Towards a Fast, Practical Alternative to Joint Inversion of Multiple Datasets: Model Fusion

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Abstract

There are many sources of data for Earth tomography models. Currently, each of these datasets is processed separately, resulting in several different Earth models that have specific coverage areas, different spatial resolutions and varying degrees of accuracy. These models often provide complimentary geophysical information on earth structure. In order to combine the information derived from these complementary models requires a joint inversion technique. While such a join inversion methods are being developed, as a first step, we propose a practical solution to fuse the Earth models coming from different datasets.

Need to Combine Data from Different Sources

In many areas of science and engineering, we have different sources of data. For example, in geophysics, there are many sources of data for Earth models:

- First-arrival passive seismic data (from the actual earthquakes),
- First-arrival active seismic data (from the seismic experiments),
- Gravity data,
- Surface waves, etc

Datasets coming from different sources provide complimentary information. For example, different geophysical datasets contain different information on earth structure (e.g., P and S wave velocity structure). For example:

- Some of the datasets provide better accuracy and/or spatial resolution in some spatial areas and in some depths, while
- Other datasets provide a better accuracy and/or spatial resolution in other areas or depths

At present, each of these datasets is often processed separately, resulting in several different models reflecting different aspects of the studied phenomena. It is therefore desirable to combine data from different datasets.

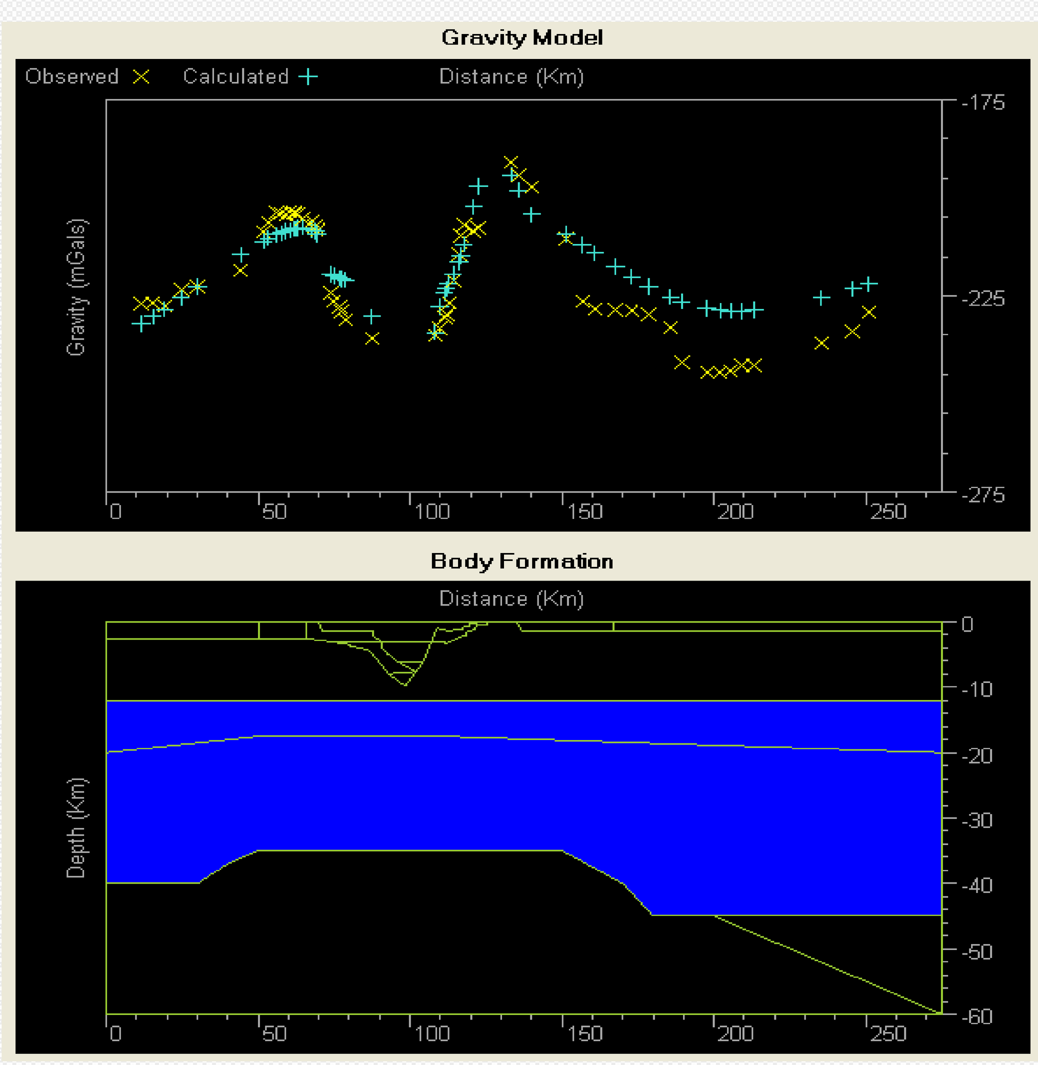

Fig 1. Gravity Data Model

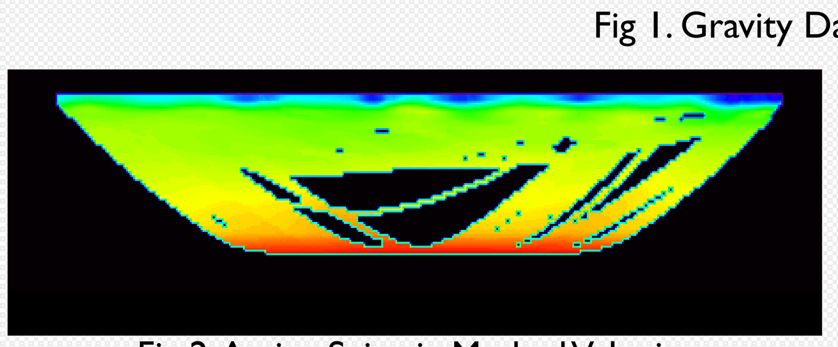

Fig 2. Active Seismic Masked Velocity

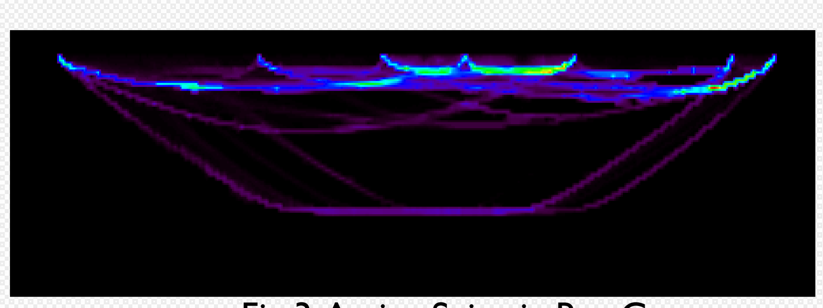

Fig 3. Active Seismic Ray Coverage

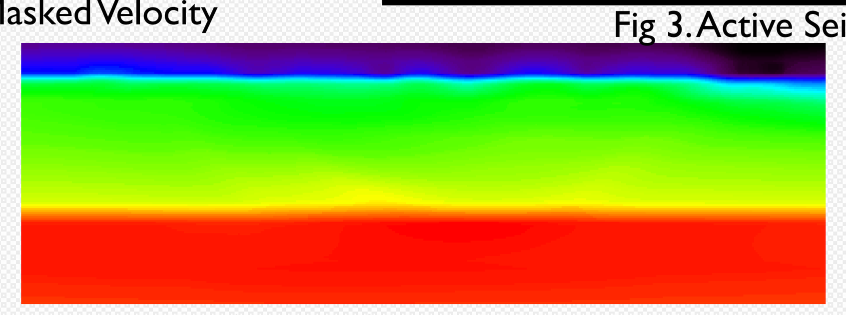

Fig 4. Active Seismic Velocity Model

Joint Inversion: An Ideal Future Approach

- Ideal approach: use all the datasets to produce a single model.
- Current situation: at present, there are no efficient algorithms for simultaneously processing all the different datasets.
- Challenge: designing such joint inversion techniques presents an important theoretical and practical challenge.

Proposed Solution: Model Fusion

- Main idea: fuse models coming from different datasets
- Simplest case: data fusion, when we have several measurements $x_1, \ldots x_n$ of the same quantity, with (possibly different) accuracy $\sigma_1, \ldots, \sigma_n$
- Data fusion algorithm: use the Least Squares method, find x for which the sum $\sum_{i=1}^{n} \frac{(x_i - x)^2}{\sigma_i^2}$ is the smallest
- Problem: in our case, different measurements have not only different accuracy, but also different spatial resolution

Model Fusion: Technical Details

Our solution: account for three different types of approximate equalities:

- Each high-resolution value $\widetilde{x}_i$ is approximately equal to the actual value x_i in the corresponding (smaller size) cell i, with the accuracy corresponding to the accuracy σ_h of the higher-resolution Earth model: $\widetilde{x}_i \approx x_i$
- Each lower-resolution value $\widetilde{X}_j$ is approximately equal to the average of values of all the smaller cells $x_{i_1j}, \ldots, x_{i_kj}$ within the corresponding larger size cell, with the accuracy σ_l corresponding to the accuracy of the lower-resolution Earth model: $\widetilde{X}_j \approx \frac{x_{i_1j}, \ldots, x_{i_kj}}{k}$
- Each lower-resolution value $\widetilde{X}_j$ is approximately equal to the value within each of the constituent smaller size cells x_{i_1j}, with the accuracy corresponding to the (empirical) standard deviation σ_e of the smaller-cell values within the larger cell: $\widetilde{X}_j \approx x_{i_lj}$

We then use the Least Squares technique to combine these approximate equalities, and find the desired combined values x_i by minimizing the resulting sum of weighted squared differences

Proof of Concept

- To assess the model fusion idea, we performed preliminary proof-of-concept experiments with simplified datasets (i.e., with synthetic data)
- Our preliminary results show that this method indeed leads to a fused model that effectively combines accuracy and resolution of different Earth models
- Illustrative example:

2.0	3.0
5.0	6.0

3.7

$\sigma_h = 0.5 \quad \sigma_e = 1.6$

$\sigma_l = 0.0$

$$\frac{(x_1 - 2.0)^2 + (x_2 - 3.0)^2 + (x_3 - 5.0)^2 + (x_4 - 6.0)^2}{0.5^2} + \frac{\frac{x_1 + x_2 + x_3 + x_4}{4} - 3.7}{0.0^2} + \frac{(x_1 - 3.7)^2 + (x_2 - 3.7)^2 + (x_3 - 3.7)^2 + (x_4 - 3.7)^2}{1.6^2} \rightarrow \min x_1, x_2, x_3, x_4$$

$$\frac{x_1 - 2.0}{0.5^2} + \frac{\frac{x_1 + x_2 + x_3 + x_4}{4} - 3.7}{0.0^2} + \frac{x_1 - 3.7}{1.6^2} = 0$$

$$x_1\left(\frac{1}{0.5^2} + \frac{1}{1.6^2}\right) = \frac{2.0}{0.5^2} + Const \qquad \frac{x_1 + x_2 + x_3 + x_4}{4} = 4.0\frac{1}{1.1} + Const = 3.7$$

$$Const = 0.06$$

$$x_1 = 2.0\frac{1}{1.1} + Const$$
$$x_2 = 3.0\frac{1}{1.1} + Const$$
$$x_3 = 5.0\frac{1}{1.1} + Const$$
$$x_4 = 6.0\frac{1}{1.1} + Const$$

$$x_1 = 1.9 \quad x_2 = 2.8 \quad x_3 = 4.6 \quad x_4 = 5.5$$

1.9	2.8
4.6	5.5

Conclusions

- We propose a new approach to combining data from different sources, an approach which is a fast practical alternative to joint inversion of multiple datasets
- On the example of simulated (synthetic) geophysical data, we show that model fusion indeed improves the accuracy and resolution of individual models

Future Work

Plans for future work:

1) apply the model fusion techniques to more realistic simulated data;

2) use the results of these applications to adjust the techniques;

3) apply the adjusted model fusion techniques to real geophysical data;

4) use the results of these applications to further adjust the techniques.

References

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