the changes in the time lapse images by adding sparse regularization.

Acknowledgments:

- I would like to thank:
  - NSERC and other CREWES sponsors, YOU,
  - CREWES faculty, staff and previous and current students,
  - Kevin Hall and Rolf Maier,

- Especial thanks to Dr. John Bancroft, and other people that helped me in last 4 years.