# Machine Learning and Inversion

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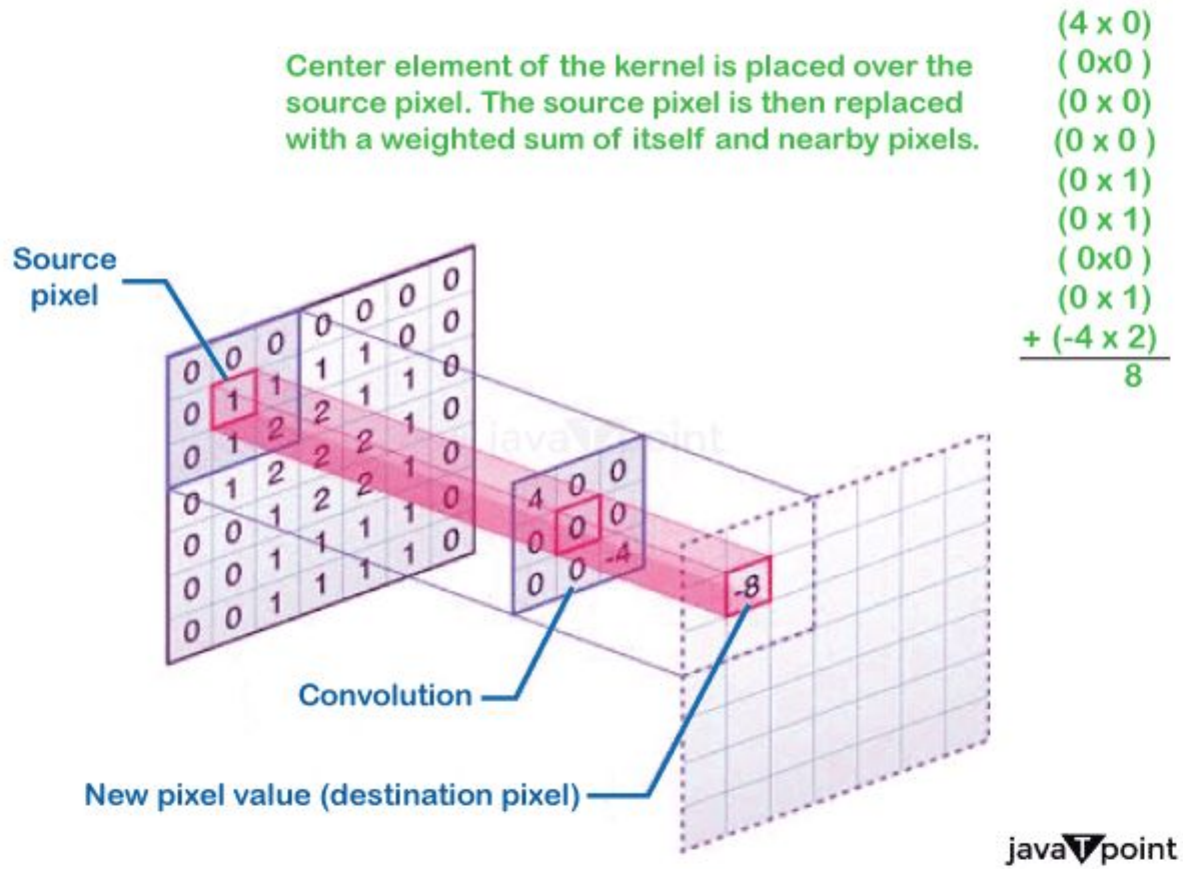
# Convolution in a nutshell

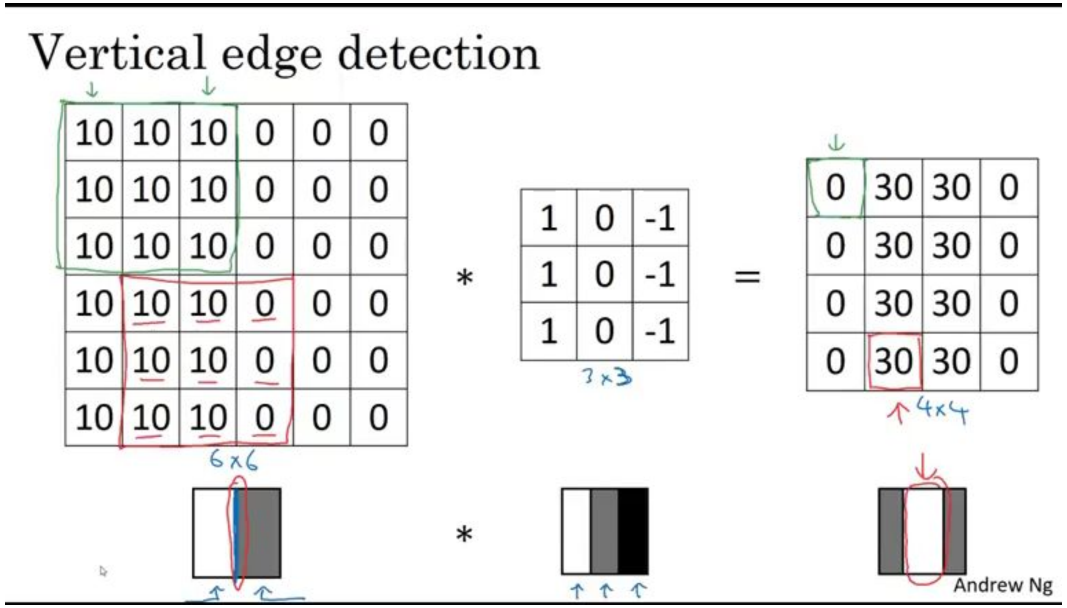


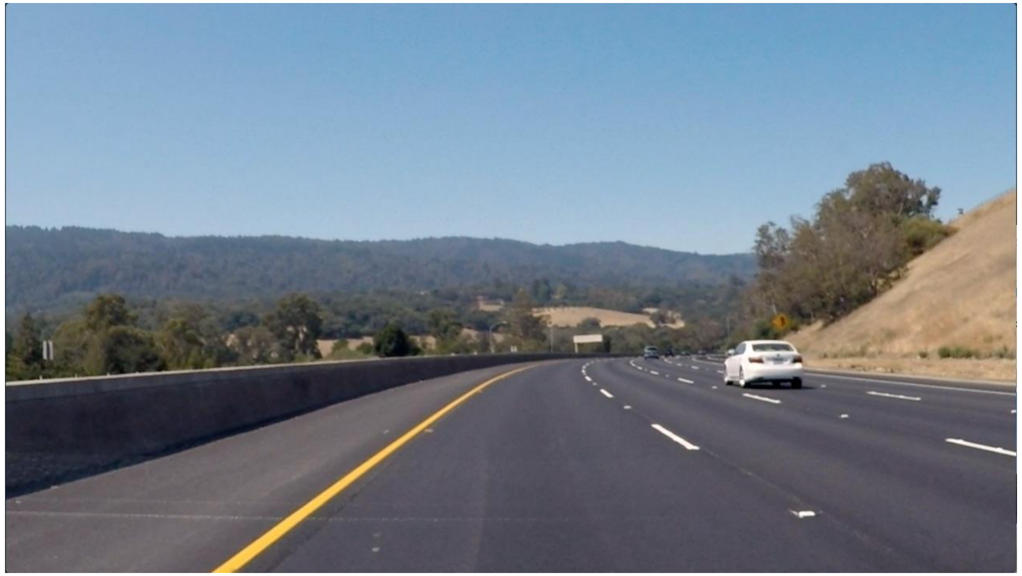

**Convolution** is a mathematical operation used in **convolutional neural networks (CNNs)** to extract important features from input images.

**Feature Extraction:** As the filter slides it produces a new image (feature map) that highlights certain features, like edges, textures, or patterns.

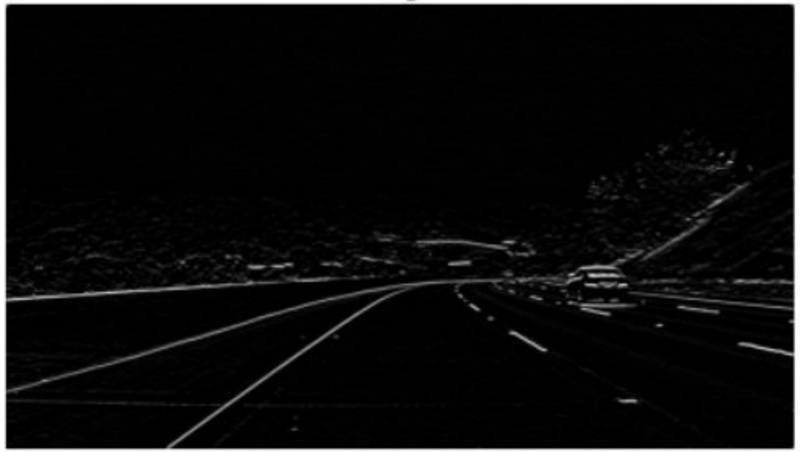
**Automatic Feature Detection:** CNNs automatically learn to detect features such as edges, shapes, or textures from raw data.

# Convolution: edge detection example



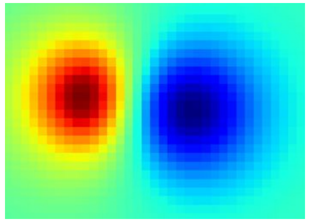
horizontal edge detection

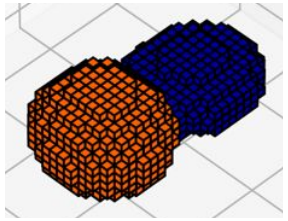


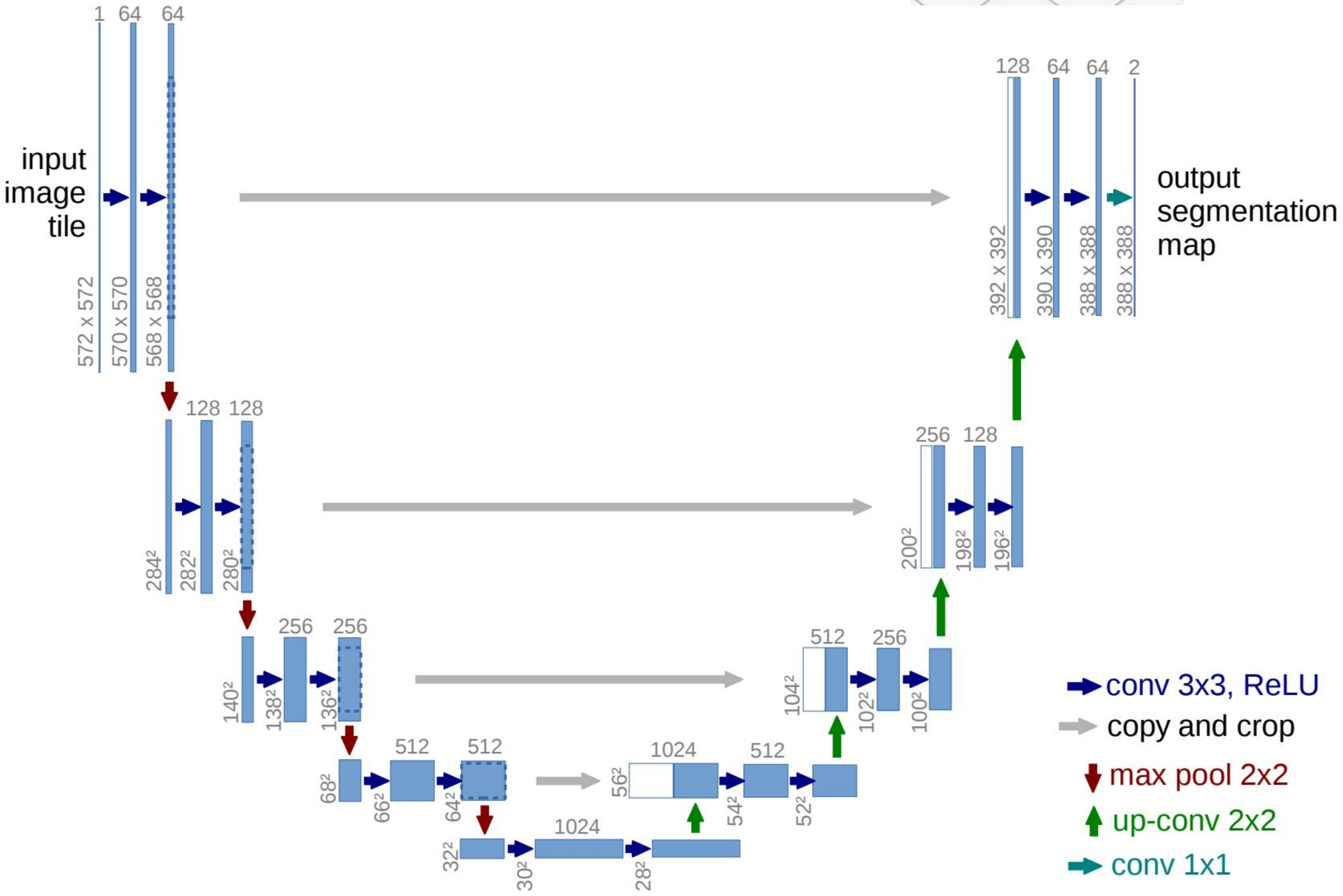
vertical edge detection

https://kharshit.github.io/blog/2018/12/14/filters-in-convolutional-neural-networks

# U-Net architecture








**Encoder (Contracting Path):**
Extracts key features from gravity data, like regions with high or low density anomalies.

**Decoder (Expanding Path):**
Reconstructs the segmented output, highlighting important geological structures.

**Skip Connections:**
Retain spatial information from the encoder, preserving the resolution needed to precisely identify geological boundaries.

# Machine Learning based gravity inversion

- Geology and petrophysical constraints are embedded into training set.
- Training set generated by Noddy 3D geological modelling platform.
- PyTorch library used.

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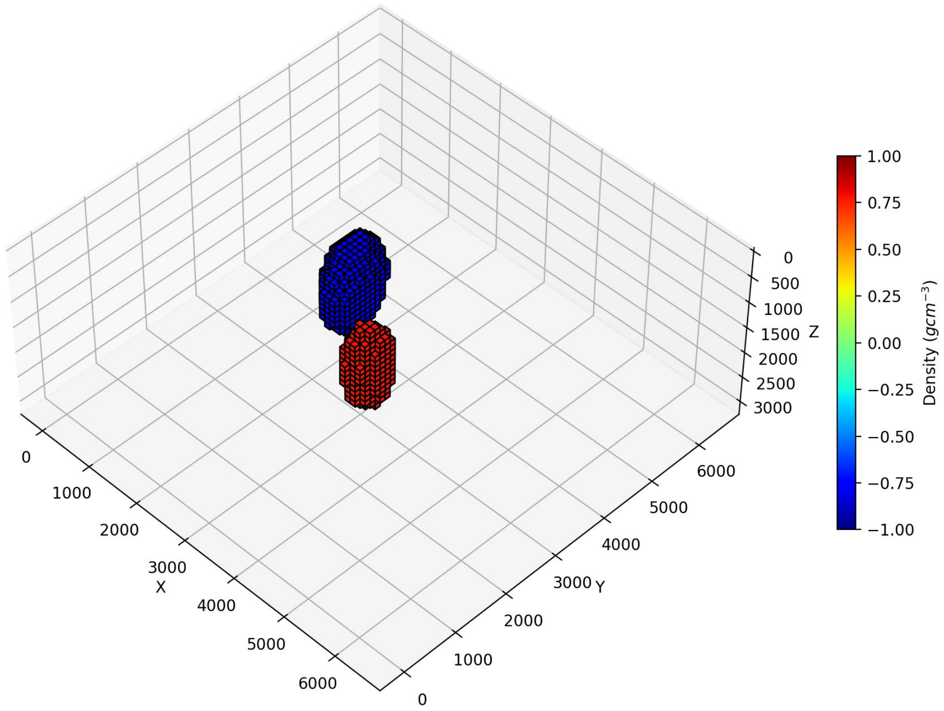
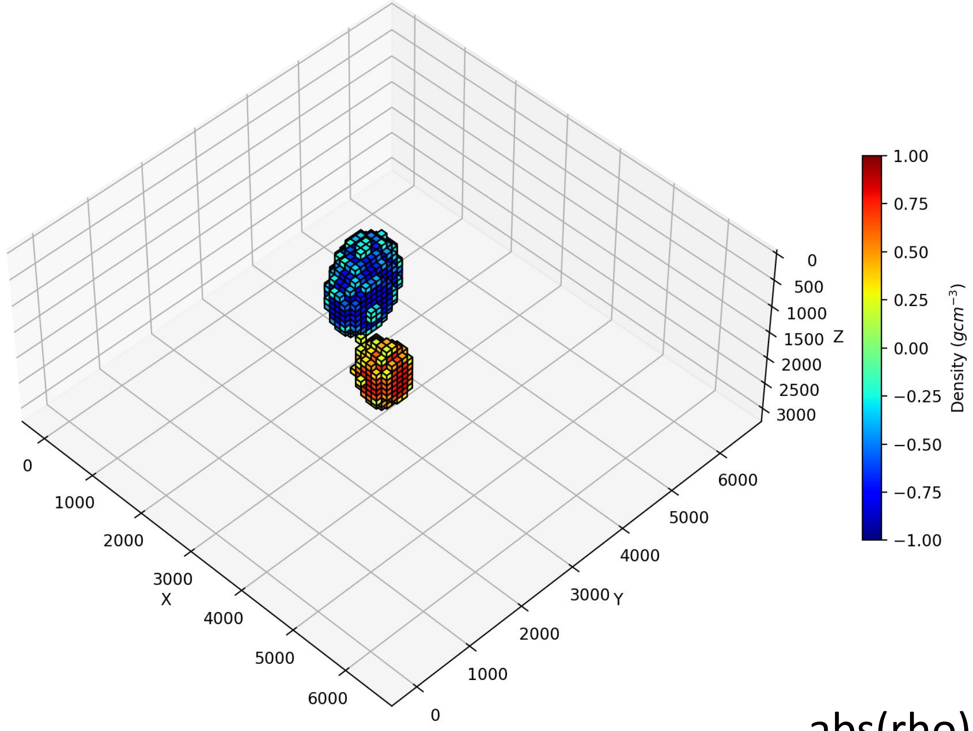
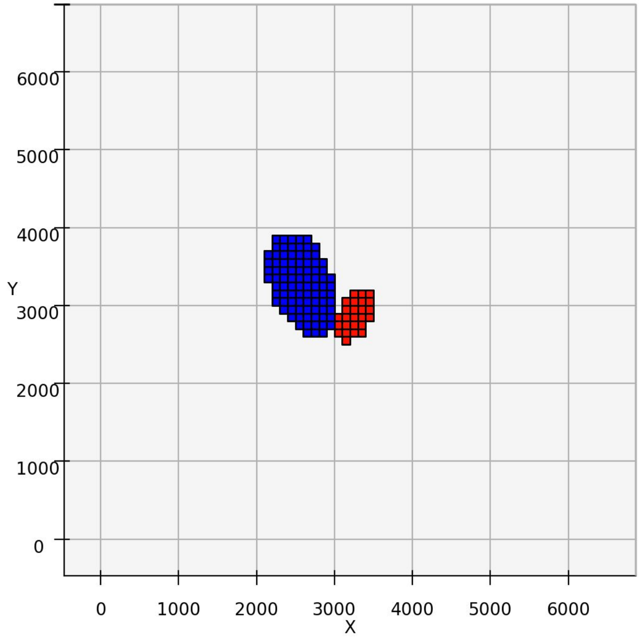
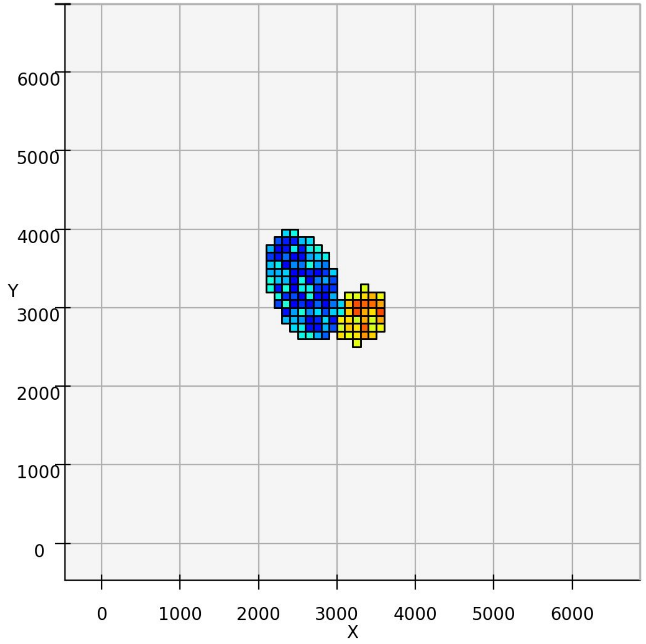
- Ellipsoidal intrusions with different density, orientation and size.
- Model size 6.4x6.4x3.2km, cell size = 100m.
- Number of data 64x64=4096, spacing = 100m.
- Training set size = 38400.
- Training time: ~ 4.5h using NVIDIA 3900.
- Inversion time: under 1 second.

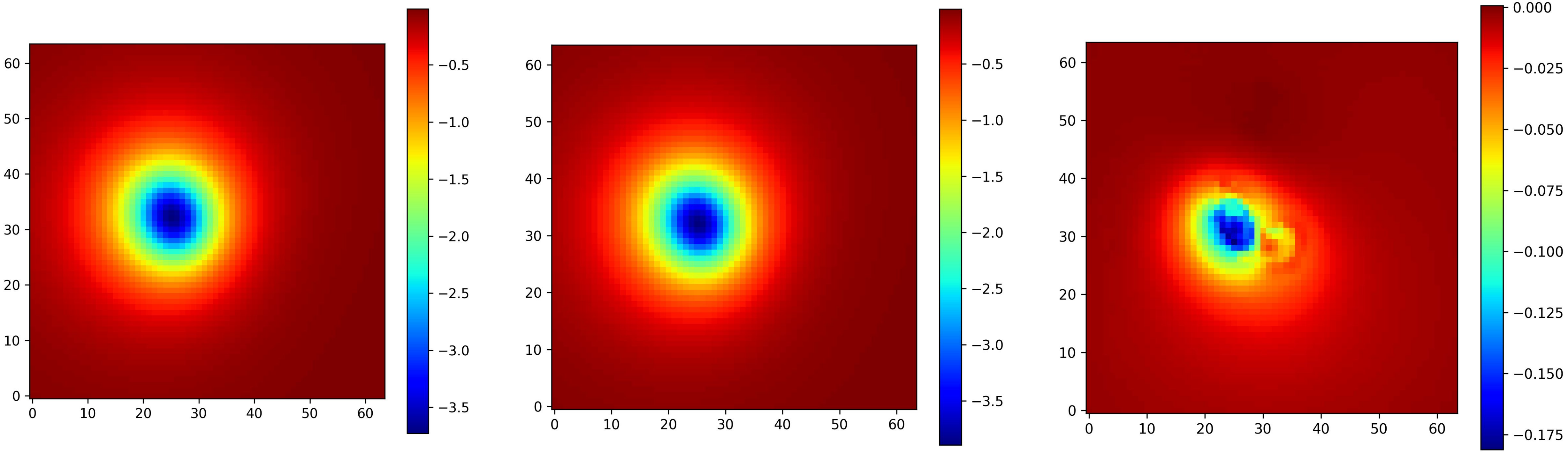


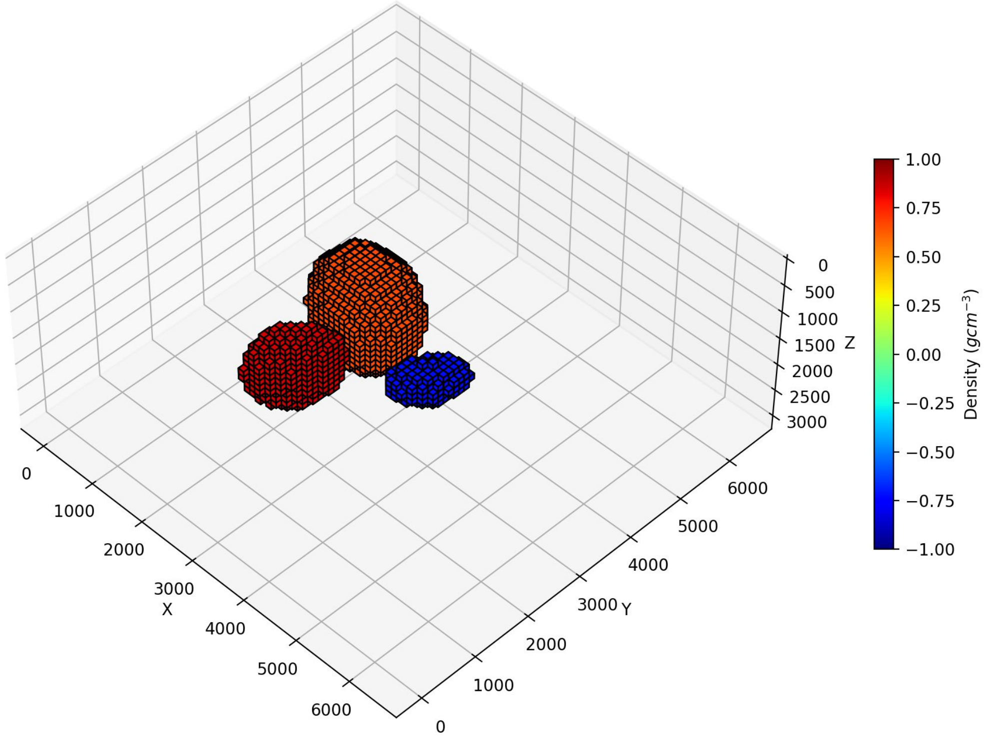

abs(rho)>0.2

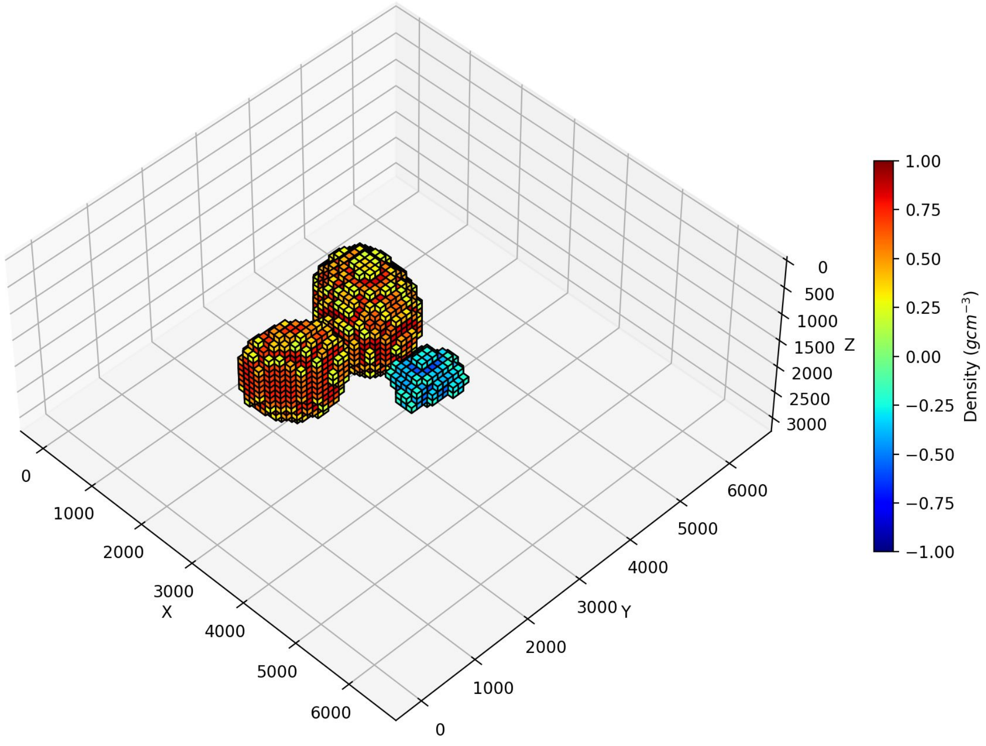


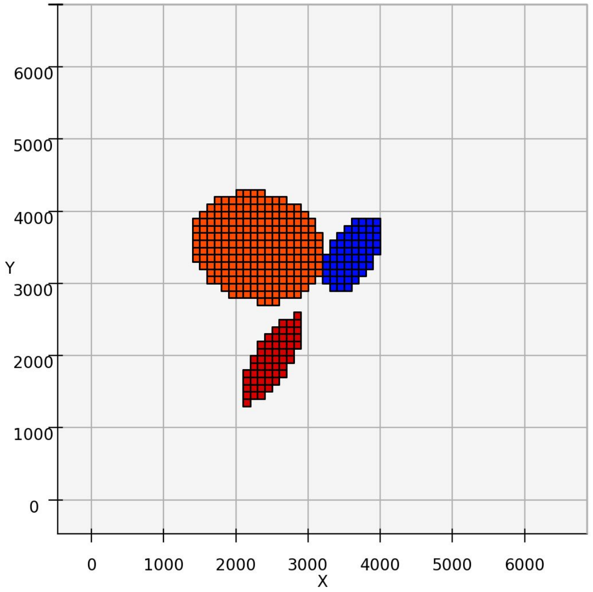



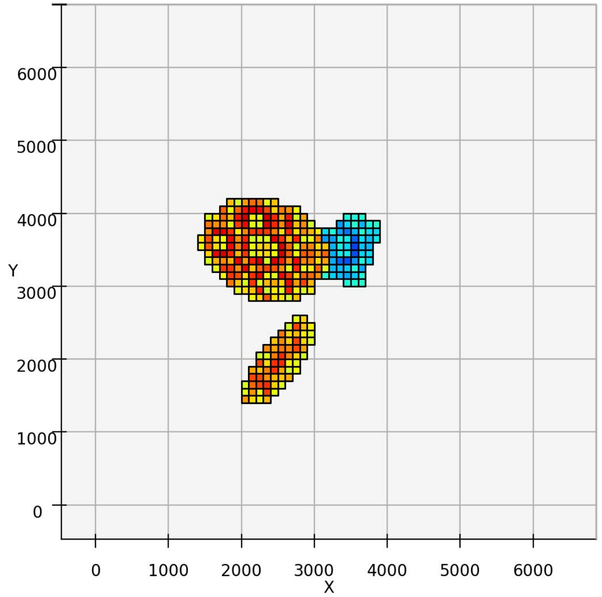



Data RMSE = 0.0239 mGal

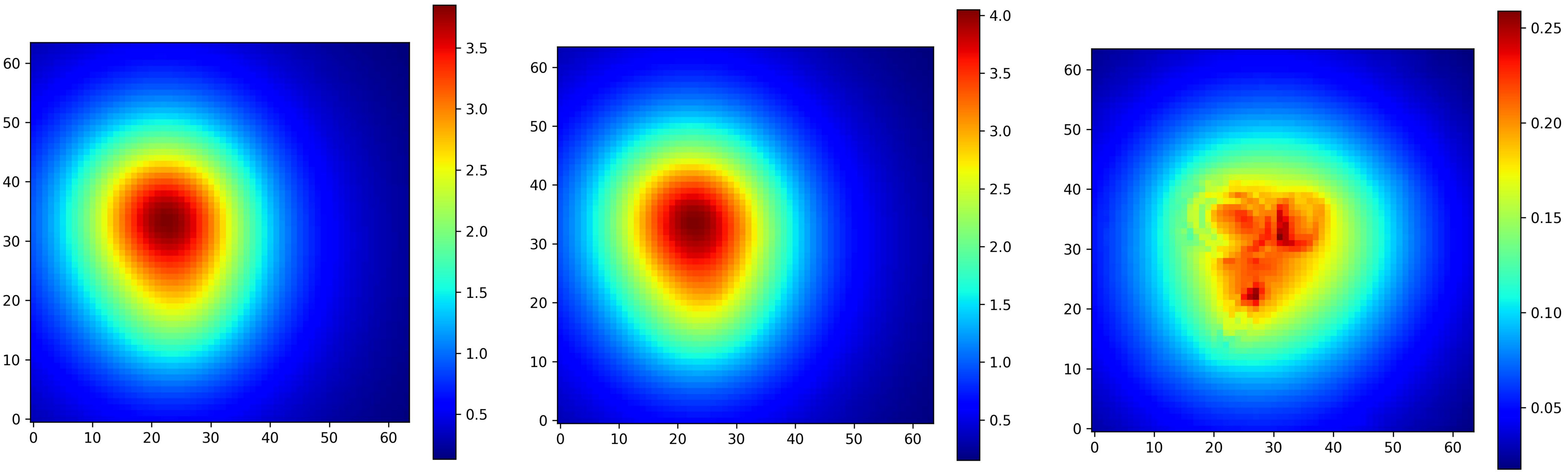




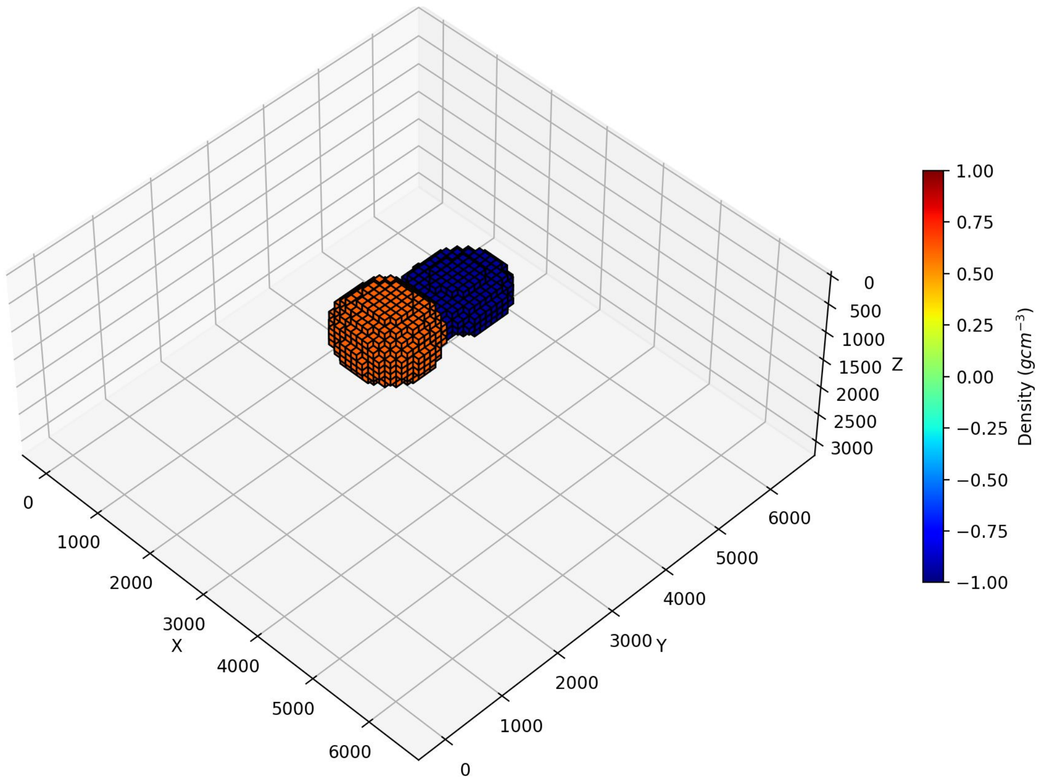


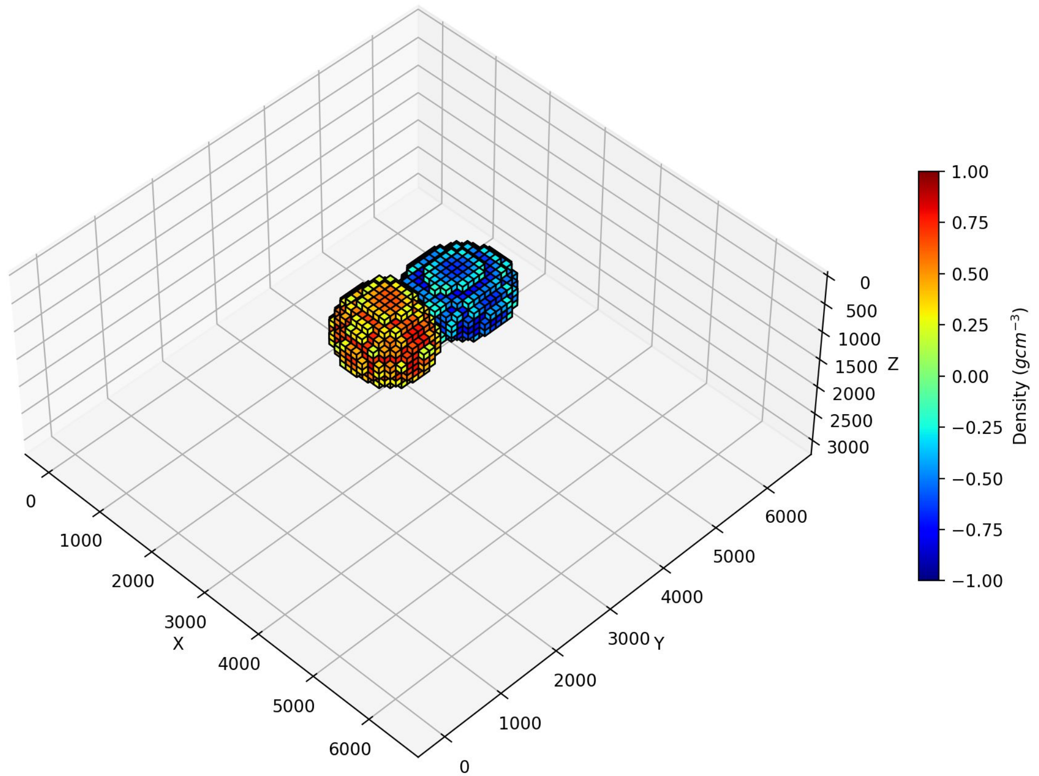



abs(rho)>0.2




Data RMSE = 0.099 mGal


X
Y
Z
Density ($gcm^{-3}$)
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00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1.00
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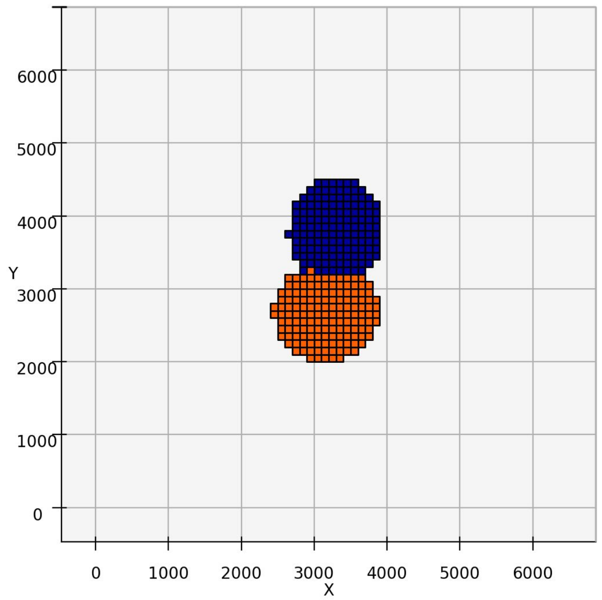
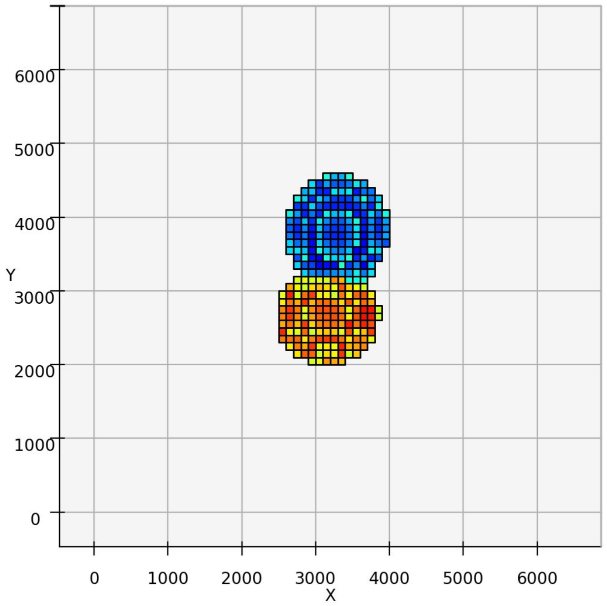
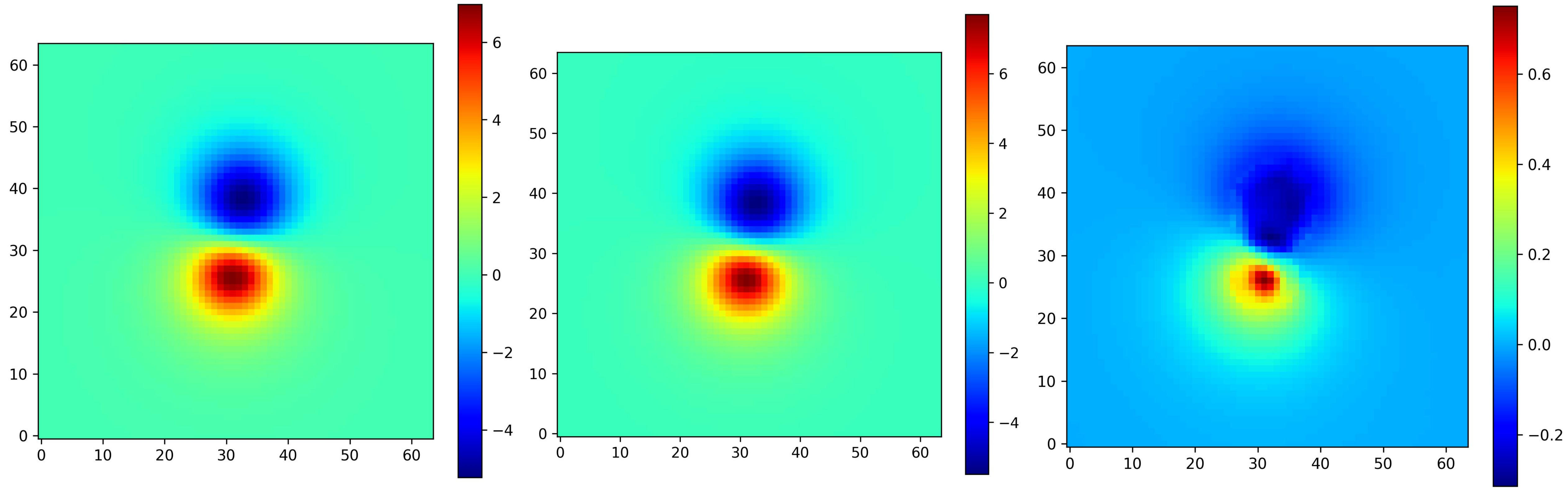
abs(rho)>0.2

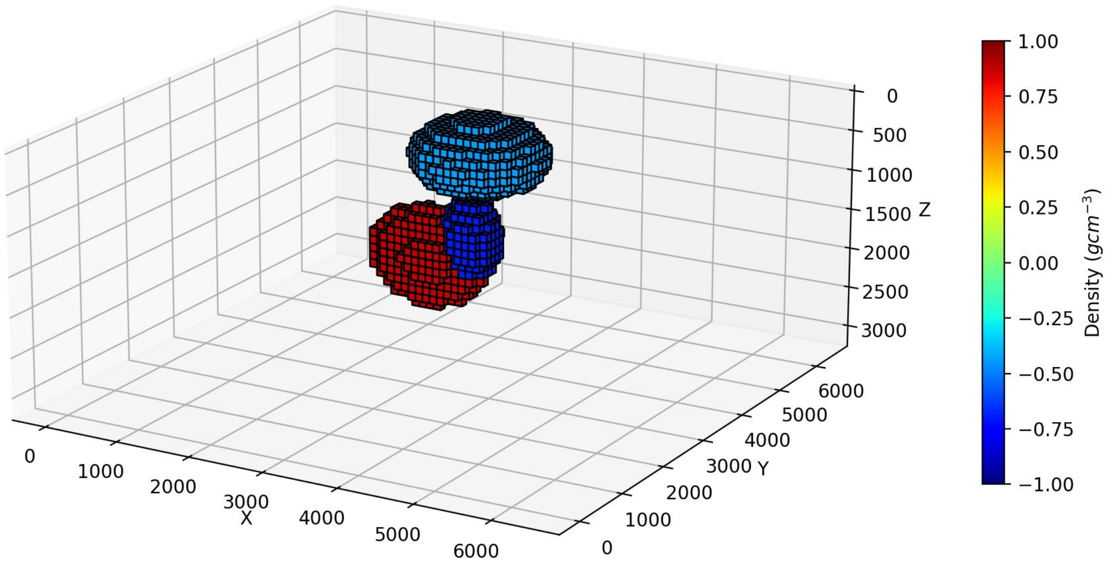

X
Y

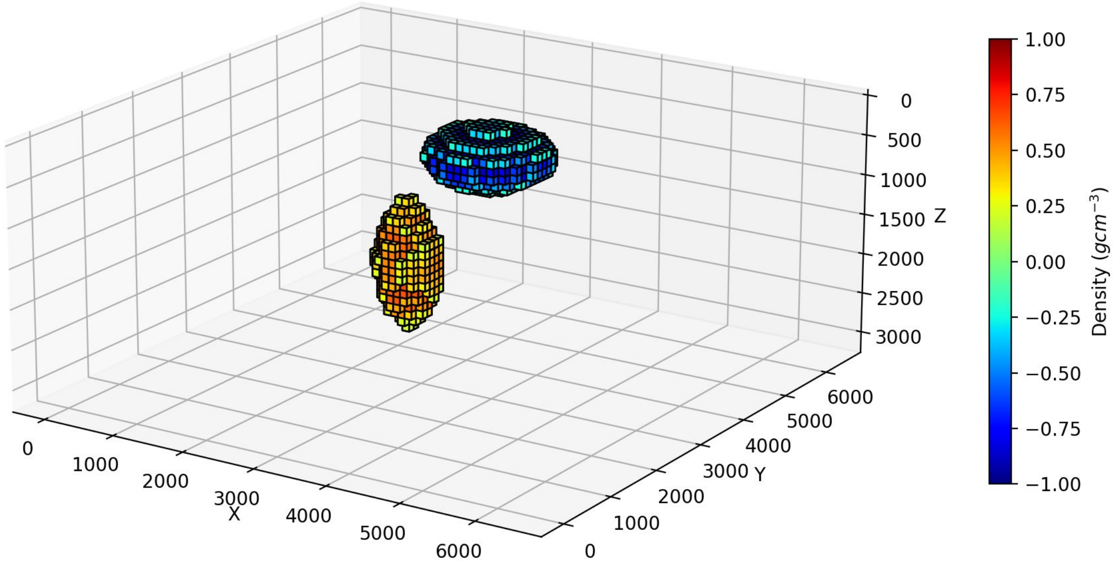

X
Y

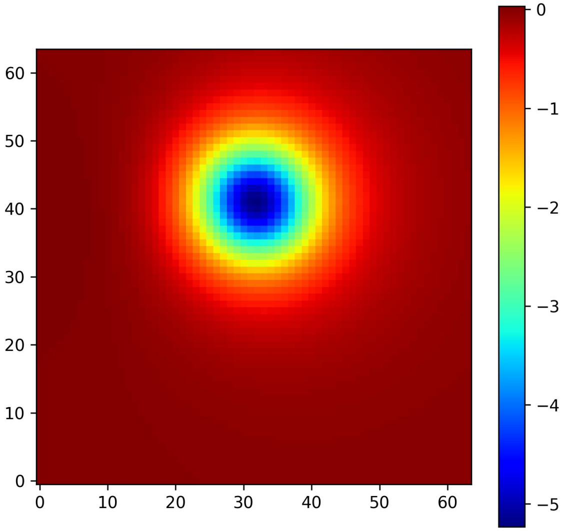


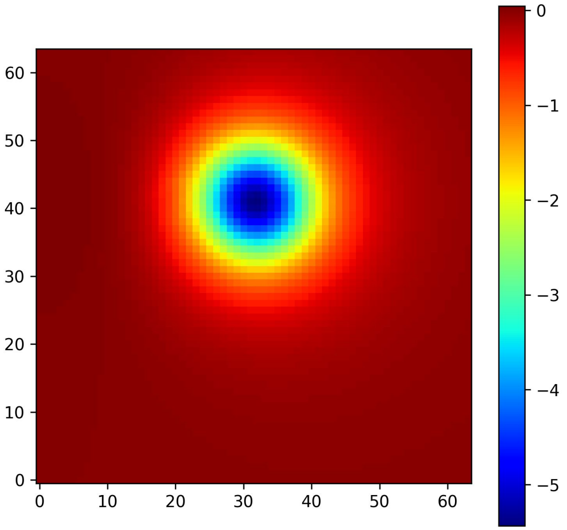

Data RMSE = 0.087 mGal

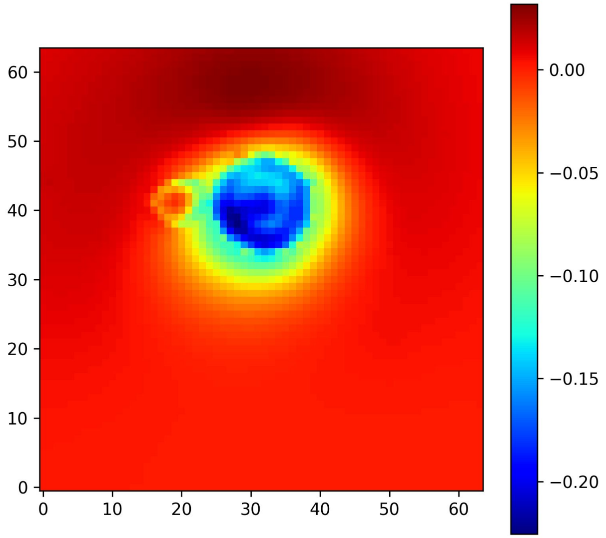
# Very complex case: deeper object signal is fully swamped



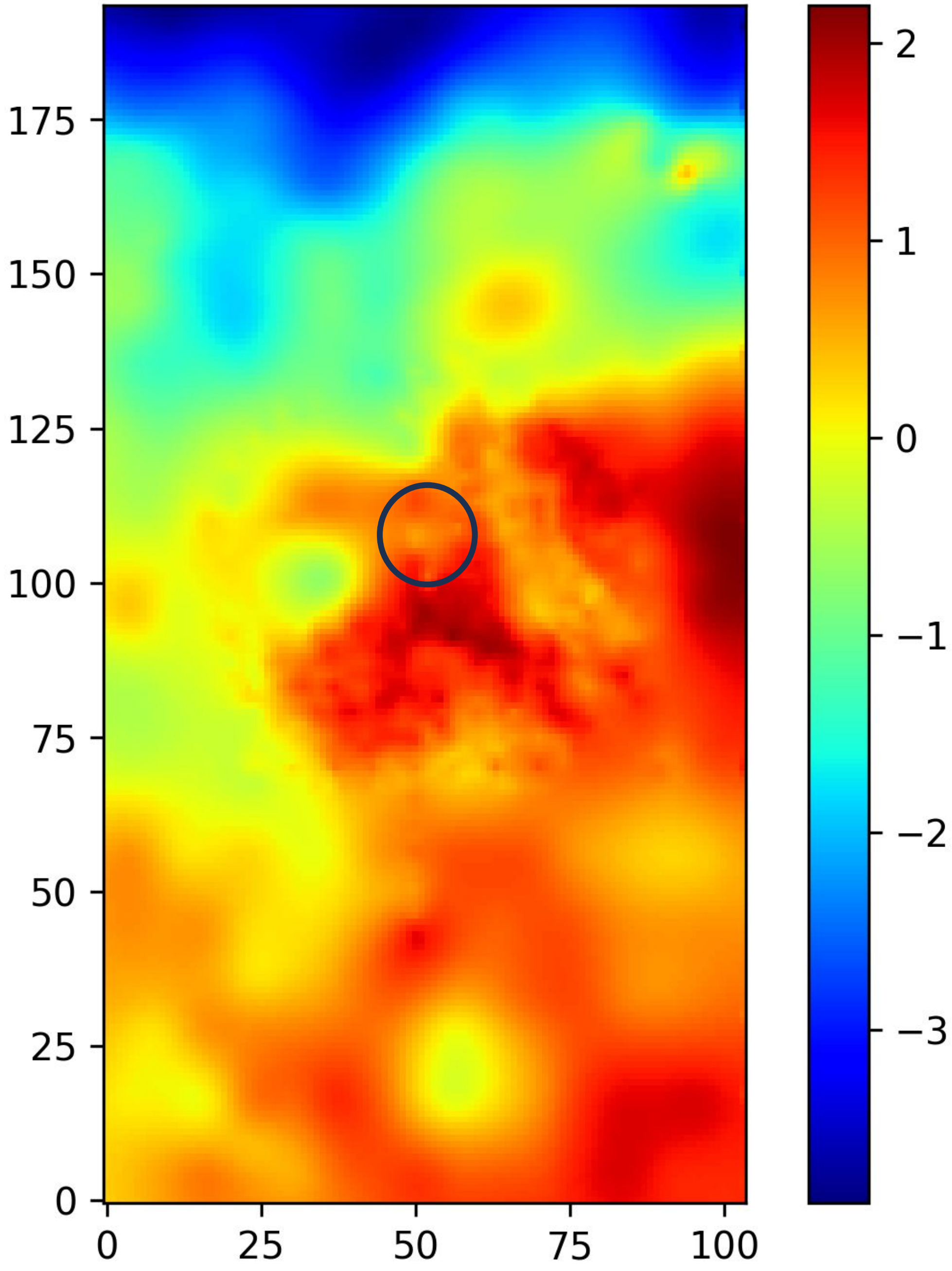







Data RMSE = 0.040 mGal

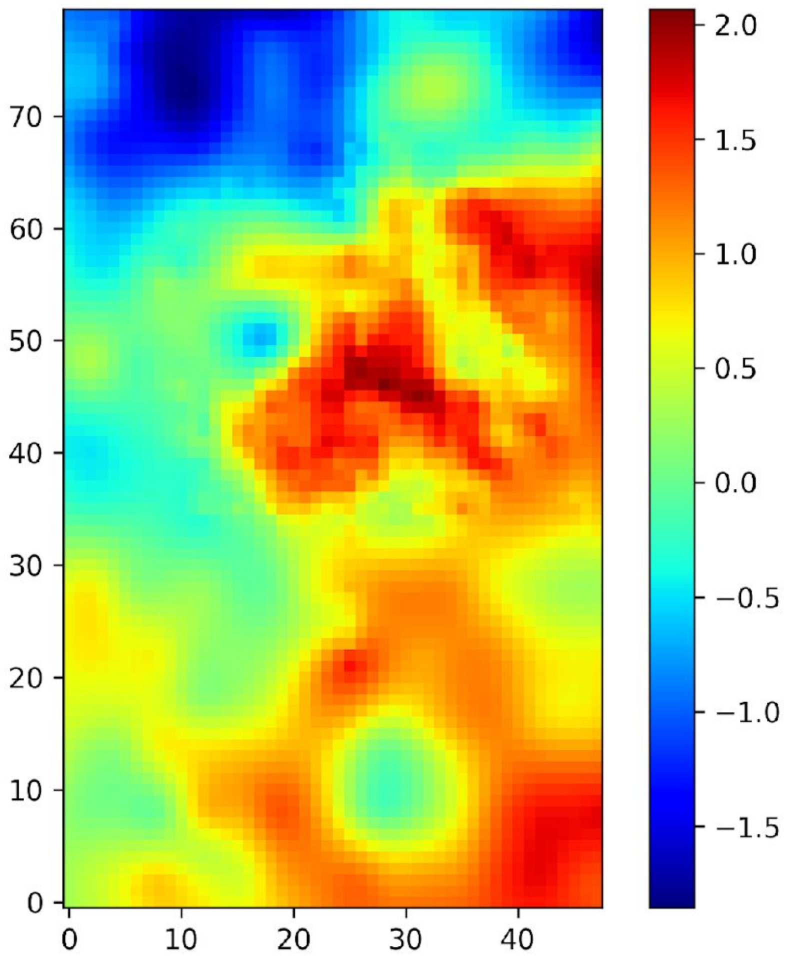



# Field Data example (data provided by ExploreGeo)

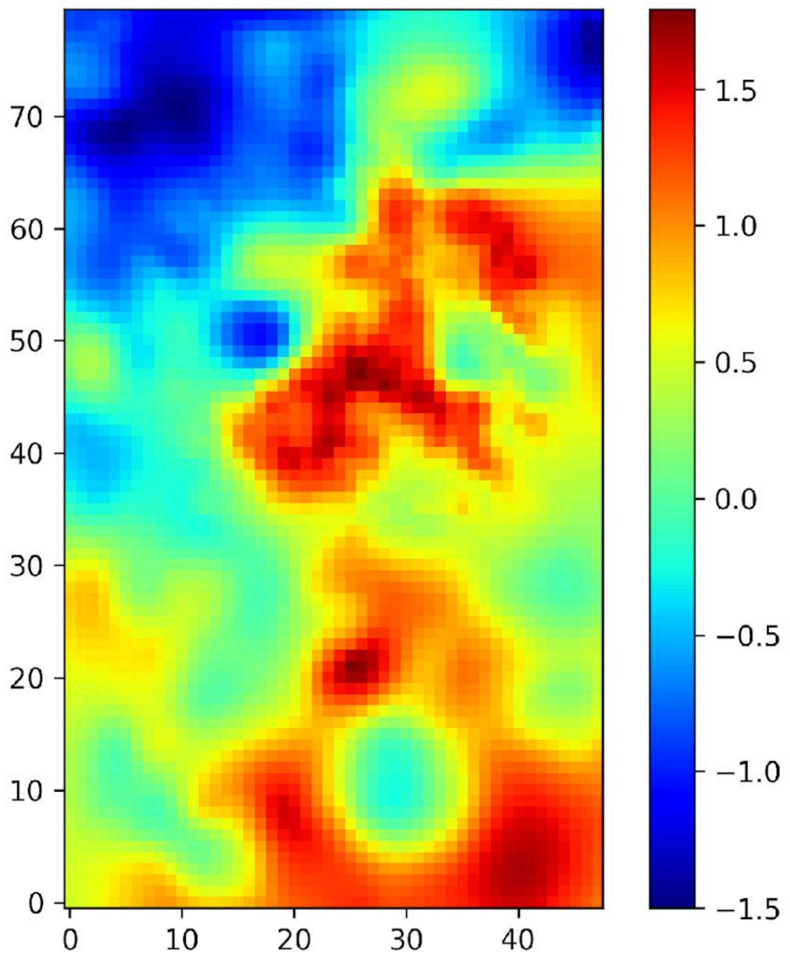
Data spacing: 30m
Area: 3km x 6km

Interested in Syenite intrusions inside Mafic.

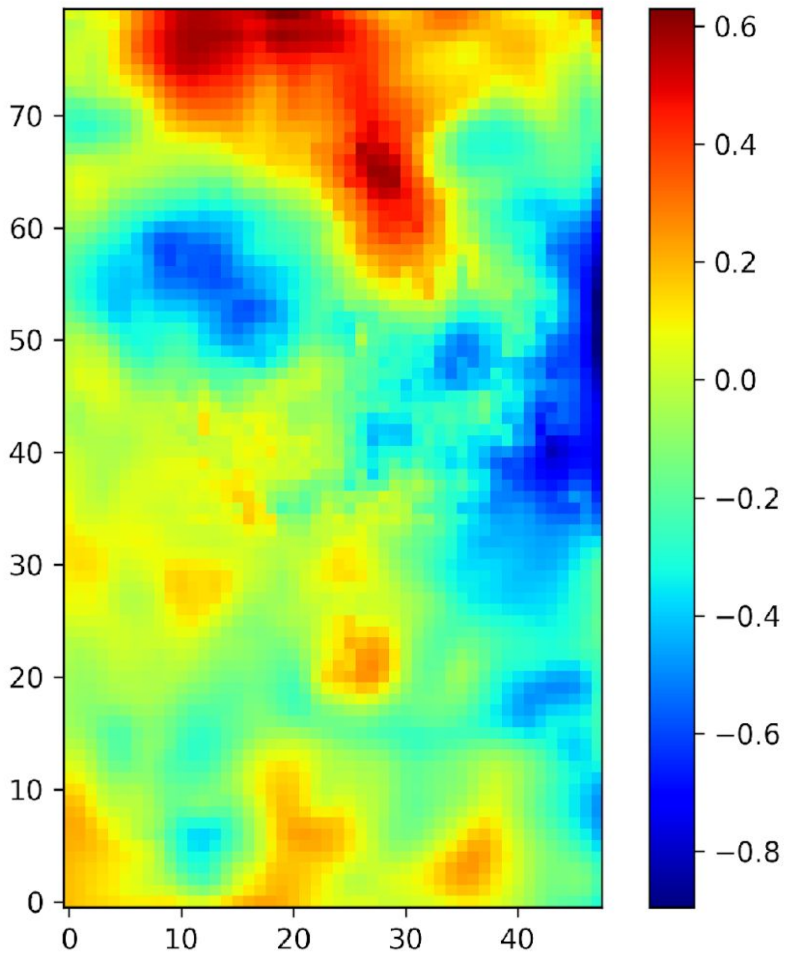
# First inversion attempt using decimated data (60m) and clipped the northern part




Observed




Calculated

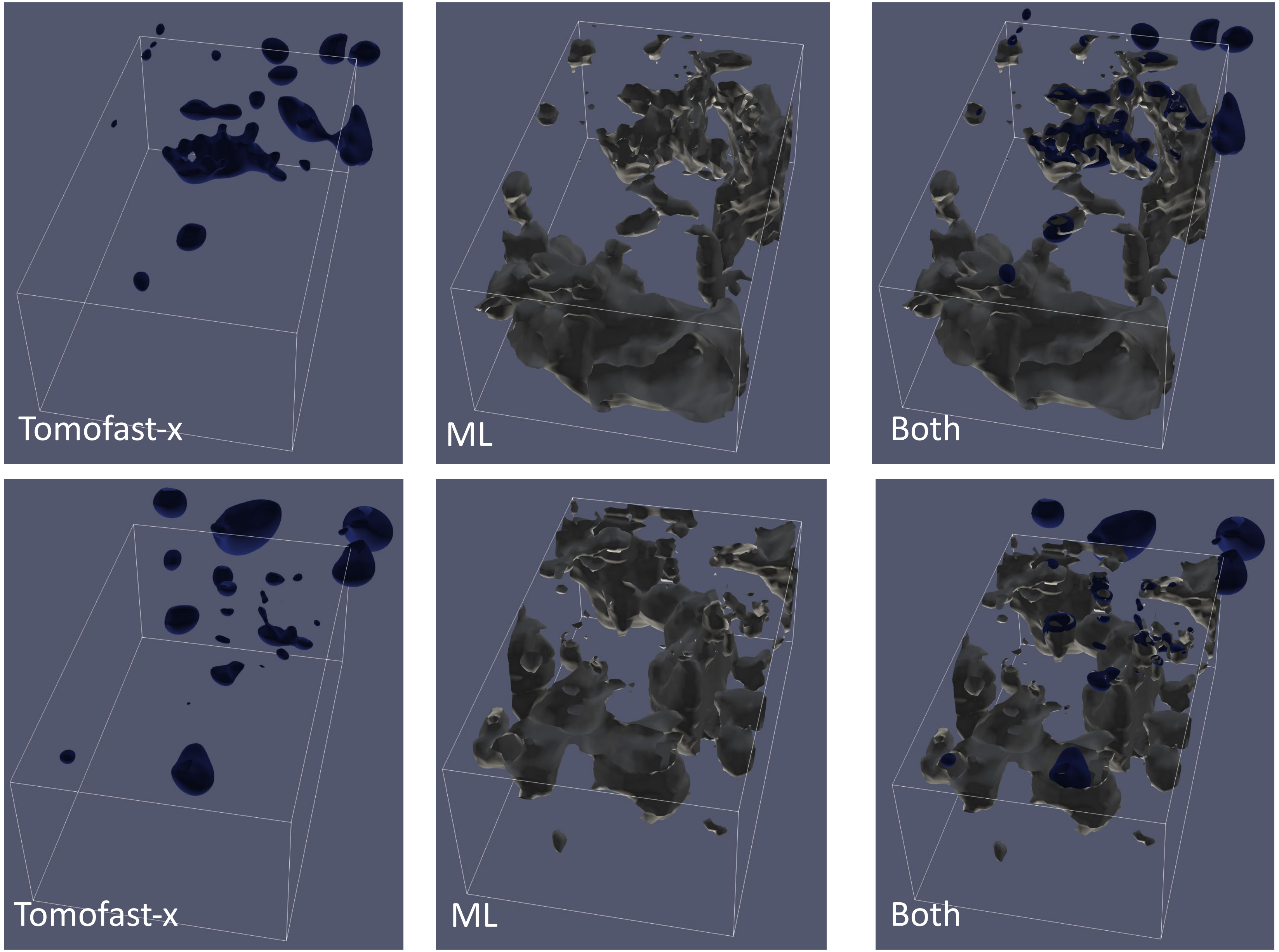



Misfit

# Comparison of inverted model with Tomofast-x

ρ=+100

ρ=-100



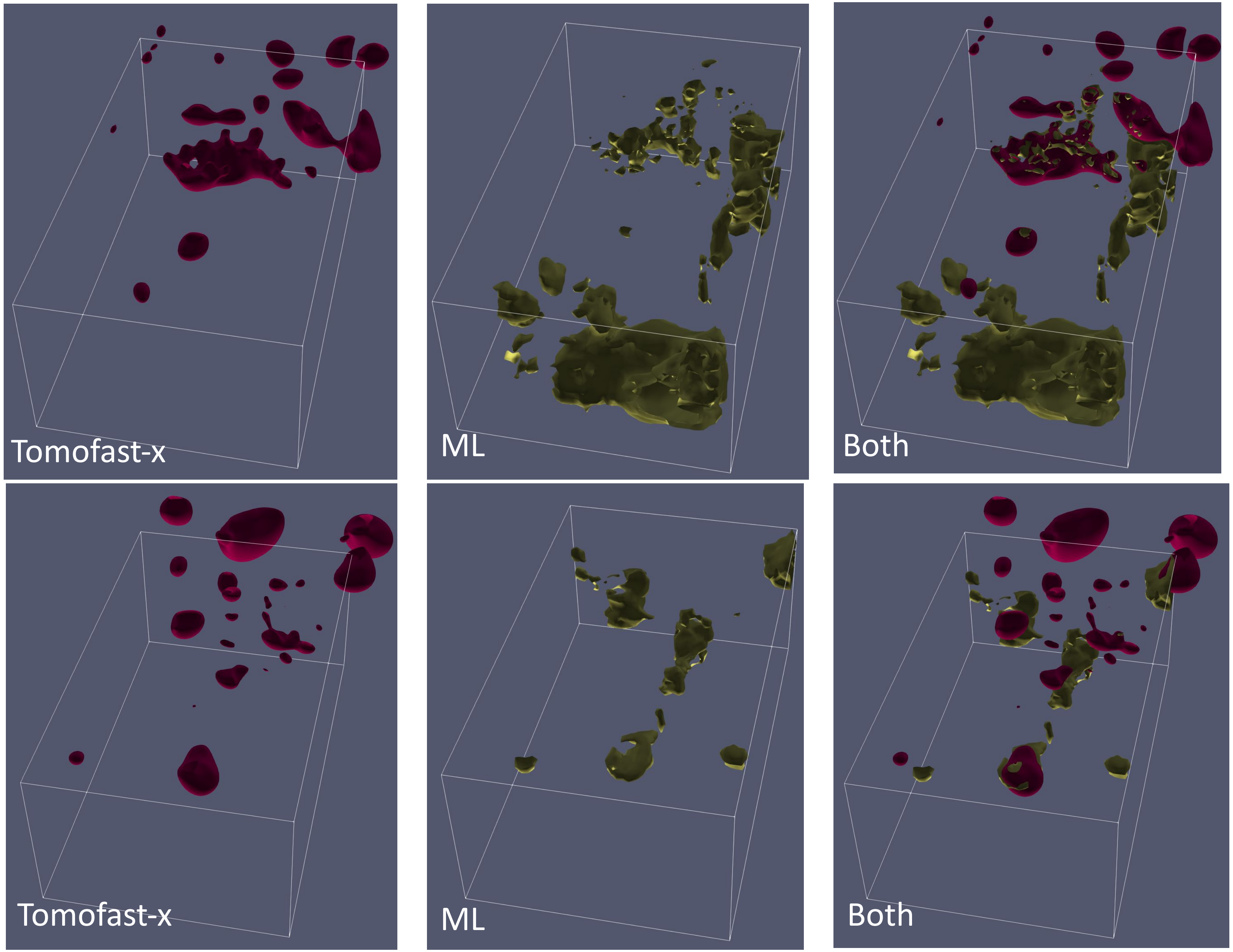
# Comparison of inverted model with Tomofast-x

ρ_tomo = +100

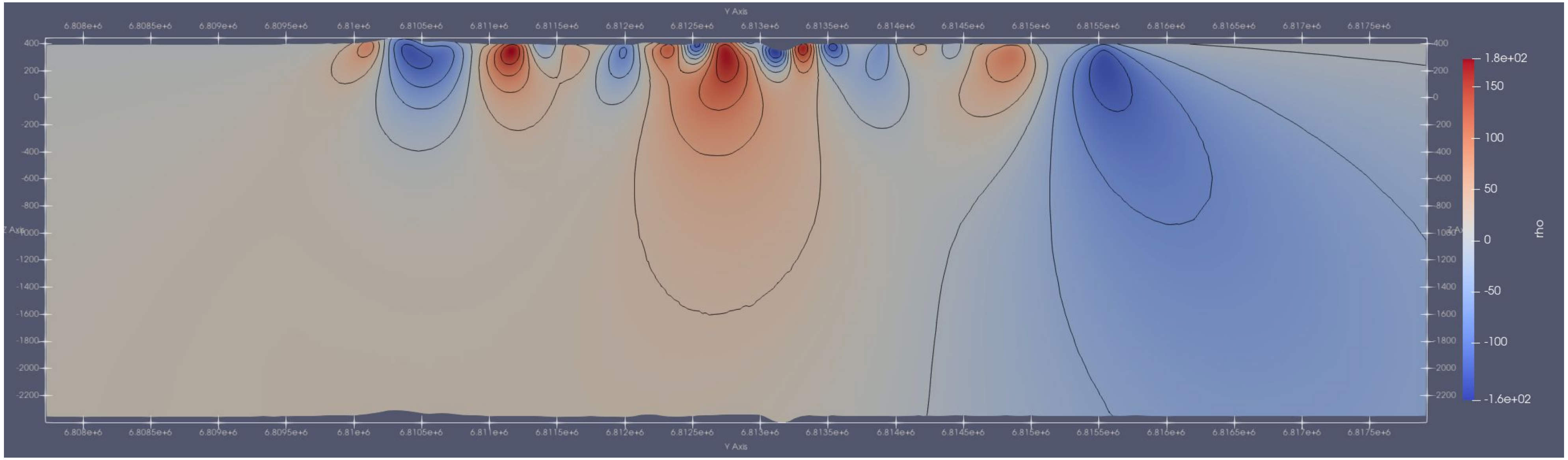
ρ_ML = +250

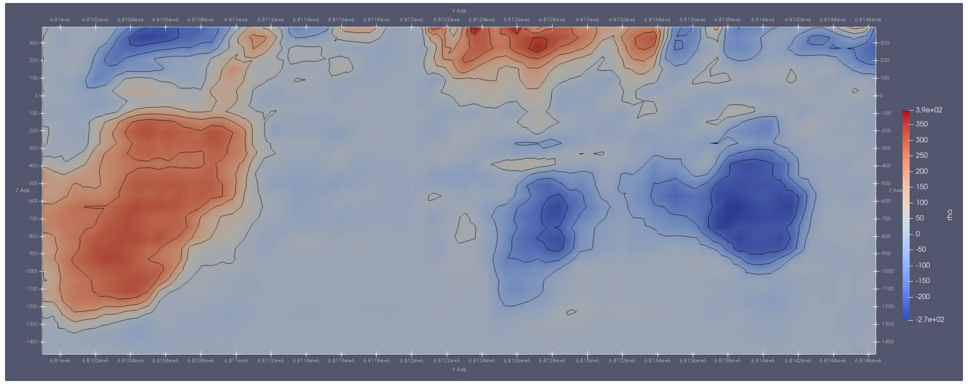
ρ_tomo = -100

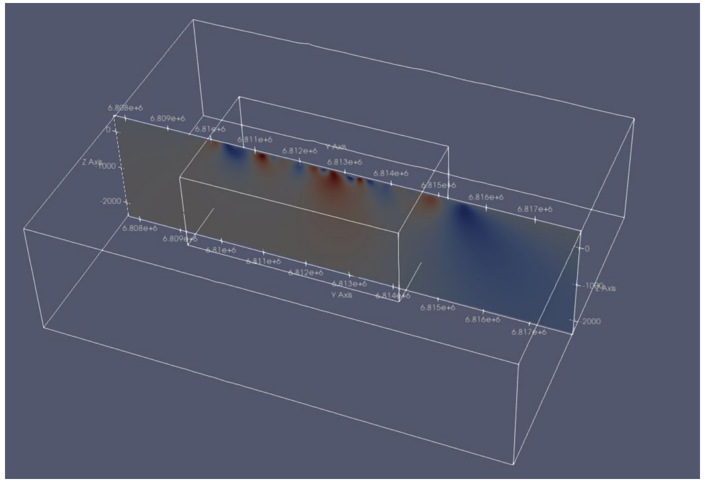
ρ_ML = -300

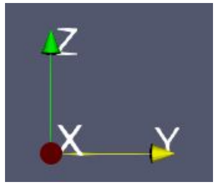


# Comparison of inverted model with Tomofast-x







# Next steps

- Address noise in data
- Extend code to *physics informed neural network*
- Other geological structures for ML training (fault, fold etc)