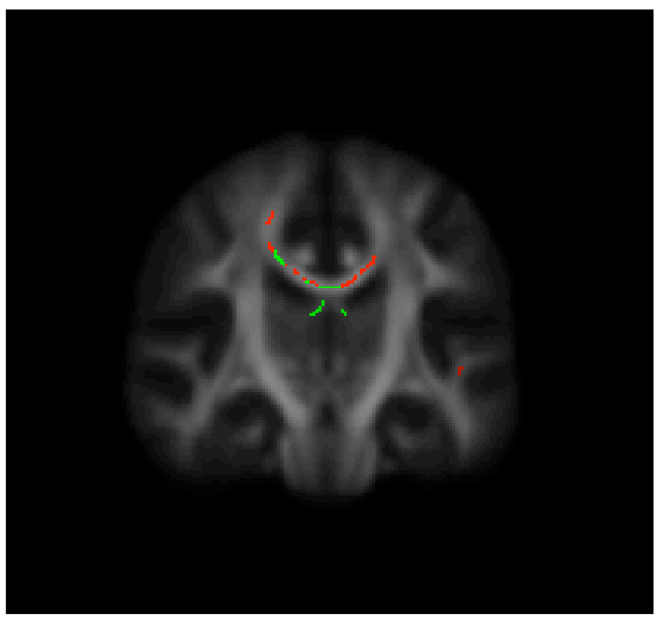
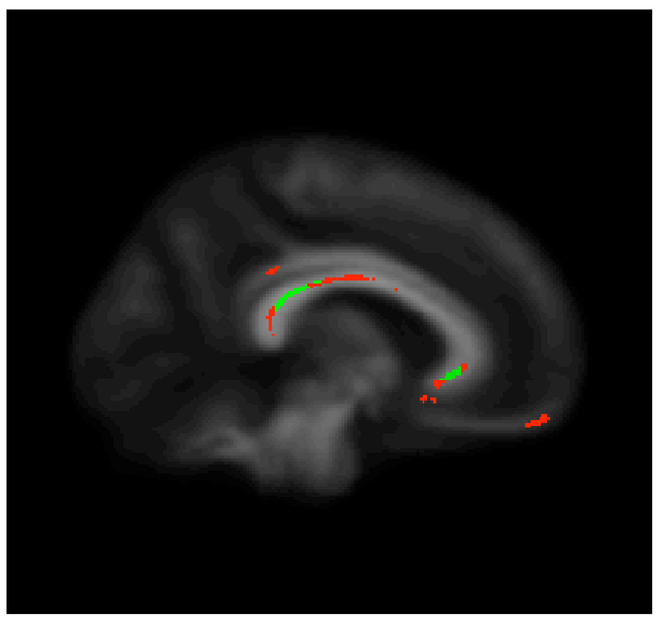
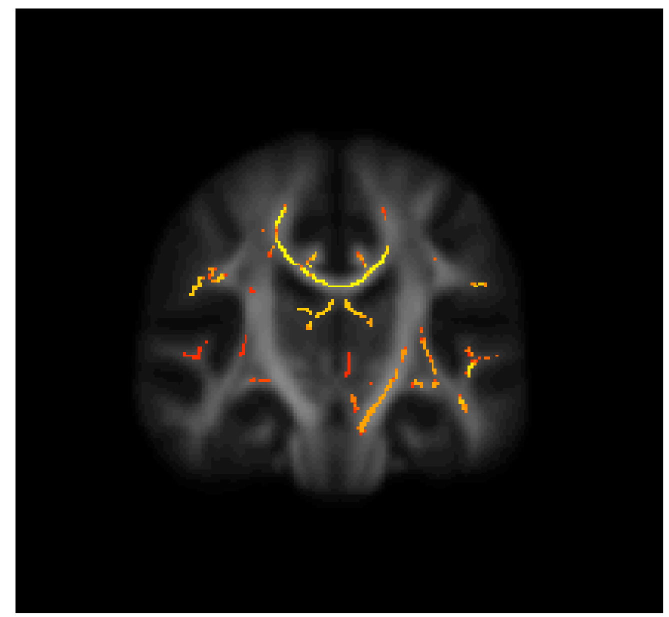
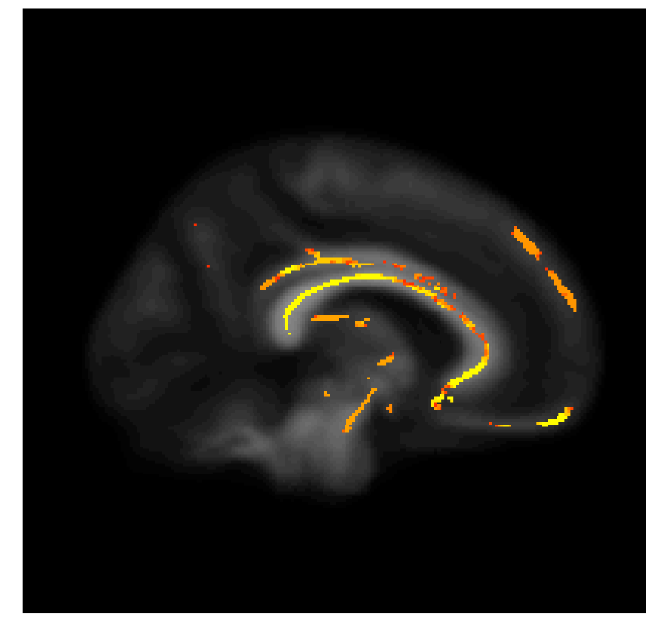
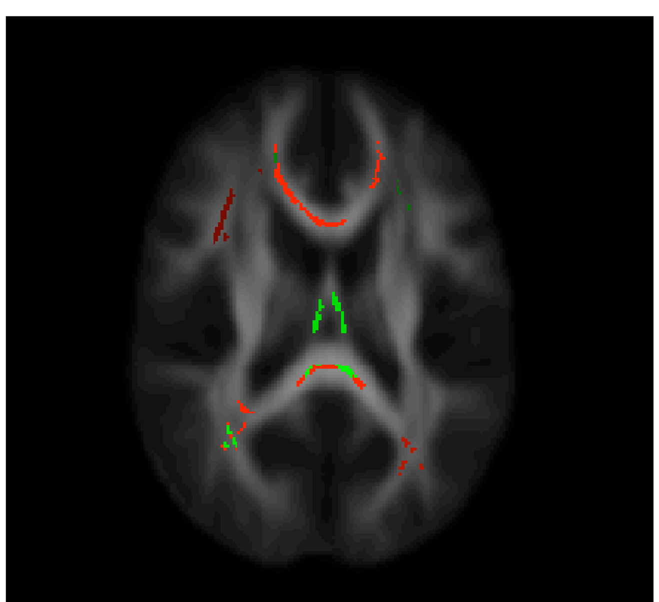
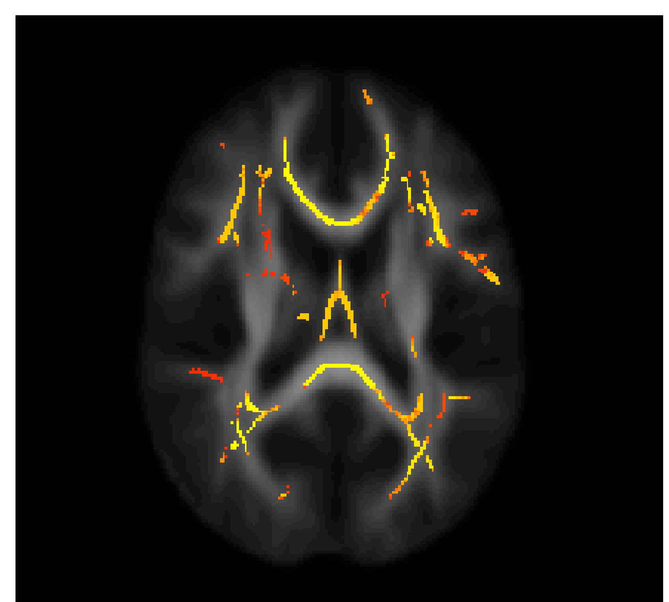
TFCE for TBSS

controls > schizophrenics
p<0.05 corrected for multiple comparisons across space, using randomise

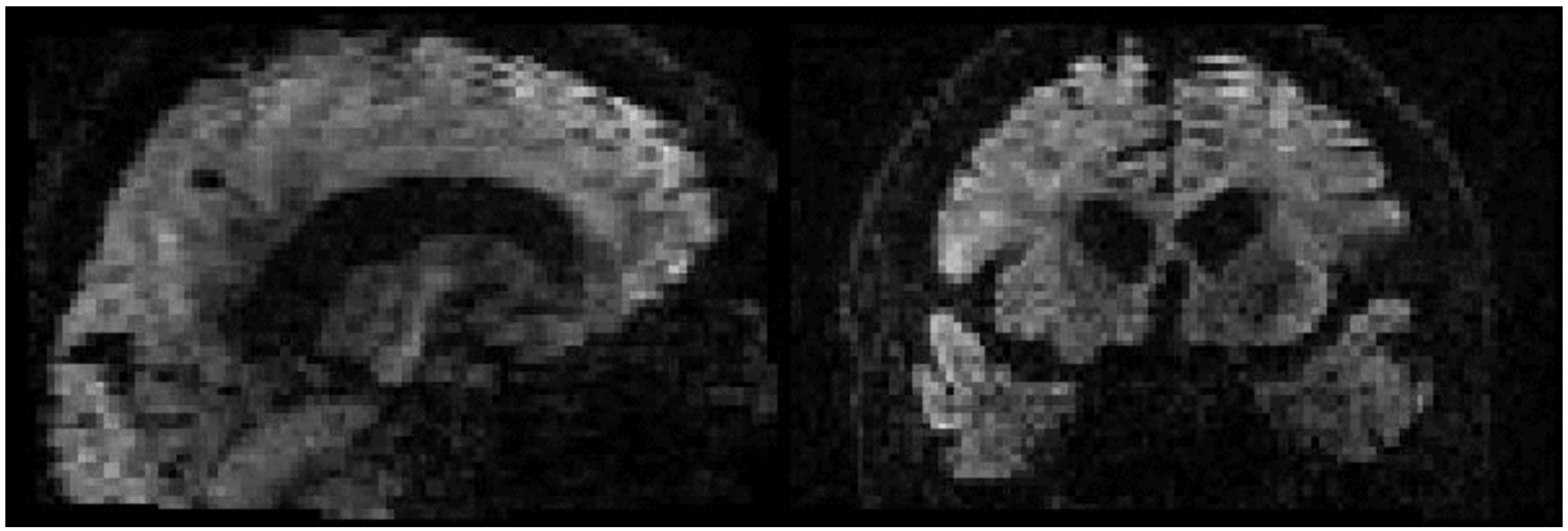


cluster-based:
cluster-forming threshold =
2 or 3



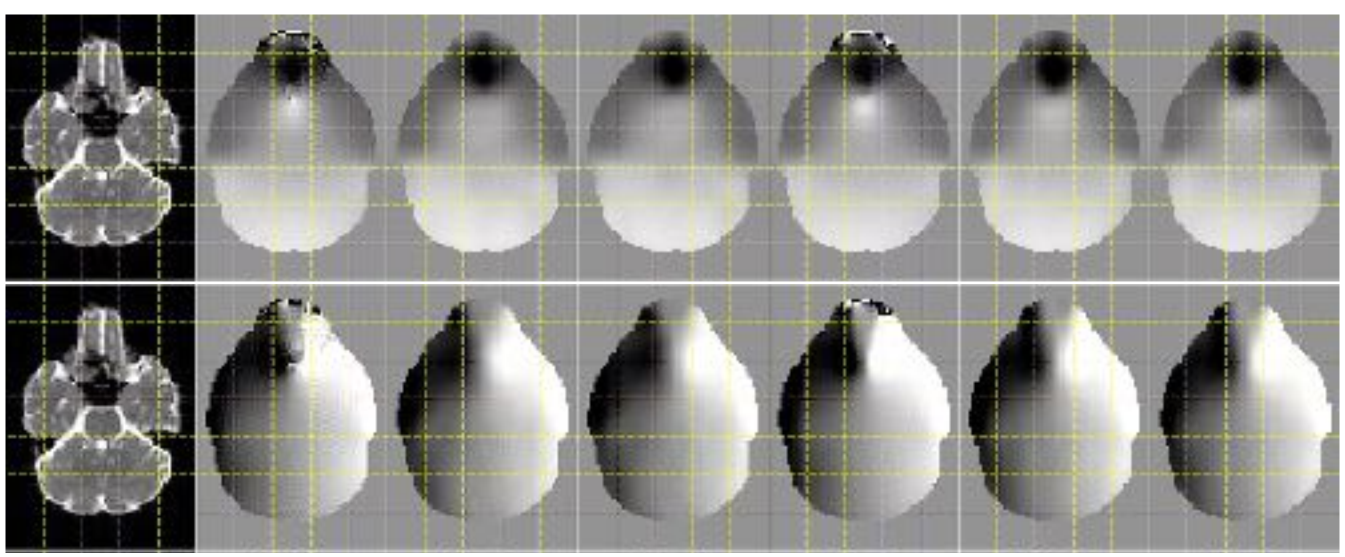
TFCE

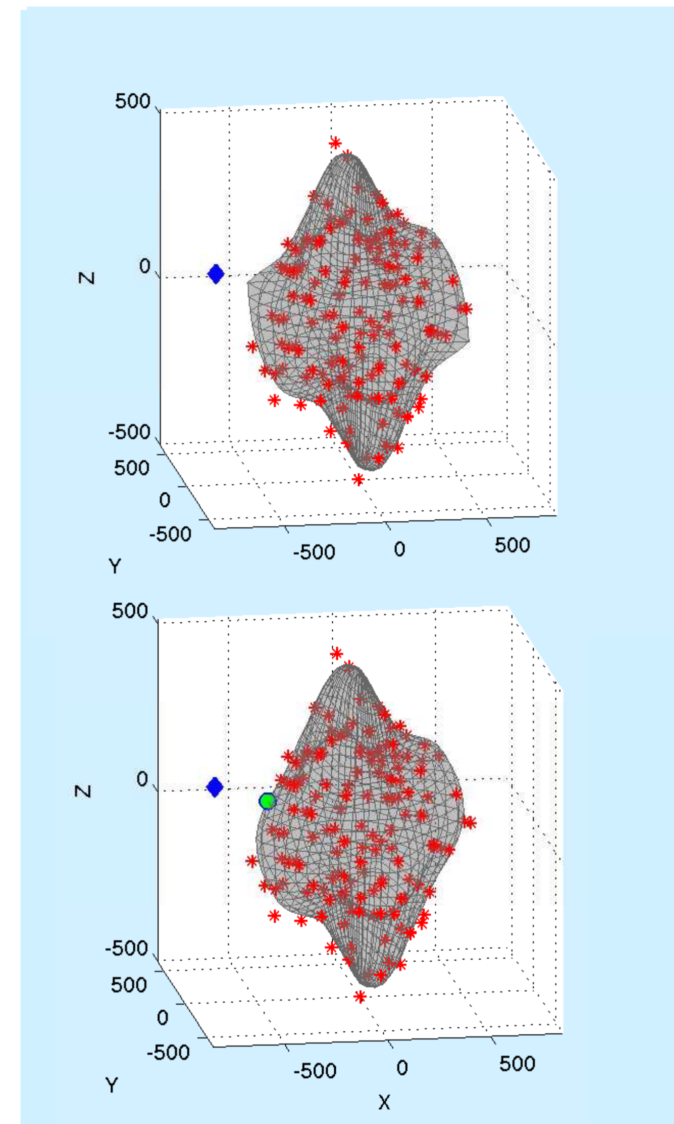
eddy - Advanced features



$$\frac{\partial \omega}{\partial \theta}$$

$$\frac{\partial \omega}{\partial \phi}$$





Outline of the talk

- “Advanced” eddy features
  - Movement-induced dropout
  - Intra-volume motion
  - Susceptibility-by-movement

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Movement induced dropout

Diffusion encoding

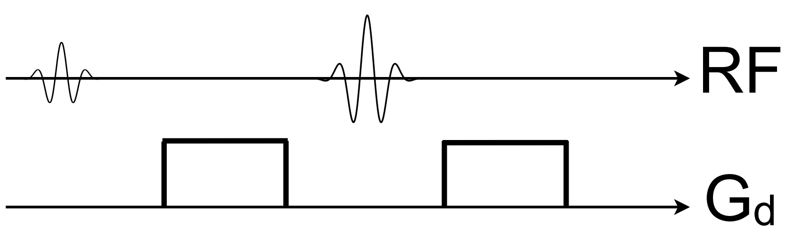
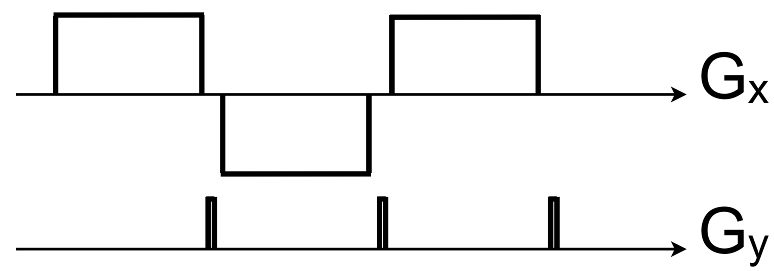
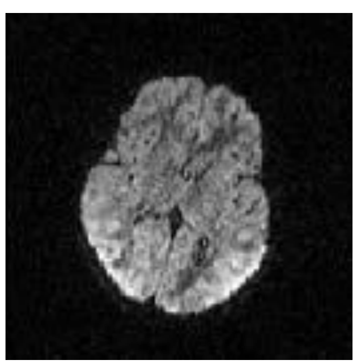


Image encoding

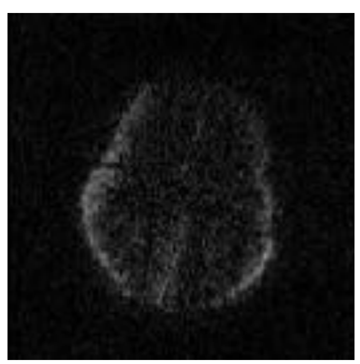


. . .

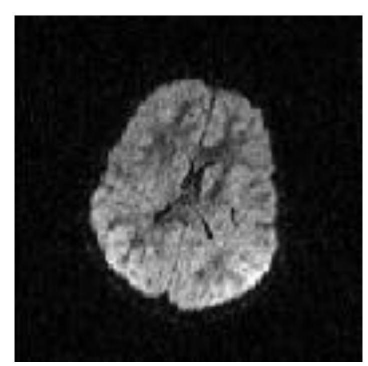
If there is movement during this part…



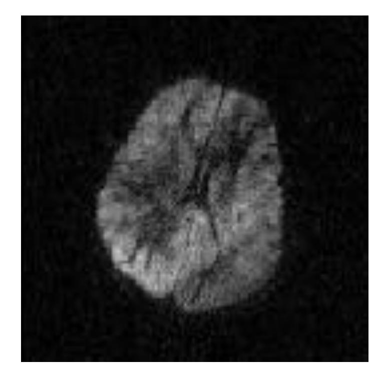
this



can turn to this

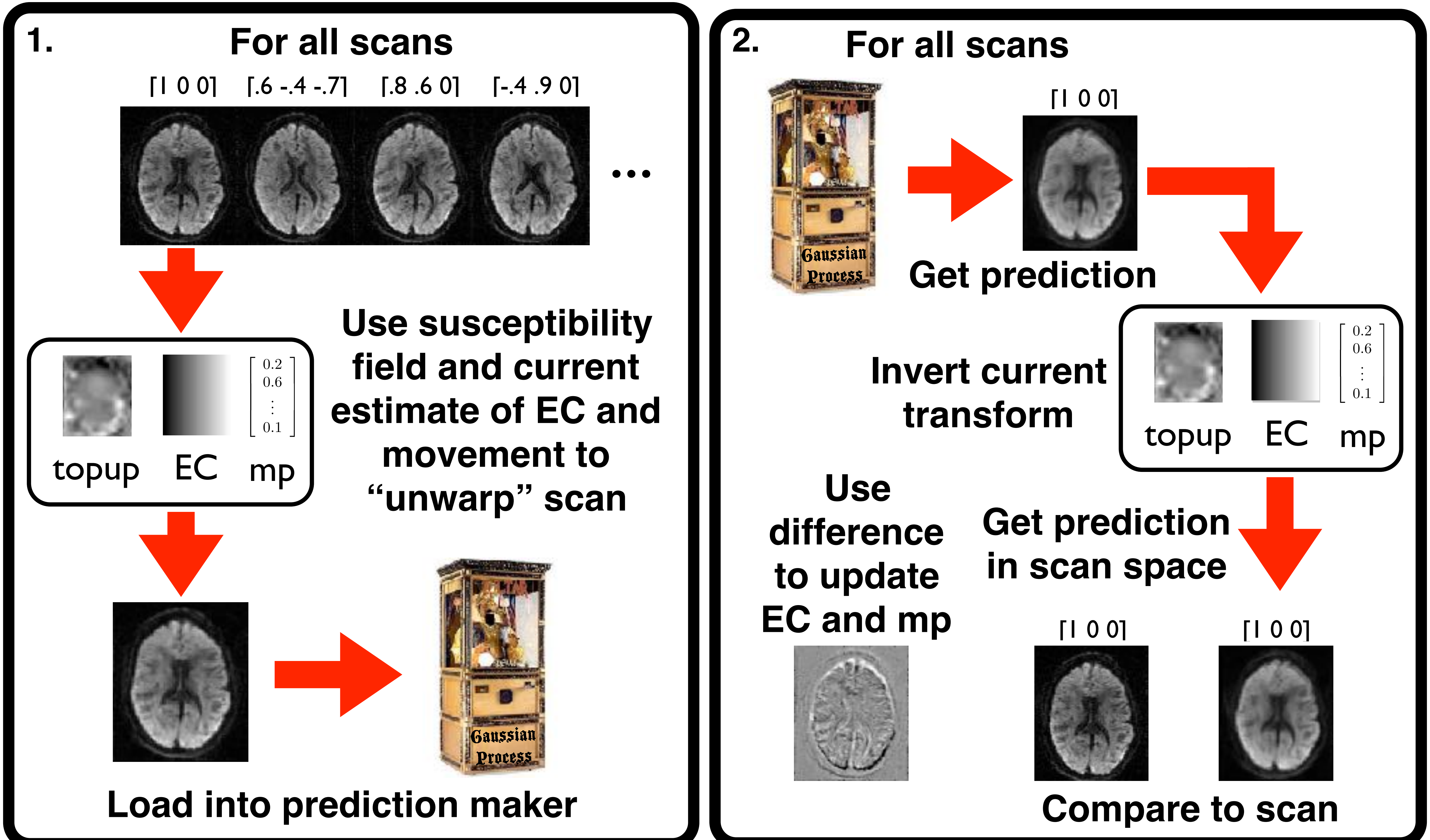


or this

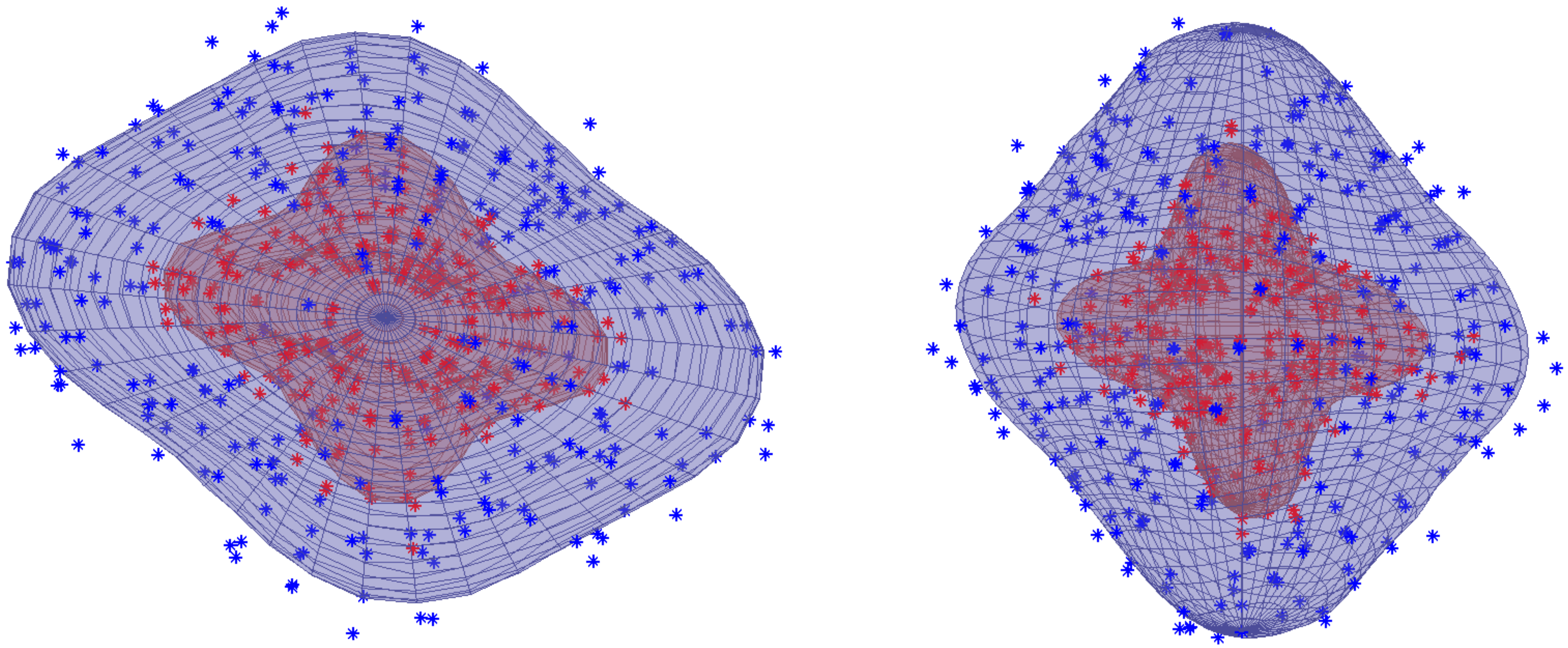


to this

What can eddy do about it?
But first a little recap of eddy



How are the predictions made?

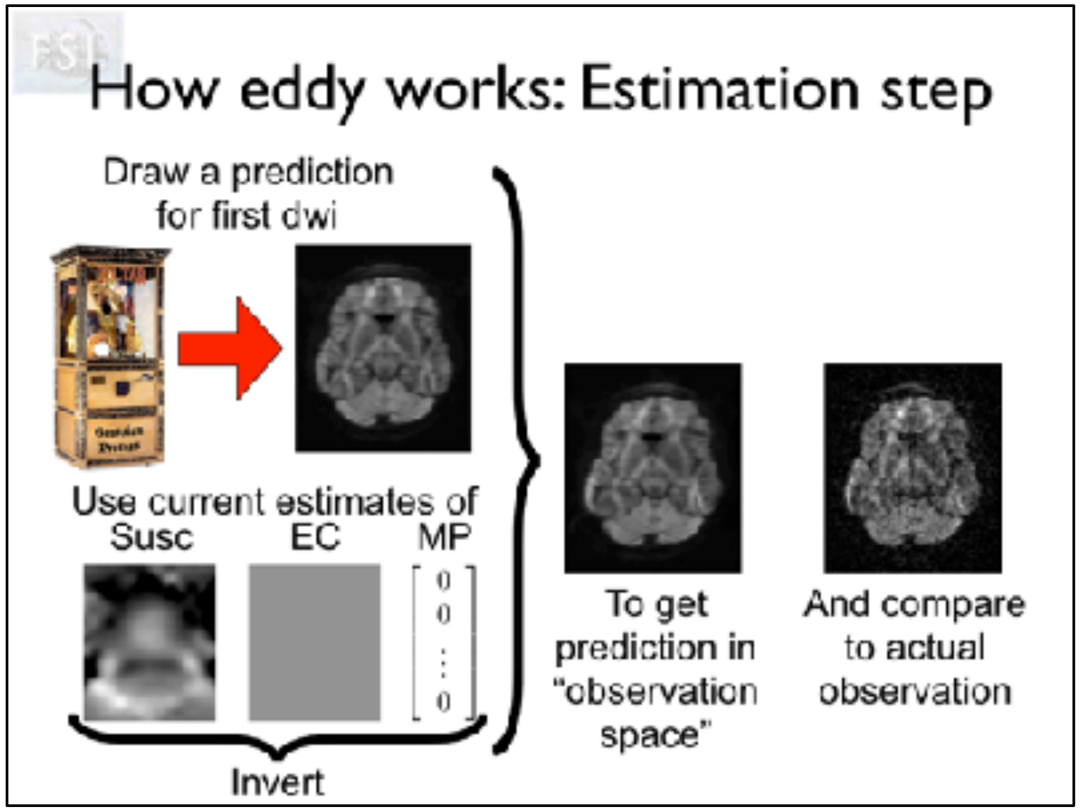


A Gaussian process that simply assumes that the signal varies smoothly as we move in Q-space

Very few assumptions. Hyperparameters calculated by leave-one-out.

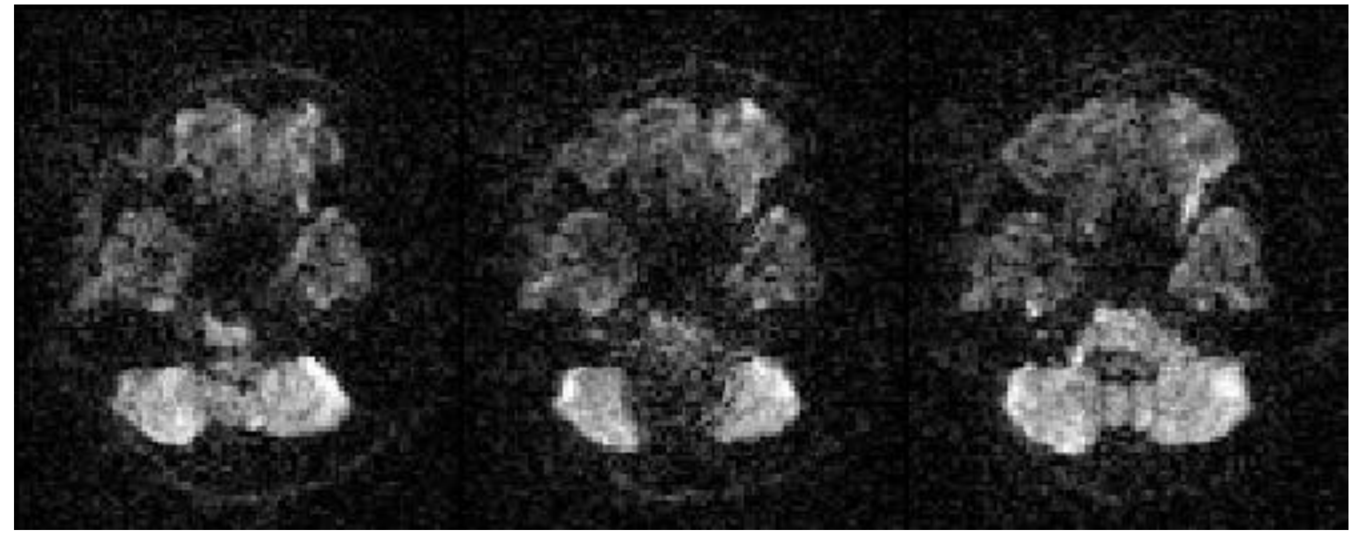
$$\hat{y}_{\mathbf{g}} = K(\mathbf{g}, \mathbf{G}) \left[K(\mathbf{G}, \mathbf{G}) + \sigma^2 \mathbf{I}\right]^{-1} \mathbf{y}$$

Outlier detection

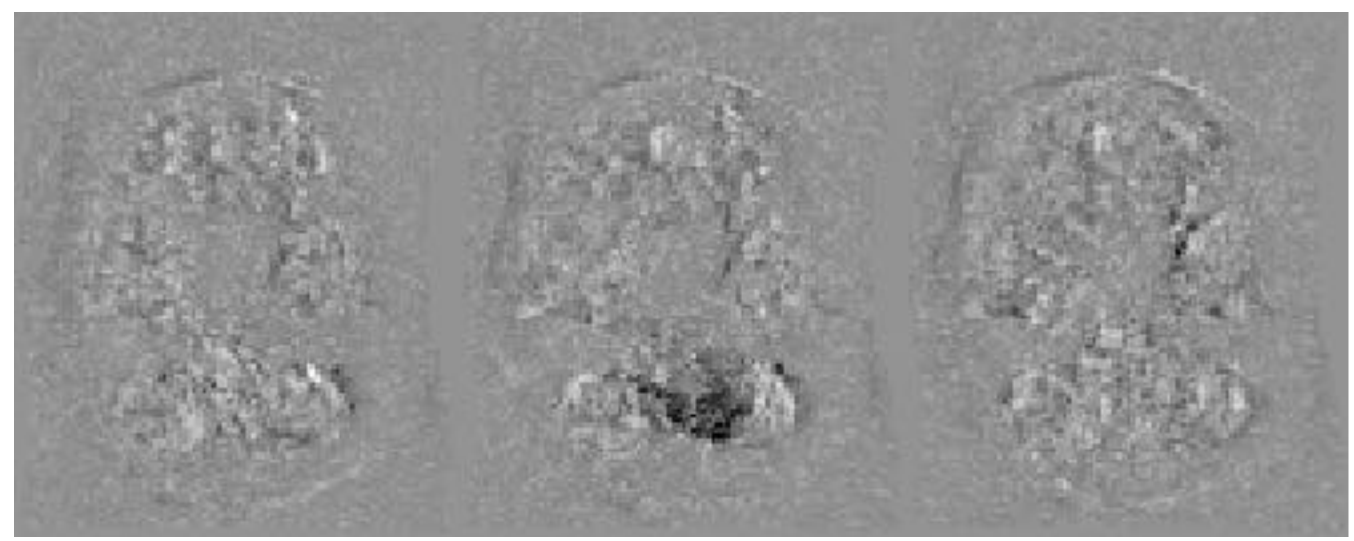


Remember that we do all comparisons in observation space.

Observed data



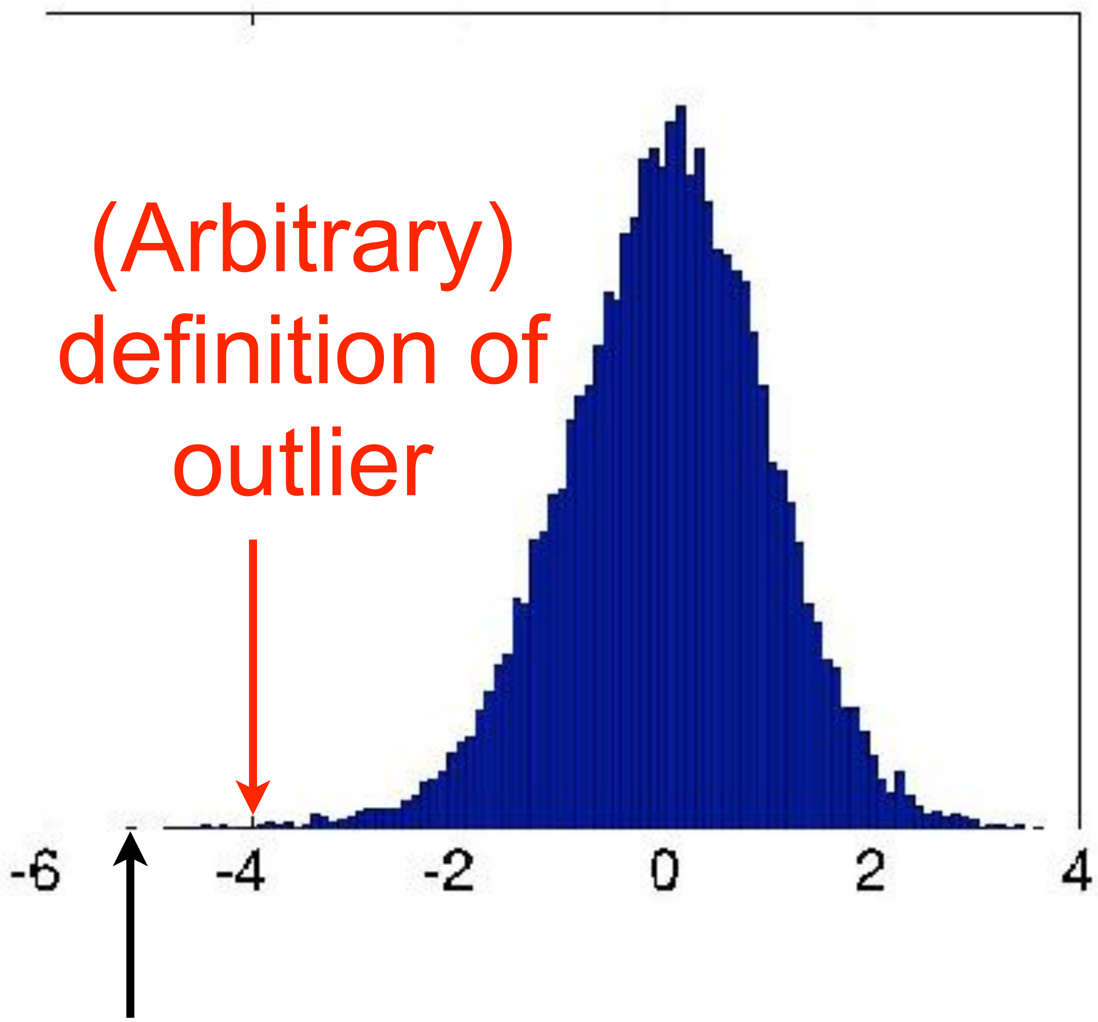
Observed - predicted



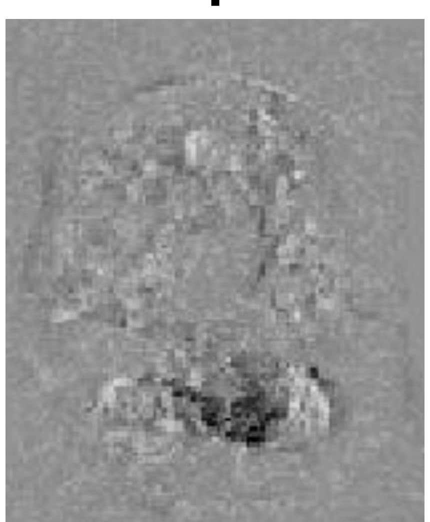
$\overline{x} = 0.084$ $\overline{x} = -0.791$ $\overline{x} = -0.125$

This allows us to calculate the per-slice mean difference between observation and prediction

Outlier detection



We can calculate the mean difference for every slice in every volume and get an empirical distribution that we can convert to z-scores

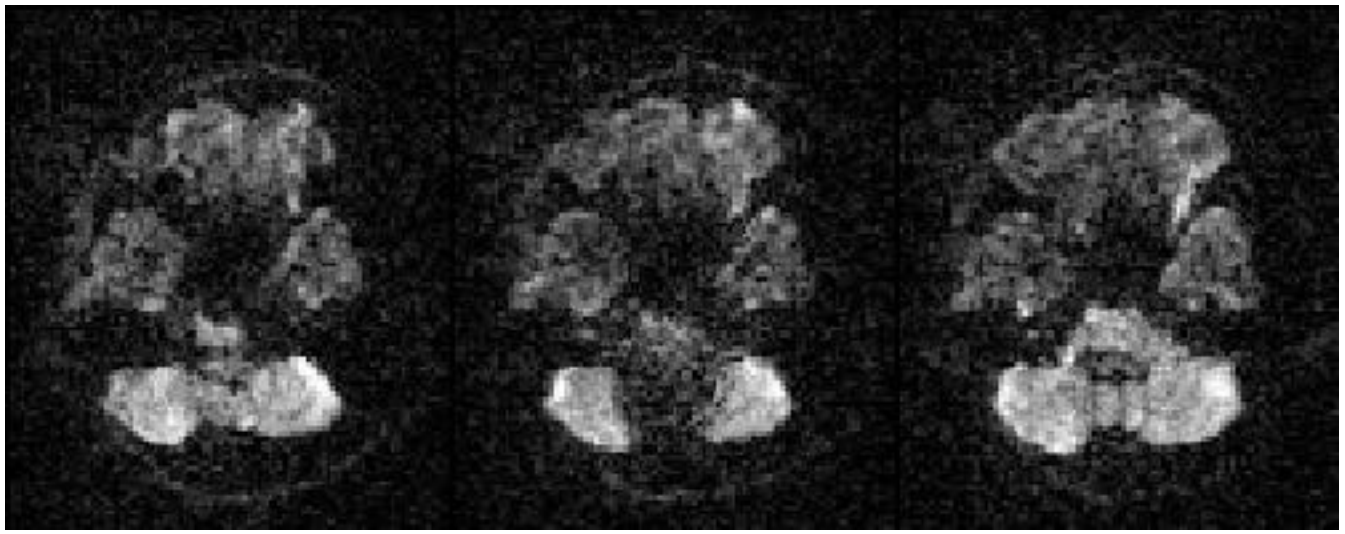


Worst slice

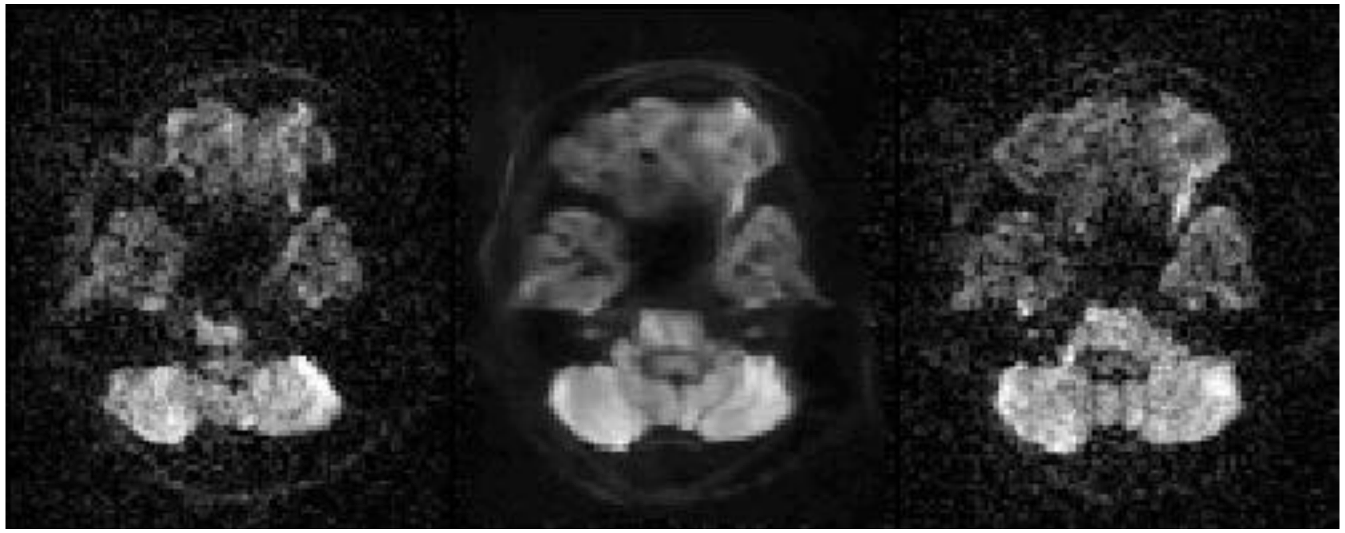
We can define an outlier slice as one with a z-score above an (arbitrary) threshold. We then have a choice of reporting outliers and/or replacing them with their predictions.

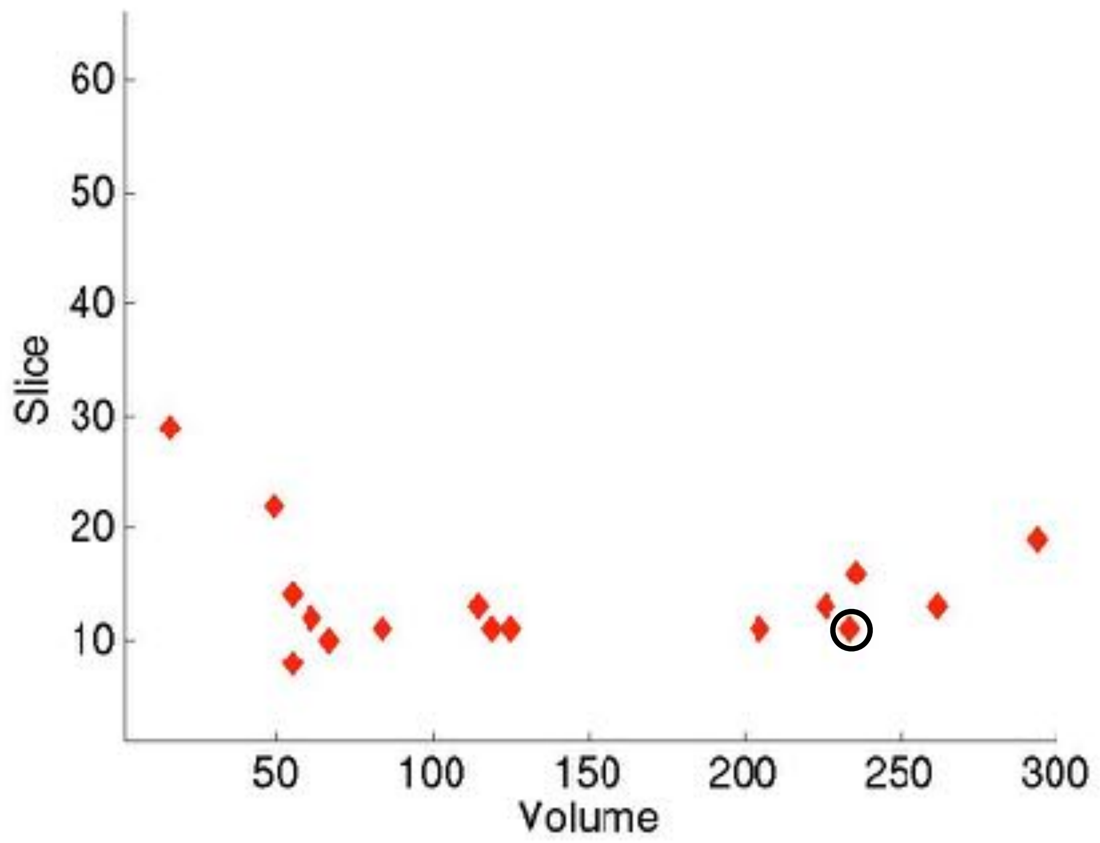
Outlier detection

Original data



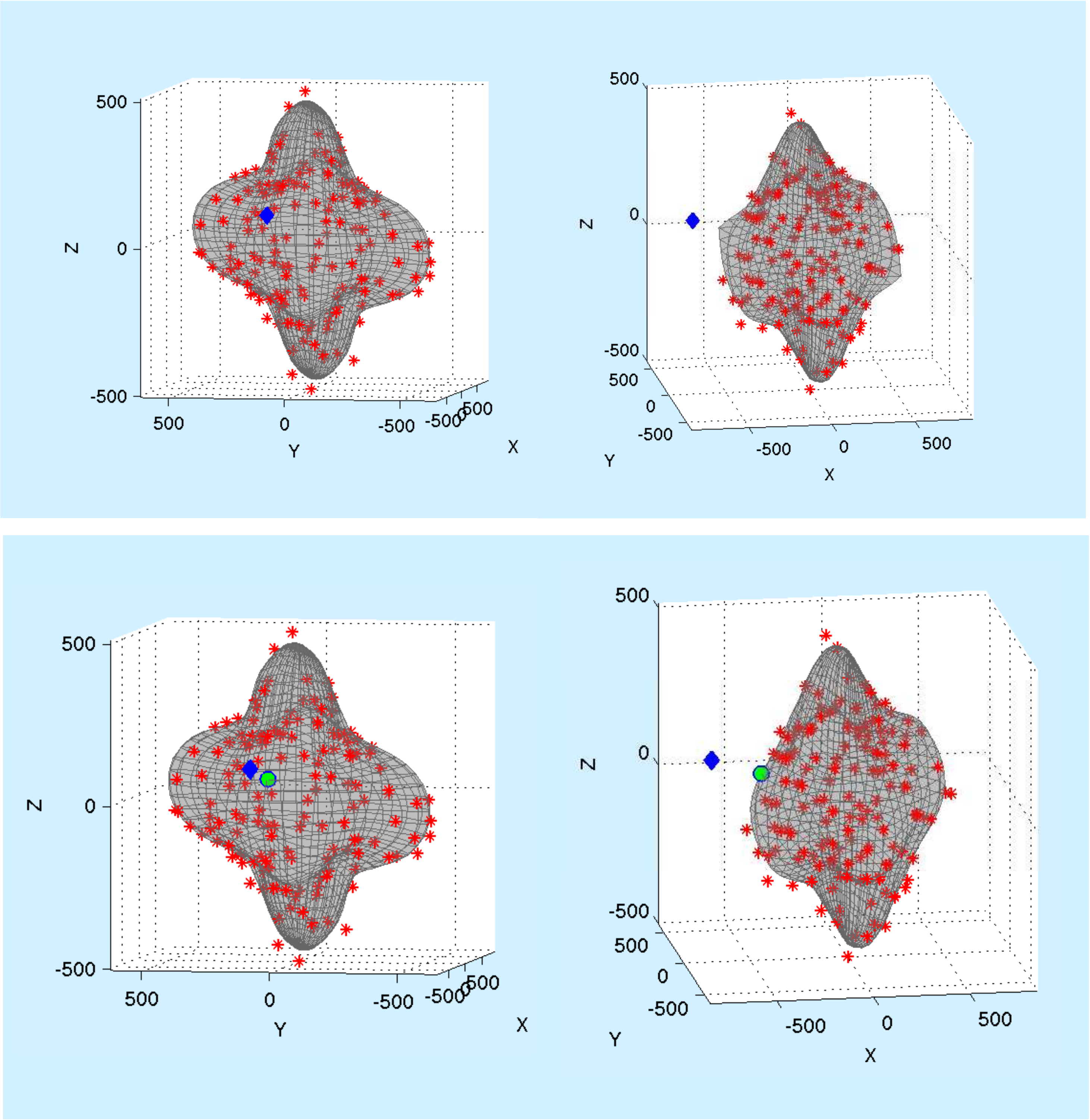
Data after replacement





Outliers for a very still volunteer. Outliers mainly in basal slices.

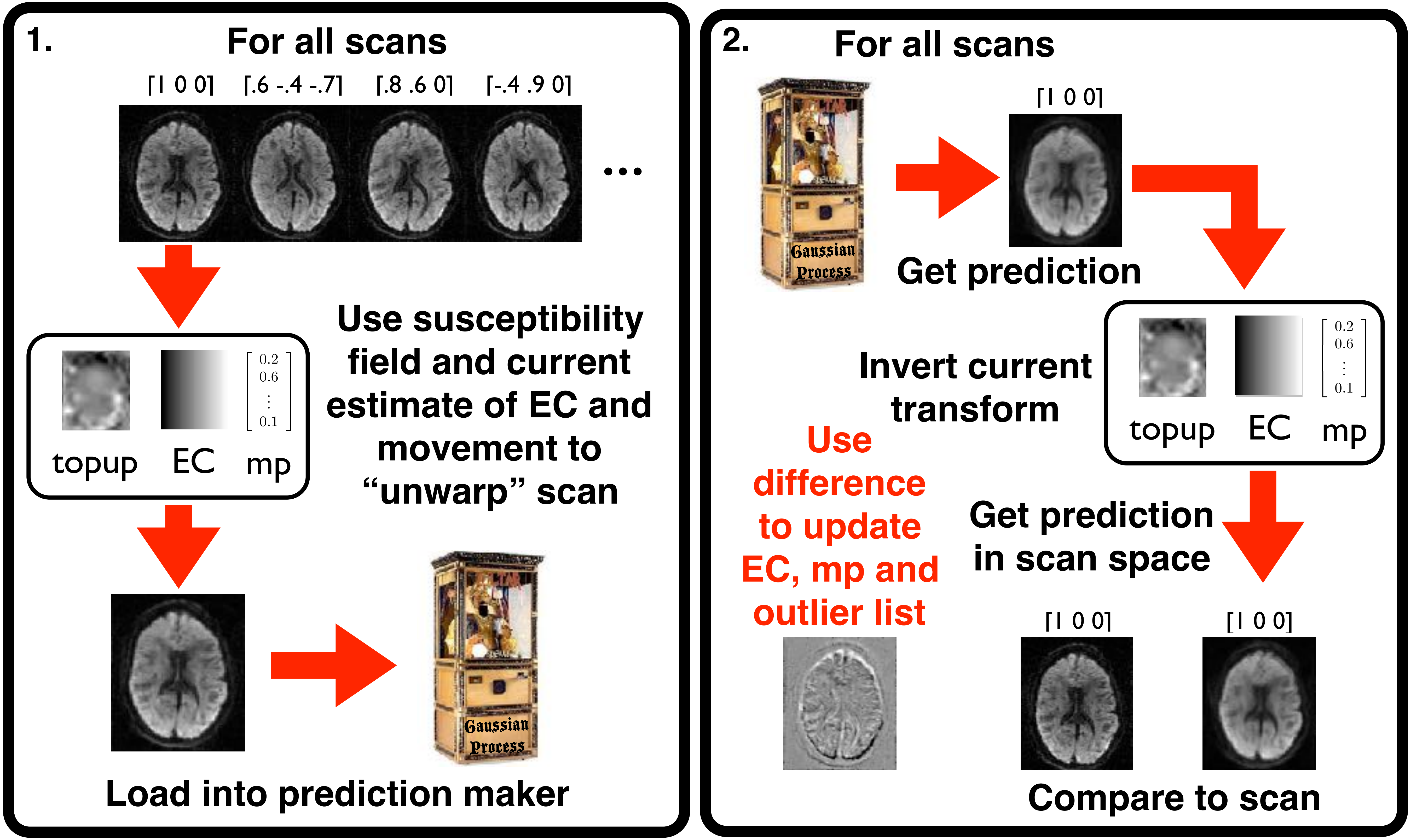
How to make the “right” prediction



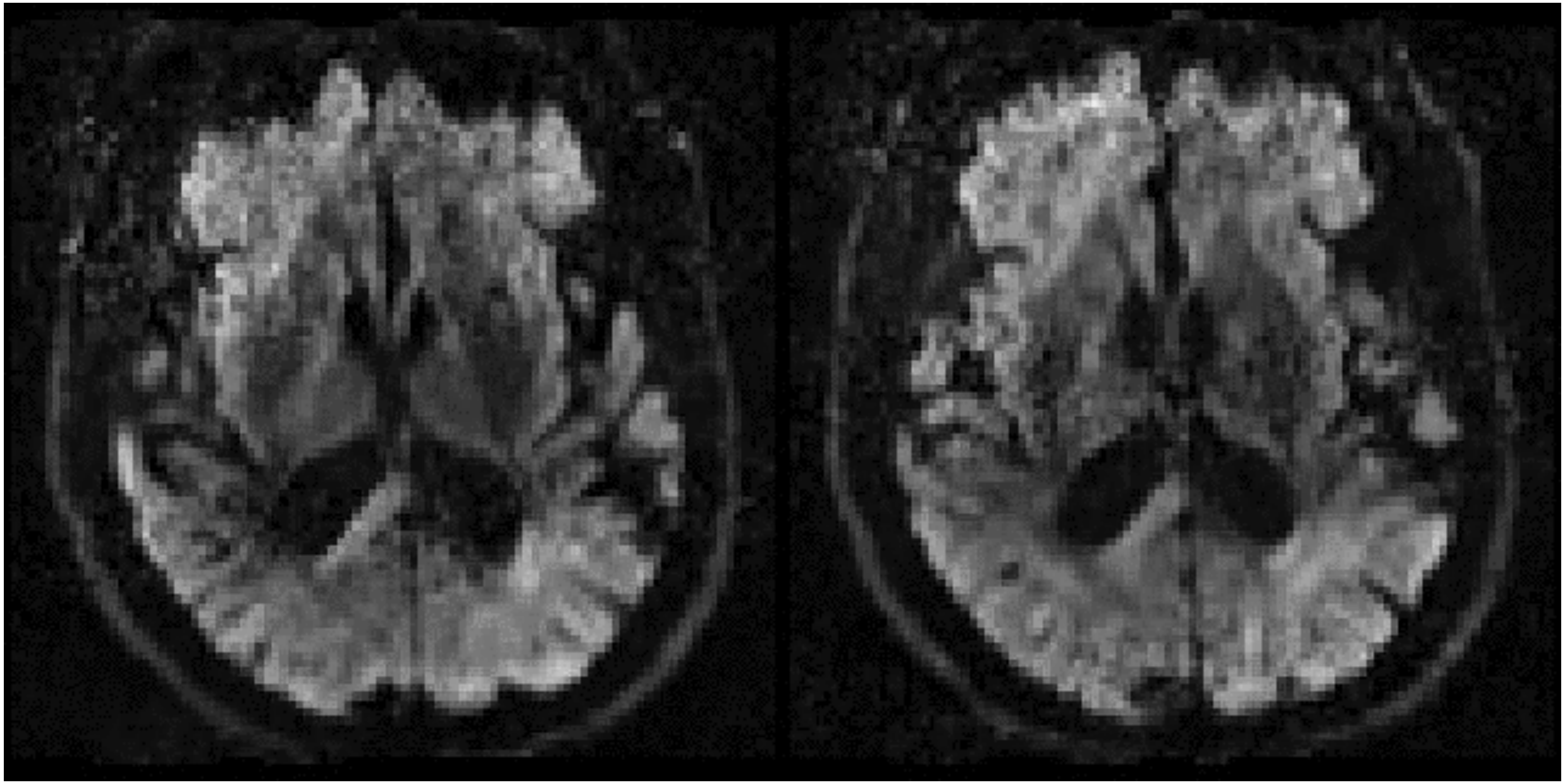
The outlier skews the predictions, but is still recognisable as an outlier

Remove the outlier and recalculate the “model”. The prediction is taken from this new “model”.

eddy revisited



Outlier detection

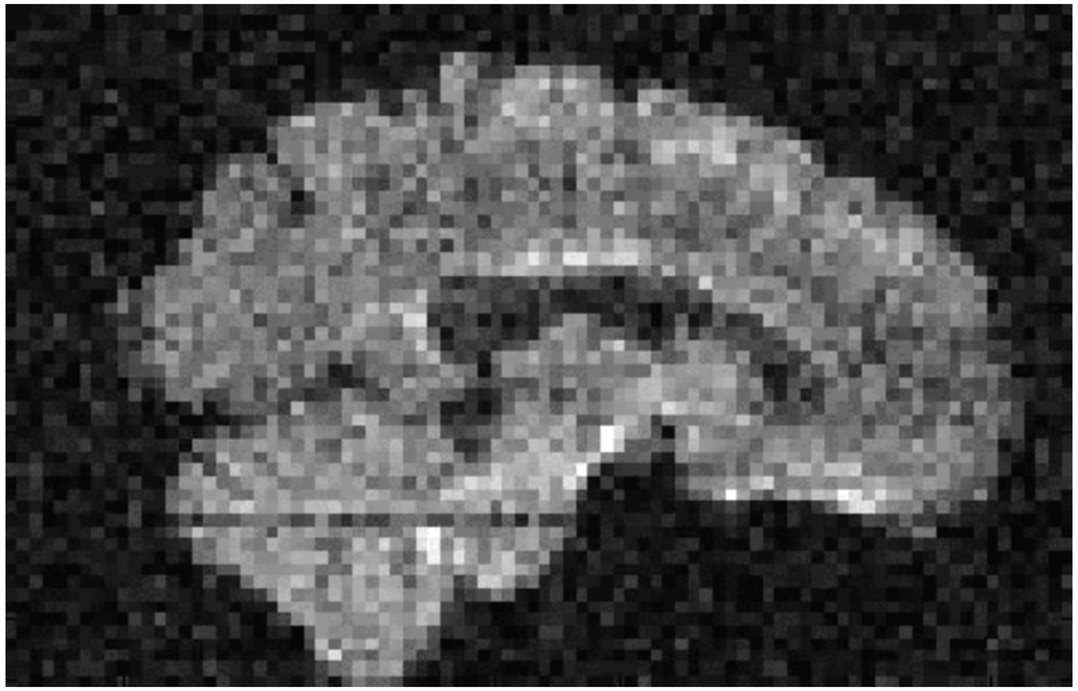


If movement correction is performed with outliers in place they will be rotated into “diagonal bands” in the corrected images.

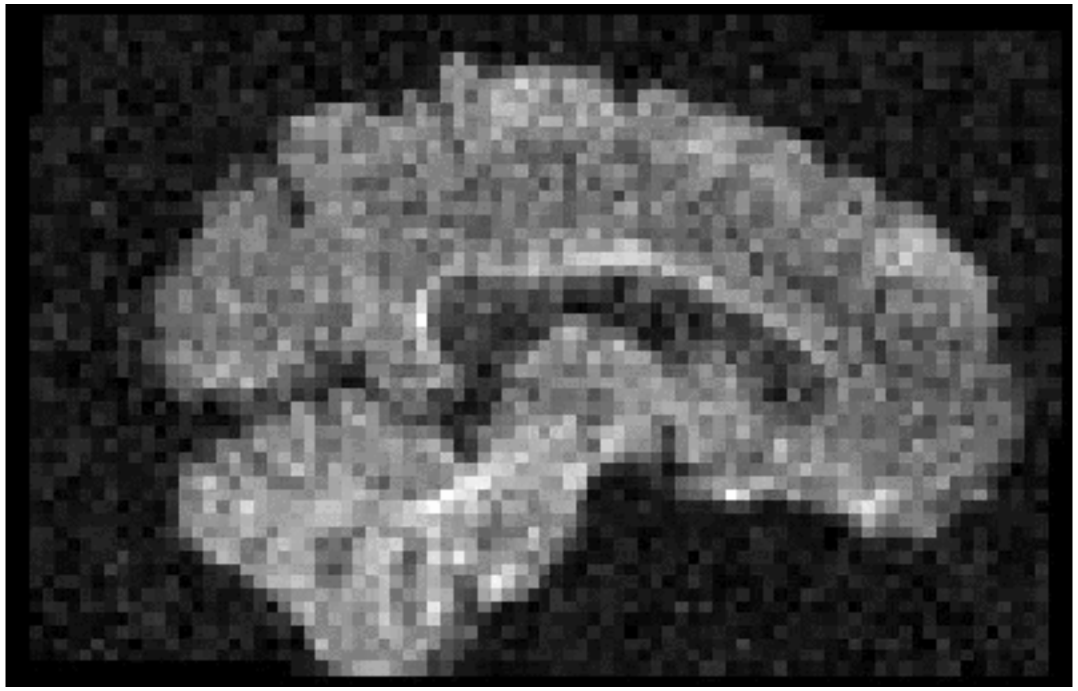
How accurate are the predictions?

Simulated data

Simulations courtesy of Mark Graham, UCL.



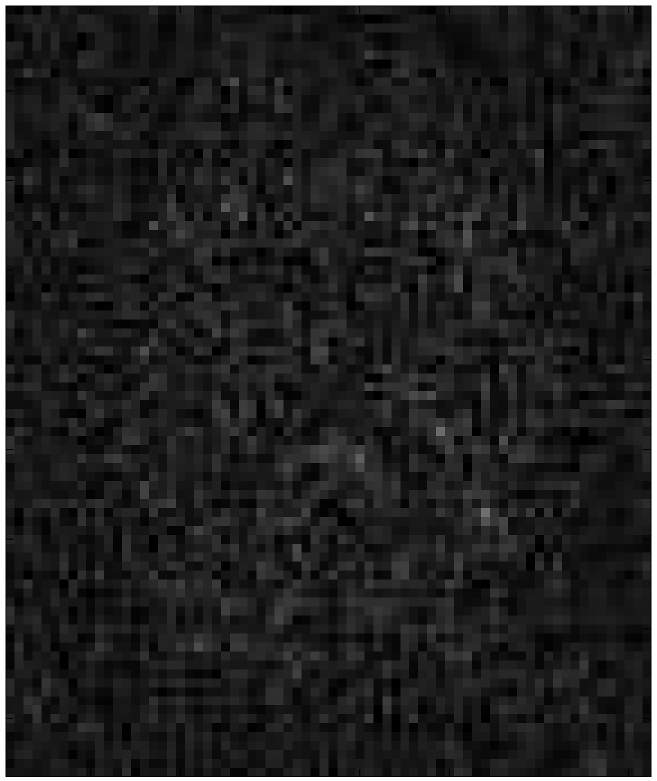
Before



After

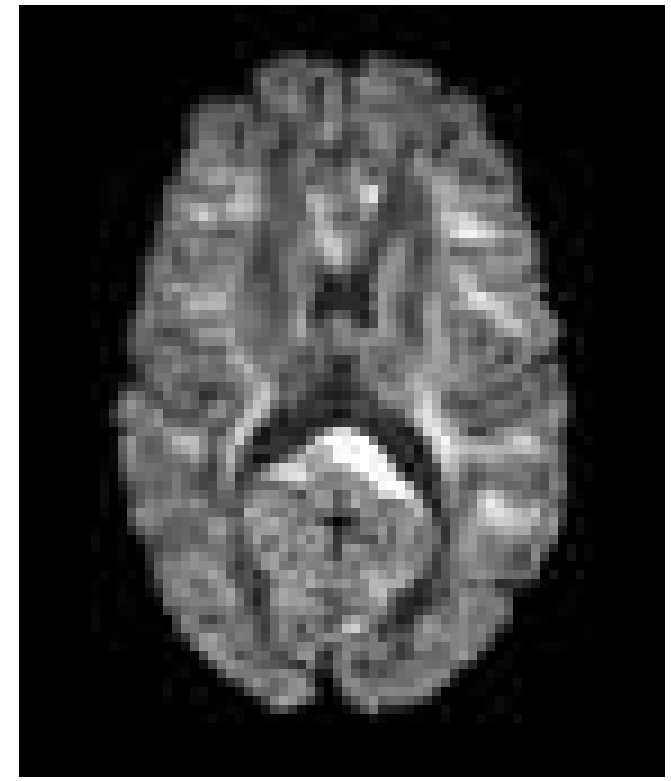
Looks good. But is it the “truth”?

How accurate are the predictions?



Outlier

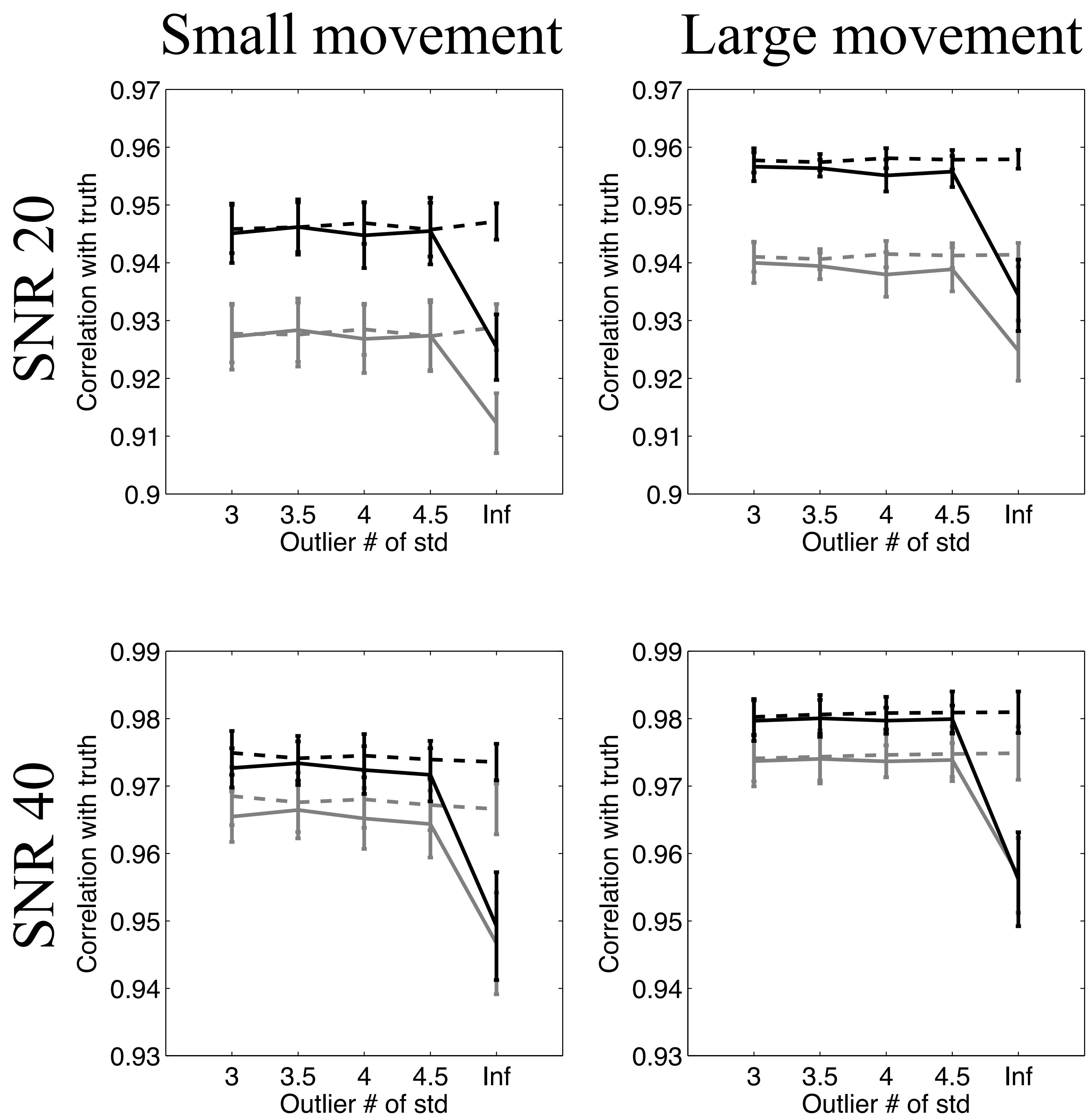
eddy's guesstimate



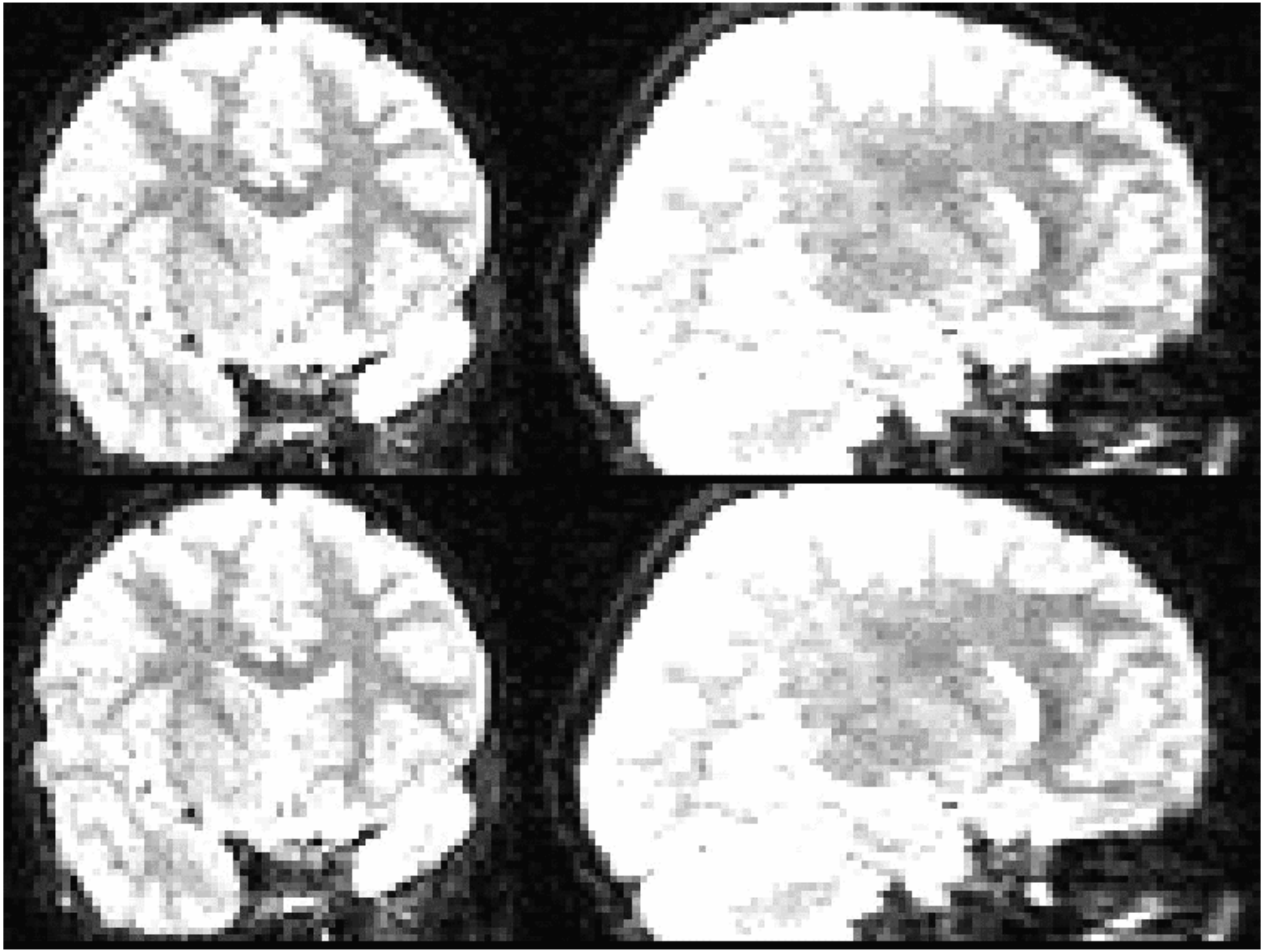
Ground truth

With the simulations we know the "ground truth"

How accurate are the predictions?



Norwegian data. 32 directions. Hundreds of children.



Eight year old who gets tired towards the end of scanning

After outlier detection and replacement by eddy

And all you need to do is to add `--repol` to your command line

```
eddy --imain=LR_RL --acqp=acqparams.txt
--index=indx.txt --bvecs=bvecs
--bvals=bvals --mask=brain_mask
--topup=my_topup --out=my_eddy --repol
```

Outline of the talk

- “Advanced” eddy features
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  - Intra-volume motion
  - Susceptibility-by-movement

Outline of the talk

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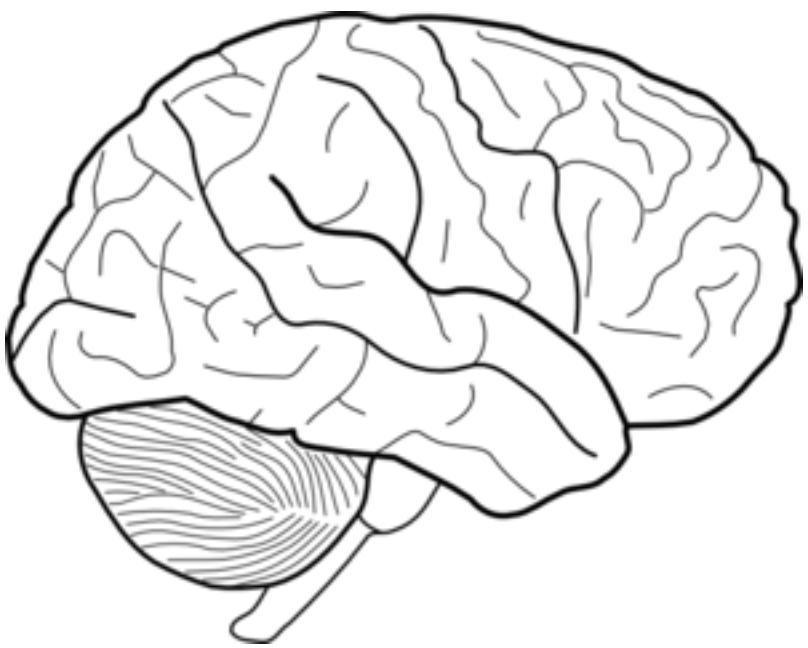
Intra-volume movement

One of the (possibly naive) assumptions of most movement correction is that any movement is instantaneous and occurs between the acquisition of consecutive volumes.



This is the brain we set out to image

Intra-volume movement

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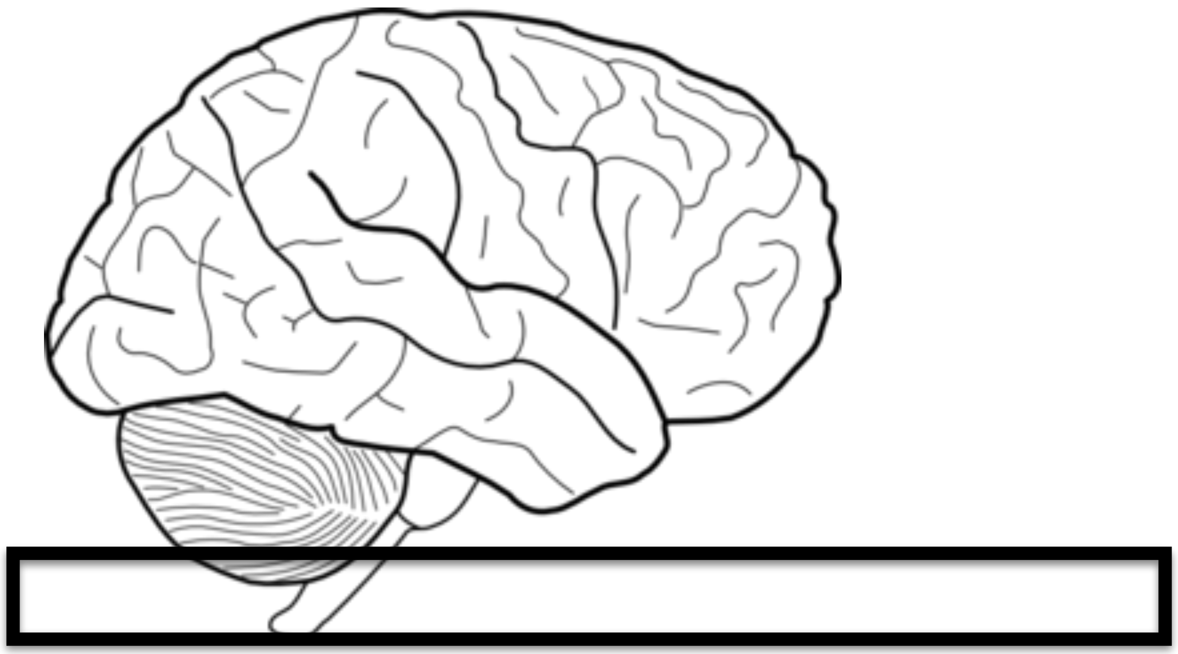


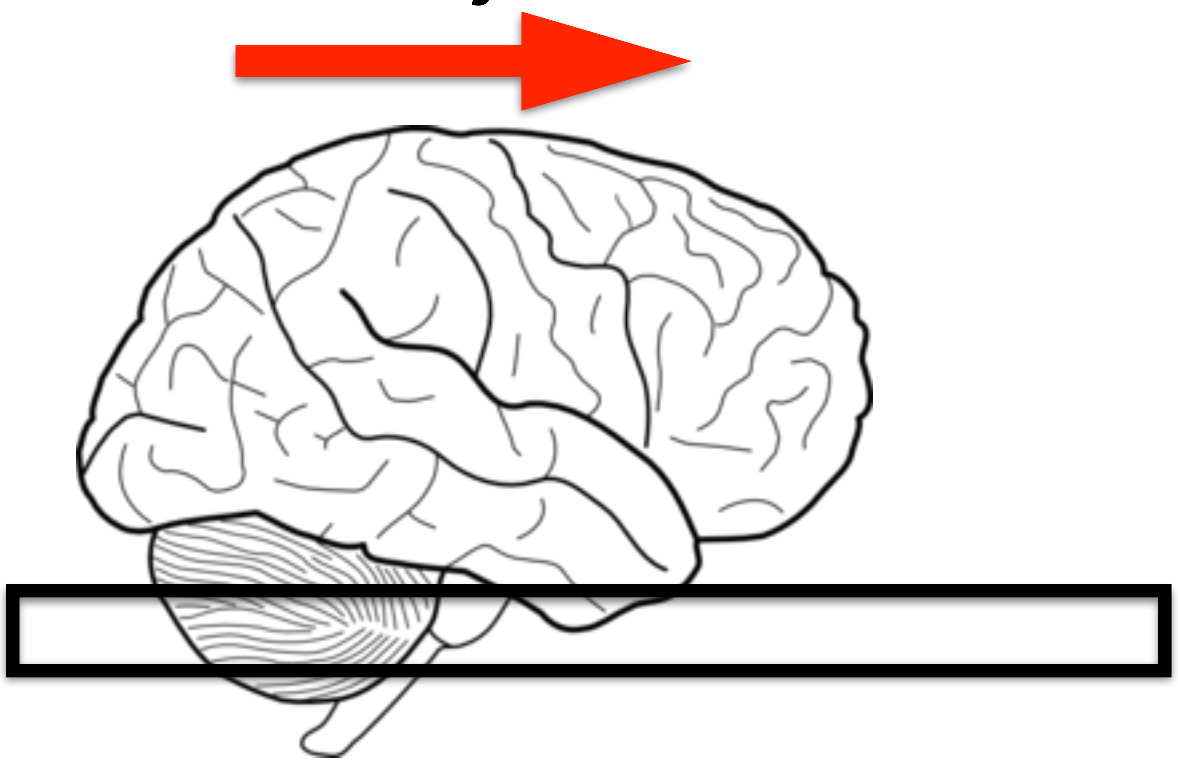
This is the brain we set out to image

And here we have acquired the first slice

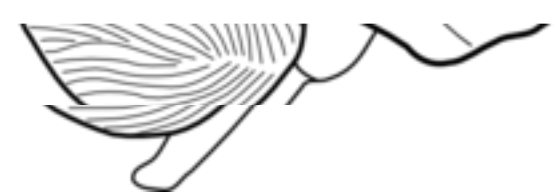
Intra-volume movement

One of the (possibly naive) assumptions of most movement correction is that any movement is instantaneous and occurs between the acquisition of consecutive volumes.

But the subject moves



This is the brain we set out to image

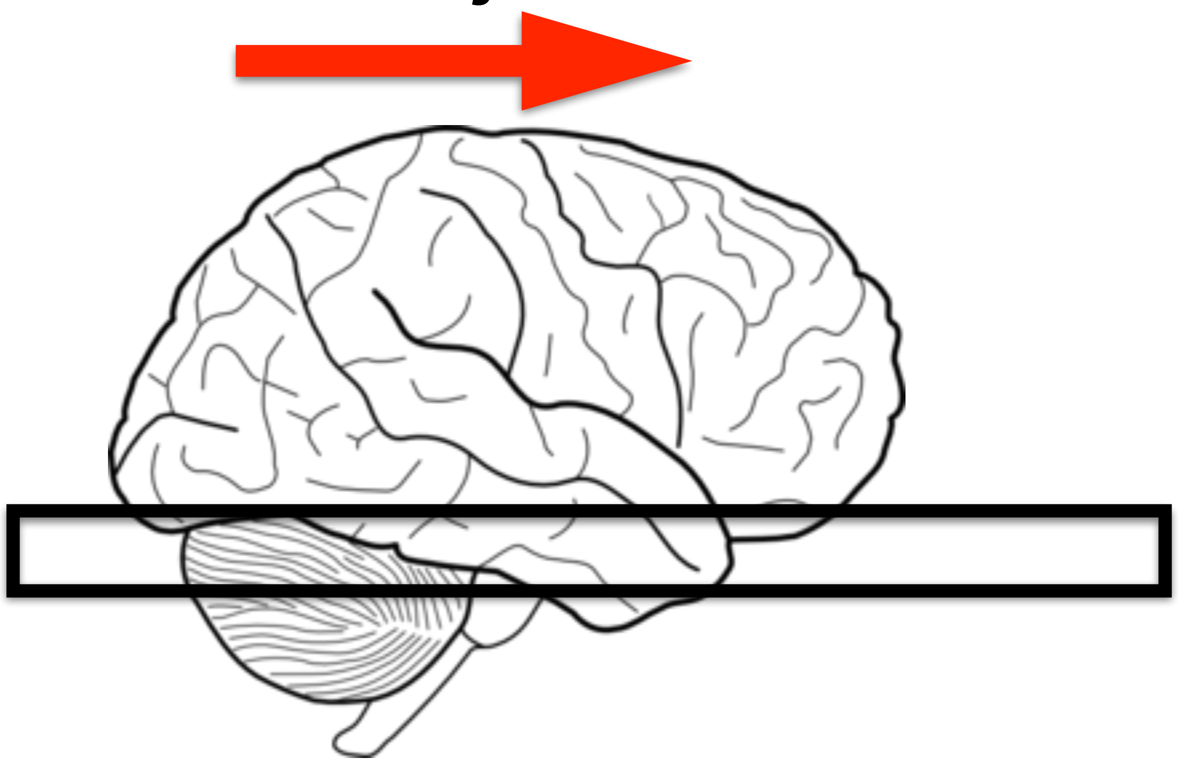


So the brain is offset in the second slice

Intra-volume movement

One of the (possibly naive) assumptions of most movement correction is that any movement is instantaneous and occurs between the acquisition of consecutive volumes.

But the subject moves



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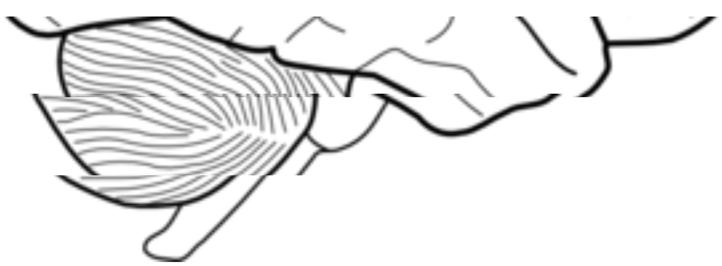
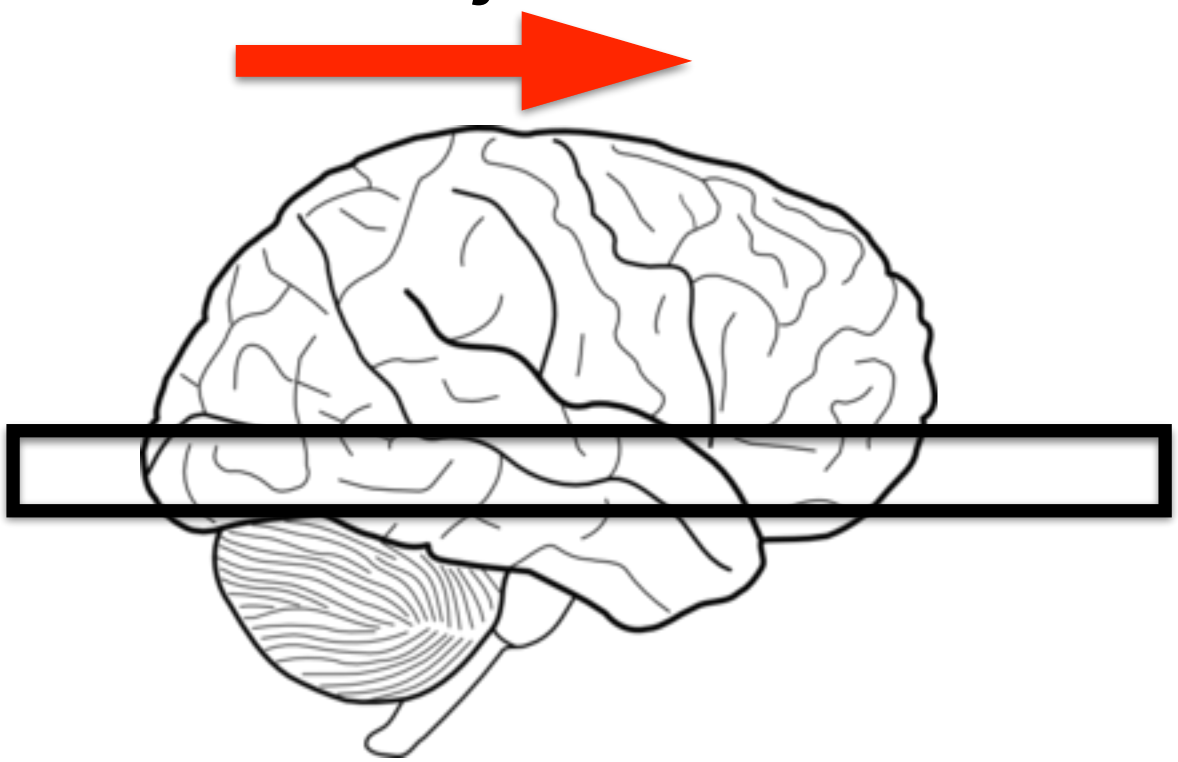


And even more so in the third slice

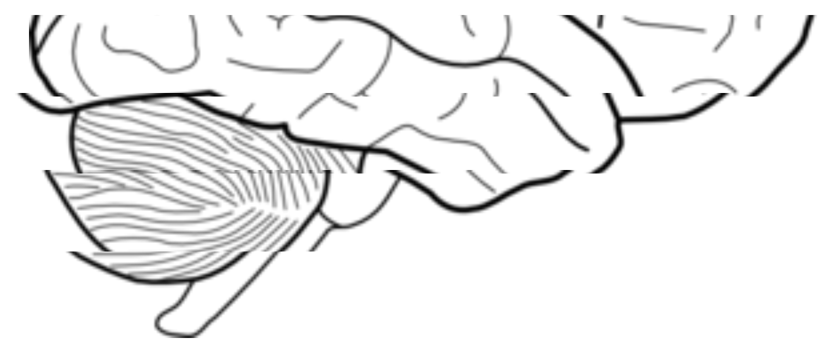
Intra-volume movement

One of the (possibly naive) assumptions of most movement correction is that any movement is instantaneous and occurs between the acquisition of consecutive volumes.

But the subject moves



This is the brain we set out to image



And more …

Intra-volume movement

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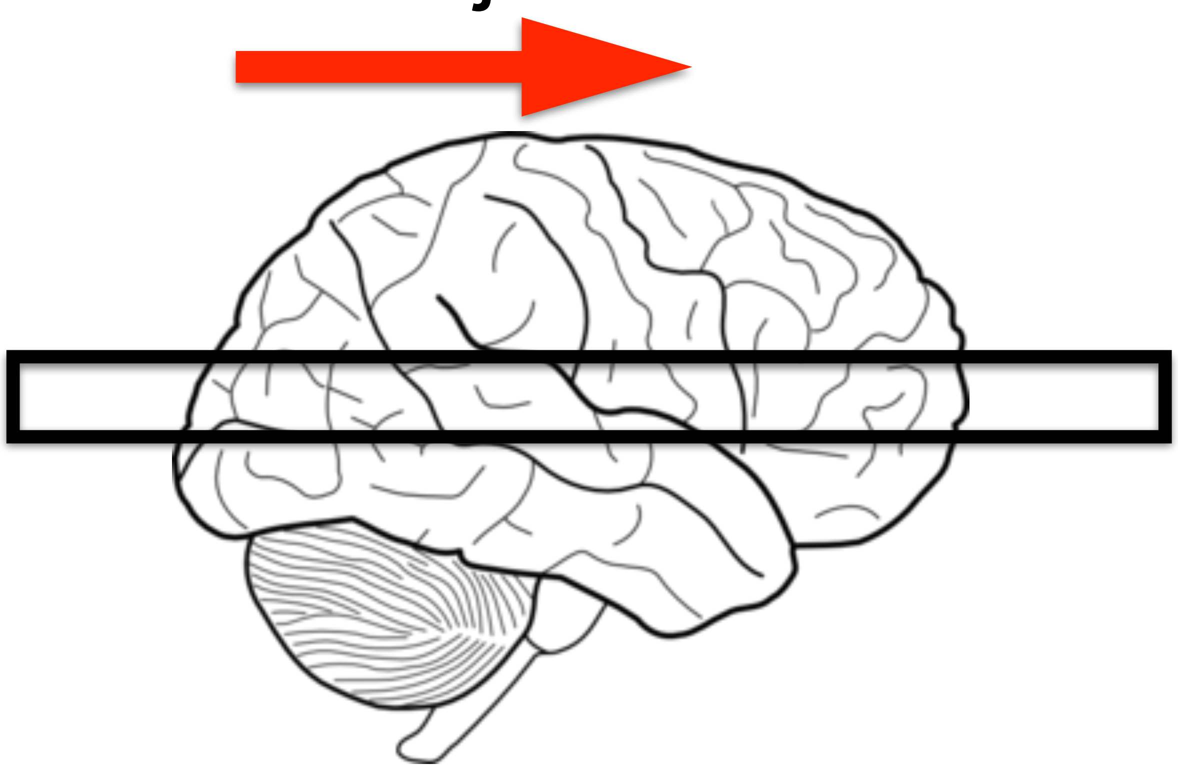
But the subject moves



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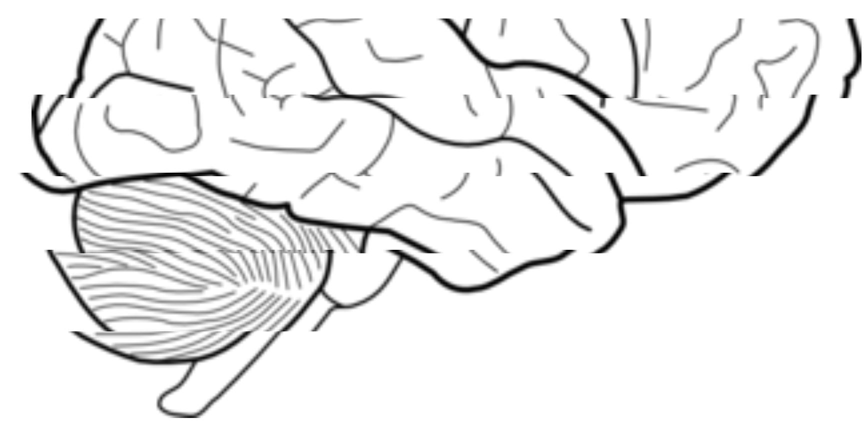
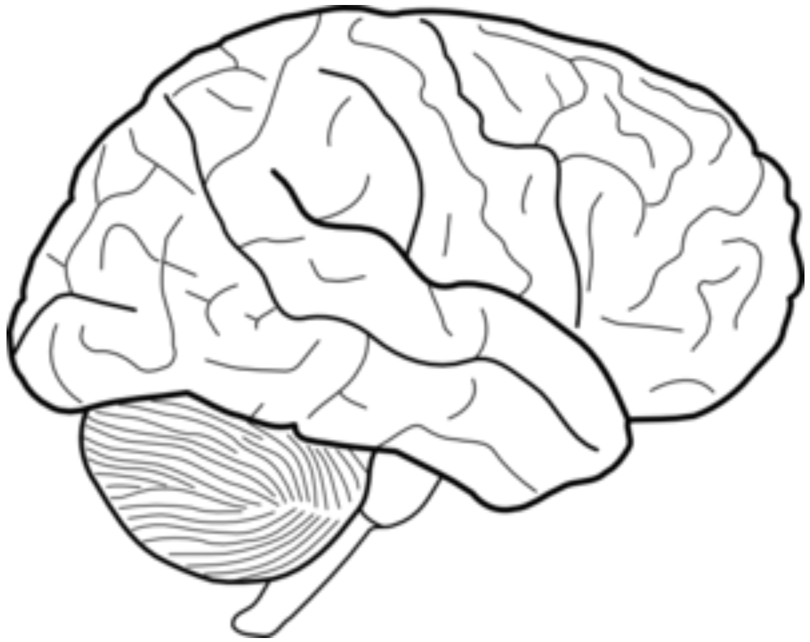


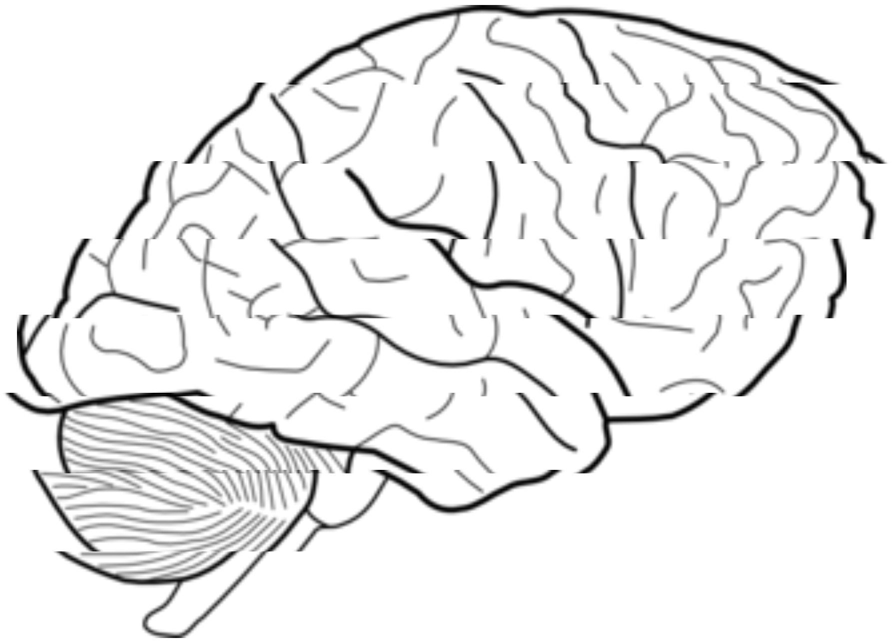
… and more …

Intra-volume movement

One of the (possibly naive) assumptions of most movement correction is that any movement is instantaneous and occurs between the acquisition of consecutive volumes.



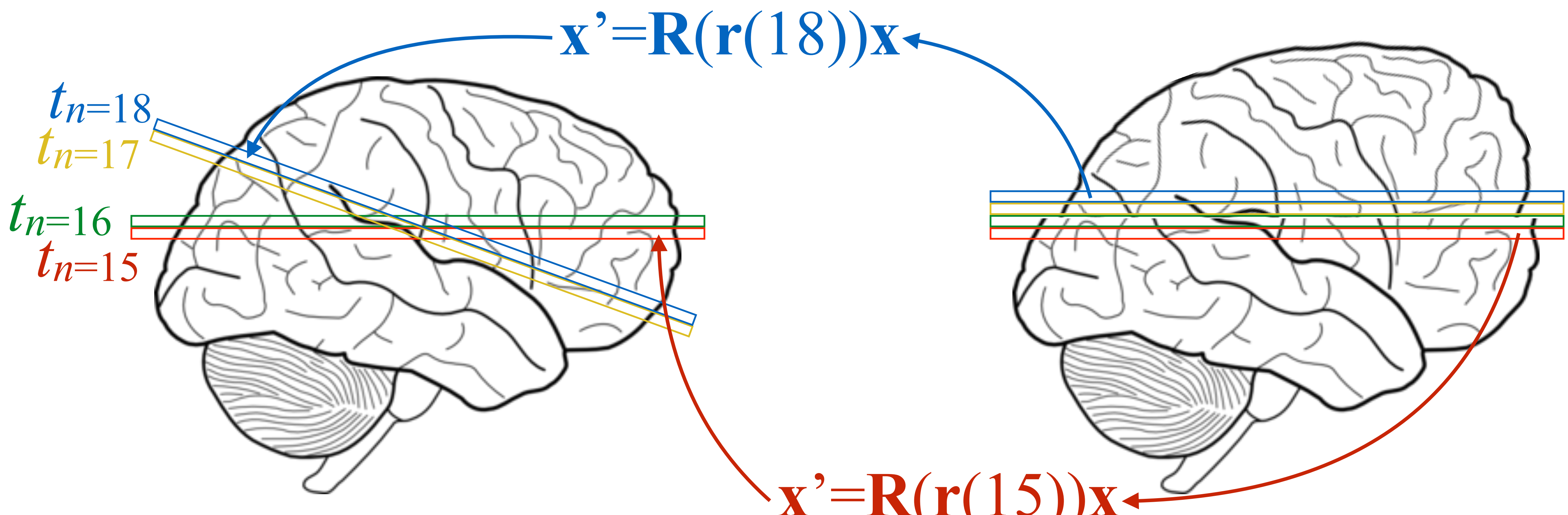
This is the brain we set out to image



etc.

Intra-volume movement

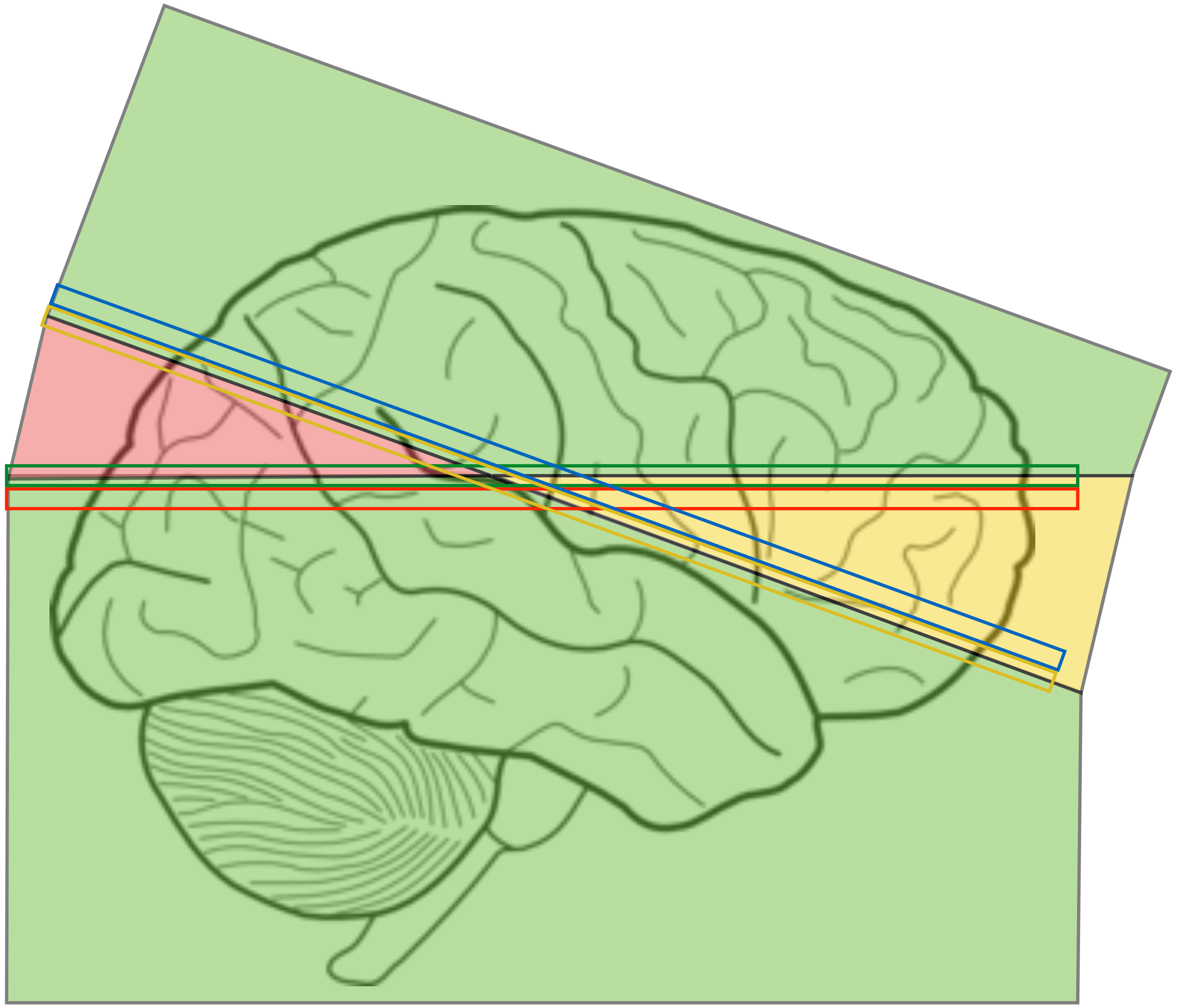
- This is known as the “slice-to-vol” problem or the “intra-volume movement” problem.
- The new version of `eddy` addresses this problem.
- It estimates the slice wise movement through the same Gaussian Process based forward model.



Intra-volume movement

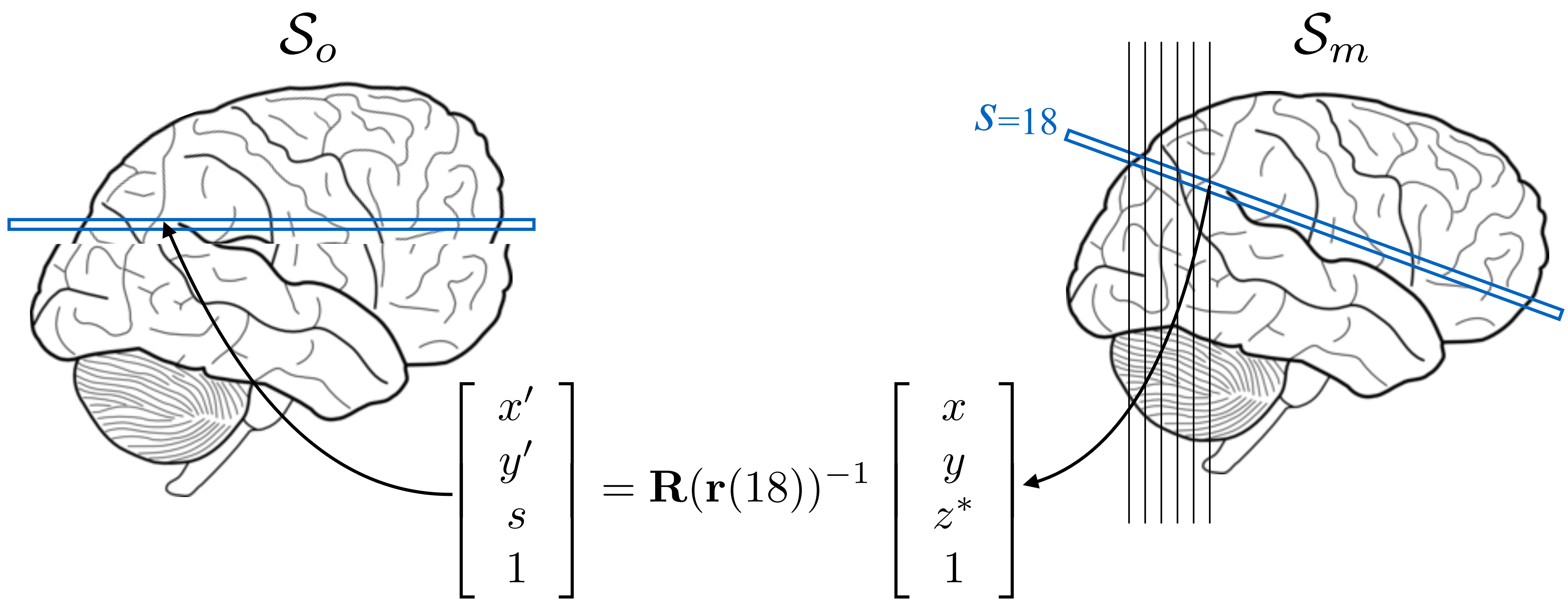
- But it is considerably harder to go the other way, *i.e.* to tell what the image should have looked like had the subject not moved.
- In particular there is a problem with data that was never acquired.

Subject “looks up” half way through acquisition.



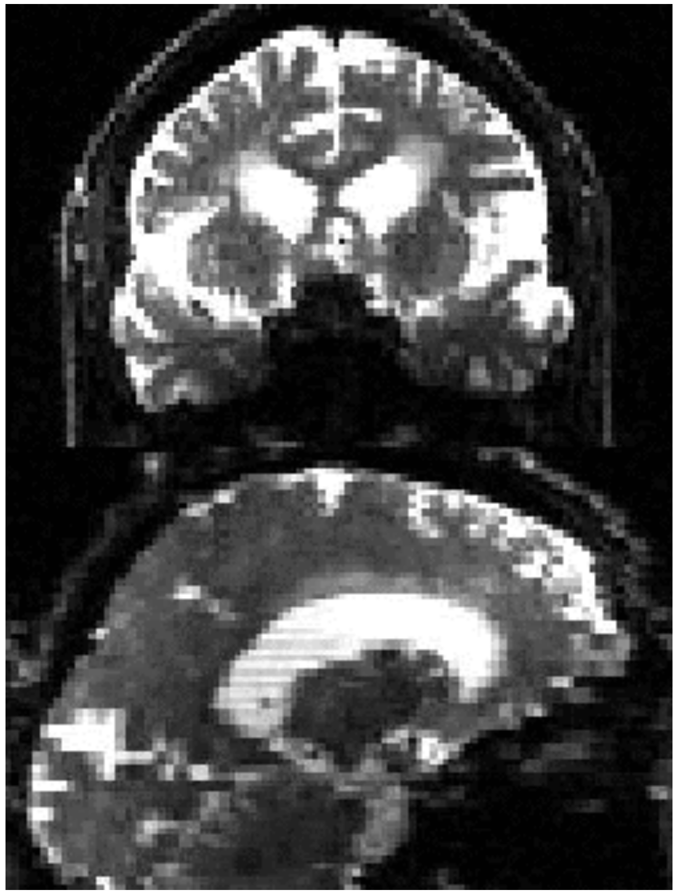
Intra-volume movement

- We have solved this through a hybrid resampling, which consists of regular in-plane interpolations followed by 1D irregular spline resampling.
- This is combined with supplementing the data with predictions.



$$\begin{bmatrix} x' \\ y' \\ s \\ 1 \end{bmatrix} = \mathbf{R}(\mathbf{r}(18))^{-1} \begin{bmatrix} x \\ y \\ z^* \\ 1 \end{bmatrix}$$

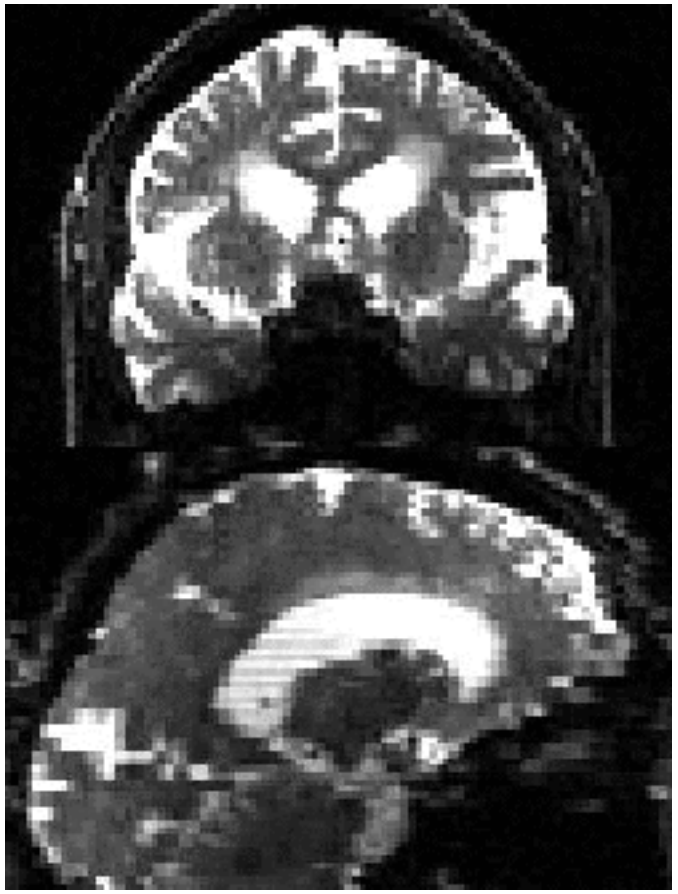
Intra-volume movement



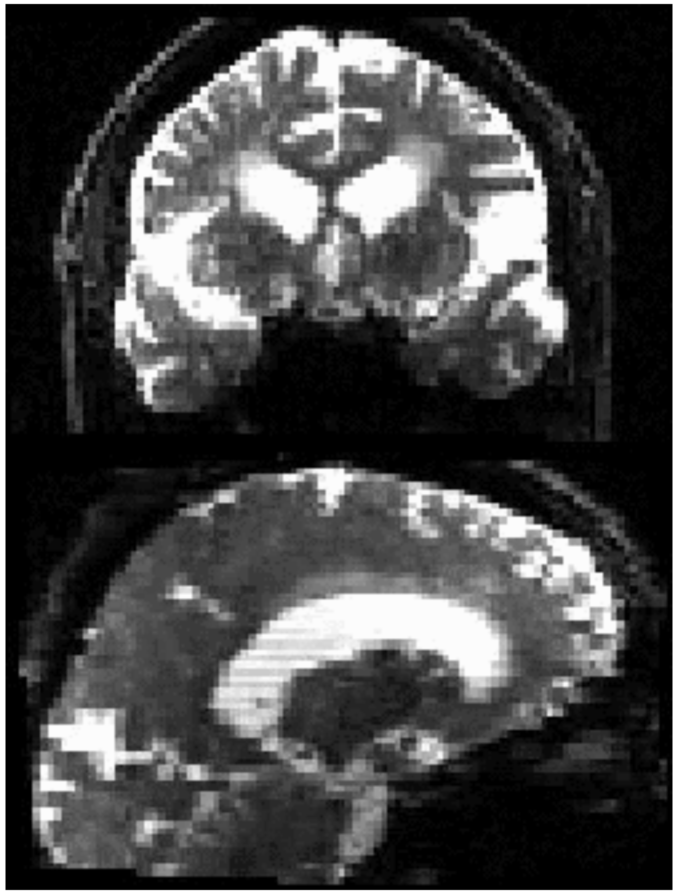
Original data

Problematic elderly subject. Lots of movement induced signal loss and intravolume movement

Intra-volume movement



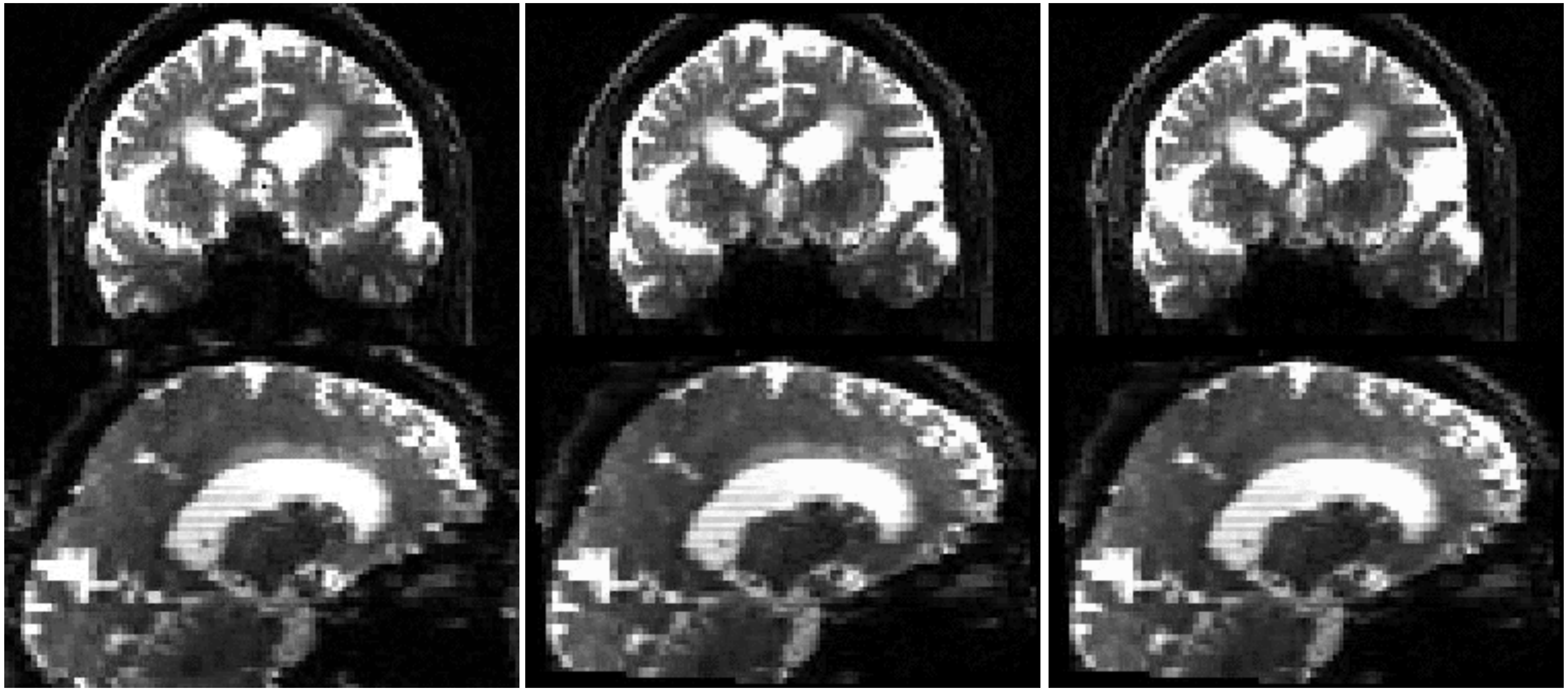
Original data



After correction without outlier correction

Problematic elderly subject. Lots of movement induced signal loss and intravolume movement

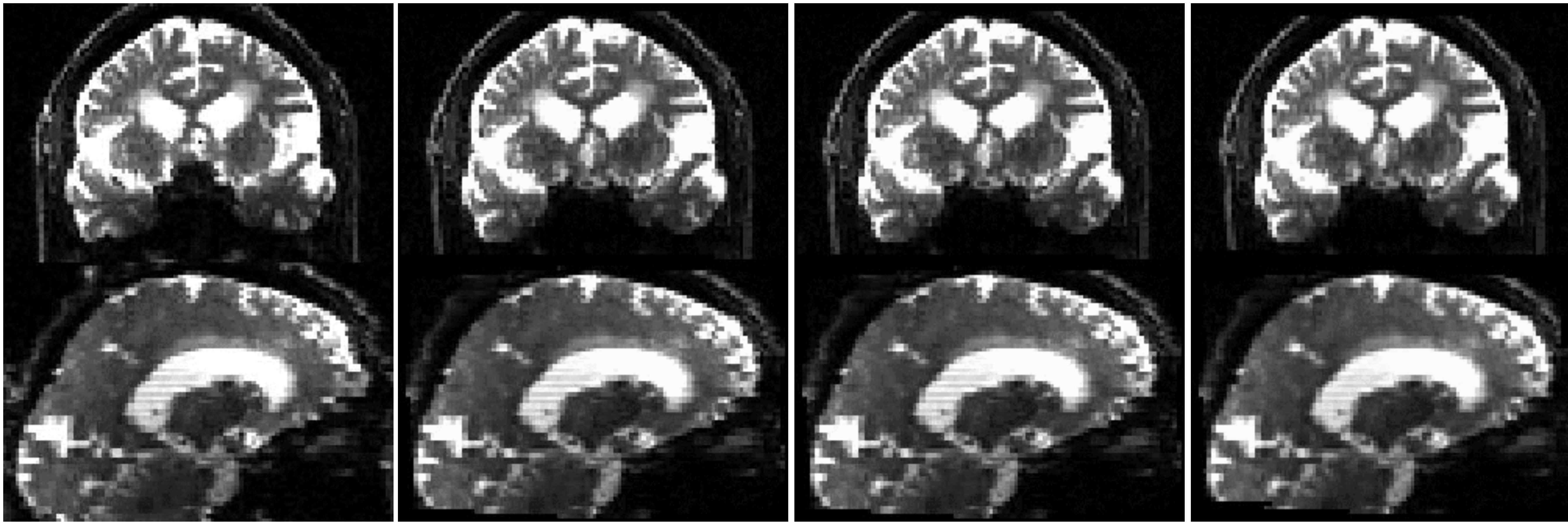
Intra-volume movement



Original data | After correction without outlier correction | After correction with outlier replacement

Problematic elderly subject. Lots of movement induced signal loss and intravolume movement

Intra-volume movement



Original data

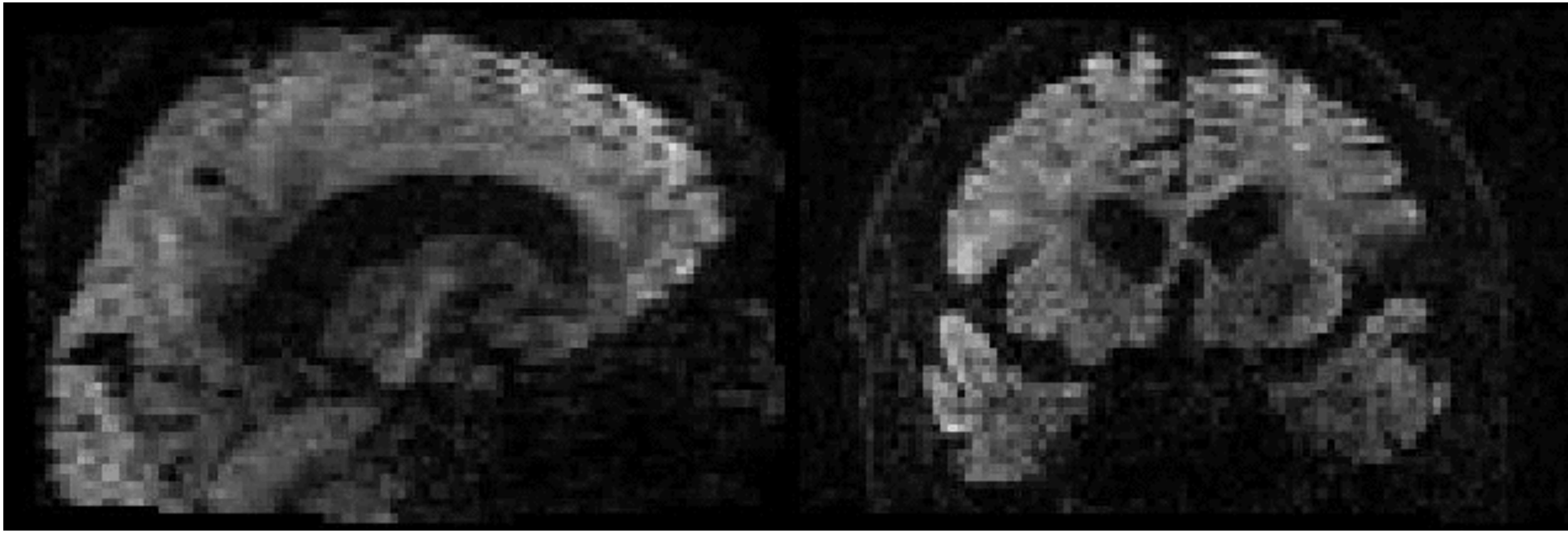
After correction without outlier correction

After correction with outlier replacement

After intravolume movement correction.

Problematic elderly subject. Lots of movement induced signal loss and intravolume movement

Intra-volume movement



Highlighting the difference between just OLR and OLR combined with S2V correction

Problematic elderly subject. Lots of movement induced signal loss and intravolume movement

And also trivial to add to your eddy command

```
eddy --imain=LR_RL --acqp=acqparams.txt
--index=indx.txt --bvecs=bvecs
--bvals=bvals --mask=brain_mask
--topup=my_topup –out=my_eddy --repol
--mporder=16
```

Outline of the talk

- What is the problem with diffusion data?
- Off-resonance field
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- Some results
- “New” eddy features
    - Movement-induced dropout
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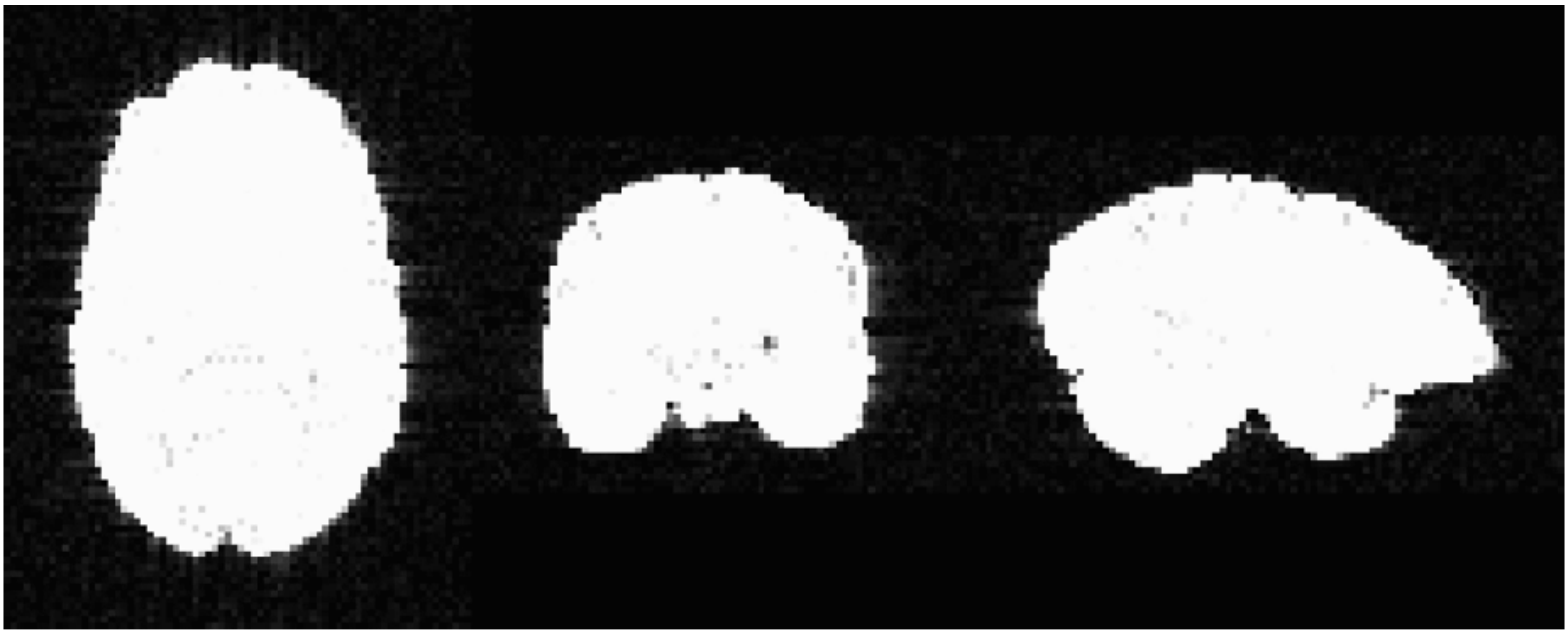
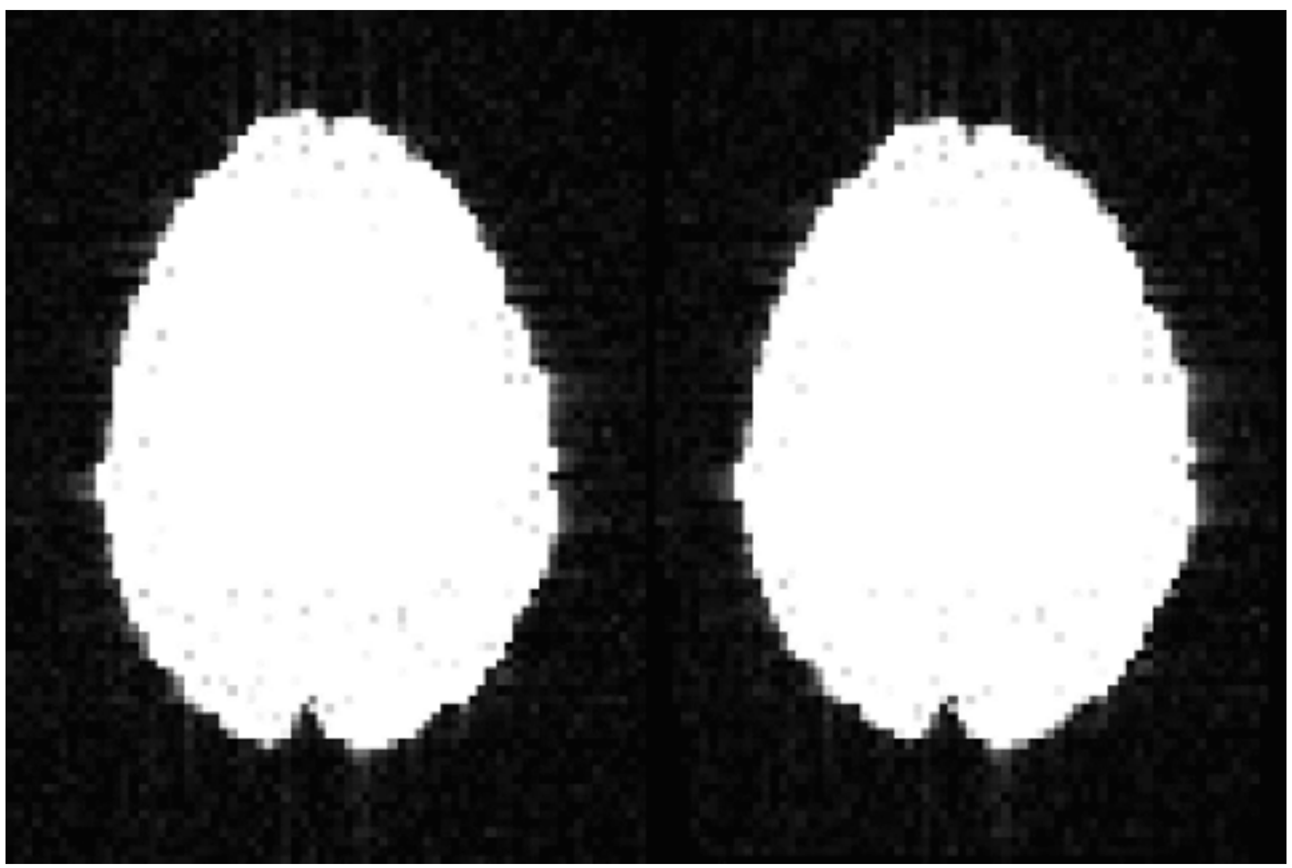
    - Susceptibility-by-movement

Some data with lots of movement

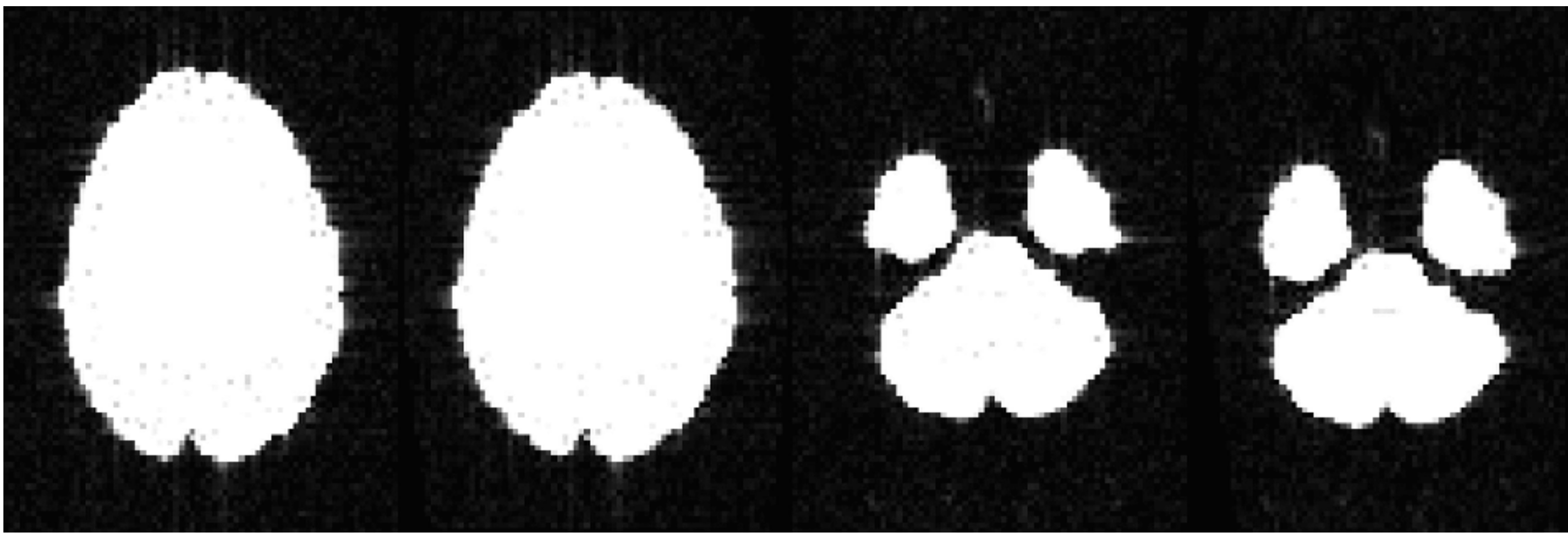


Some data with lots of movement, aligned with eddy



Some data with lots of movement, aligned with eddy

Before	After	Before	After



Why is that then?

Motion-induced Magnetic Field Changes Inside the Brain

Jiaen Liu[1], Jacco de Zwart[1], Peter van Gelderen[1], and Jeff Duyn[1]

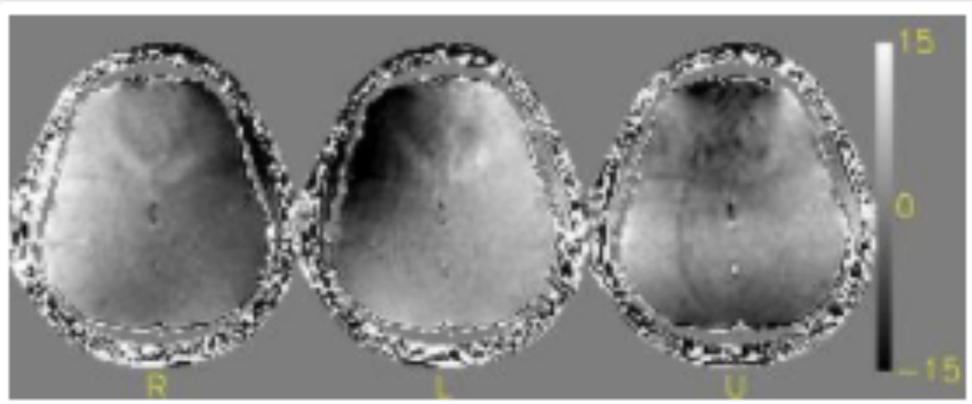


Fig. 1 Changes of field maps in four different positions relative to the field map in the reference position obtained under the "phantom shim" setting. The unit of the field maps is Hz.

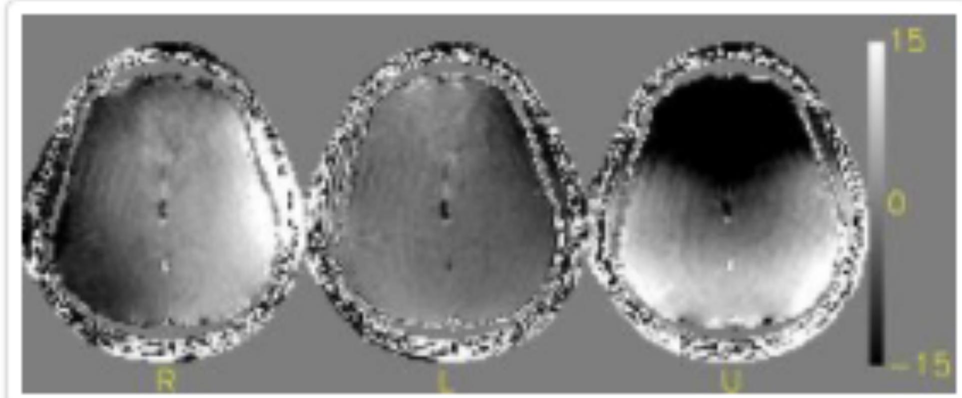
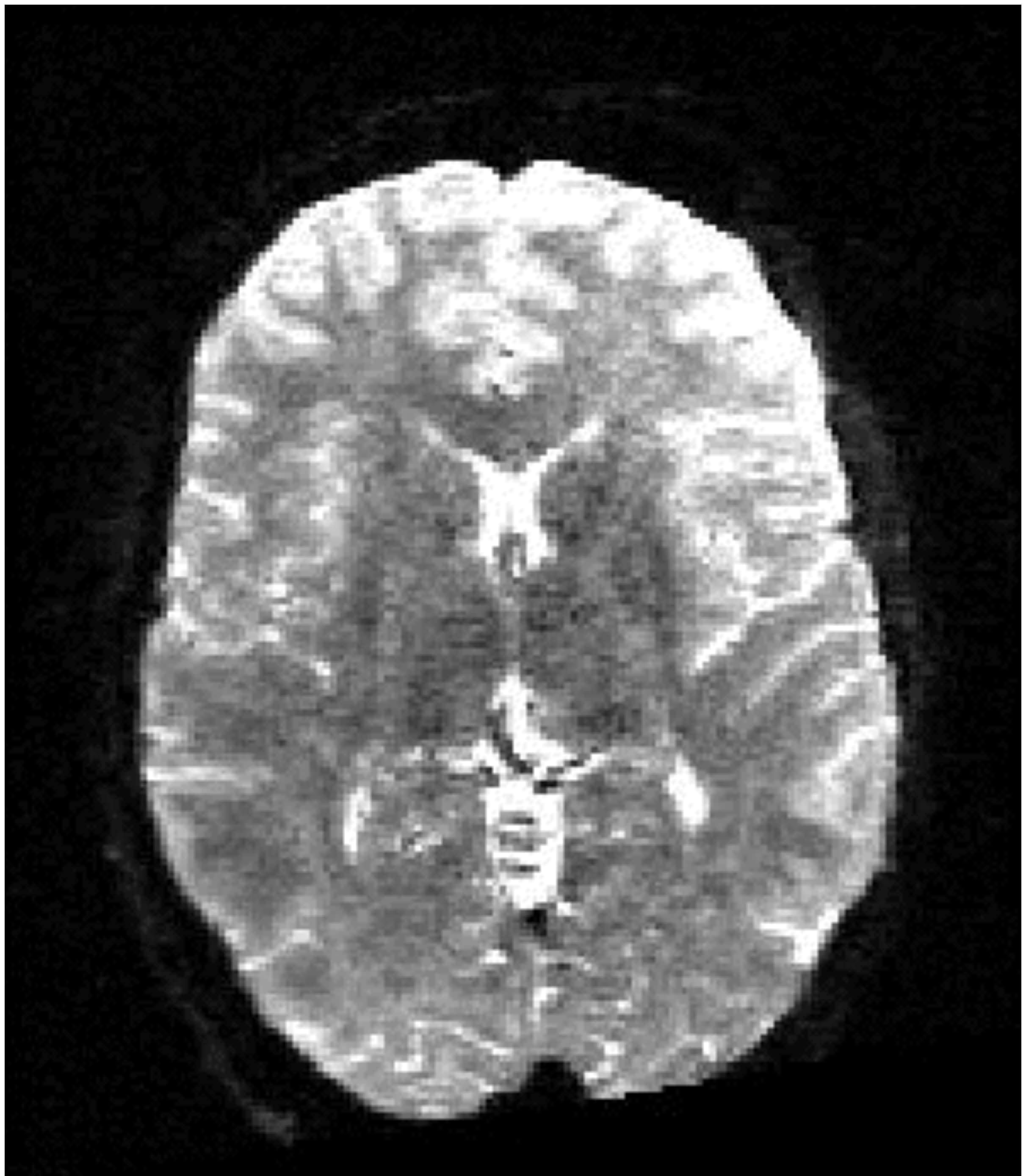


Fig. 2 Changes of field maps in four different positions relative to the field map in the reference position obtained under the "subject shim" setting. The unit of the field maps is Hz.

ISMRM Honolulu

In case you think that was exaggerated



Problematic HCP subject.

Why is that then?

Richard Bowtell

Will field shifts due to head rotation compromise motion correction?

Aleksandra Sulikowska[1], Samuel Wharton[1], Paul M Glover[1], and Penny A Gowland[1]
[1]*Sir Peter Mansfield Magnetic Resonance Centre, University of Nottingham, Nottingham, Nottinghamshire, United Kingdom*

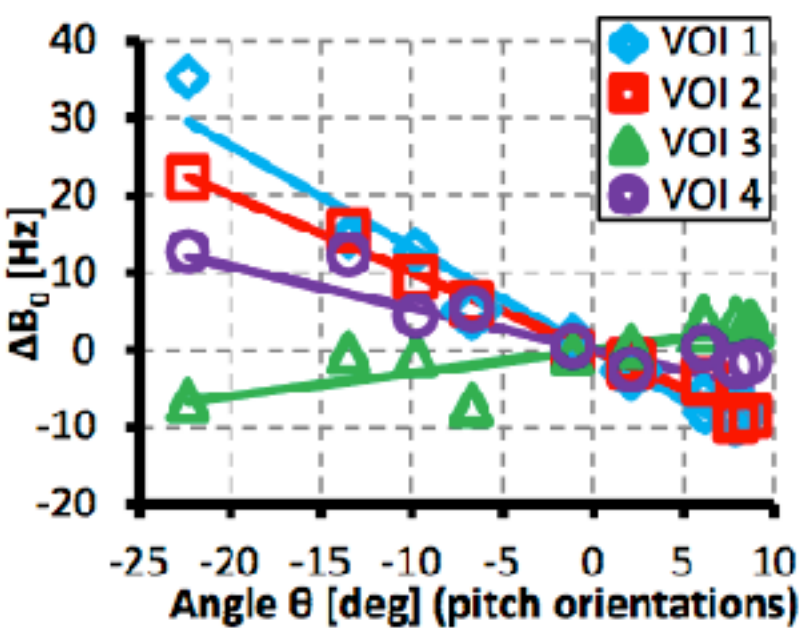


Fig. 3. *Figure showing mean field shift in the VOIs during* ***pitch*** *rotations.*

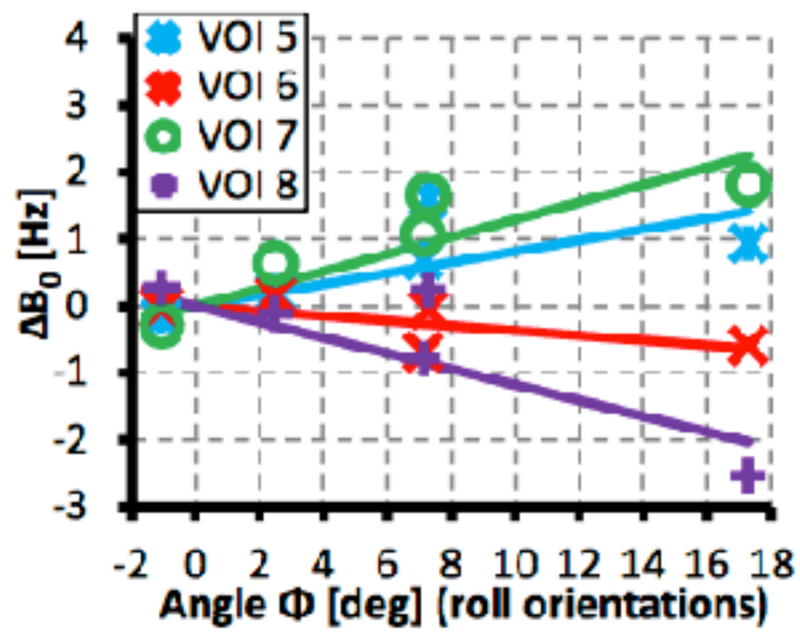


Fig. 4. *Figure showing mean field shift in the VOIs during* ***roll*** *rotations.*

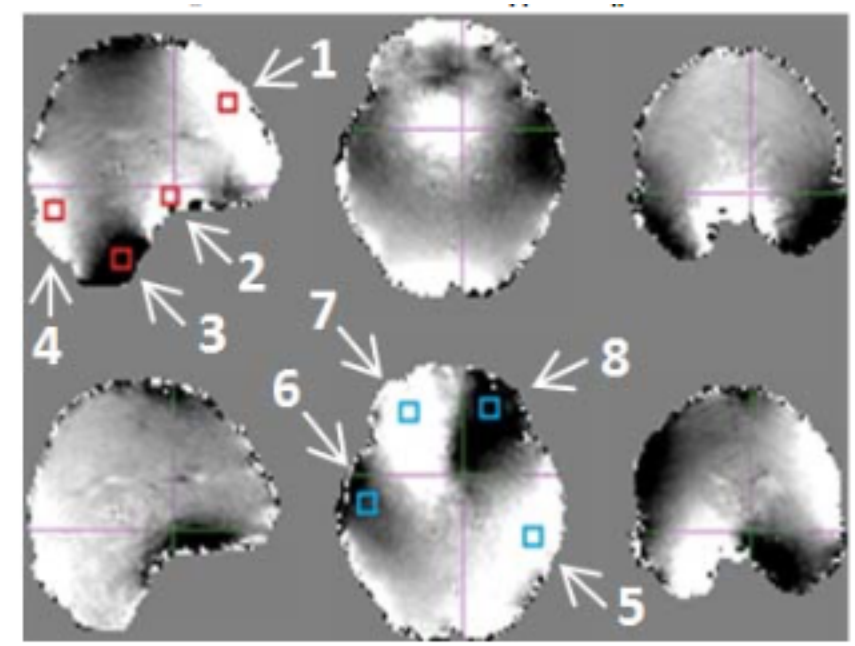
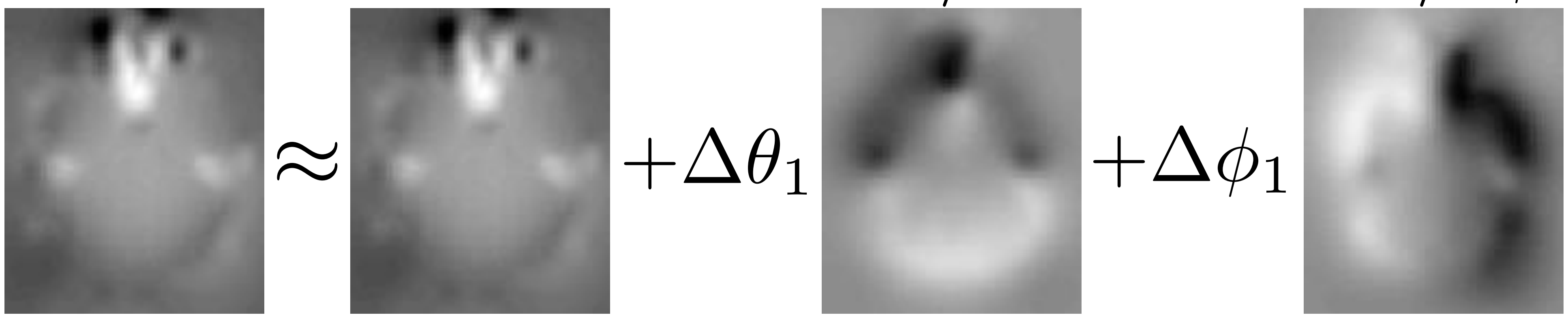


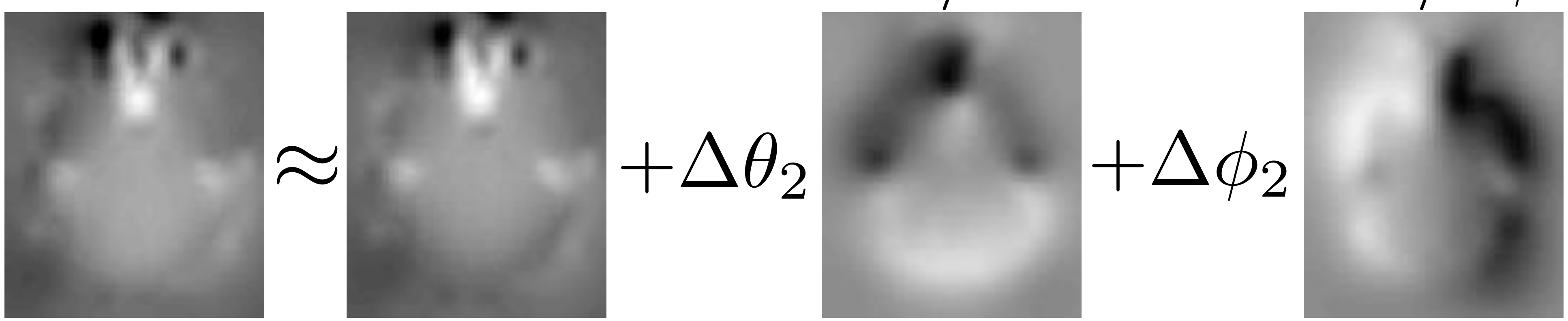
Fig. 2. *B_0 field difference maps for 2 head orientations,* ***TOP:*** *pitch* ***θ=7.87 deg,*** ***BOTTOM:*** *roll* ***Φ=7.13 deg.*** *Squares indicate VOIs (**red**: volumes 1-4; **blue**: volumes 5-8). Grey scale= -5 Hz to 5 Hz.*

ISMRM Milan

So, maybe we can use a low order Taylor expansion

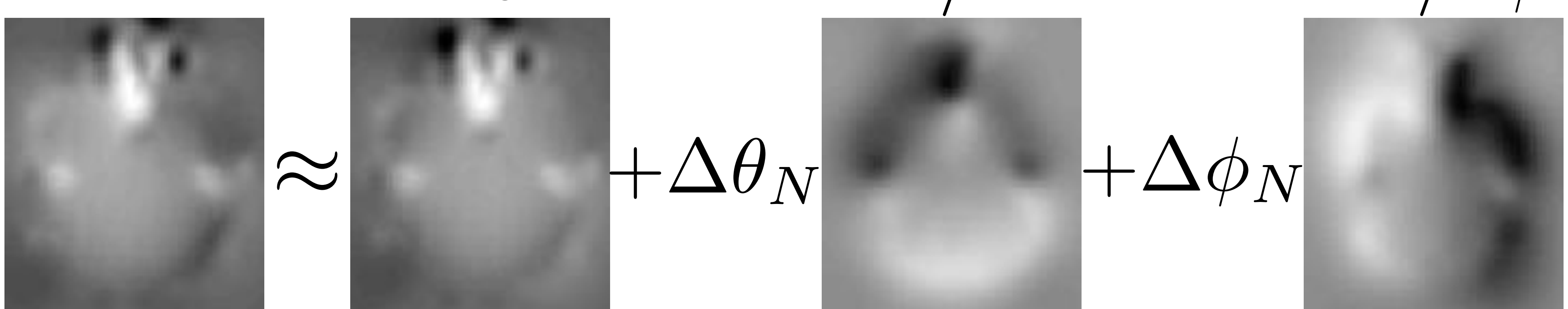


$$\omega_1 \approx \omega_0 + \Delta\theta_1 \, \partial\omega/\partial\theta + \Delta\phi_1 \, \partial\omega/\partial\phi$$



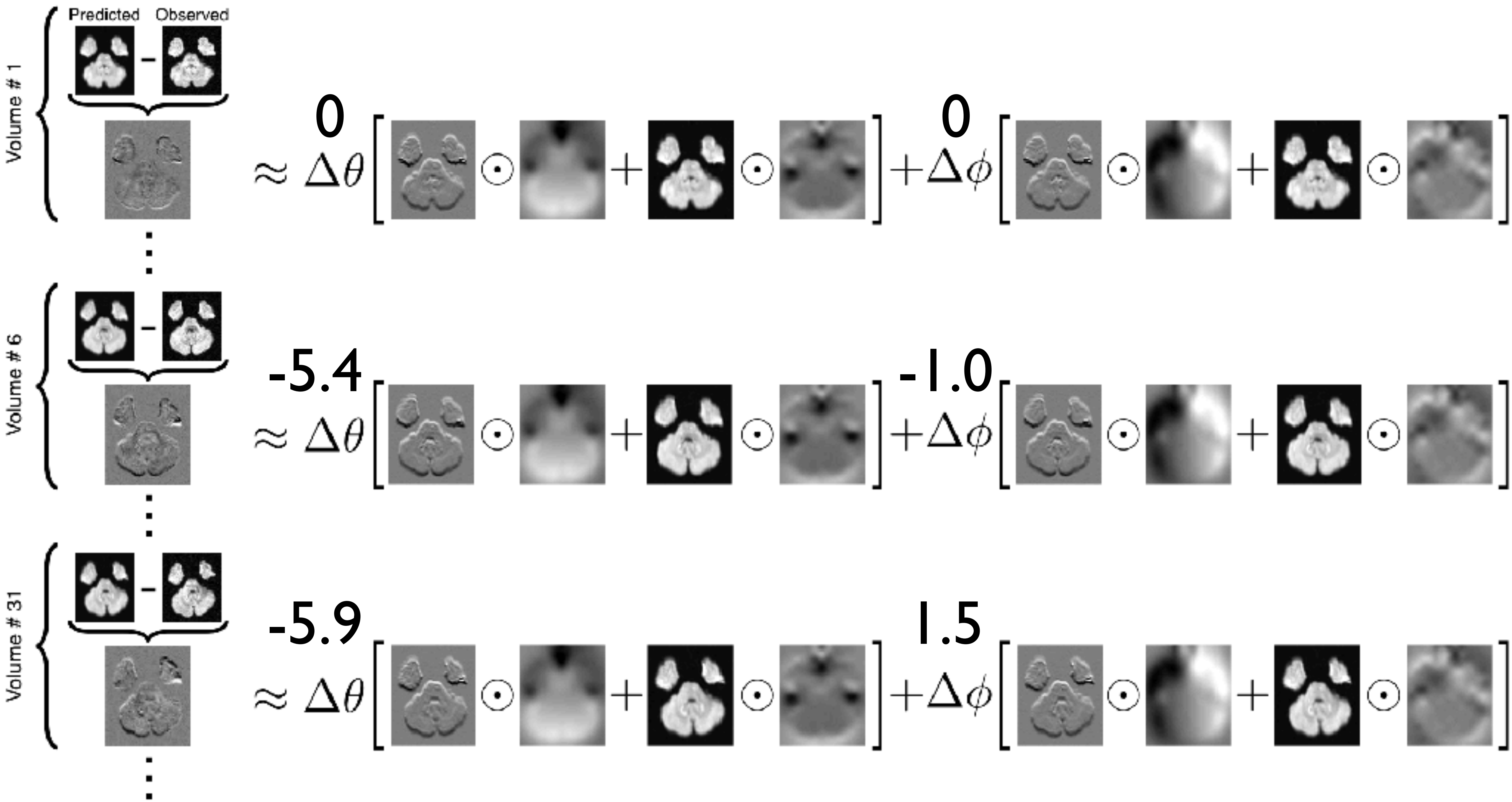
$$\omega_2 \approx \omega_0 + \Delta\theta_2 \, \partial\omega/\partial\theta + \Delta\phi_2 \, \partial\omega/\partial\phi$$

$$\vdots \qquad \vdots \qquad \vdots \qquad \vdots$$

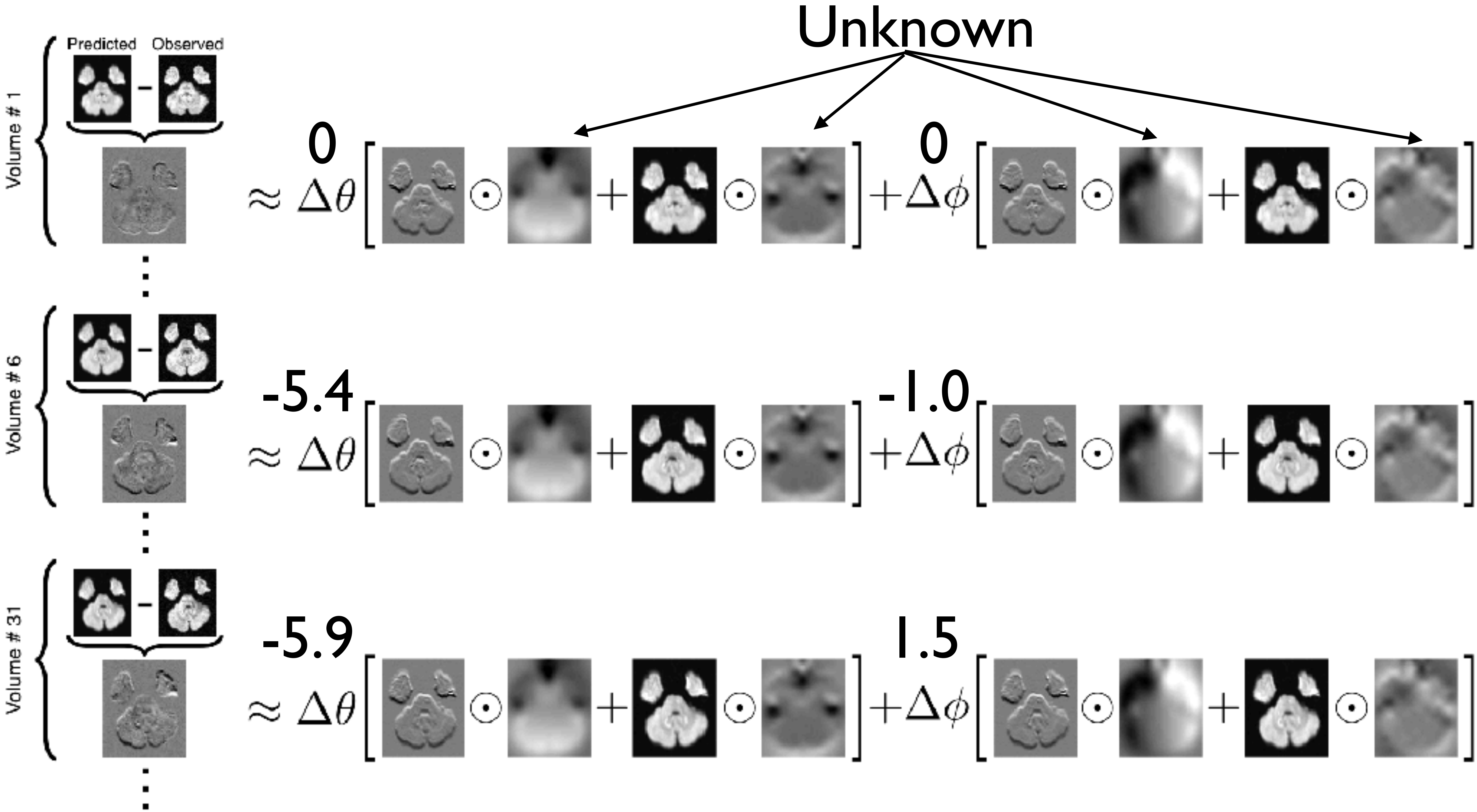


$$\omega_N \approx \omega_0 + \Delta\theta_N \, \partial\omega/\partial\theta + \Delta\phi_N \, \partial\omega/\partial\phi$$

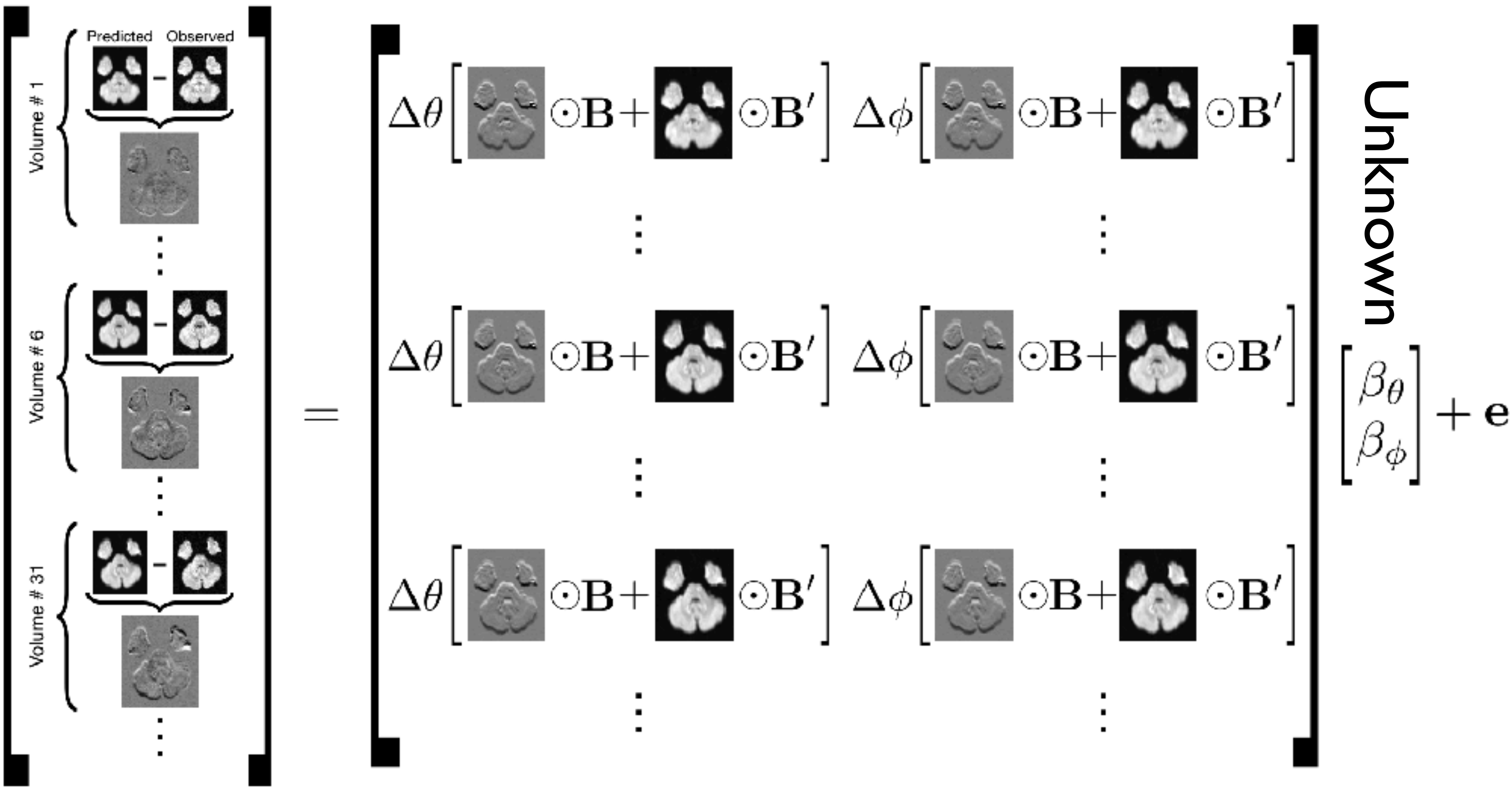
We need a forward model for the observed changes



We need a forward model for the observed changes



And then to invert that model to find the unknowns



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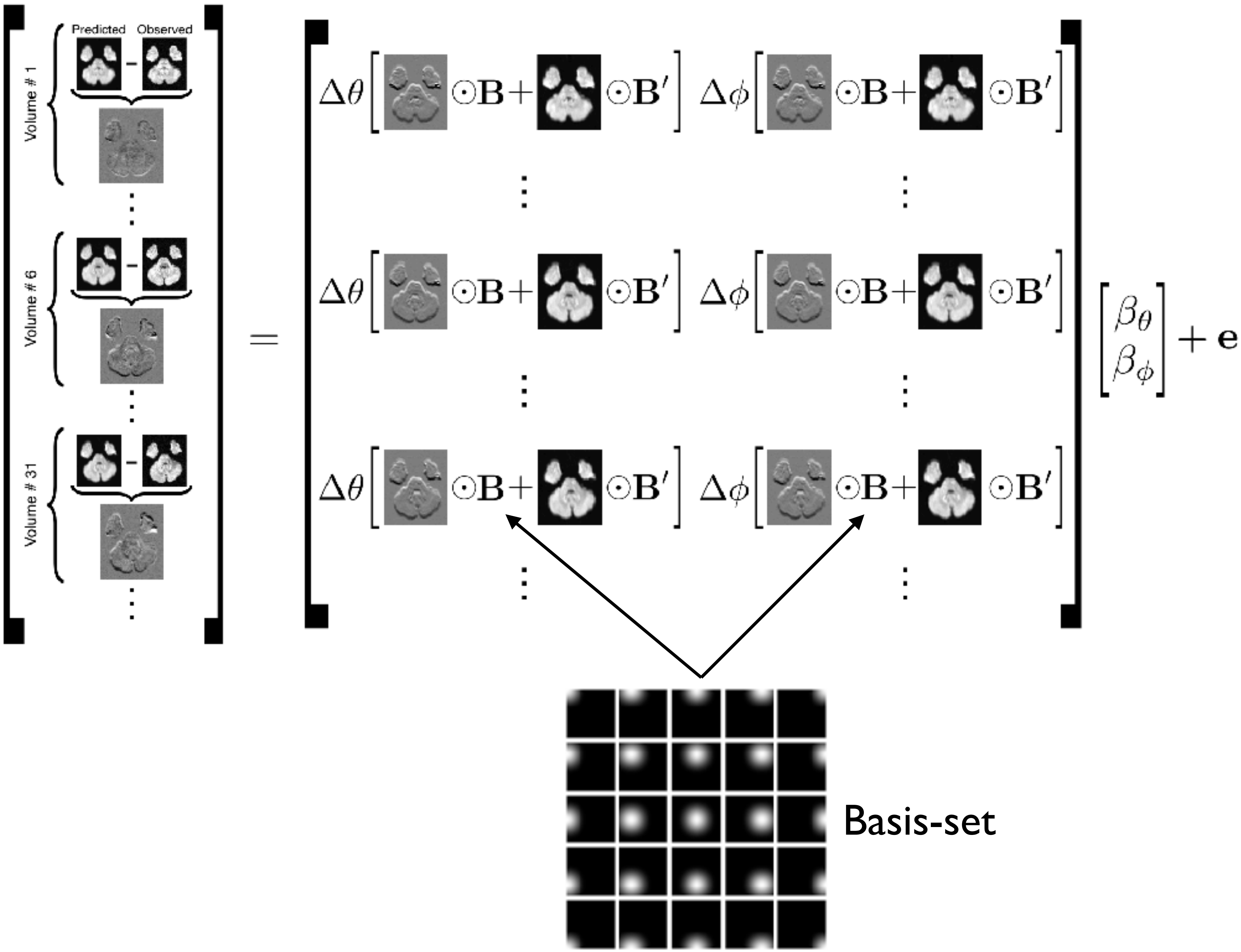

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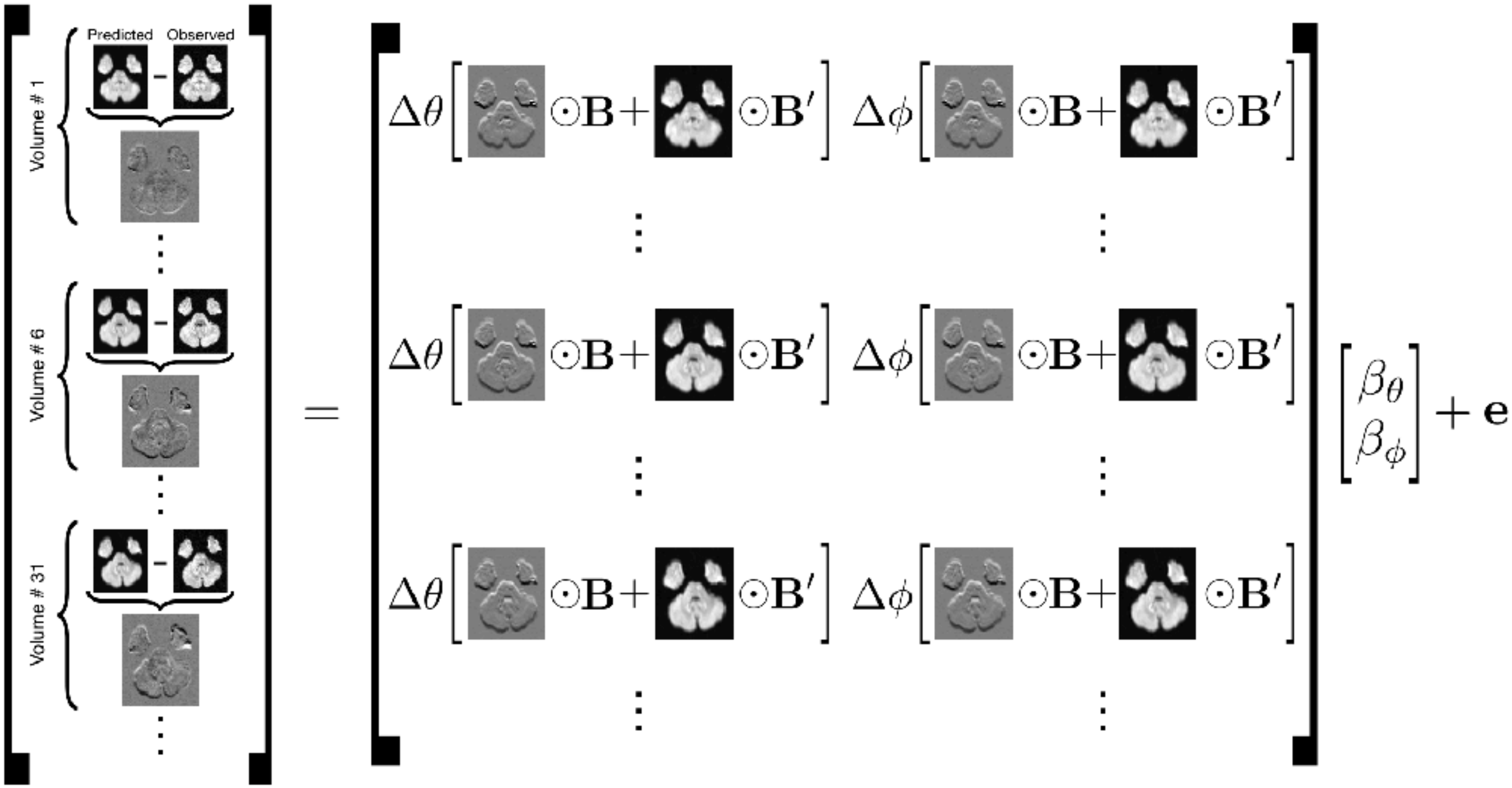
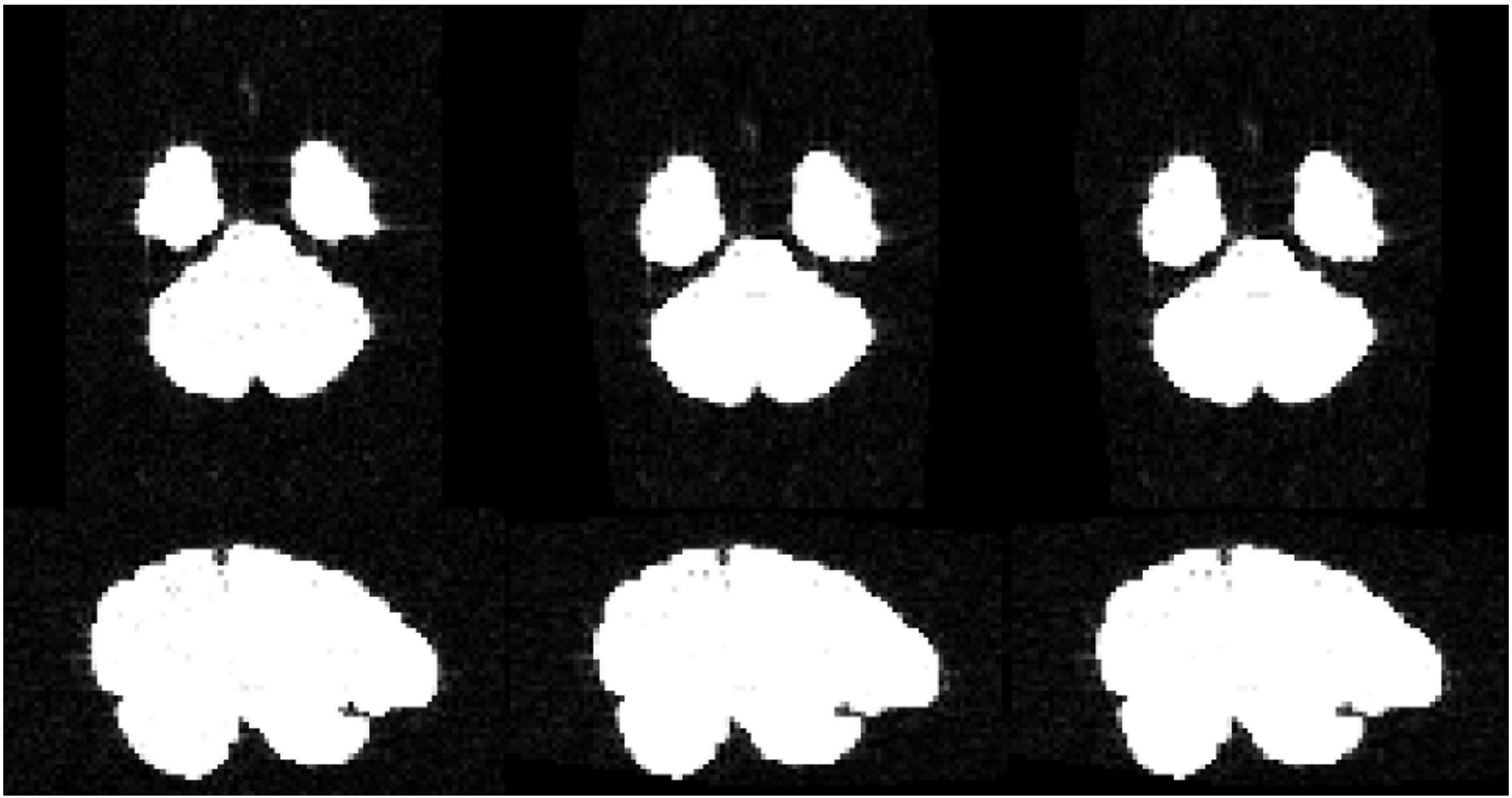


$$\mathbf{y} = \mathbf{X} \mathbf{b} + \mathbf{e}$$

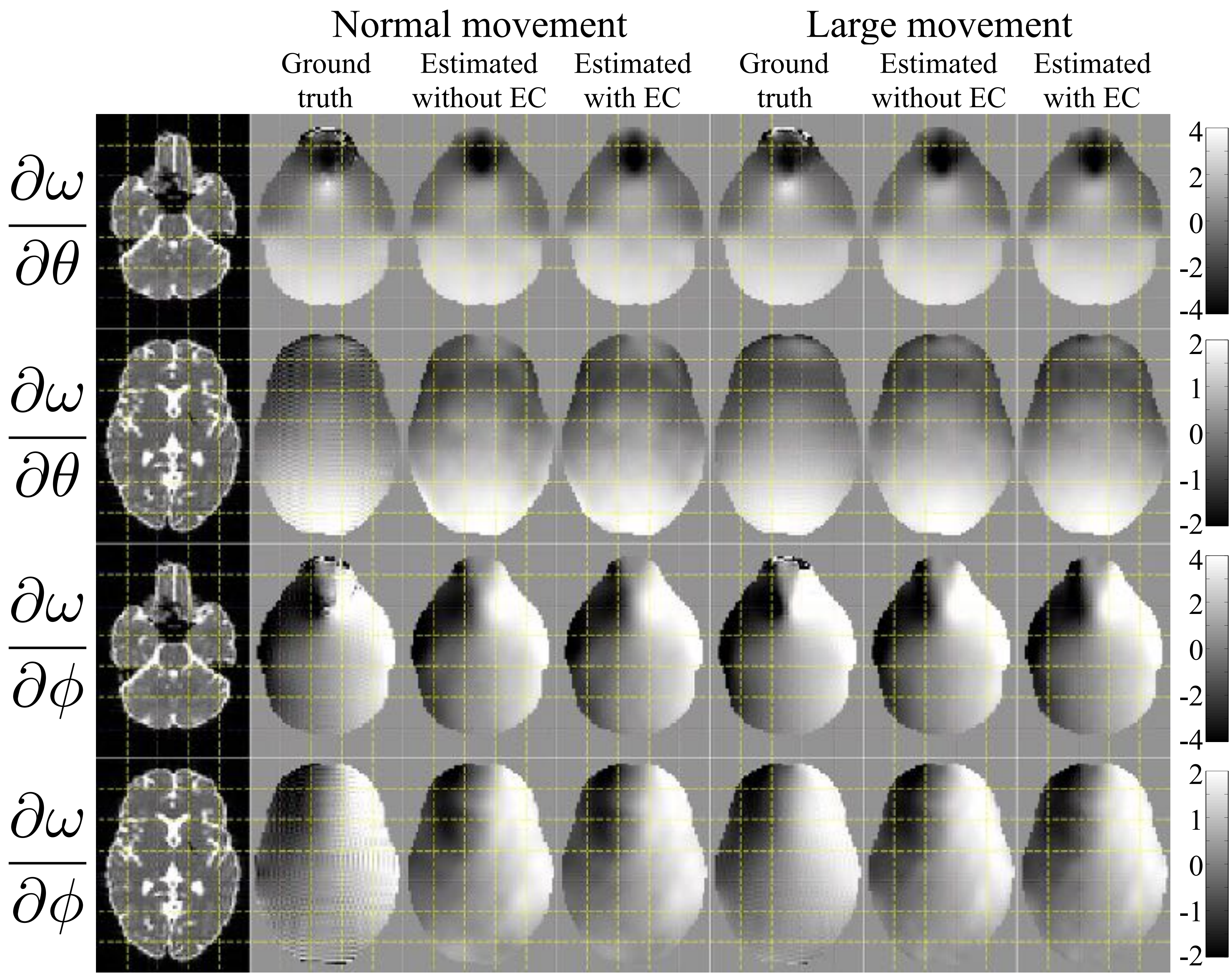
$$\hat{\mathbf{b}}^{(k+1)} = \hat{\mathbf{b}}^{(k)} + \left(\mathbf{X}^T\mathbf{X}\right)^{-1}\mathbf{X}^T\mathbf{y}$$

And now things look a lot better

Before After With Susc-by-move



And this is what the estimated derivative fields look like



And the problematic HCP subject