Seismic Data Interpolation With Symmetry

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joint work with Gilles Hennenfent

2008 Consortium Meeting

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Outline

- Introduction
  - Reciprocity
  - Real Data Example
- Data Interpolation Problem Statement
  - CRSI
  - sCRSI
- Results
  - Synthetic Data
  - Comparison With Previous Work
- Future Work
- Conclusions

Introduction

- Seismic Data interpolation
  - Data Volumes are often under-sampled and/or missing traces
  - Have to interpolate missing data

- Reciprocity
  - Trace from receiver at (x,y) for shot at (j,k) same as trace from receiver at (j,k) for shot at (x,y) [1]
  - Makes seismic data volumes symmetric
  - Source/Receiver geometry and characteristics important in preserving reciprocity
    - Monopole receiver, Dipole source for typical survey

Introduction

- Real data example of reciprocity
  - Central Valley of California[2], Not done as a test of reciprocity
  - Vertical vibrators, vertical geophones
    - Receiver characteristics match source characteristics
    - Improves symmetry of data
  - Small lateral offset of sources from receivers
  - 3 pairs of traces (small medium large offsets) overlain

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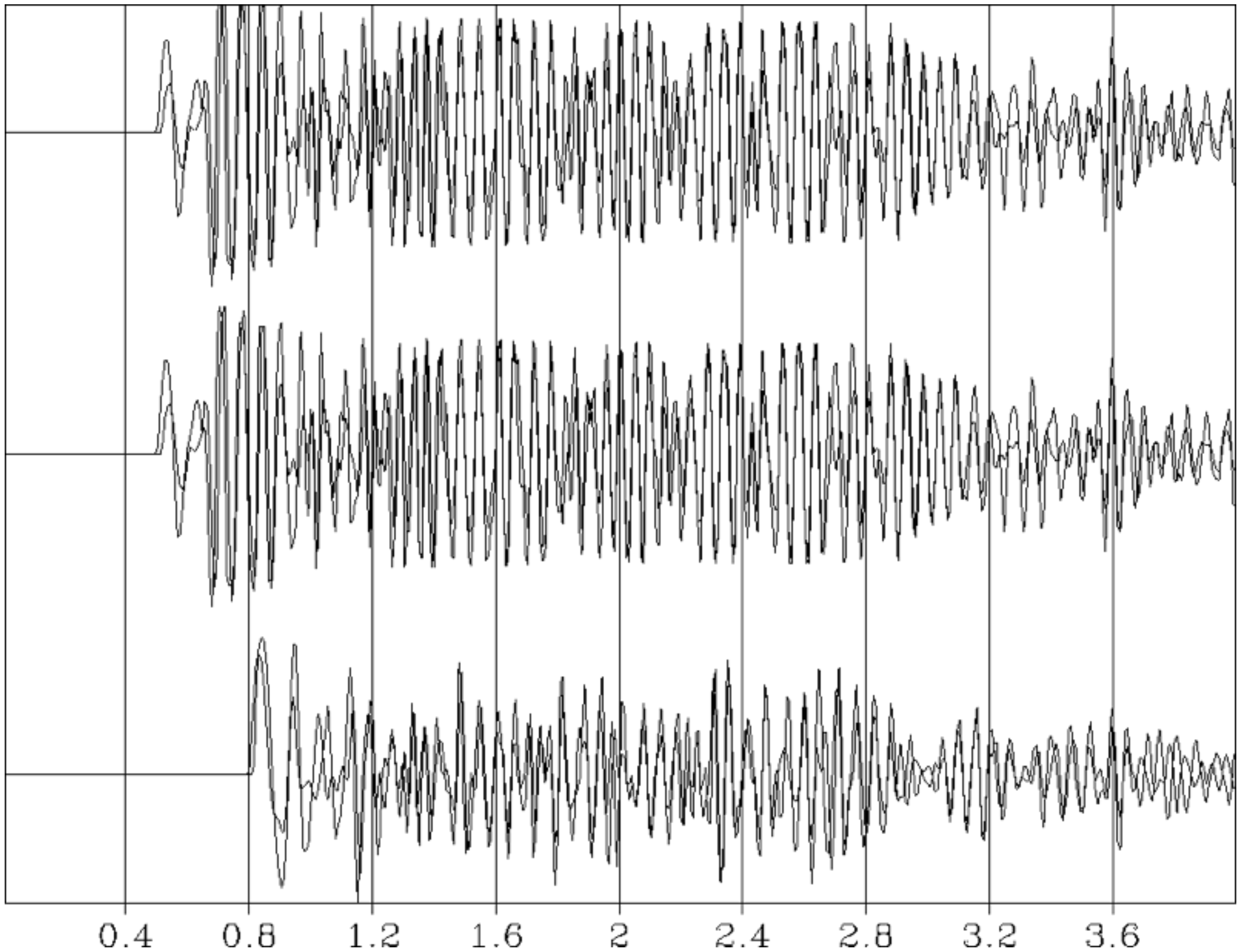
Introduction



- Well matched at mid times
- Early and late times show larger discrepancies

Introduction

- Q: Can the reciprocity of seismic data be exploited when performing interpolation?

- A: YES!

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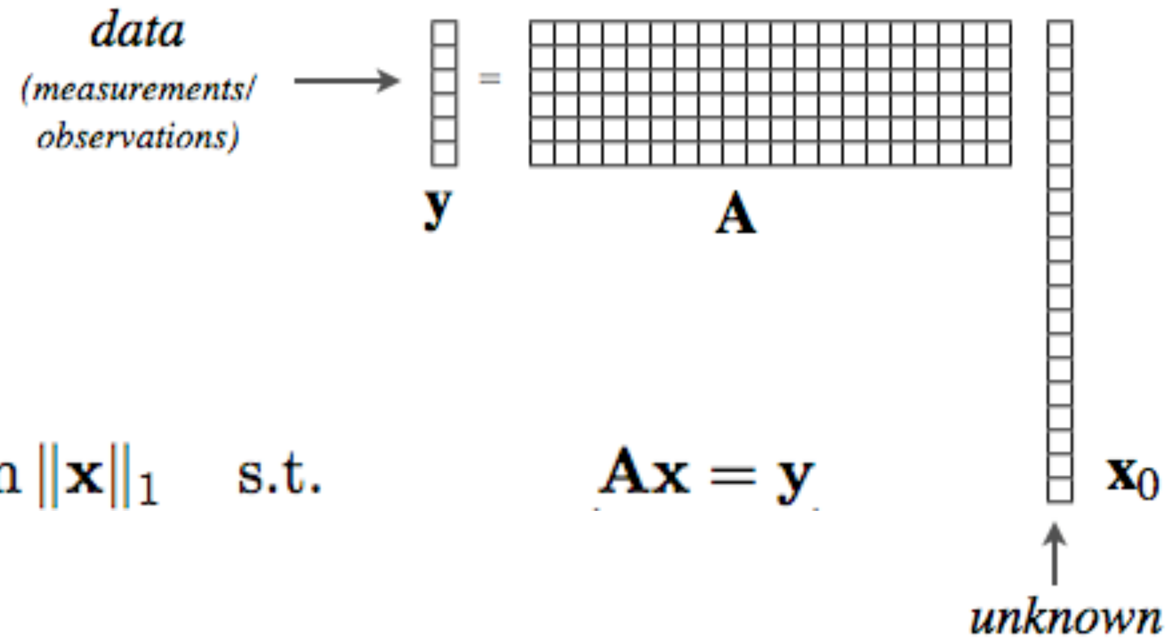
Data Interpolation

- The data interpolation problem can be stated as[3]:

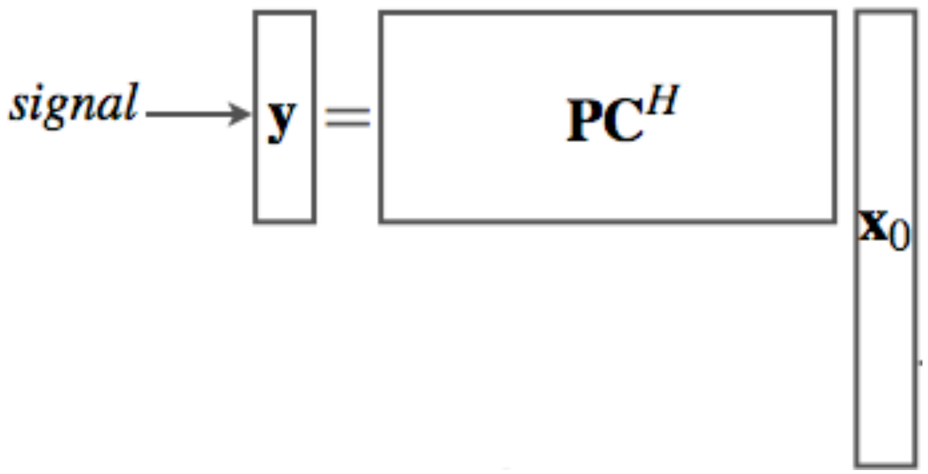


$$\min \|\mathbf{x}\|_1 \quad \text{s.t.} \quad \mathbf{A}\mathbf{x} = \mathbf{y}$$

- Compressed sensing framework
  - A restricted measurement operator
  - x sparse signal representation

Data Interpolation

- CRSI formulation[3]:



$$(P_1)\begin{cases}\tilde{\mathbf{x}} = \arg\min_{\mathbf{x}} \overbrace{\|\mathbf{W}\mathbf{x}\|_1}^{\text{sparsity constraint}} \quad \text{s.t.} \quad \overbrace{\|\mathbf{y}-\mathbf{P}\mathbf{C}^H\mathbf{x}\|_2}^{\text{data misfit}} \leq \epsilon \\ \tilde{\mathbf{f}} = \mathbf{C}^H\tilde{\mathbf{x}}\end{cases}$$

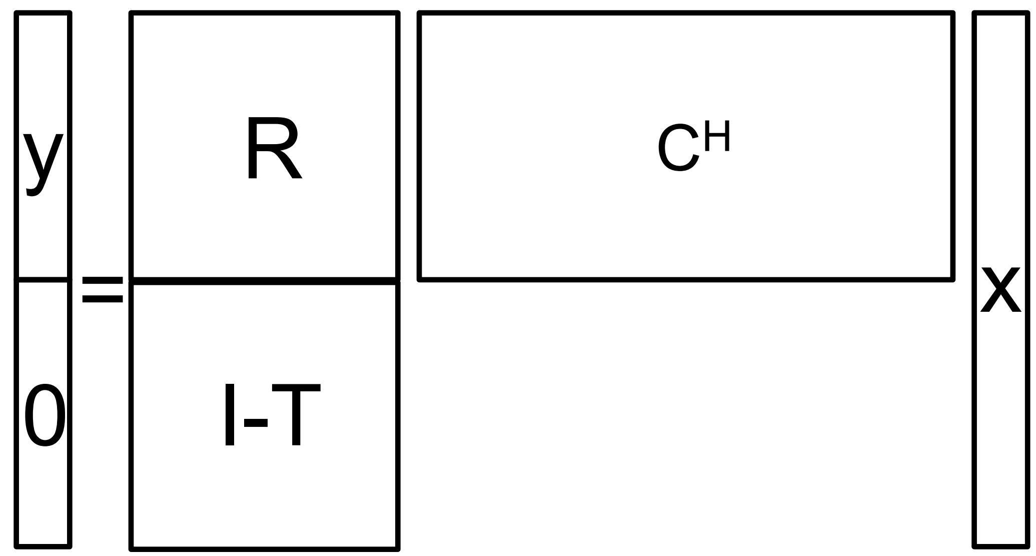
Data Interpolation

- symmetric CRSI formulation:

$$b = \begin{pmatrix} y \\ 0 \end{pmatrix}$$

$$A = \begin{pmatrix} R \\ I - T \end{pmatrix} C^H$$

$$f' = C^H x'$$

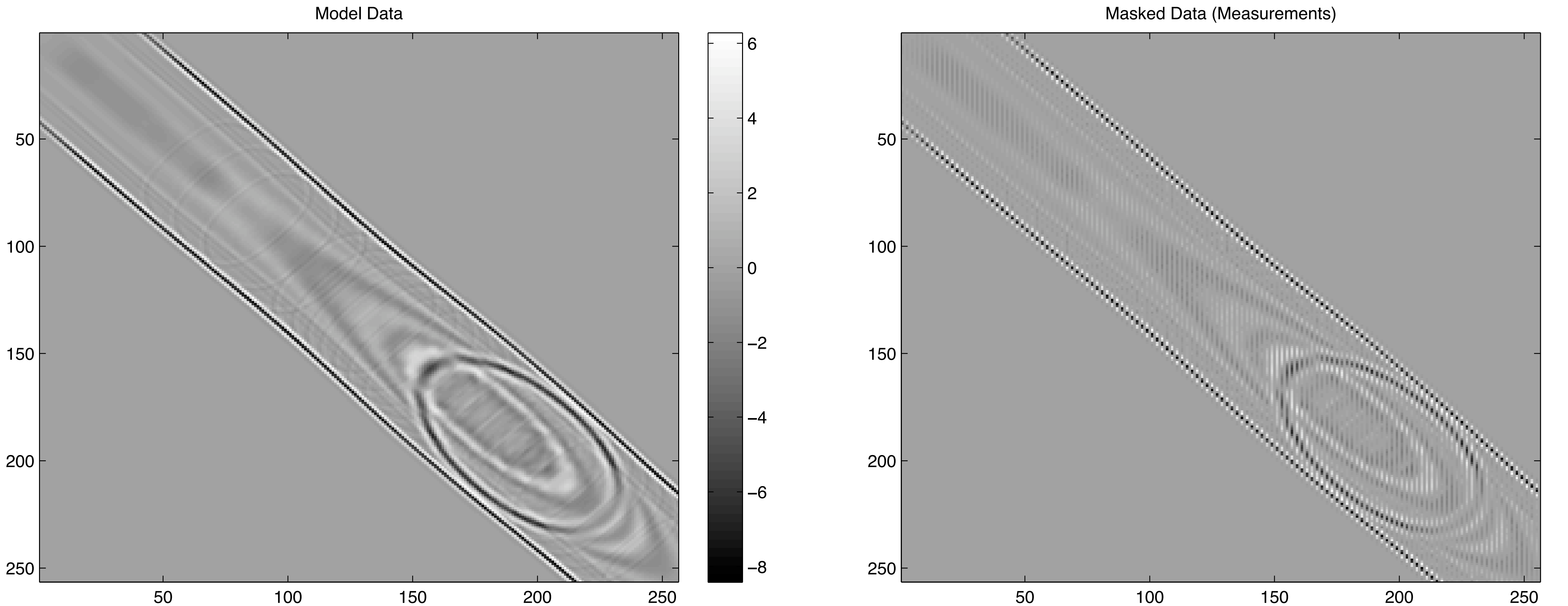


$$P1: \quad [x' = argmin \|Wx\|_1 \quad s.t. \quad \|b - Ax\|_2 \leq \epsilon]$$

- R pads missing traces with zeros
- T is transpose operator

Results

- Time slice from a synthetic data set



- Removed every other column
  - Regular undersampling, Highly unfavorable

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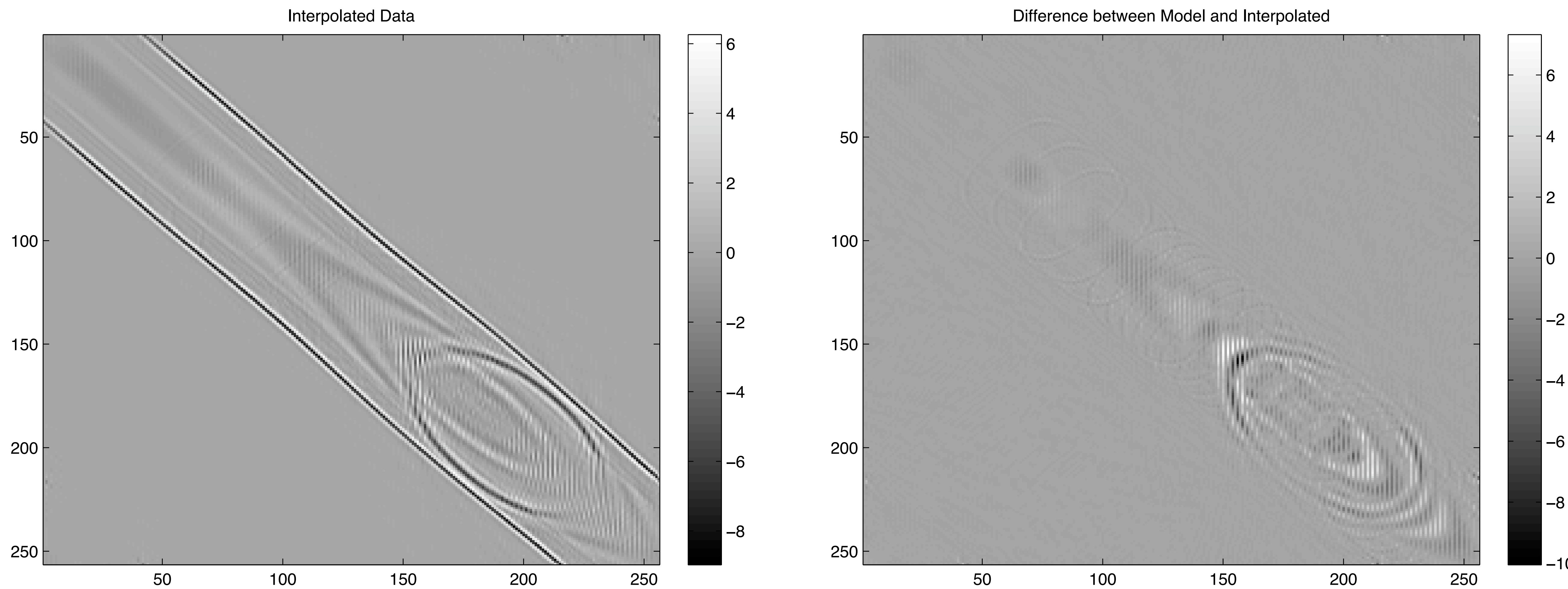
Results

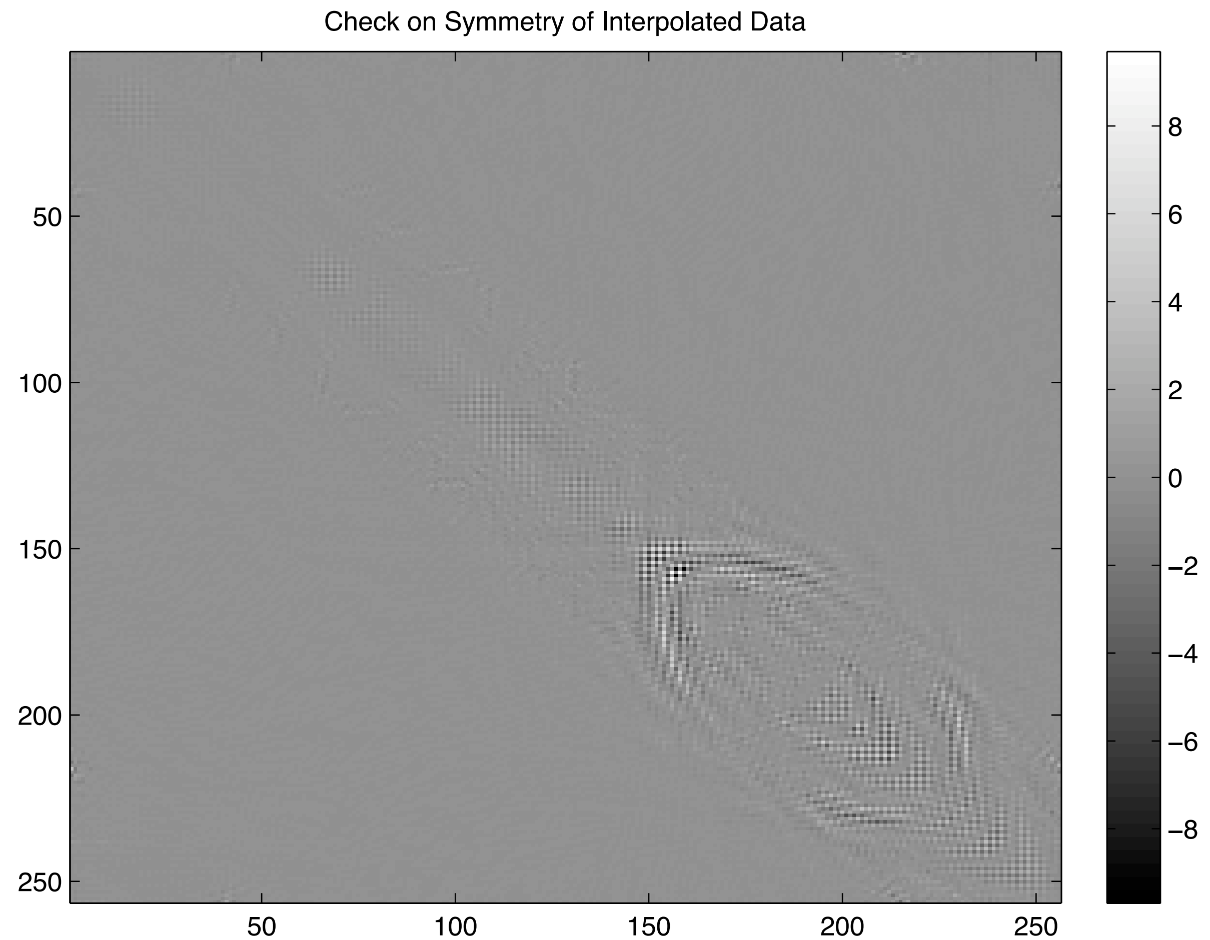
- Standard interpolation



- SNR: 4.07 dB

Results

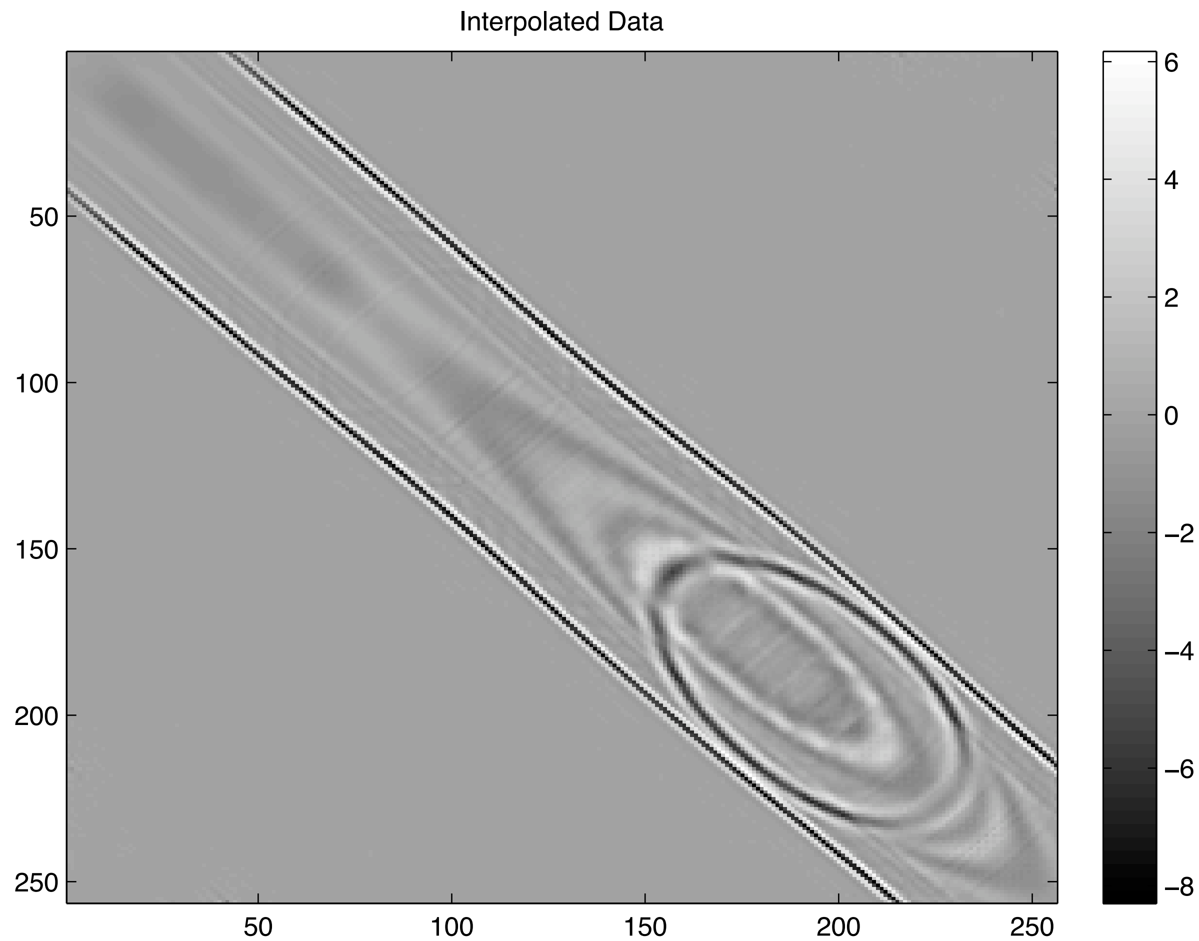
- Standard interpolation

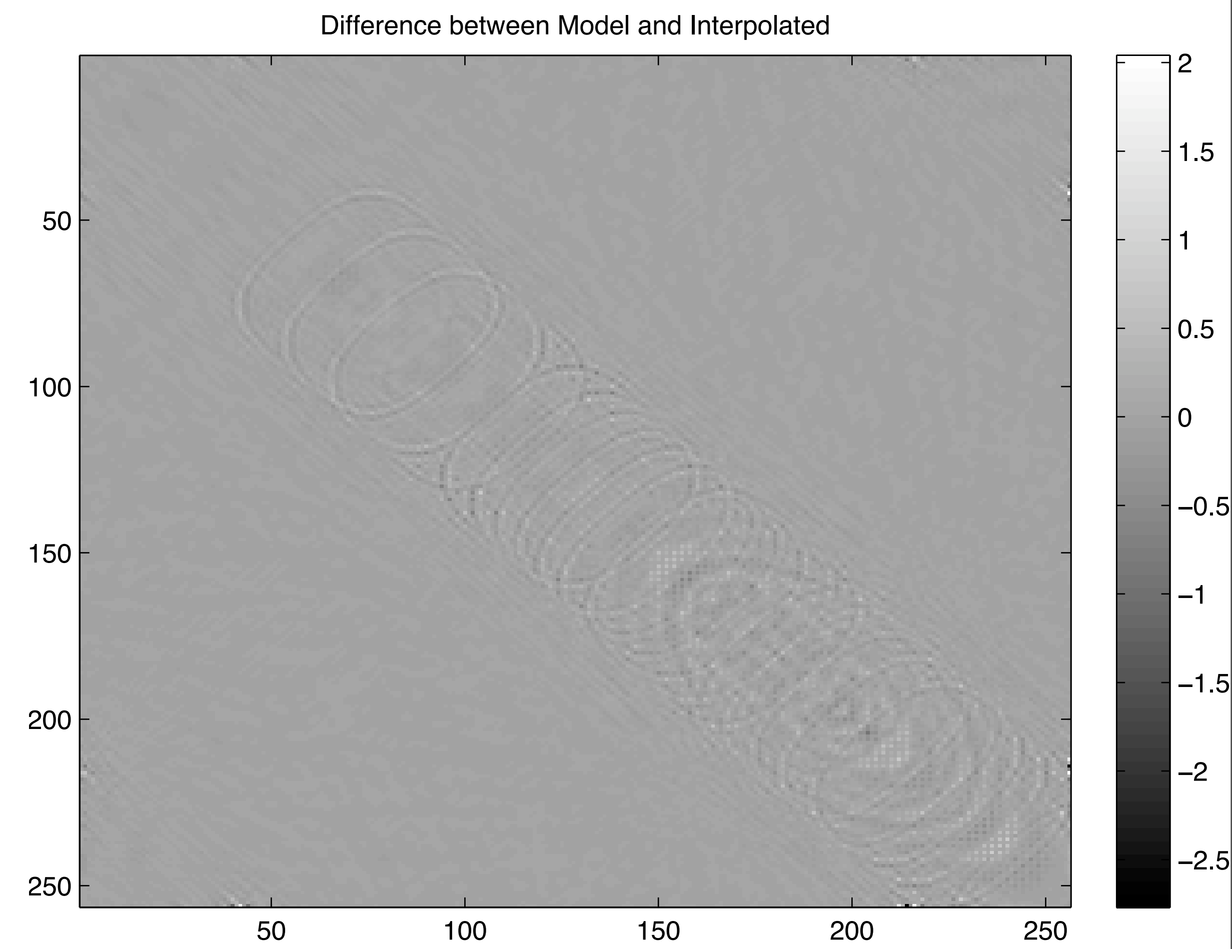


- Highly non symmetric

Results

- sCRSI interpolation

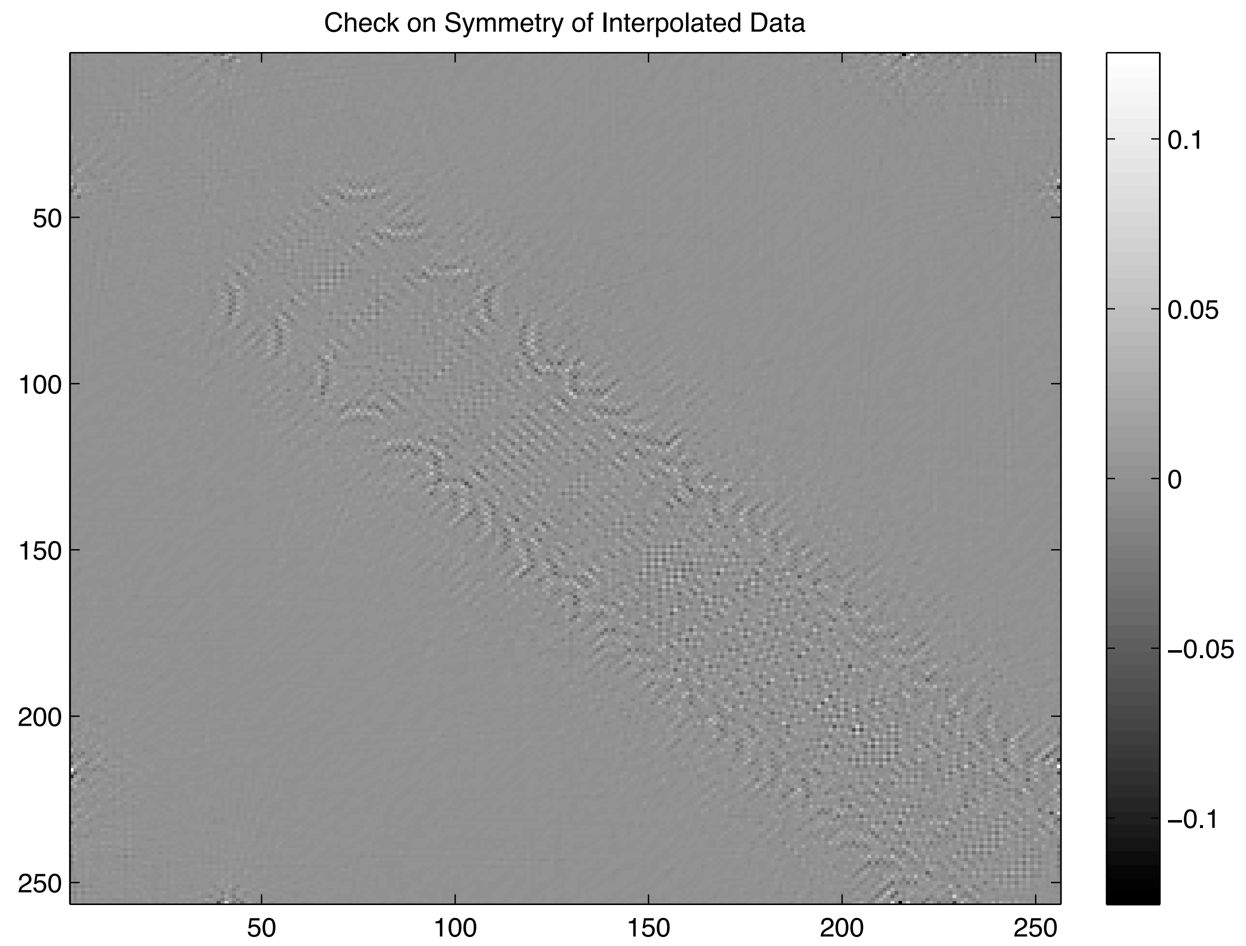




- SNR: 12.09 dB

Results

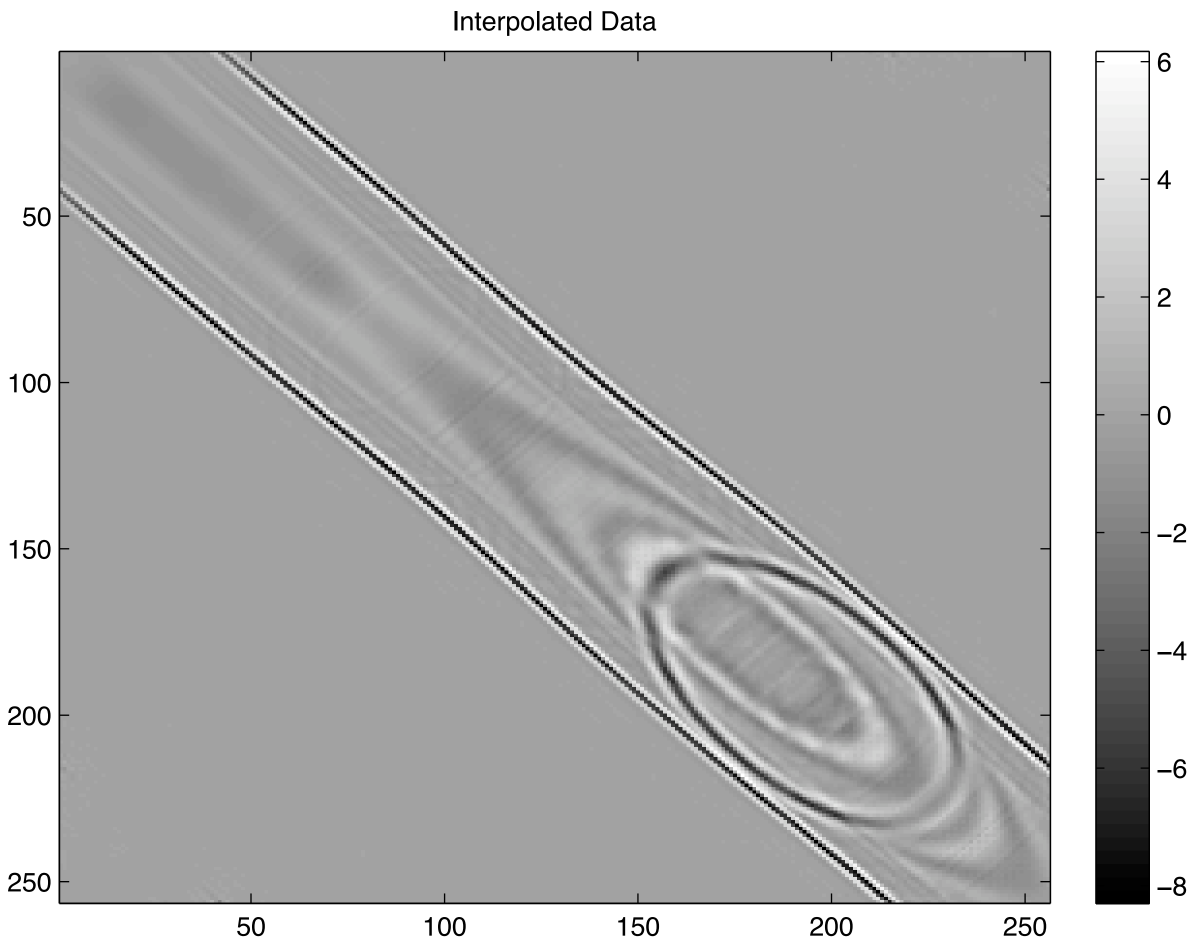
- sCRSI

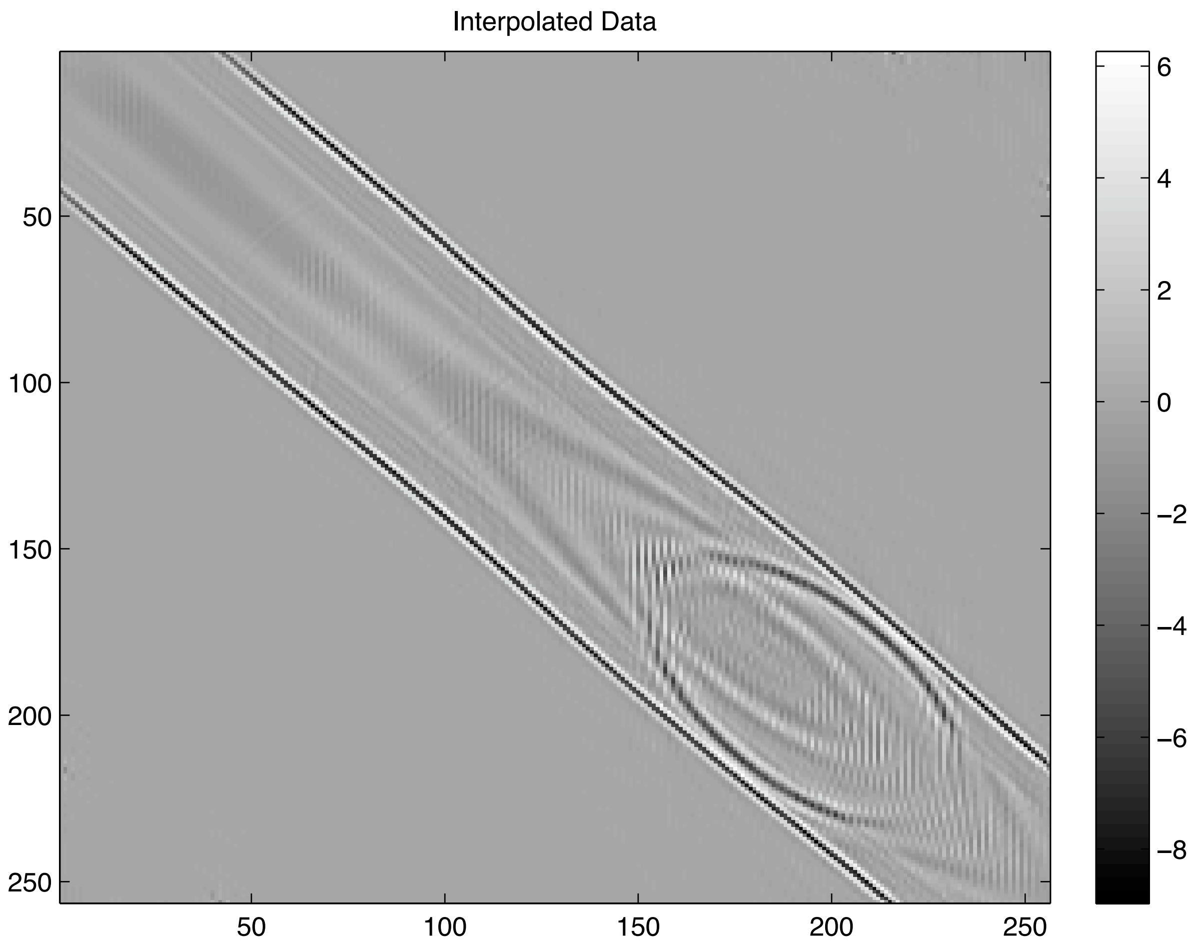


- Almost symmetric-> $\left\|f'\right\|_2 = 281, \left\|f' - f'^t\right\|_2 = 0.1$

Results

- Comparison of two methods





- 8 dB improvement in SNR

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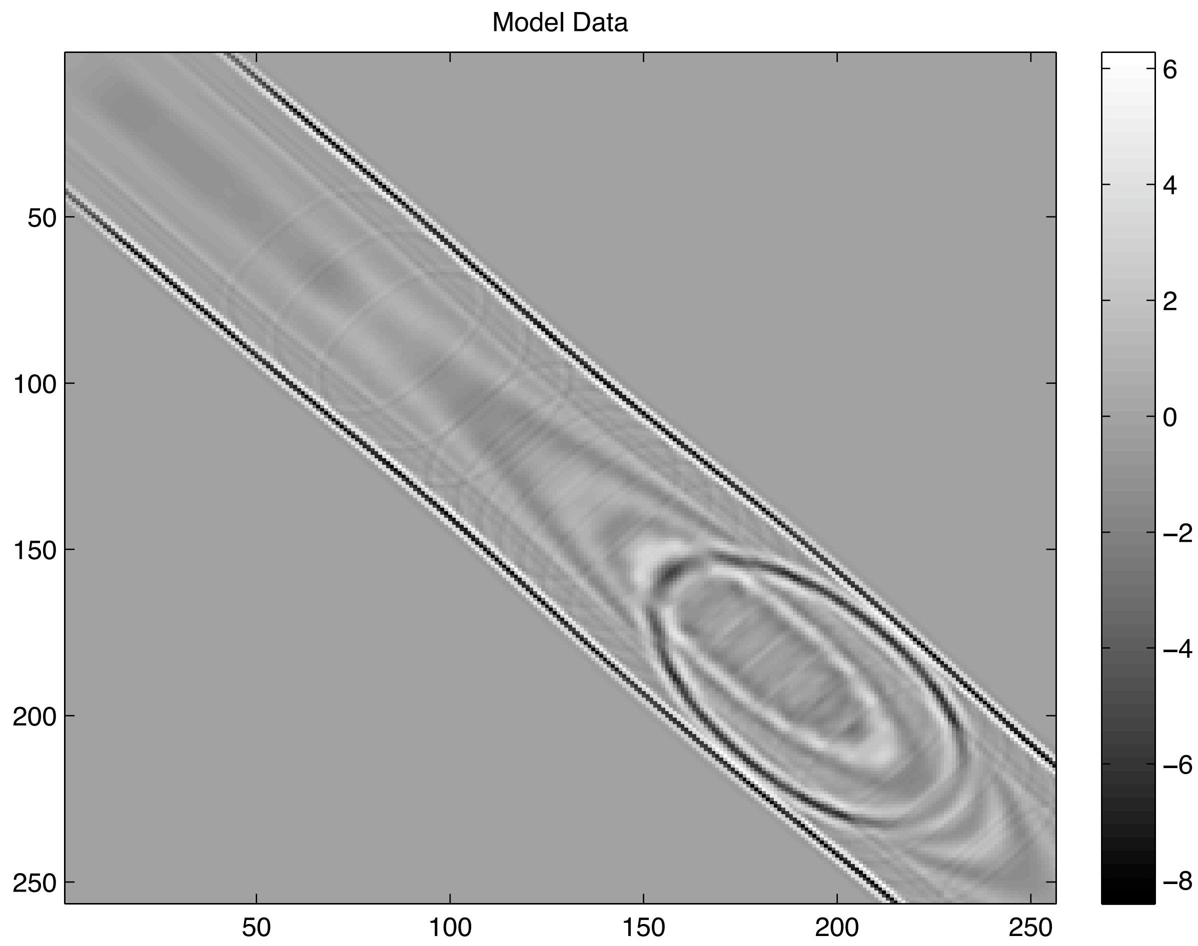
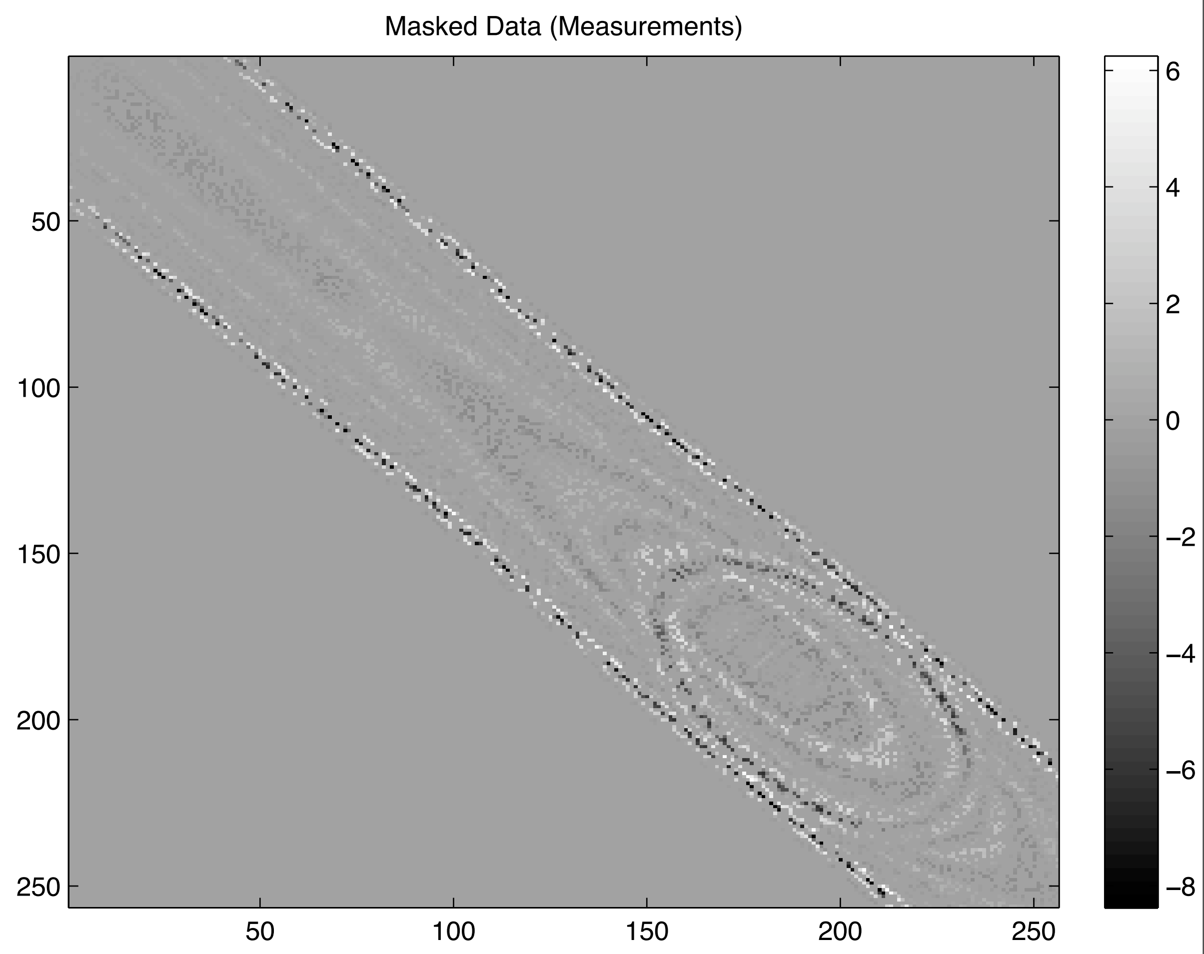
Results

- Same time slice





- Randomly removed 2/3 of the data points

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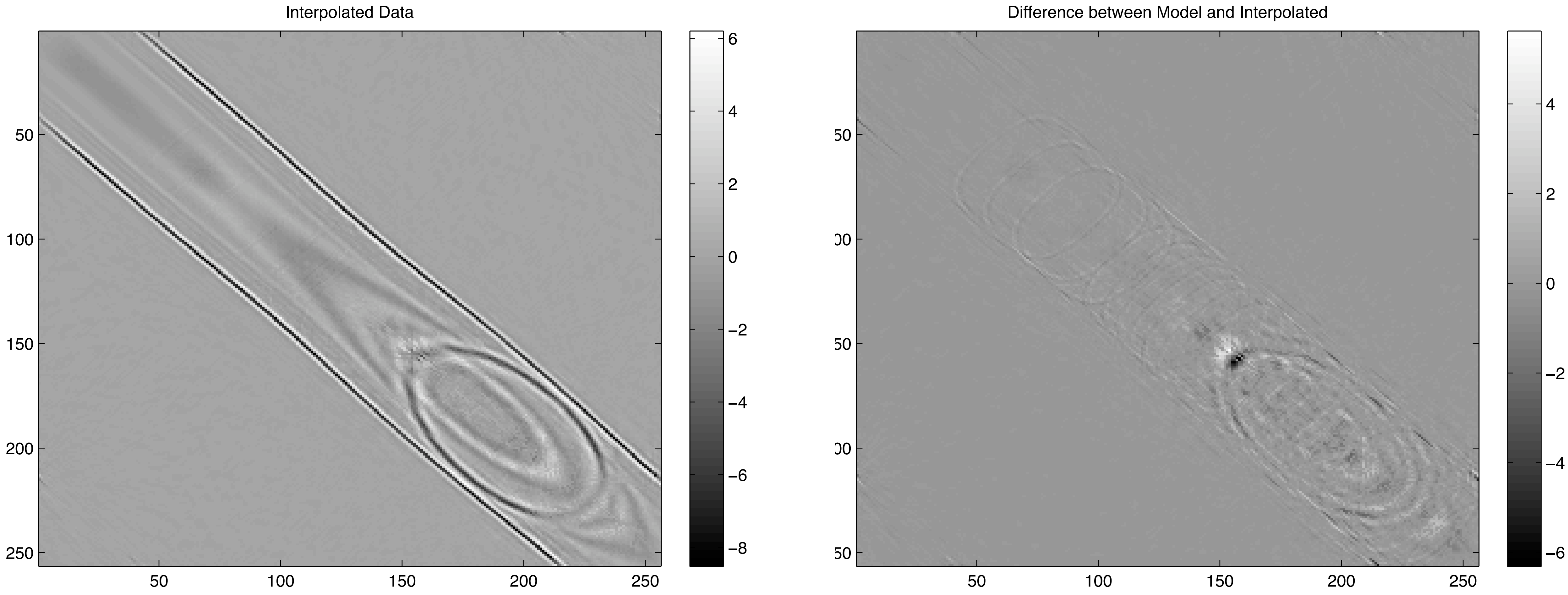
Results

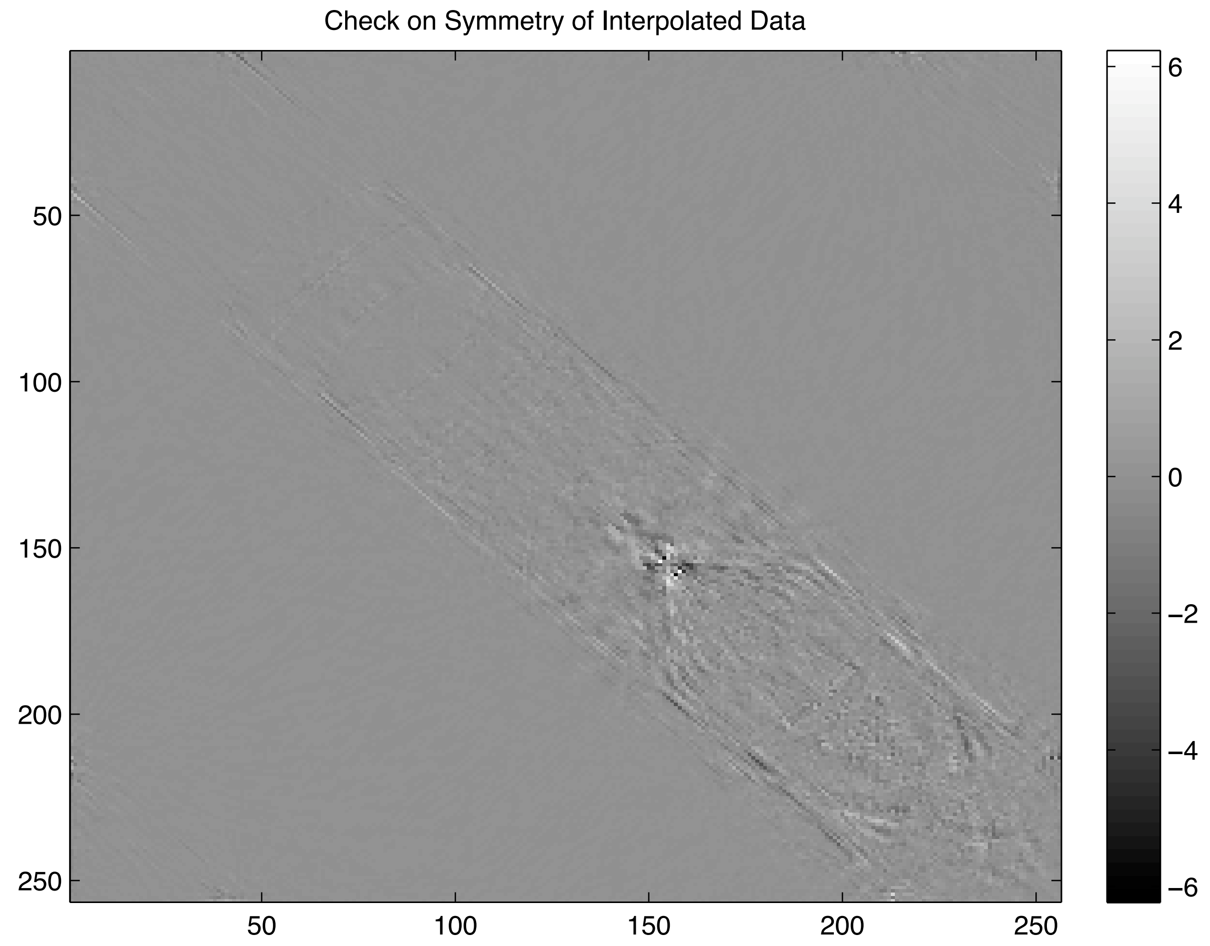
- Standard interpolation



- SNR: 6.19 dB

Results

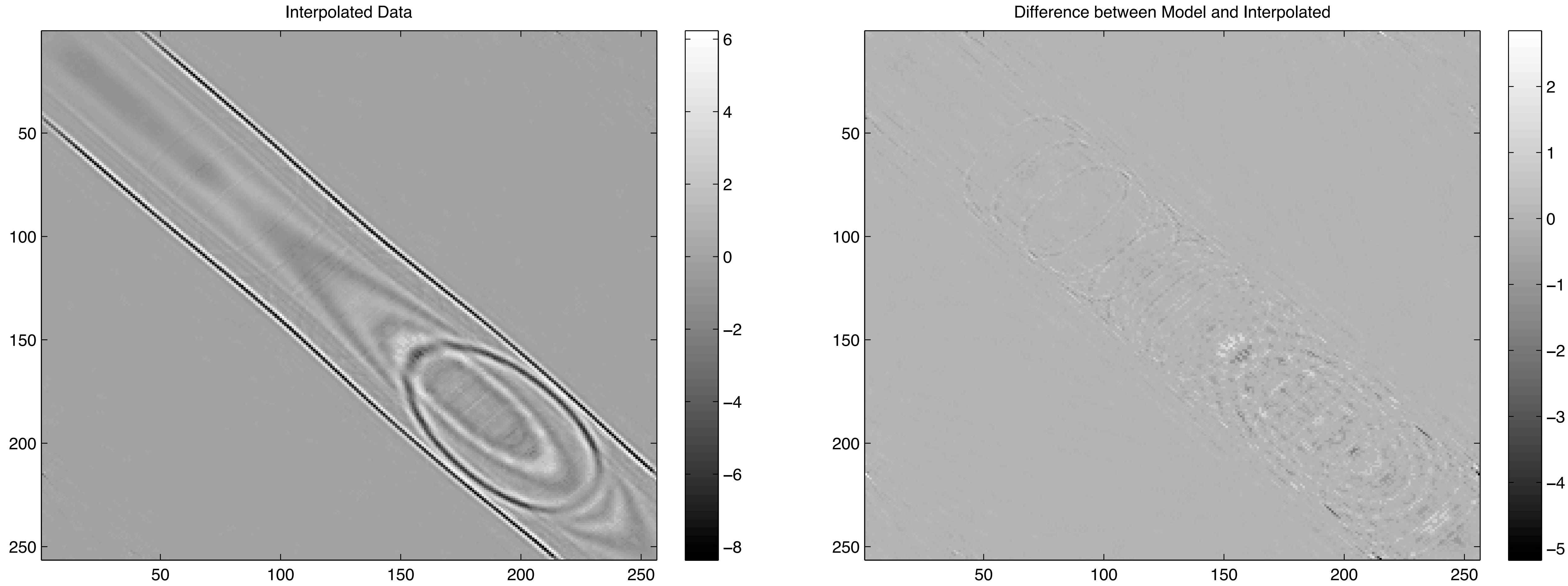
- Standard interpolation



- Non Symmetric

Results

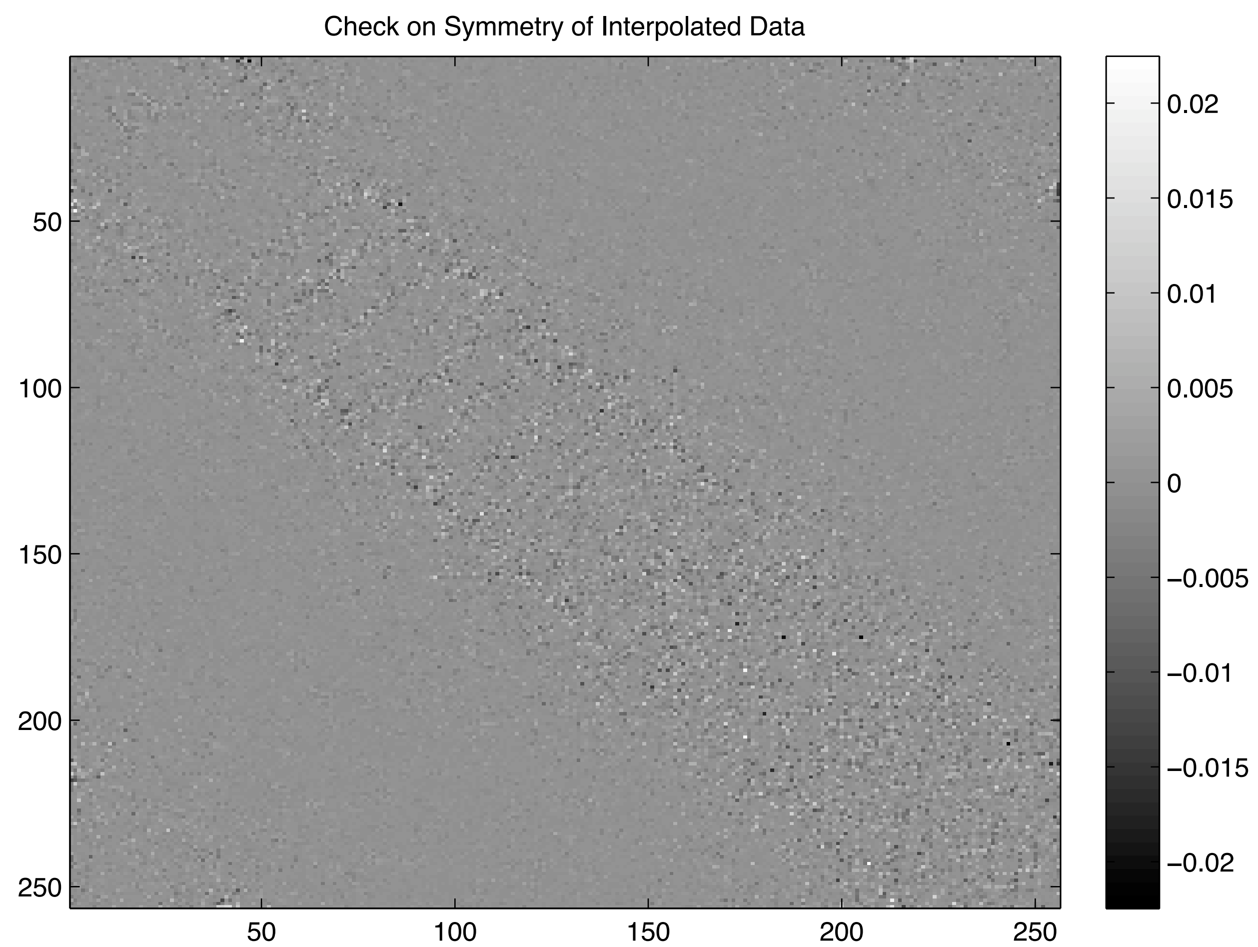
- sCRSI interpolation



- SNR: 8.95 dB

Results

- sCRSI



- Almost symmetric-> $\left\|f'\right\|_2 = 281, \left\|f' - f'^t\right\|_2 = 0.5$

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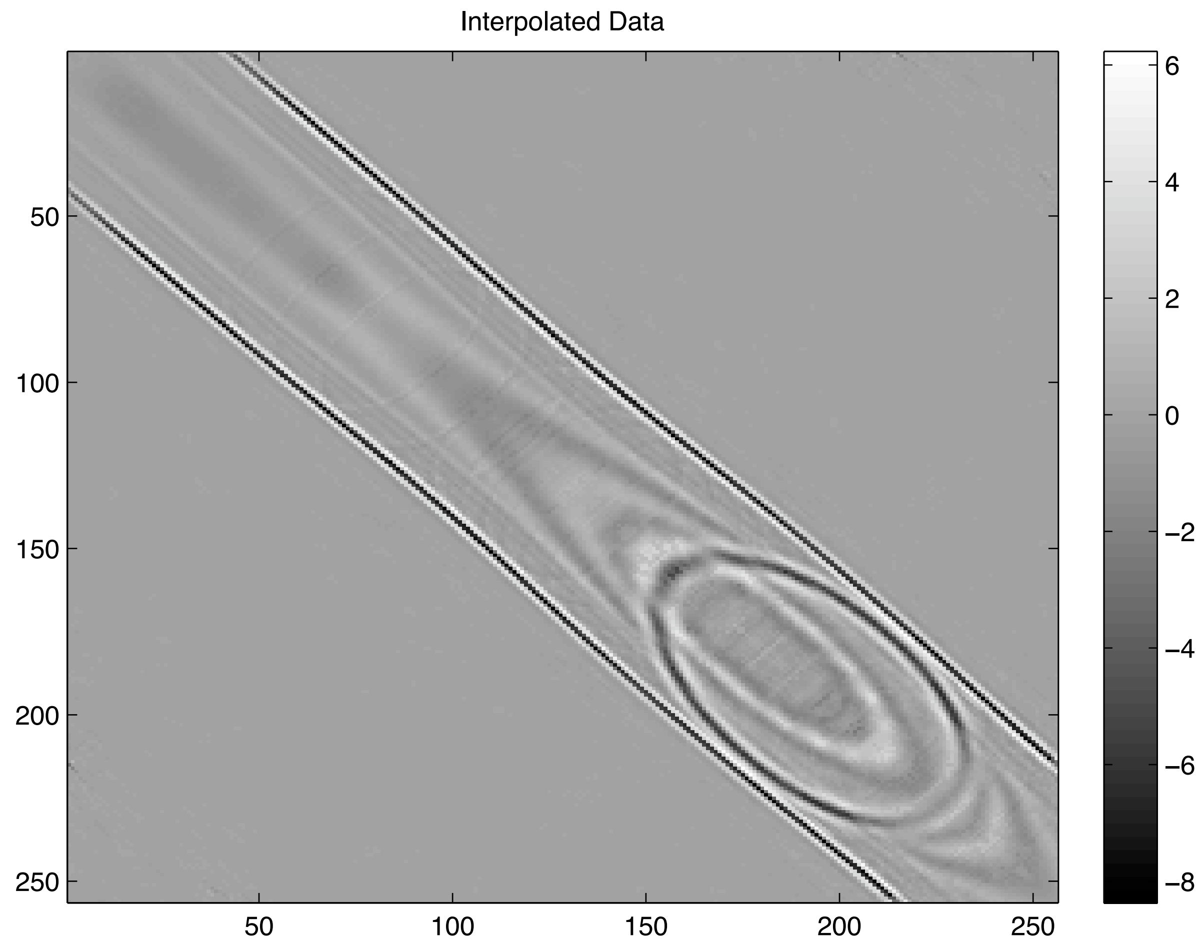
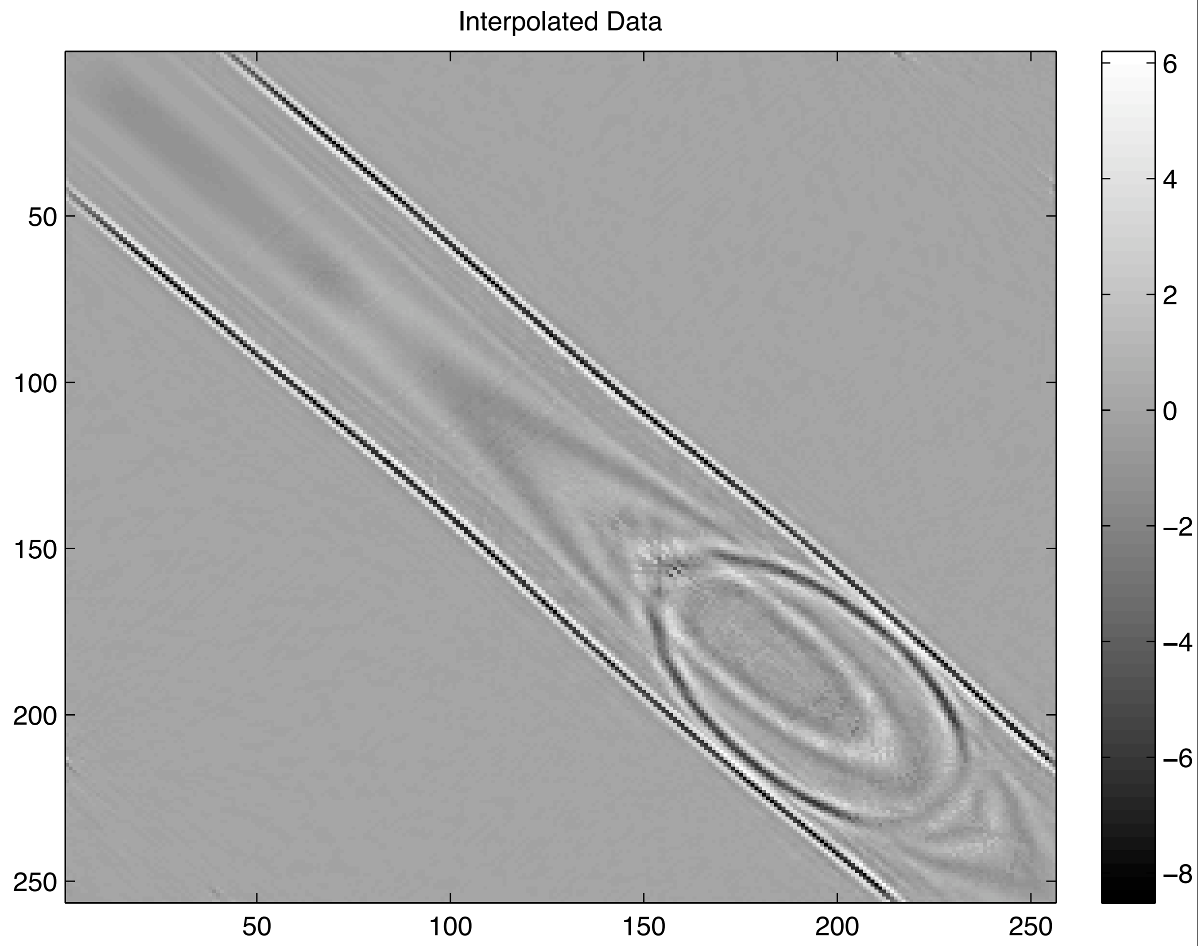
Results

- Comparison of two methods





- Enforcing symmetry outperforms regular methods

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Future Work

- Try method on real data
  - See how well assumptions hold up
    - Can a correction for source receiver geometry be made?
  - Curvelets should offer stability w.r.t moderate phase rotations and shifts

- 3d Interpolation
  - Exploit full dimensionality of data rather then working on each individual time slice
  - Should further improve results

- Work with solver so symmetry constraint given its own separate weight

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Conclusion

- Showed example of reciprocity in real data from survey done in California
- Reformulated data interpolation problem to enforce symmetry in results
- Results on synthetic data show significant improvements over previous work

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