generate_map_example

January 3, 2023

[ ]:

```
import sys
import datetime as dt
from copy import deepcopy
from os import getcwd
from os.path import dirname, join

import numpy as np
import matplotlib.pyplot as plt
import pandas as pd
from matplotlib import cm
from scipy import interpolate
import pytz

import MAMMAL
import MAMMAL.Diurnal as Diurnal
from MAMMAL.Parse import parseIM as pim
from MAMMAL.Parse import parseRaster as pr
from MAMMAL.Utils import mapUtils as mu
from MAMMAL.Utils import ProcessingUtils as pu


%matplotlib inline
plt.rcParams["figure.figsize"] = (15, 10) # (w, h)


debug = False # Set to True to enable debug printouts plus plots
```

1 Map-Maker Initialization

[ ]:

```
loc_alt_msl_m    = 69 # Height of Fredericksburg above MSL
survey_alt_agl_m = 30 # Height of survey AGL
survey_alt_msl_m = loc_alt_msl_m + survey_alt_agl_m

survey = MAMMAL.MapMaker(map_loc_name = 'reconstructed_example',
                         alt_m_msl    = survey_alt_msl_m,
                         alt_m_agl    = survey_alt_agl_m,
                         data_dir     = getcwd(),
                         debug        = debug)

survey.interp_type = 'rbf'

survey.spin_fname   = join(getcwd(), r'spin_2019_9_12_0.csv')
survey.tl_fname     = join(getcwd(), r'tl_2019_9_12_0.csv')
survey.ref_fname    = join(getcwd(), r'ref_2019_9_12_0.csv')
survey.survey_fname = join(getcwd(), r'survey_2019_9_12_0.csv')
```

2 Load Truth Map

[ ]:

```
TRUTH_MAP_FNAME = join(getcwd(), r'example_99m_2019_9_12_0.tiff')

truth_map = pr.parse_raster(TRUTH_MAP_FNAME)
```

3 Find Spin Test Calibration Parameters

[ ]:

```
a, b = survey.spin_params()

print(a)
print(b)
```

```
[[ 9.99999999e-02  5.57695083e-10 -2.91527922e-11]
 [-2.27964052e-10  2.00000000e-01  1.30701651e-09]
 [ 2.65361785e-11  1.86757457e-08  1.00000000e+00]]
[ 0.99998747  9.99999273 20.00002557]
```

4 Find Tolles-Lawson Calibration Parameters

[ ]:

```
c = survey.tl_params()

print(c)
```

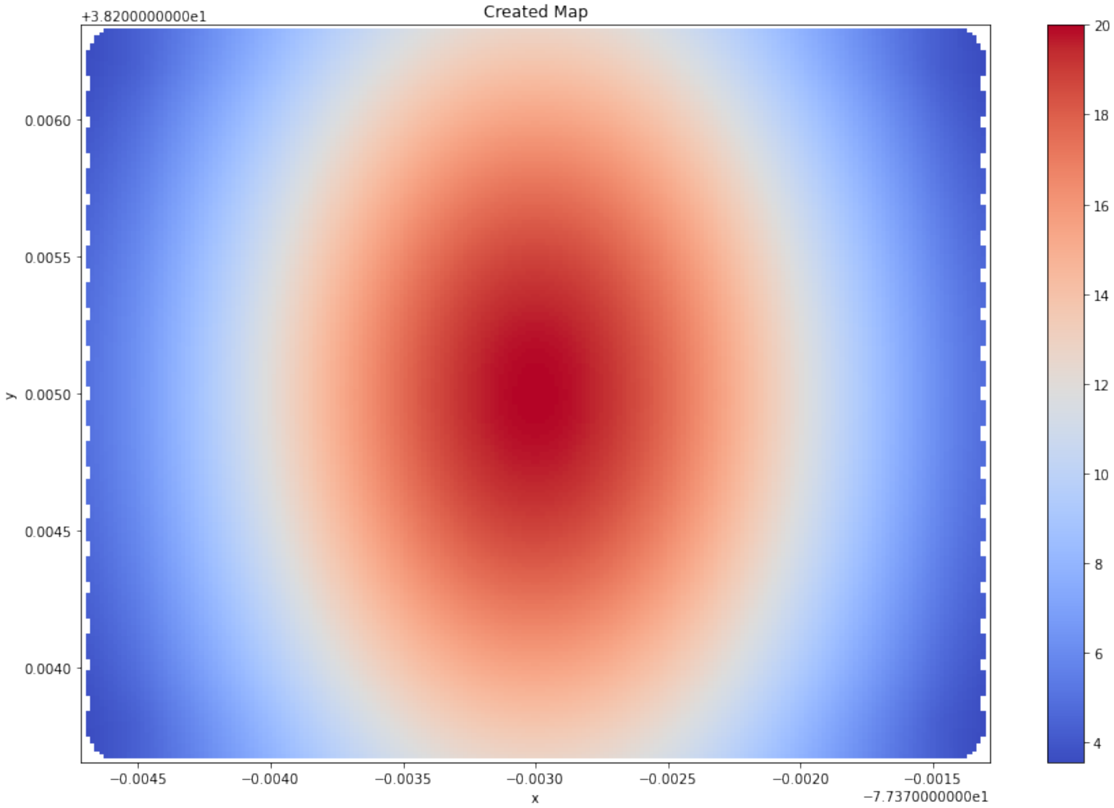
```
[-2.53712549e-03  7.48175161e-03 -3.11947526e-02 -3.41711931e-07
 -3.18443778e-07  6.60171150e-07  8.37594903e-08  5.57889498e-08
 -1.99531115e-09 -2.05085081e-07 -3.78049611e-07 -4.81279418e-07
 -5.74745693e-08  1.83084903e-08 -8.09687986e-08  1.49256175e-07
 -1.30927883e-07  8.88101495e-08]
```

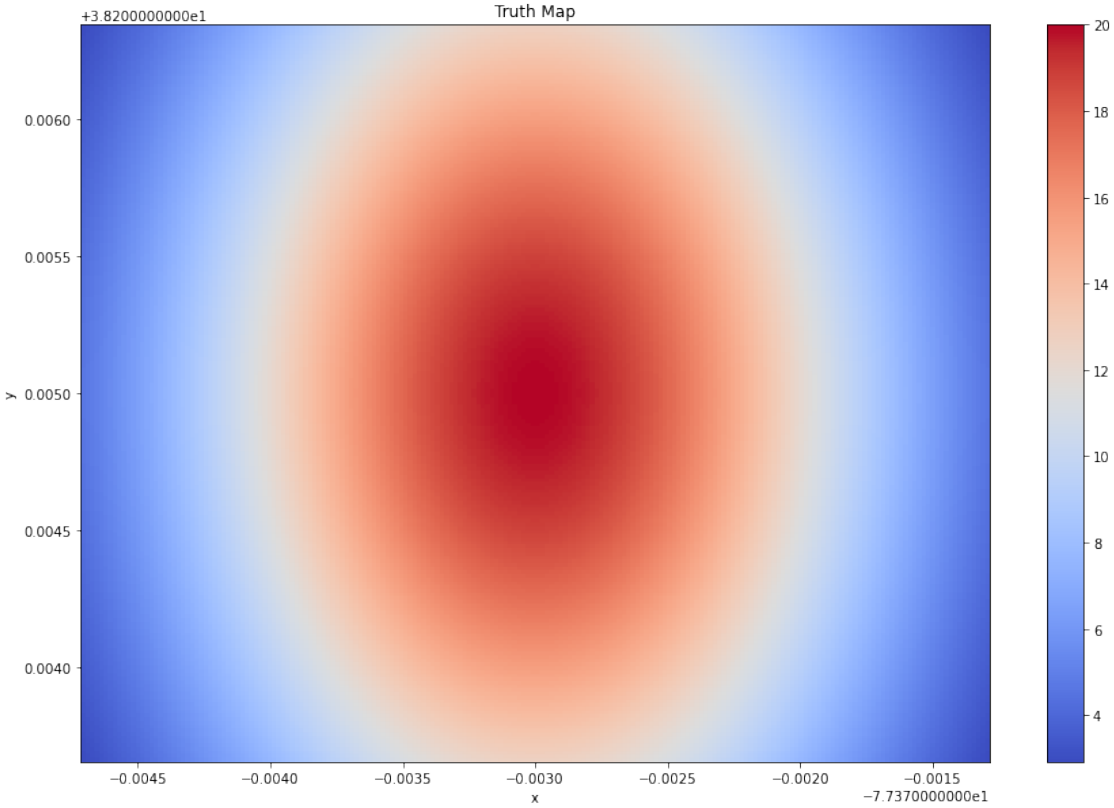
5 Generate Map Using “Truth” Reference Station Data (Fredricksburg - FRD)

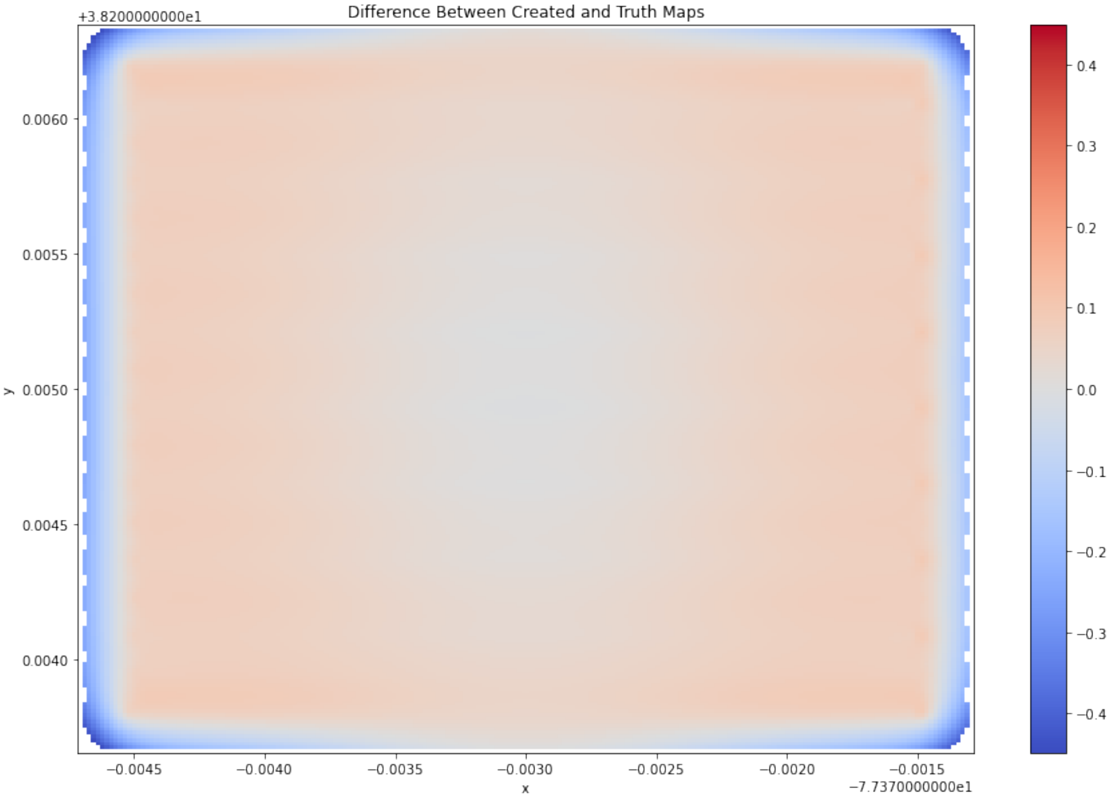
[ ]:

```
map = survey.gen_map()

interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

plt.figure()
interp_map.plot(cmap=cm.coolwarm)
plt.title('Created Map')

plt.figure()
truth_map[0].plot(cmap=cm.coolwarm)
plt.title('Truth Map')

plt.figure()
error_map = truth_map[mu.SCALAR] - interp_map
error_map.plot(cmap=cm.coolwarm)
plt.title('Difference Between Created and Truth Maps')

map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
print('Generated scalar map RMSE: {}nT'.format(map_rmse))
```

```
100%|      | 39204/39204 [00:02<00:00, 16934.57it/s]

Generated scalar map RMSE: 0.06657043985851316nT
```


Created Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4


Truth Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4

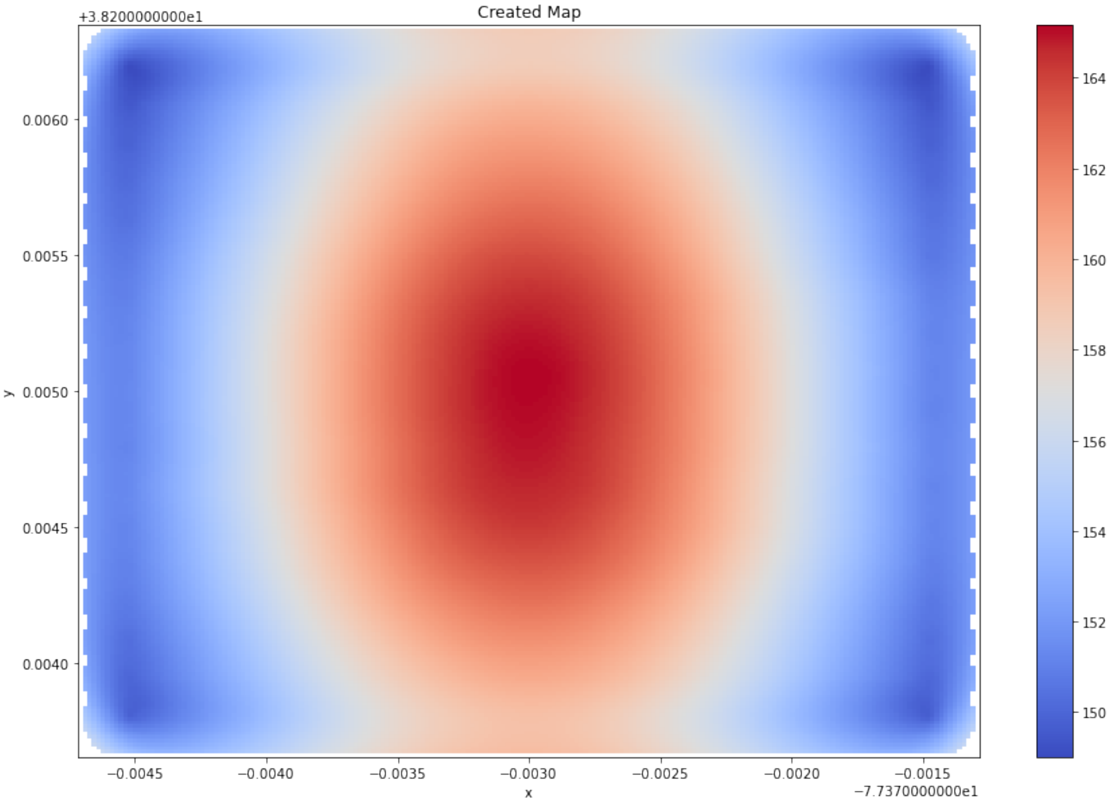


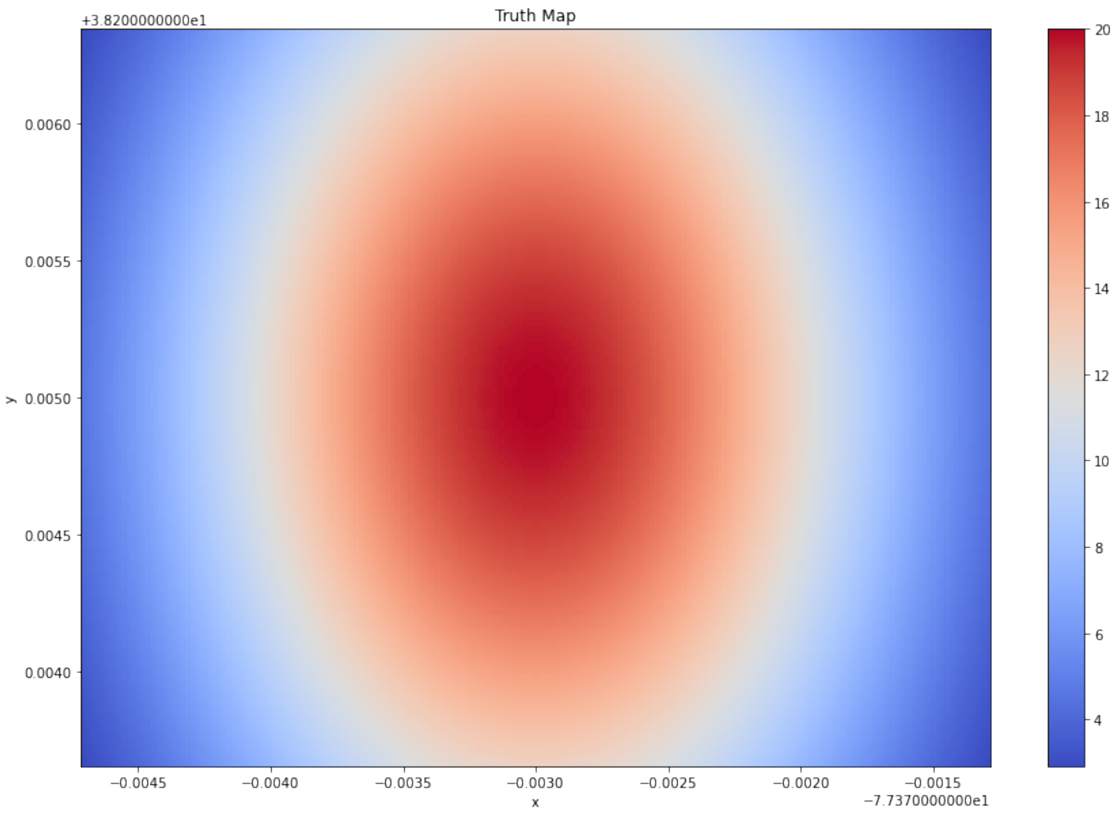
6 Generate Map Without Reference Station Data

```
[ ]: survey.map_loc_name = 'reconstructed_no_ref'
     survey.ref_df       = None

     map = survey.gen_map(ref_use_internal=True)

     interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

     plt.figure()
     interp_map.plot(cmap=cm.coolwarm)
     plt.title('Created Map')

     plt.figure()
     truth_map[0].plot(cmap=cm.coolwarm)
     plt.title('Truth Map')

     plt.figure()
     error_map = truth_map[mu.SCALAR] - interp_map
     error_map.plot(cmap=cm.coolwarm)
     plt.title('Difference Between Created and Truth Maps')
```

```
map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
print('Generated scalar map RMSE: {}nT'.format(map_rmse))
```

```
100%|      | 39204/39204 [00:02<00:00, 17162.57it/s]

Generated scalar map RMSE: 145.30984423308965nT
```




Truth Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
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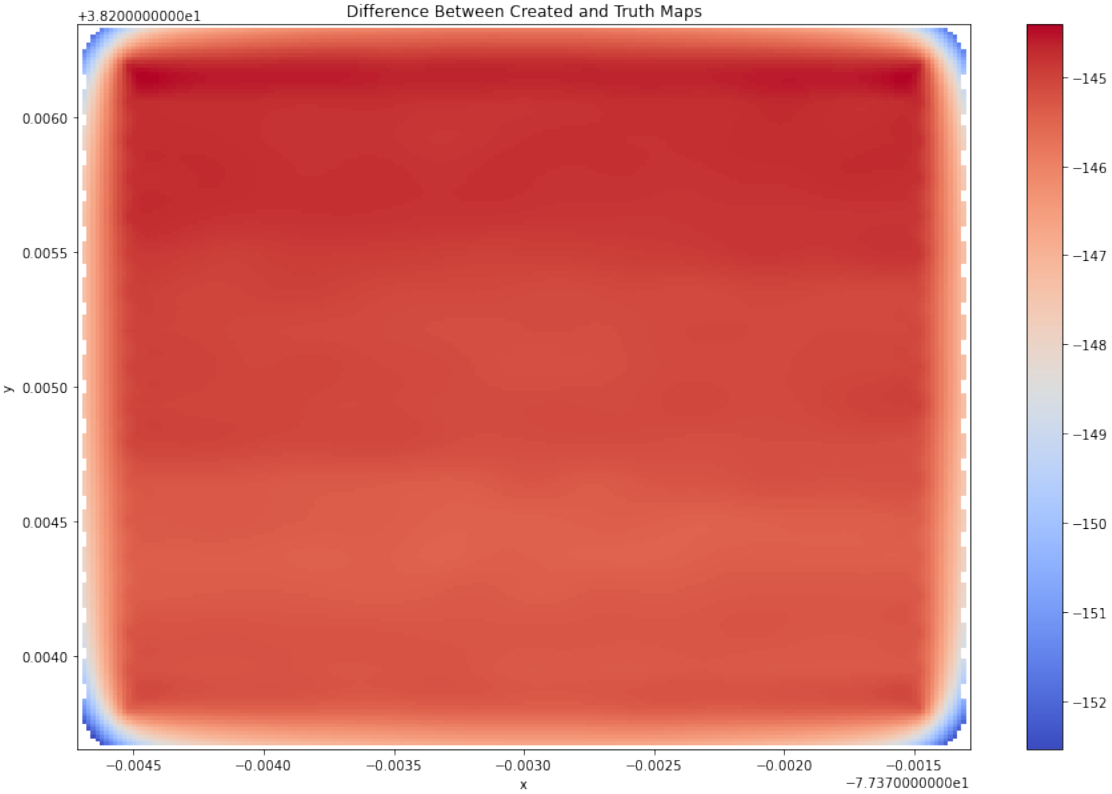
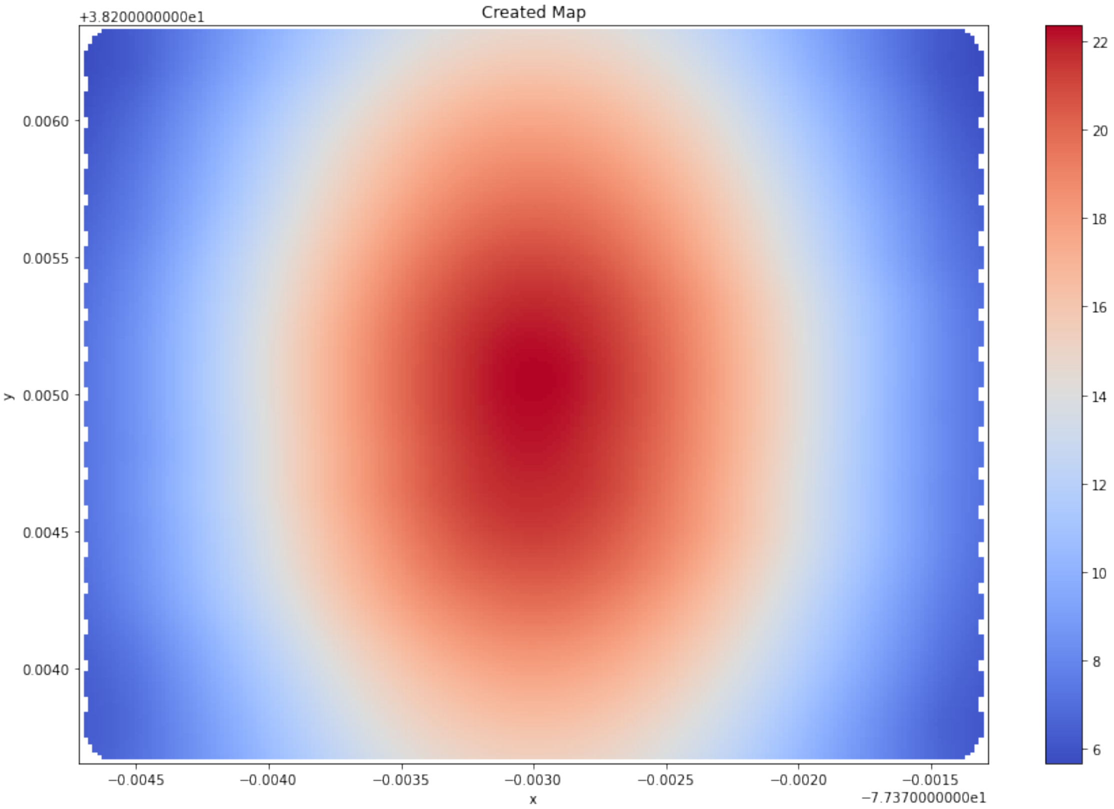


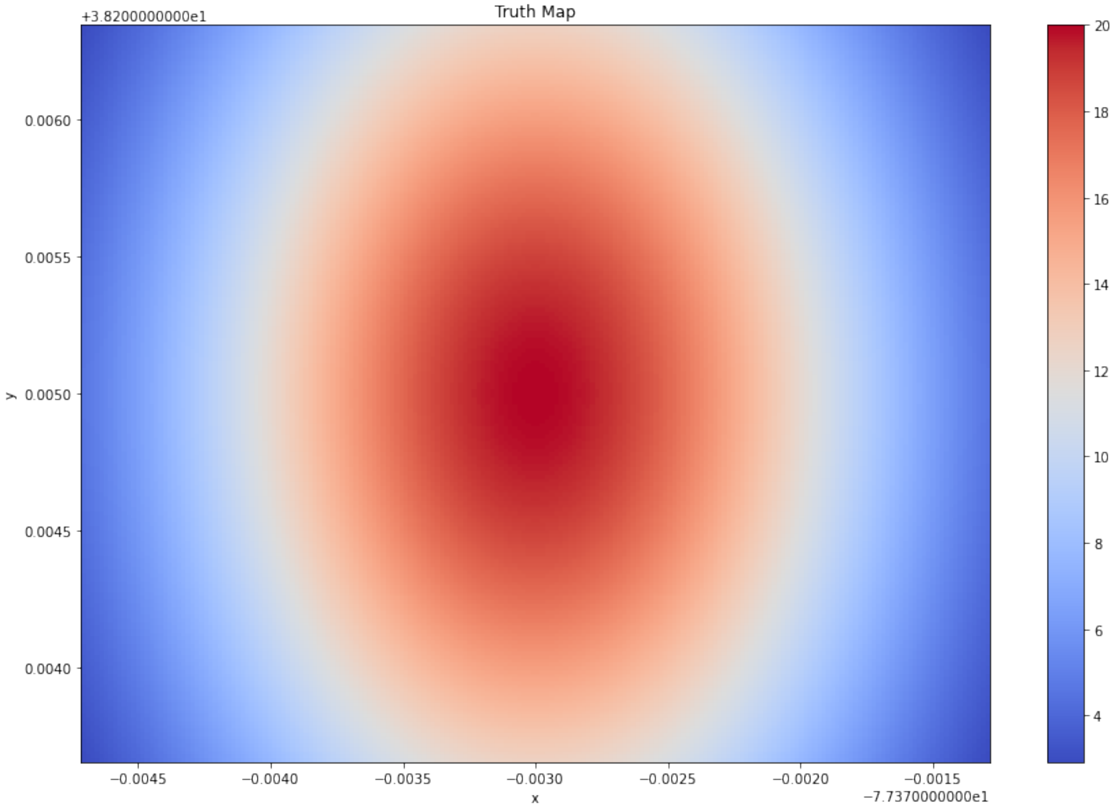
7 Generate Map Using Calibrated Reference Station Data from Boulder (BOU) - 2400km from FRD

[ ]:
```
ref_dict = pim.loadInterMagData(TEST_DIR)

truth_ref_df = ref_dict['FRD']
bou_ref_df   = ref_dict['BOU']
frn_ref_df   = ref_dict['FRN']

truth_t         = np.array(truth_ref_df.epoch_sec)
truth_f         = np.array(truth_ref_df.F)
truth_IGRF_f    = np.array(truth_ref_df.IGRF_F)[0]
truth_f_no_core = truth_f - truth_IGRF_f

bou_t, bou_f, _, _ , _ = Diurnal.longitude_norm(bou_ref_df,
                                                truth_ref_df.LONG.mean())
bou_f_no_core = bou_f - np.array(bou_ref_df.IGRF_F)[0]

interp_combined = interpolate.interp1d(bou_t, bou_f_no_core, 'cubic')
```

```
survey_t    = np.array(survey.survey_df.epoch_sec)
interp_mask = np.logical_and(np.logical_and(truth_t >= bou_t.min(),
                                            truth_t <= bou_t.max()),
                             np.logical_and(truth_t >= (survey_t[0]  - 86400 -␣
 ↪2*3600),
                                            truth_t <= (survey_t[-1] - 86400 +␣
 ↪2*3600))) # Interpolate based on data from around the time of the survey on␣
 ↪the previous day
interp_t    = truth_t[interp_mask] # Clip interpolation times

far_interp = interp_combined(interp_t)

offset, scale = Diurnal.calibrate([0, 1], far_interp,␣
 ↪truth_f_no_core[interp_mask])
far_opt_f     = Diurnal.apply_cal([offset, scale], bou_f_no_core)

print('Optimal scale:',  scale)
print('Optimal offset:', offset)

survey.map_loc_name = 'reconstructed_bou_ref'
survey.ref_scale    = scale
survey.ref_offset   = offset

map = survey.gen_map(ref_df=bou_ref_df)

interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

plt.figure()
interp_map.plot(cmap=cm.coolwarm)
plt.title('Created Map')

plt.figure()
truth_map[0].plot(cmap=cm.coolwarm)
plt.title('Truth Map')

plt.figure()
error_map = truth_map[mu.SCALAR] - interp_map
error_map.plot(cmap=cm.coolwarm)
plt.title('Difference Between Created and Truth Maps')

map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
print('Generated scalar map RMSE: {}nT'.format(map_rmse))

# Clean up
survey.ref_scale  = 1
survey.ref_offset = 0
```

```
Loaded bou20190911psec.sec
Loaded bou20190912psec.sec
Loaded frd20190911psec.sec
Loaded frd20190912psec.sec
Loaded frn20190911psec.sec
Loaded frn20190912psec.sec
Optimal scale: 0.1354037206490241
Optimal offset: 159.832254129058

100%|     | 39204/39204 [00:02<00:00, 16890.77it/s]

Generated scalar map RMSE: 2.286562816950017nT
```




Truth Map
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
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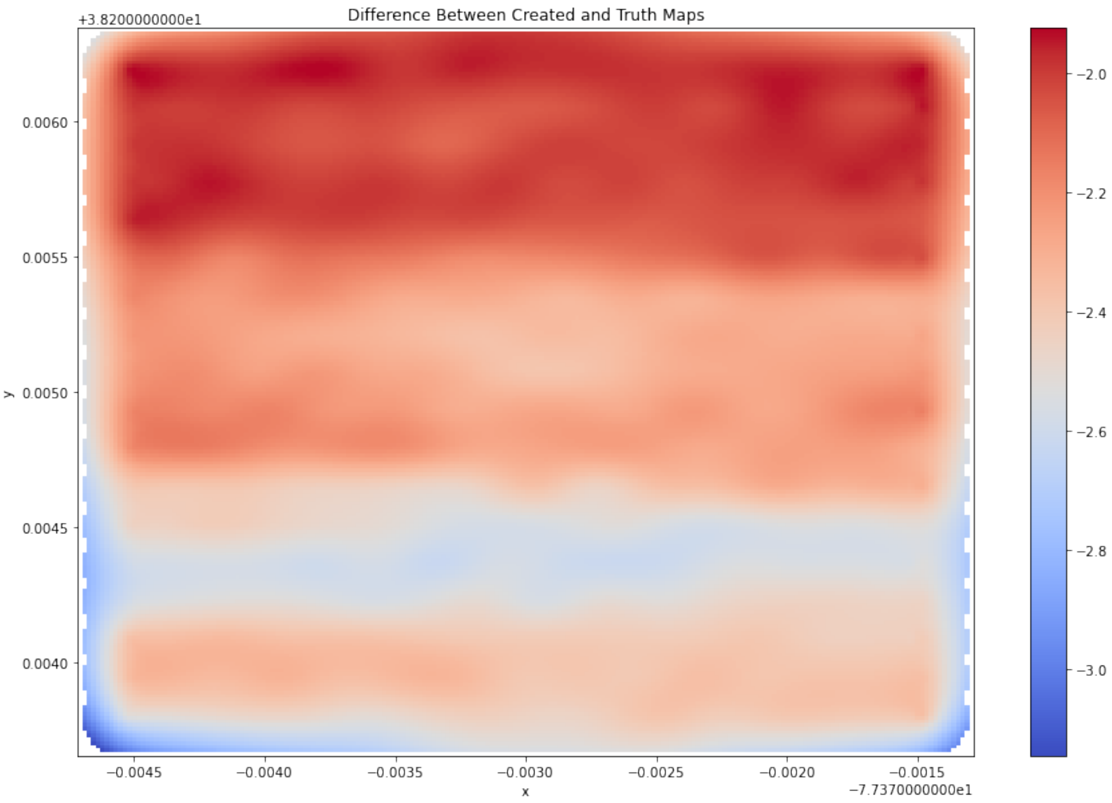


8 Generate Map Using Calibrated Reference Station Data from Fresno (FRN) - 4400km from FRD

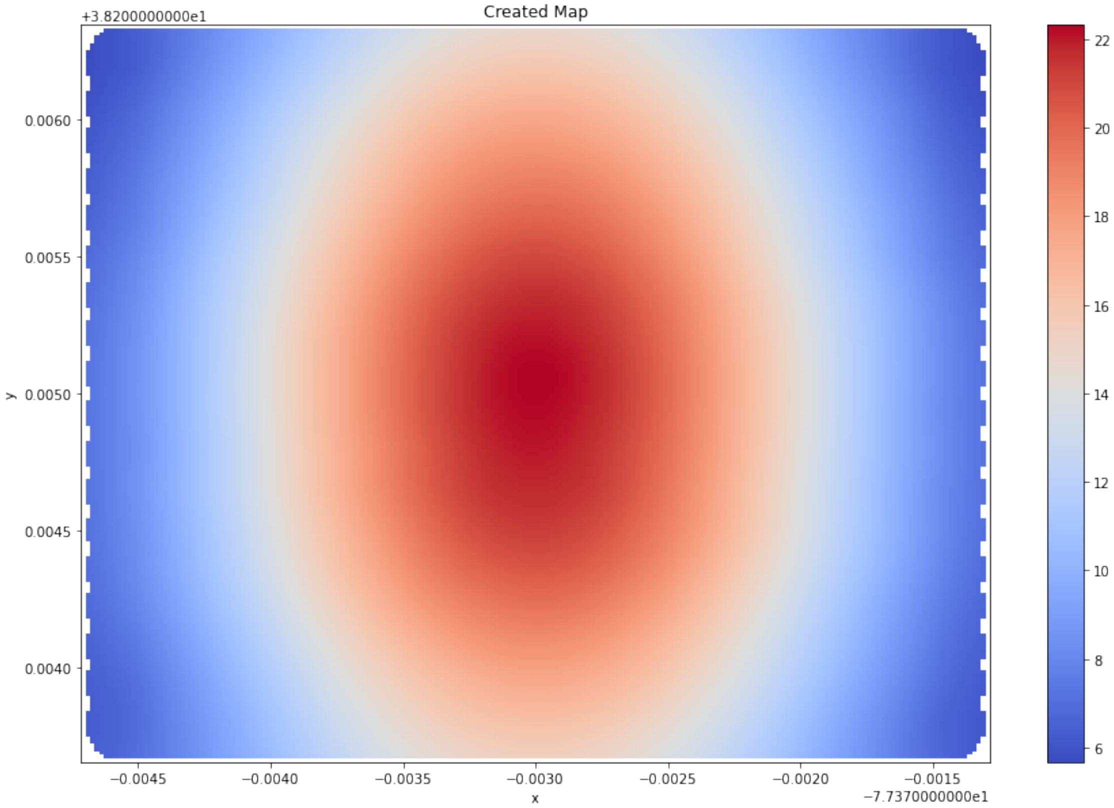
```
[ ]: frn_t, frn_f, _, _ , _ = Diurnal.longitude_norm(frn_ref_df,
                                                truth_ref_df.LONG.mean())
     frn_f_no_core = frn_f - np.array(frn_ref_df.IGRF_F)[0]

     interp_combined = interpolate.interp1d(frn_t, frn_f_no_core, 'cubic')

     survey_t    = np.array(survey.survey_df.epoch_sec)
     interp_mask = np.logical_and(np.logical_and(truth_t >= bou_t.min(),
                                                 truth_t <= bou_t.max()),
                                  np.logical_and(truth_t >= (survey_t[0]  - 86400 -␣
       ↪2*3600),
                                                 truth_t <= (survey_t[-1] - 86400 +␣
       ↪2*3600))) # Interpolate based on data from around the time of the survey on␣
       ↪the previous day
     interp_t    = truth_t[interp_mask] # Clip interpolation times

     far_interp = interp_combined(interp_t)
```

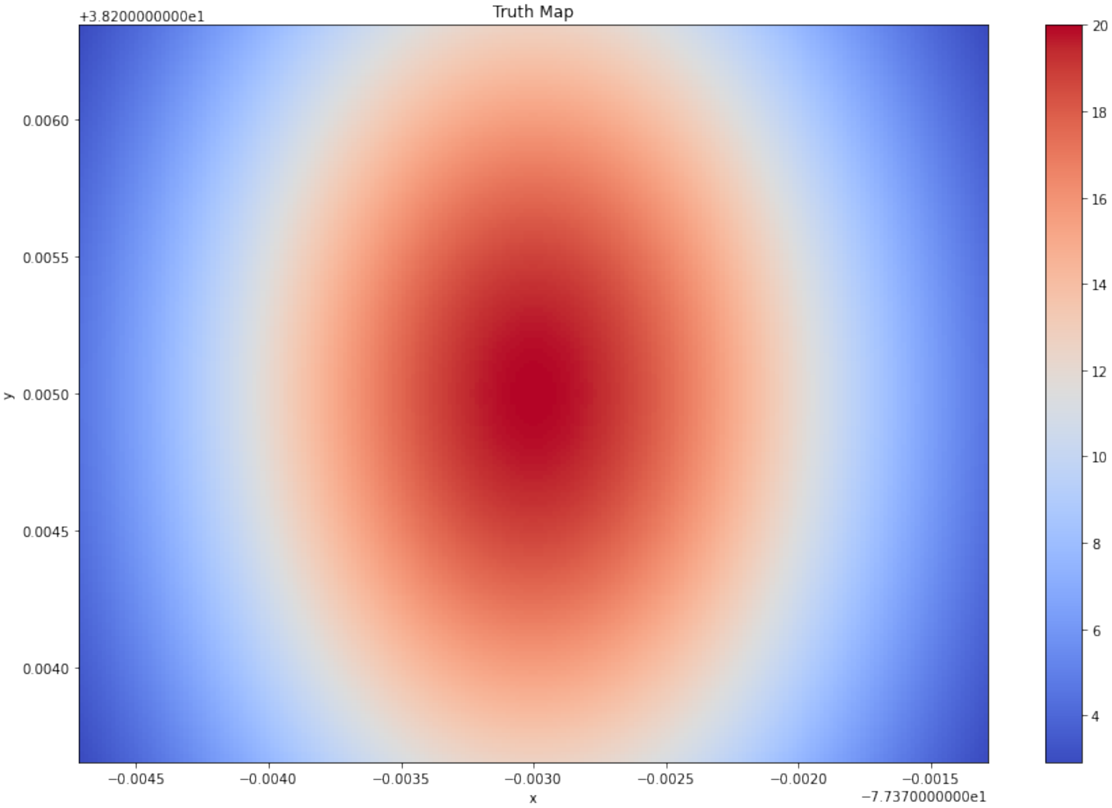
```
offset, scale = Diurnal.calibrate([0, 1], far_interp,␣
 ↪truth_f_no_core[interp_mask])
far_opt_f     = Diurnal.apply_cal([offset, scale], frn_f_no_core)

print('Optimal scale:',  scale)
print('Optimal offset:', offset)

survey.map_loc_name = 'reconstructed_frn_ref'
survey.ref_scale    = scale
survey.ref_offset   = offset

map = survey.gen_map(ref_df=frn_ref_df)

interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

plt.figure()
interp_map.plot(cmap=cm.coolwarm)
plt.title('Created Map')

plt.figure()
truth_map[0].plot(cmap=cm.coolwarm)
plt.title('Truth Map')

plt.figure()
error_map = truth_map[mu.SCALAR] - interp_map
error_map.plot(cmap=cm.coolwarm)
plt.title('Difference Between Created and Truth Maps')

map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
print('Generated scalar map RMSE: {}nT'.format(map_rmse))

# Clean up
survey.ref_scale  = 1
survey.ref_offset = 0
```

```
Optimal scale: 0.14690255812962025
Optimal offset: 173.34683437172754
```

```
100%|     | 39204/39204 [00:02<00:00, 16971.40it/s]
```

```
Generated scalar map RMSE: 2.2613877196742886nT
```


Created Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
22
20
18
16
14
12
10
8
6


Truth Map
+3.8200000000e1
0.0060
0.0055
y
0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
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10
8
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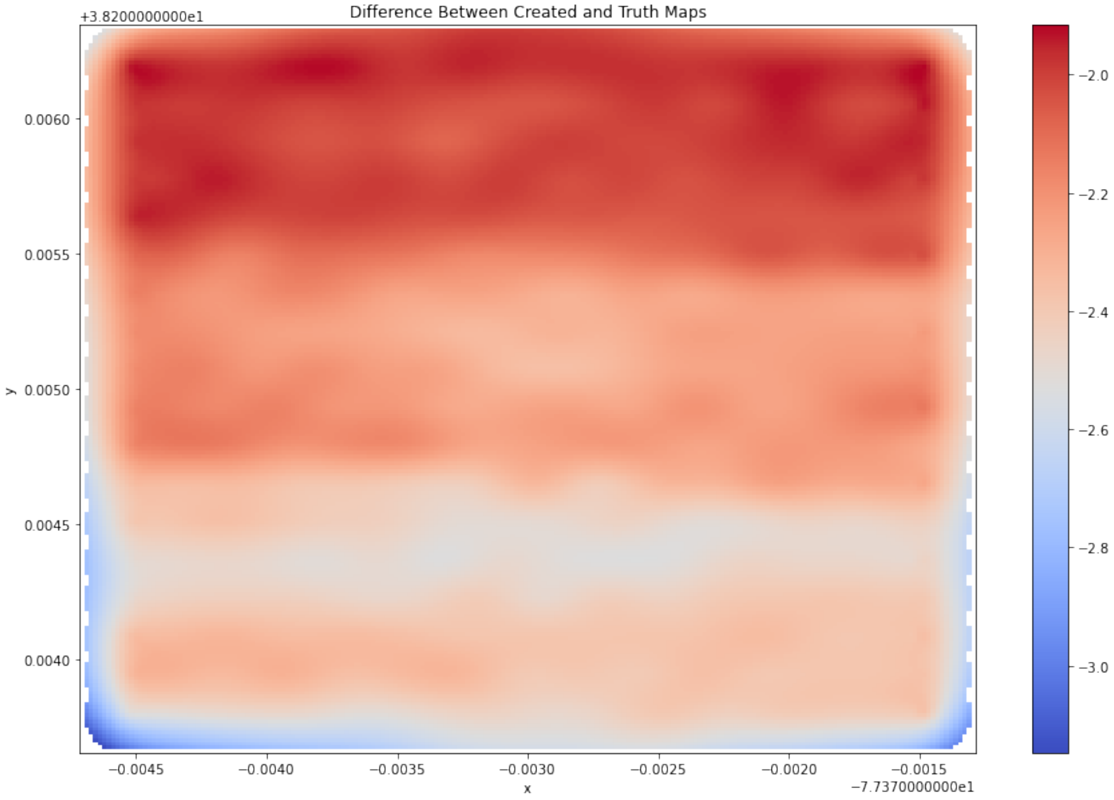
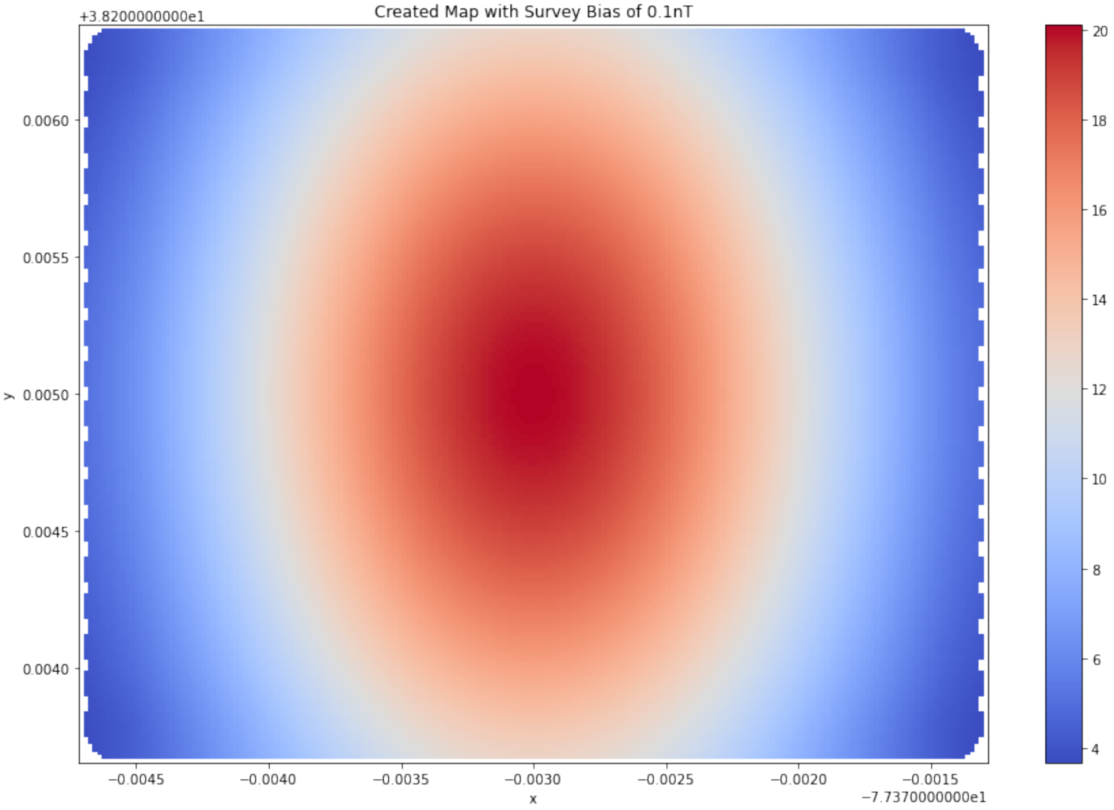


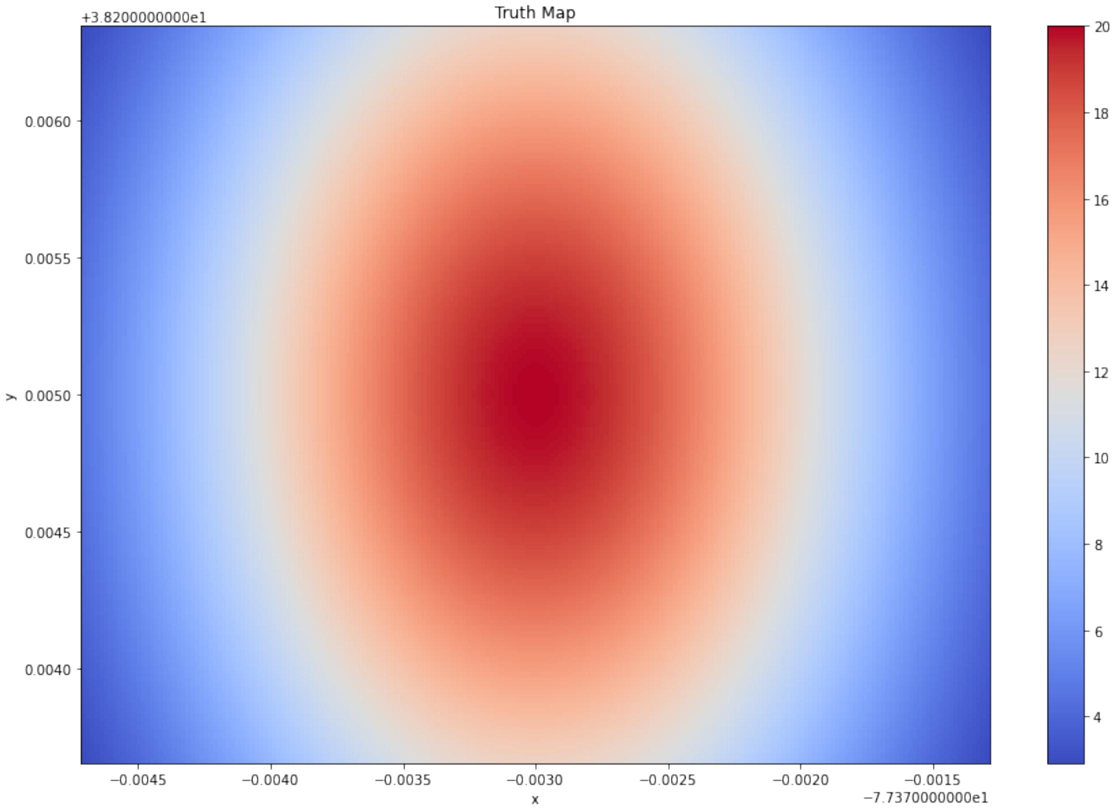
9 Generate Map Using Biased Scalar Measurements

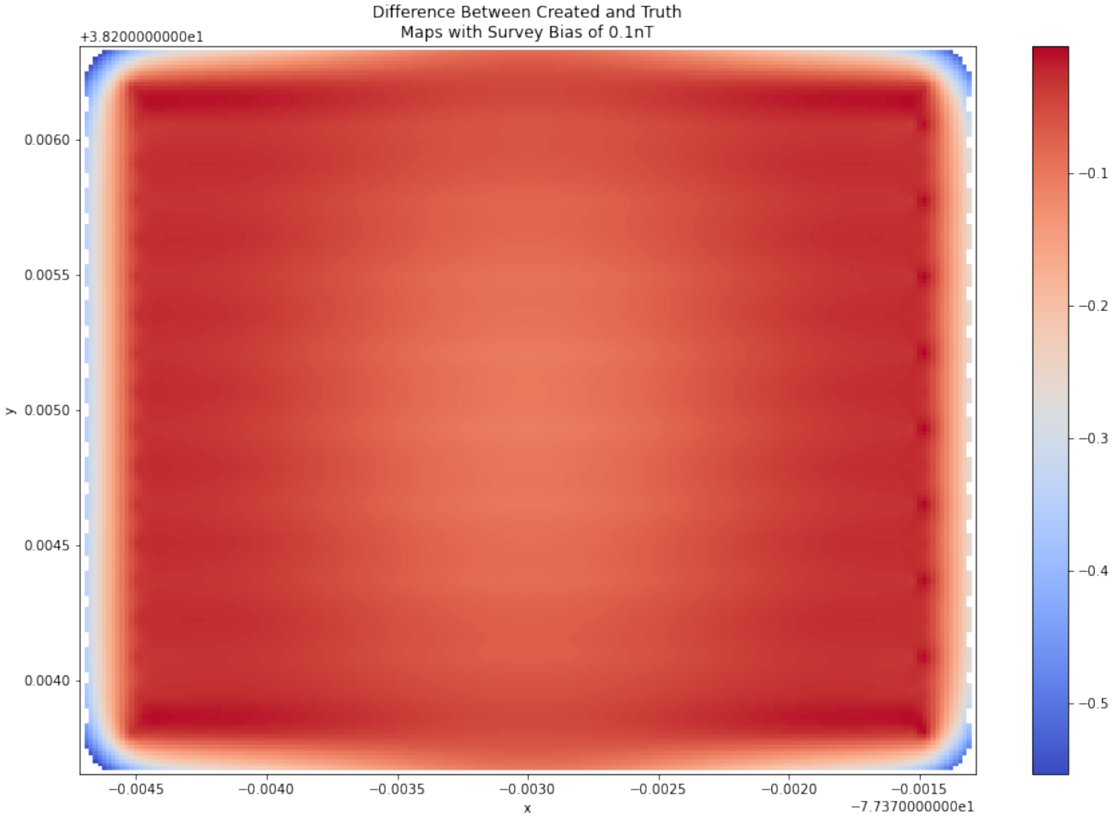
```
[ ]: biases    = [0.1, 1, 10]
     survey_df = deepcopy(survey.survey_df)

     for bias in biases:
         biased_survey_df = deepcopy(survey_df)
         biased_survey_df.F += bias

         survey.map_loc_name = 'reconstructed_{}nT_bias'.format(bias)

         map = survey.gen_map(survey_df=biased_survey_df)

         interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

         plt.figure()
         interp_map.plot(cmap=cm.coolwarm)
         plt.title('Created Map with Survey Bias of {}nT'.format(bias))

         plt.figure()
         truth_map[0].plot(cmap=cm.coolwarm)
```

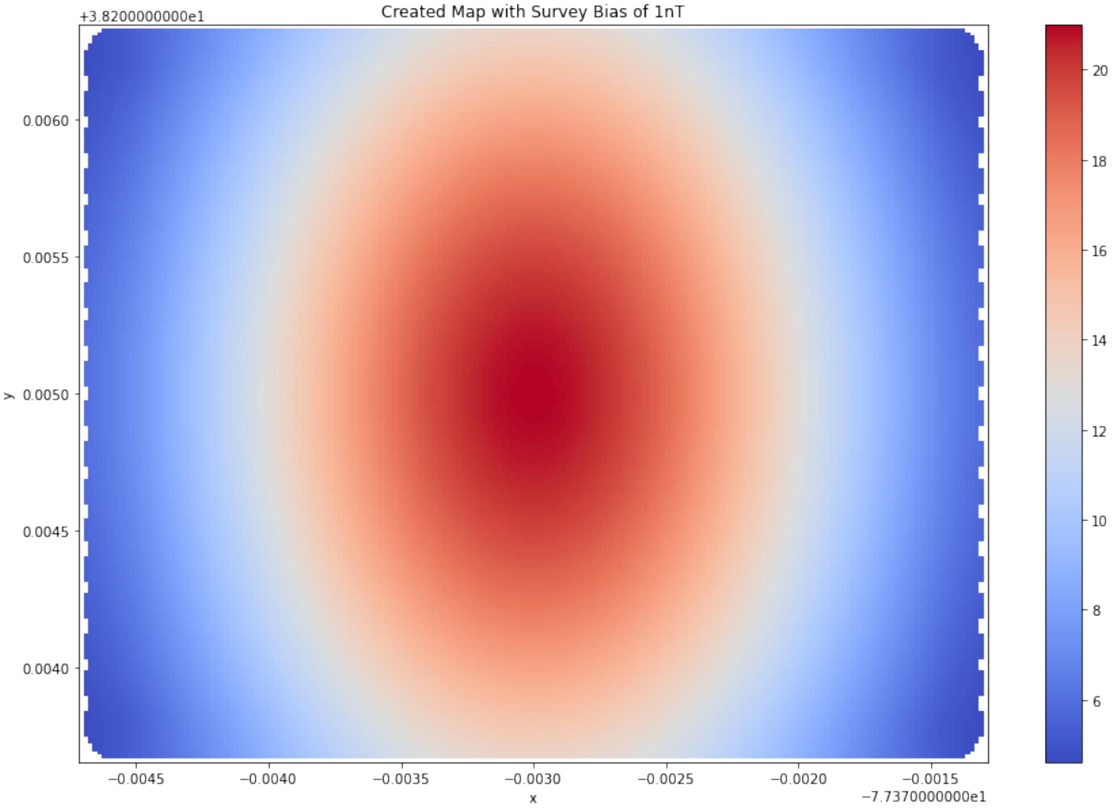
```
    plt.title('Truth Map')

    plt.figure()
    error_map = truth_map[mu.SCALAR] - interp_map
    error_map.plot(cmap=cm.coolwarm)
    plt.title('Difference Between Created and Truth\nMaps with Survey Bias of␣
↪{}nT'.format(bias))

    map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
    print('Generated scalar map RMSE with survey bias of {}nT: {}nT'.
↪format(bias, map_rmse))
```

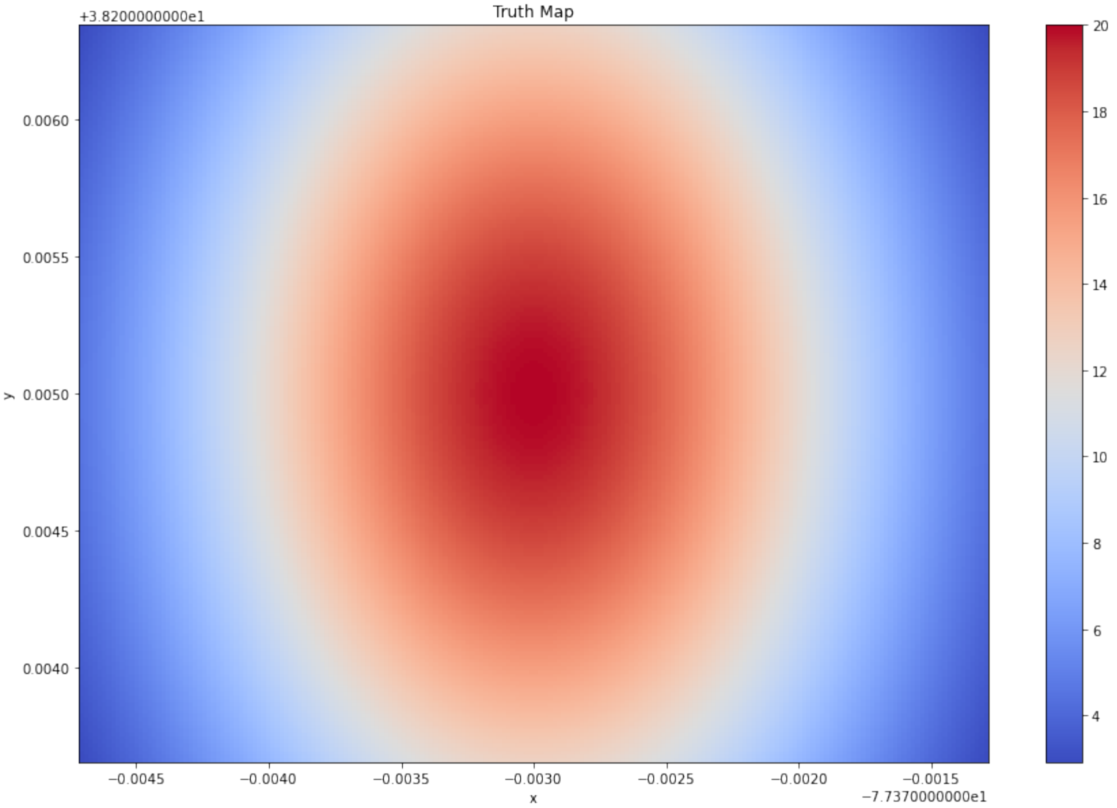
```
100%|      | 39204/39204 [00:02<00:00, 16561.72it/s]

Generated scalar map RMSE with survey bias of 0.1nT: 0.09149344671020931nT

100%|      | 39204/39204 [00:02<00:00, 16775.36it/s]

Generated scalar map RMSE with survey bias of 1nT: 0.9727882906087355nT

100%|      | 39204/39204 [00:02<00:00, 15236.69it/s]

Generated scalar map RMSE with survey bias of 10nT: 9.983606669552199nT
```

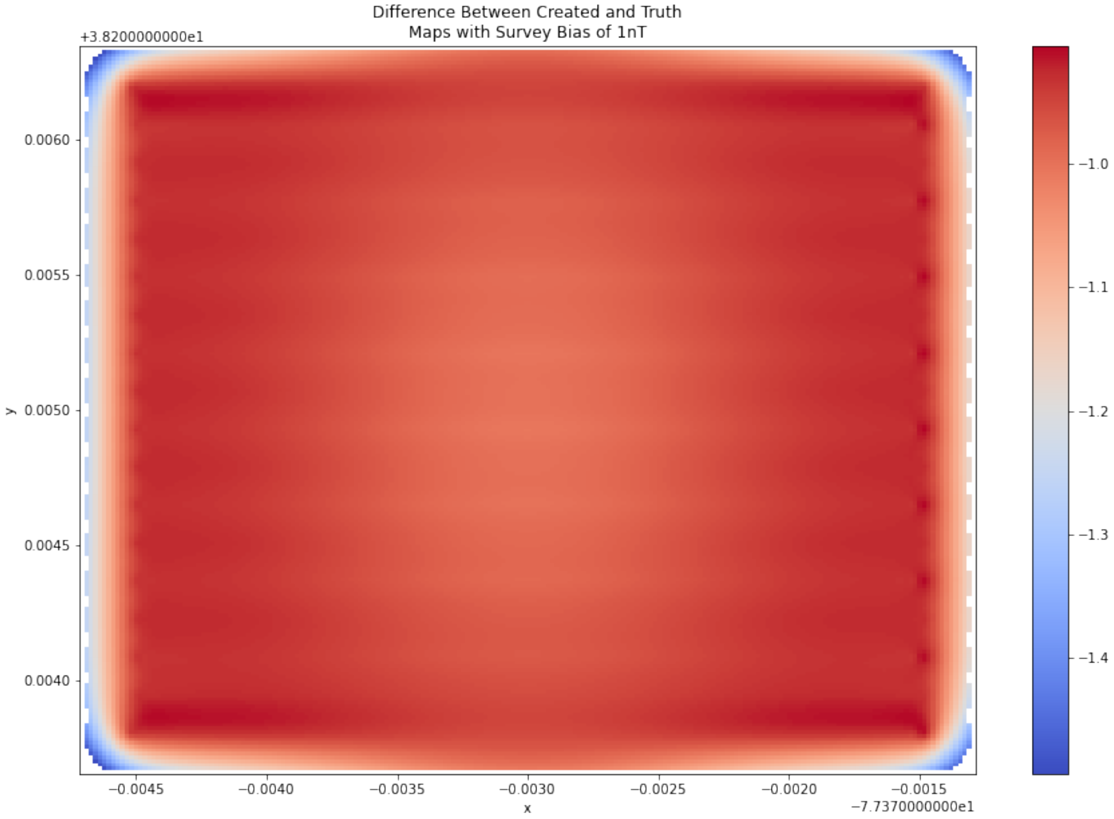


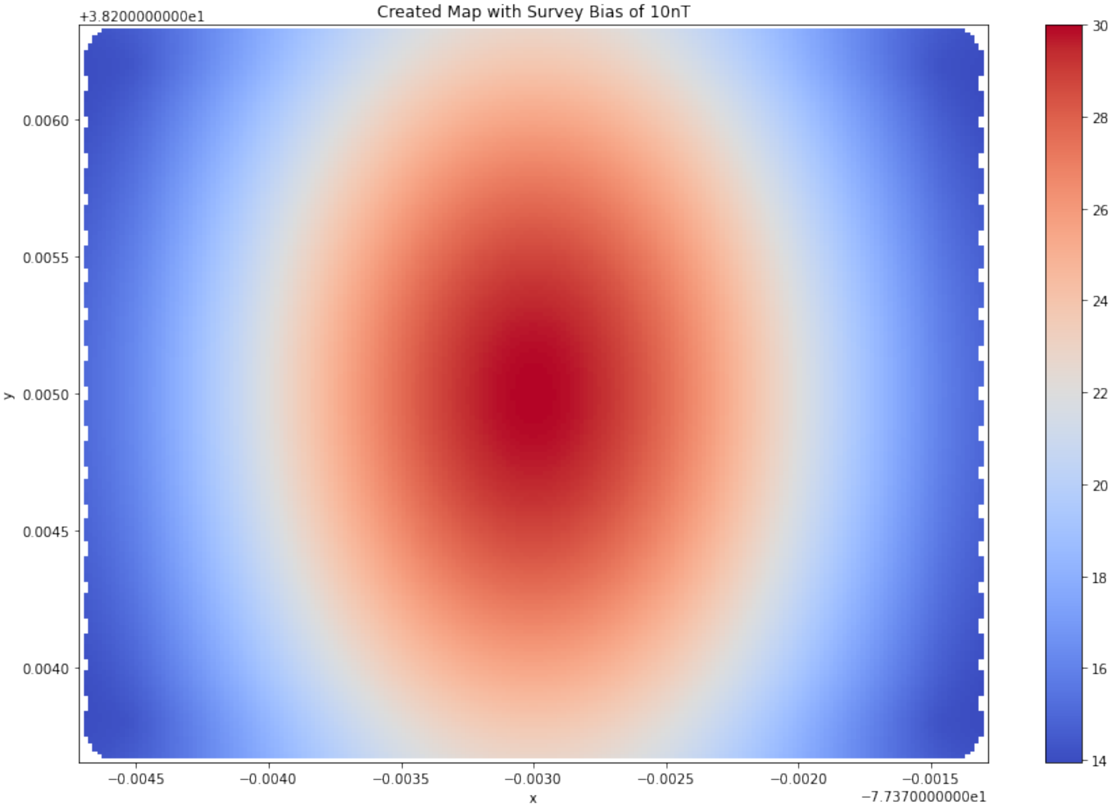

Truth Map
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4

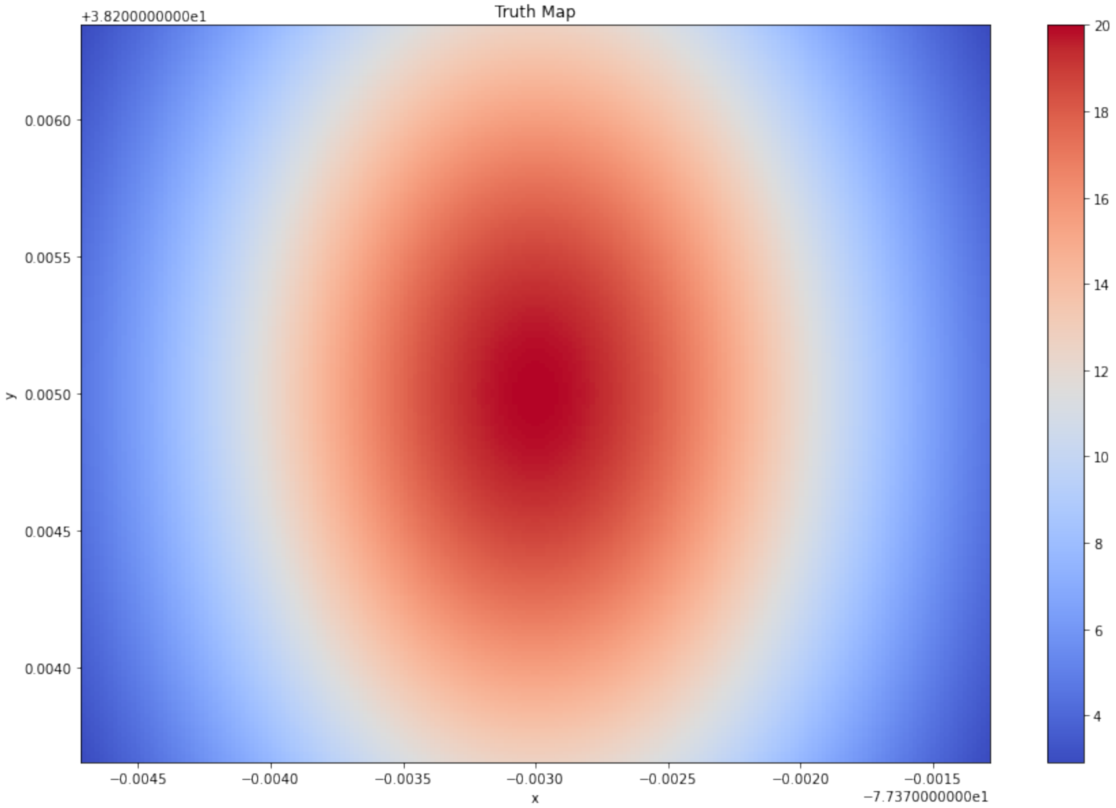

Difference Between Created and Truth
Maps with Survey Bias of 0.1nT
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
−0.1
−0.2
−0.3
−0.4
−0.5

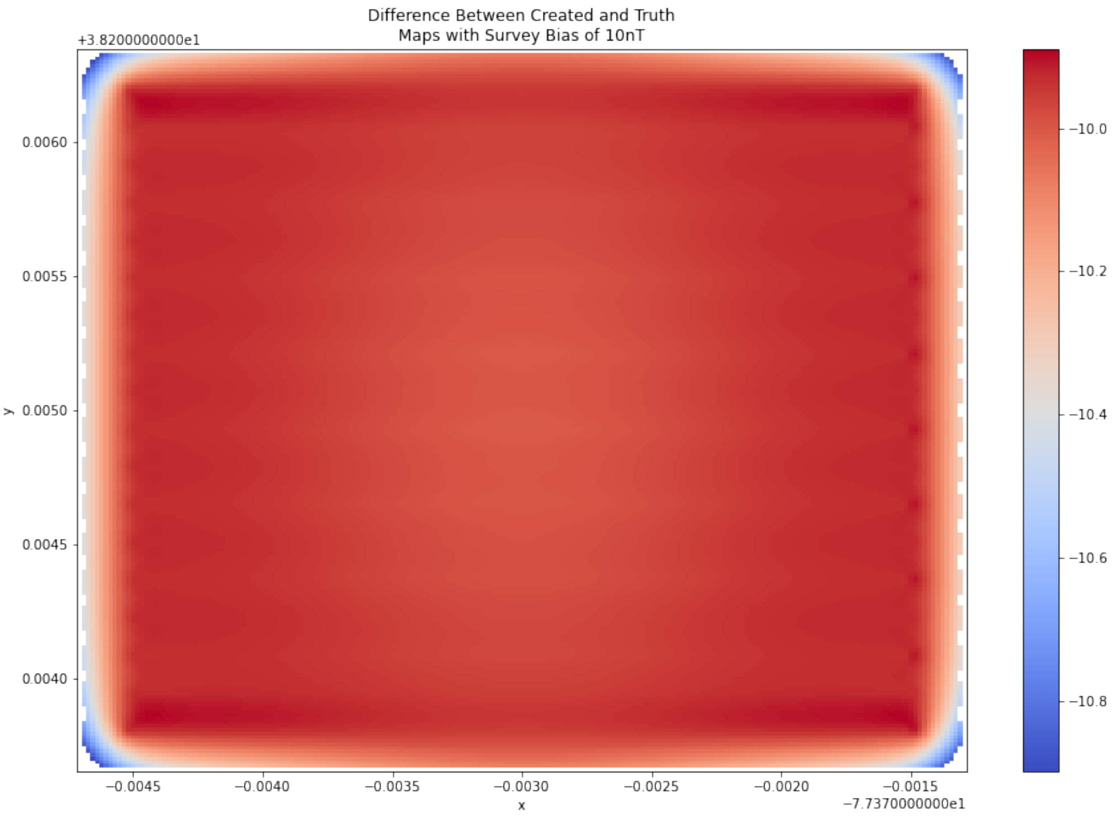

Created Map with Survey Bias of 1nT
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6


Truth Map
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4


Difference Between Created and Truth
Maps with Survey Bias of 1nT
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
−1.0
−1.1
−1.2
−1.3
−1.4


Created Map with Survey Bias of 10nT
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
30
28
26
24
22
20
18
16
14


Truth Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4

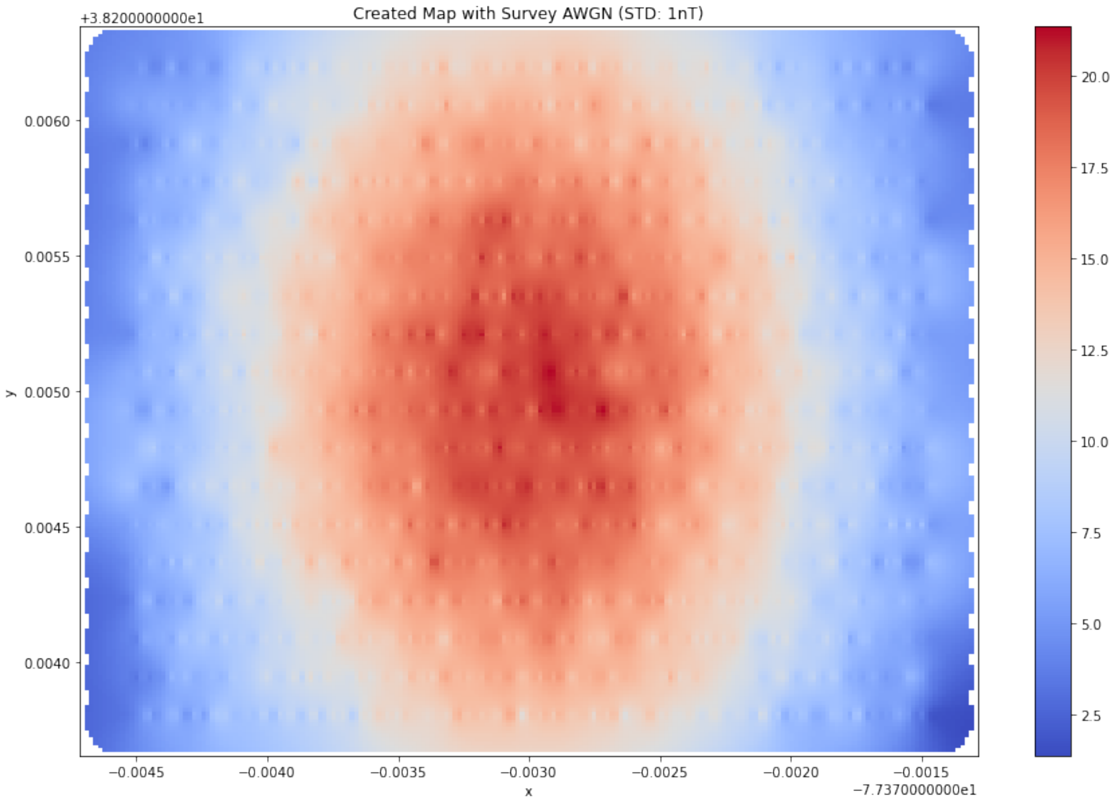


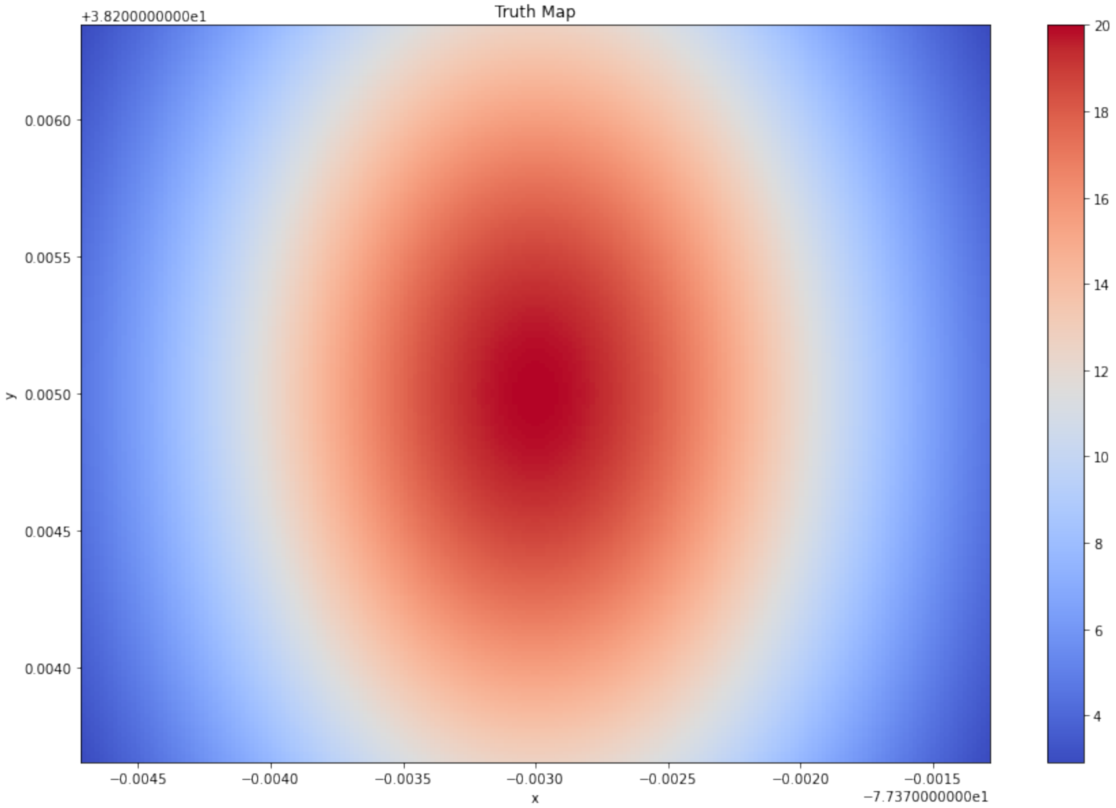
10 Generate Map Using Scalar Measurements with Additive White Gaussian Noise (AWGN)

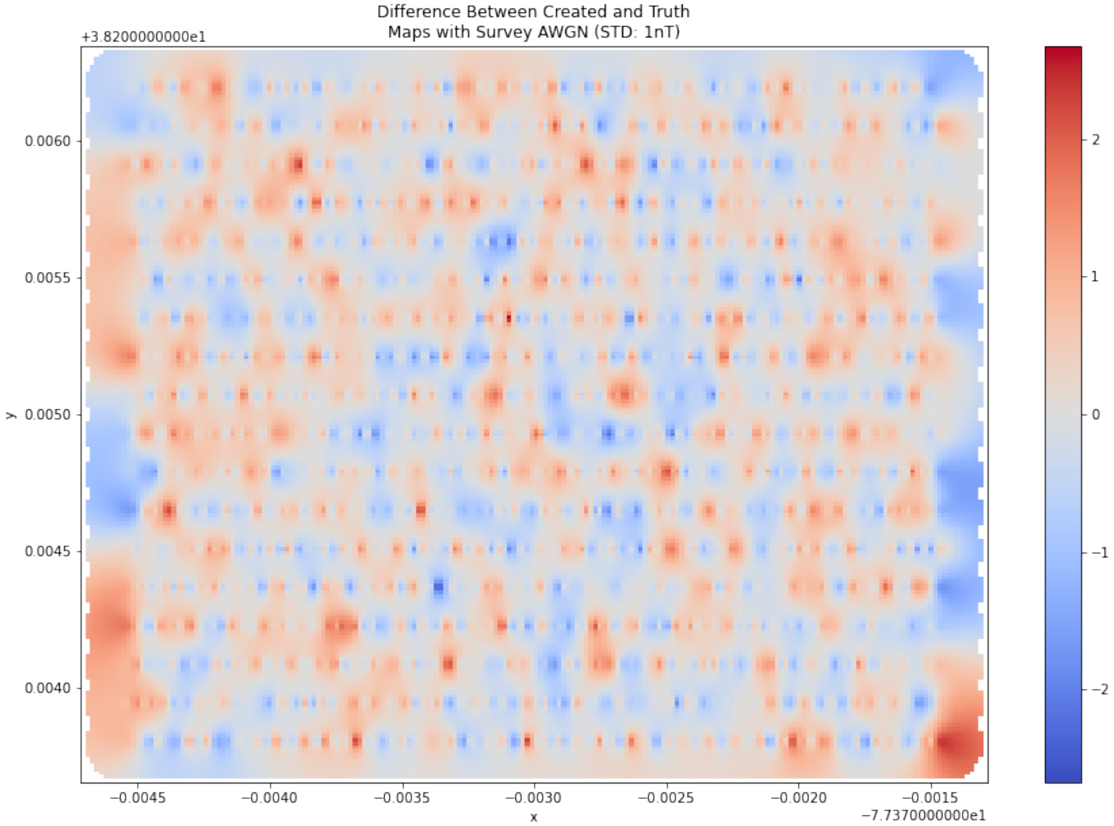
[ ]:

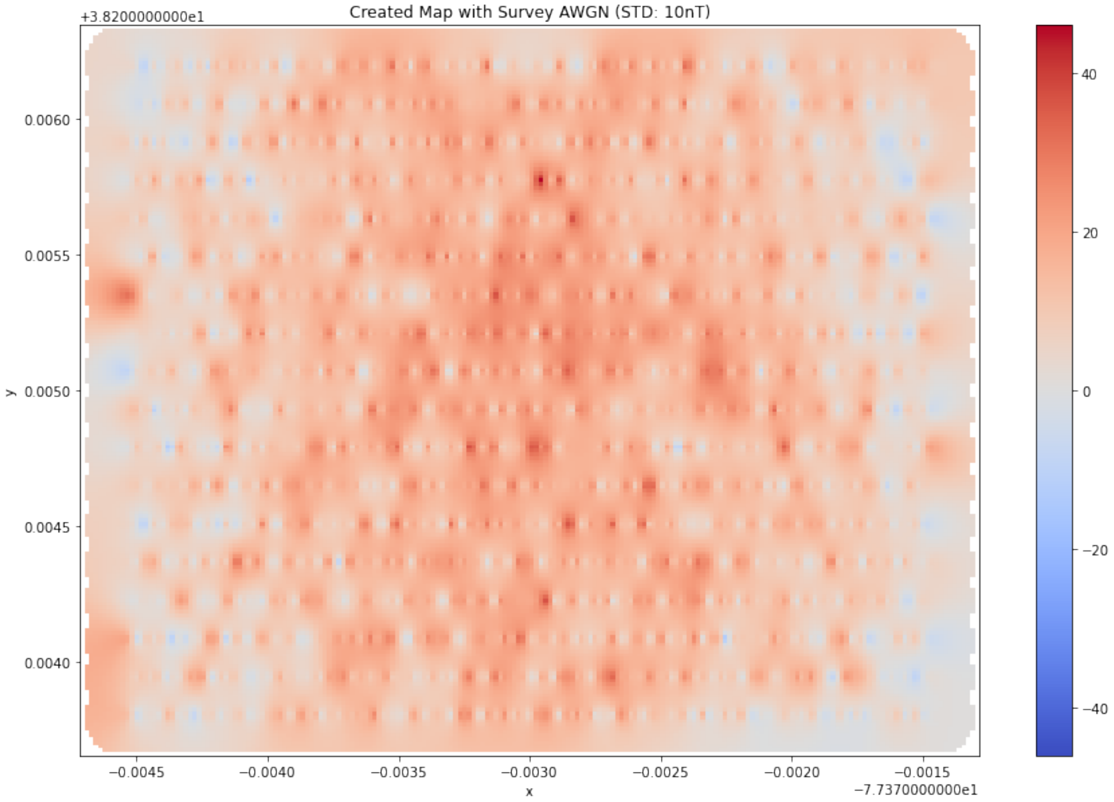
```
awgn_stds = [1, 10, 100]

for awgn_std in awgn_stds:
    noised_survey_df = deepcopy(survey_df)
    noised_survey_df.F += np.random.randn(len(noised_survey_df.F)) * awgn_std

    map = survey.gen_map(survey_df=noised_survey_df)

    interp_map = map[mu.SCALAR].interp(x=truth_map.x, y=truth_map.y)

    plt.figure()
    interp_map.plot(cmap=cm.coolwarm)
    plt.title('Created Map with Survey AWGN (STD: {}nT)'.format(awgn_std))

    plt.figure()
    truth_map[0].plot(cmap=cm.coolwarm)
    plt.title('Truth Map')
    plt.figure()
    error_map = truth_map[mu.SCALAR] - interp_map
    error_map.plot(cmap=cm.coolwarm)
    plt.title('Difference Between Created and Truth\nMaps with Survey AWGN (STD:
↪ {}nT)'.format(awgn_std))

    map_rmse = pu.rmse(interp_map.data, truth_map[mu.SCALAR].data)
    print('Generated scalar map RMSE with survey AWGN (STD: {}nT): {}nT'.
↪format(awgn_std, map_rmse))
```

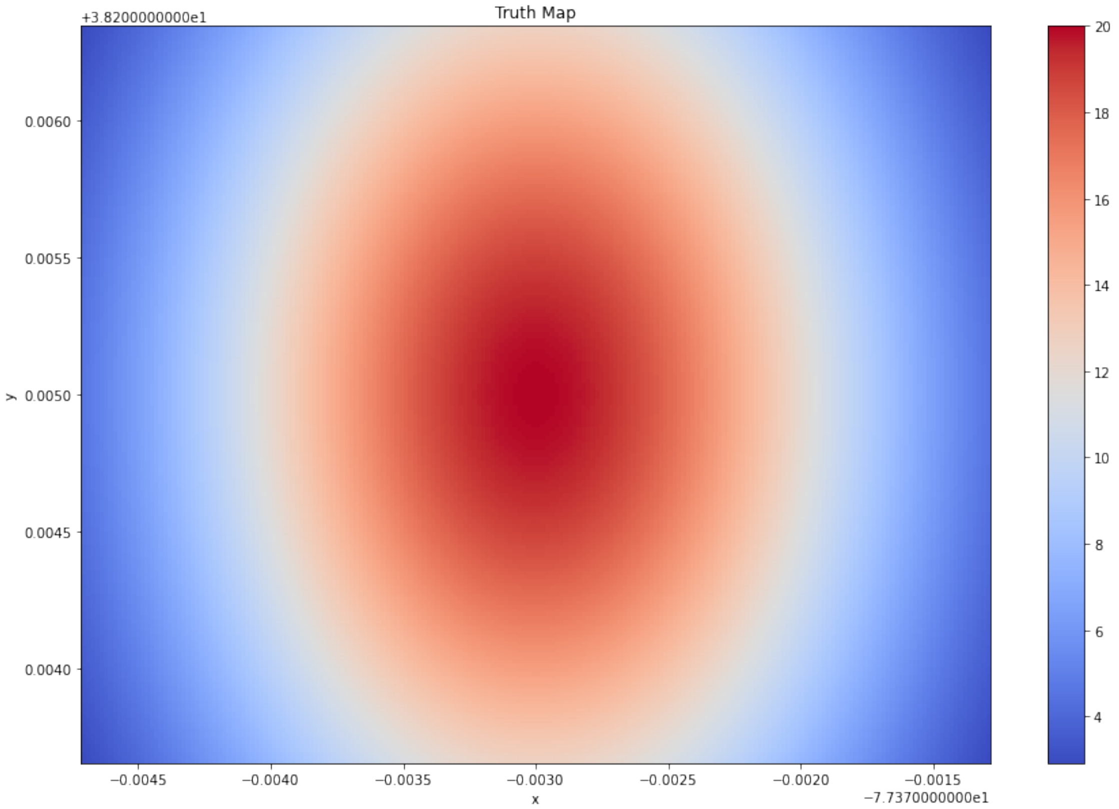
```
100%|      | 39204/39204 [00:02<00:00, 16647.15it/s]

Generated scalar map RMSE with survey AWGN (STD: 1nT): 0.5214322025204605nT

100%|      | 39204/39204 [00:02<00:00, 16625.77it/s]

Generated scalar map RMSE with survey AWGN (STD: 10nT): 4.661728818571068nT

100%|      | 39204/39204 [00:02<00:00, 16668.05it/s]

Generated scalar map RMSE with survey AWGN (STD: 100nT): 48.39170483060359nT
```

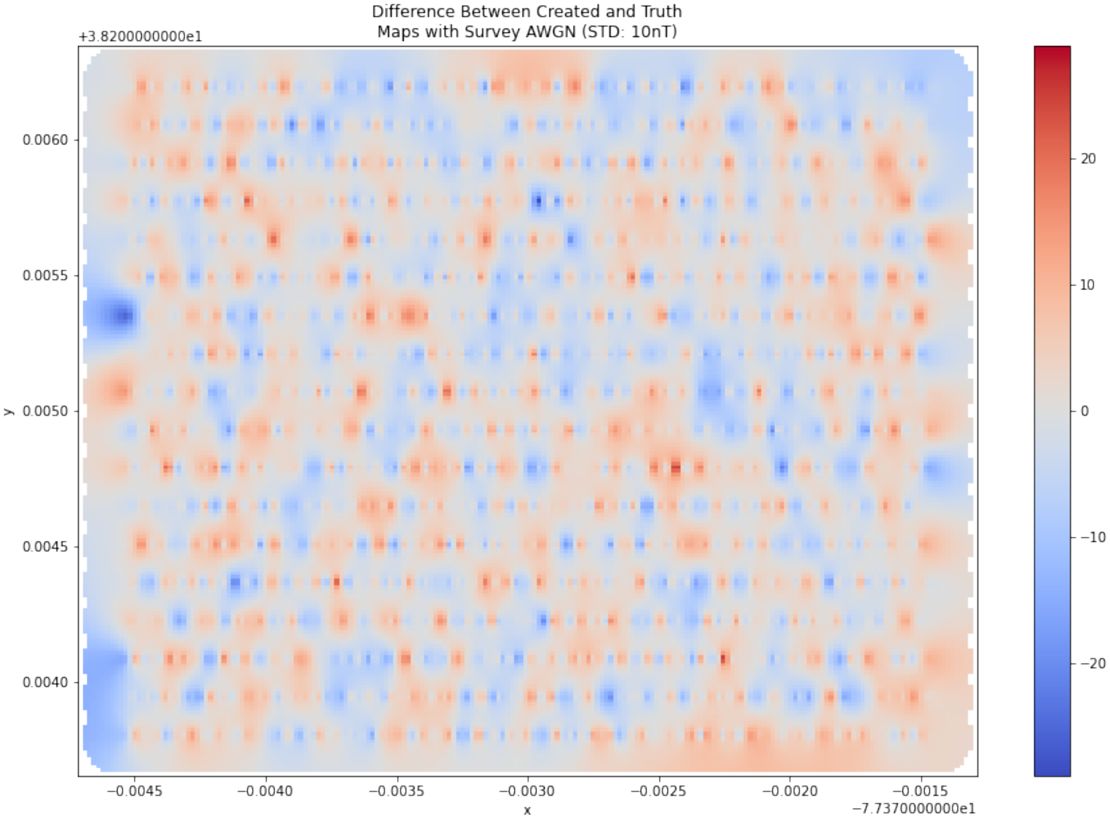


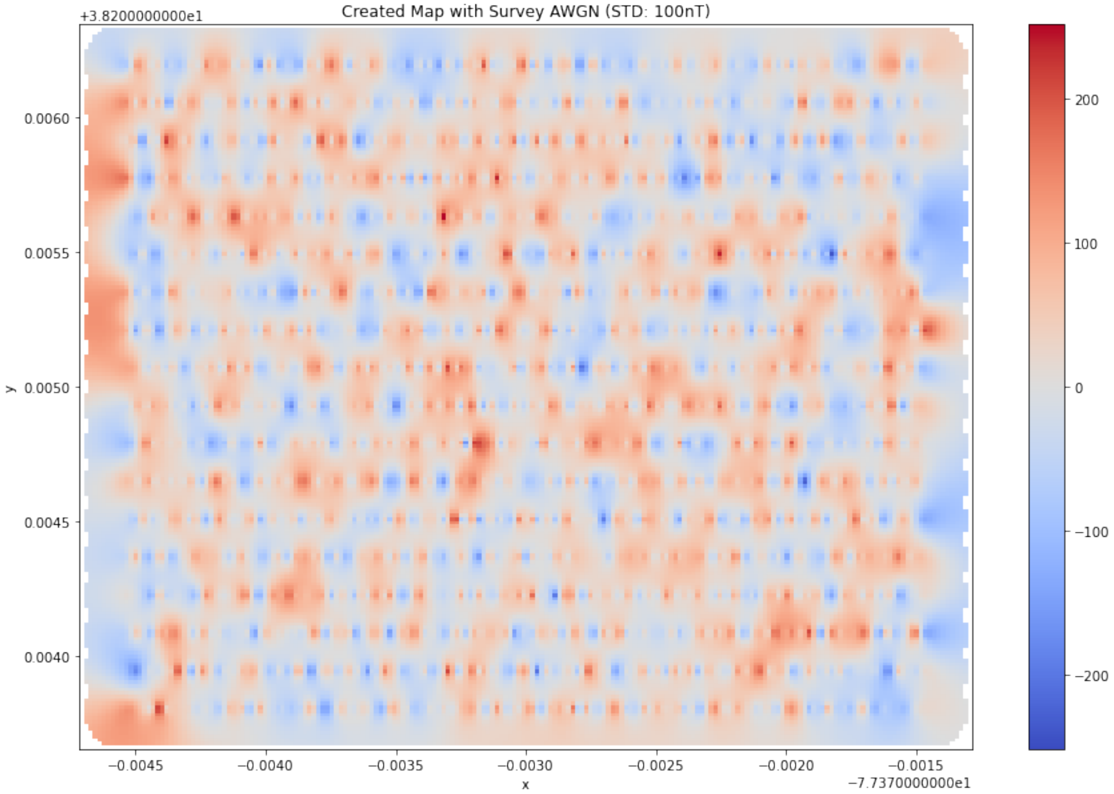

Truth Map
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4

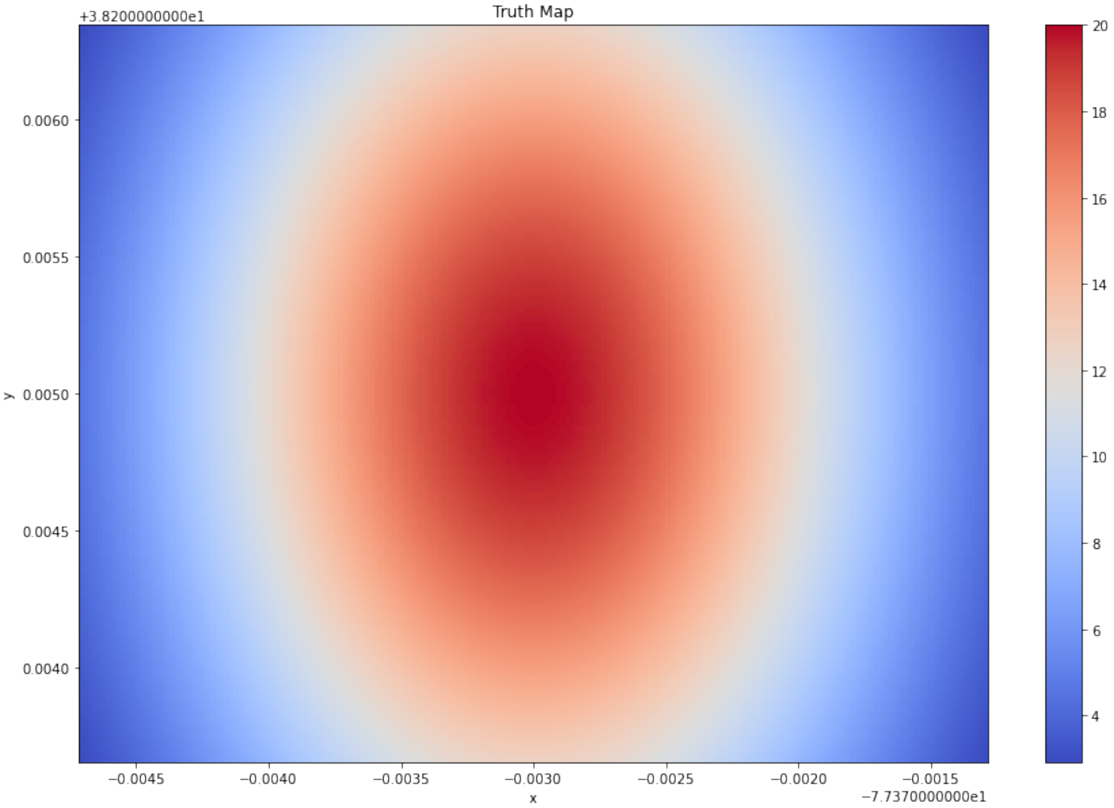

Difference Between Created and Truth
Maps with Survey AWGN (STD: 1nT)
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
2
1
0
−1
−2

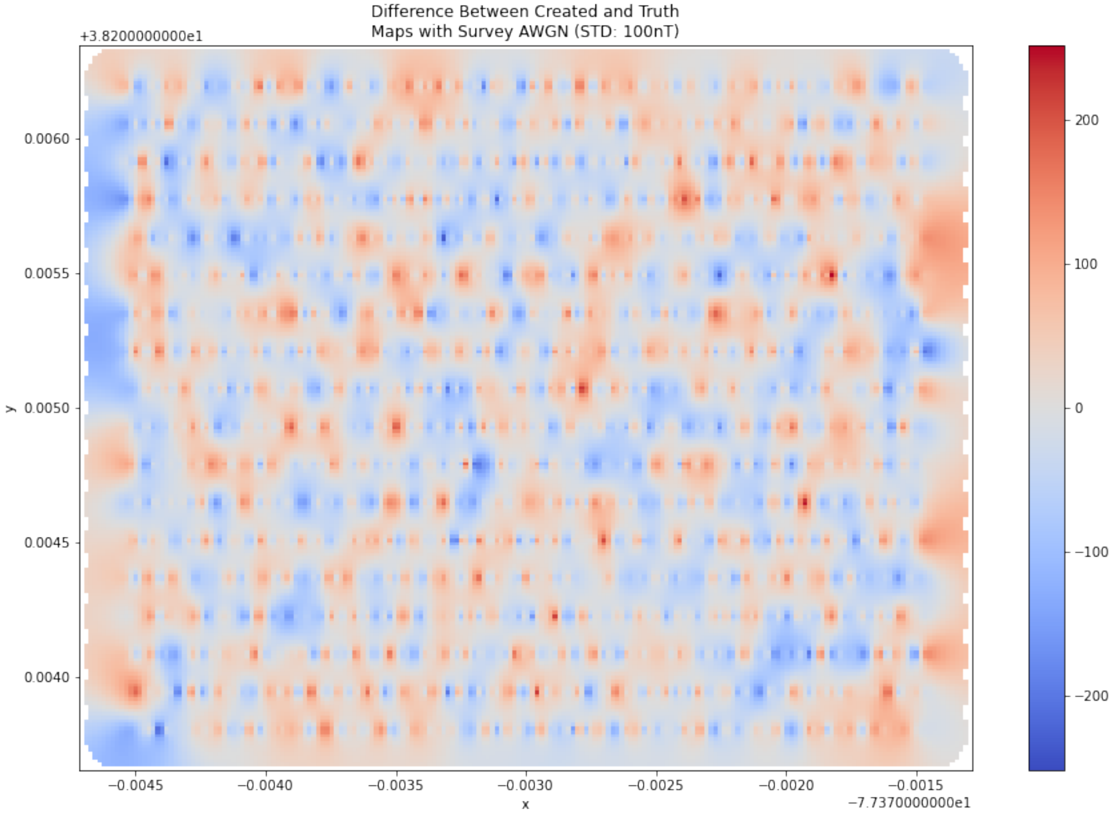

Created Map with Survey AWGN (STD: 10nT)
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
40
20
0
−20
−40


Truth Map
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4


Difference Between Created and Truth
Maps with Survey AWGN (STD: 10nT)
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
10
0
−10
−20


Created Map with Survey AWGN (STD: 100nT)
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
200
100
0
−100
−200


Truth Map
+3.8200000000e1
0.0060
0.0055
y 0.0050
0.0045
0.0040
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
20
18
16
14
12
10
8
6
4


Difference Between Created and Truth
Maps with Survey AWGN (STD: 100nT)
+3.8200000000e1
0.0060
0.0055
0.0050
0.0045
0.0040
y
−0.0045
−0.0040
−0.0035
−0.0030
−0.0025
−0.0020
−0.0015
x
−7.7370000000e1
200
100
0
−100
−200