MTPy User Guide

October 2, 2018

1 Introduction

This workbook contains some examples for reading, analysing and plotting processed MT data. It covers most of the steps available in MTPy. For more details on specific input parameters and other functionality, we recommend looking at the mtpy documentation, which can be found at: https://mtpy2.readthedocs.io/en/develop/master_doc.html.

This workbook is structured according to some of the key modules in MTPy: Core, Analysis, Imaging, and Modeling.

1.1 Getting Started

To start with, you will need to make sure MTPy is installed and is working correctly. Please see the installation guide (https://github.com/MTgeophysics/mtpy/wiki/MTPy-installation-guide-on-Windows-PC) for details.

Before you begin these examples, we suggest you make a temporary folder (e.g. C:/tmp) to save all example outputs.

1.2 Useful tricks and tips

This workbook exists as a Jupyter notebook and a pdf. If you are running the Jupyter notebook, you can run each of the cells, modifying the inputs to suit your requirements. Most of these examples have been written to be self contained.

In Jupyter, you can add the following line to the top of any cell and it will write the contents of that cell to a python script: %%writefile example.py

You can also select multiple cells and copy them to a new Jupyter notebook.

Many of the examples below make use of the matplotlib colour maps. Please see https://matplotlib.org/examples/color/colormaps_reference.html for colour map options.

2 Core

These first few examples cover some of the basic functions and tools that can be used to look at data contained in an edi file, plot it, and make changes (e.g. sample onto different frequencies).

2.1 Read an edi file into an MT object

```
In [1]: # import required modules
        from mtpy.core.mt import MT

        # Define the path to your edi file
        edi_file = "C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"

        # Create an MT object
        mt_obj = MT(edi_file)
```

The mt_obj contains all the data from the edi file, e.g. impedance, tipper, frequency as well as station information (lat/long). To look at any of these parameters you can type, for example:

```
In [2]: # To see the latitude and longitude
        print mt_obj.lat, mt_obj.lon

-19.01 136.01
```

```
In [3]: # To see the easting, northing, and elevation
        print mt_obj.east, mt_obj.north, mt_obj.elev

606300.40602 7897760.86059 95.0
```

There are many other parameters you can look at in the mt_obj. Just type mt_obj.[TAB] to see what is available. In the MT object are the Z and Tipper objects (mt_obj.Z; mt_obj.Tipper). These contain all information related to, respectively, the impedance tensor and the tipper.

```
In [4]: # for example, to see the frequency values represented in the impedance tensor:
        print mt_obj.Z.freq

[1.256500e+04 9.751601e+03 7.876300e+03 6.188500e+03 5.250801e+03
 4.265799e+03 3.515799e+03 8.437800e+02 6.562798e+02 4.922399e+02
 3.867599e+02 3.164400e+02 2.578400e+02 2.109600e+02 1.728900e+02
 1.367200e+02 1.015600e+02 7.421900e+01 5.761700e+01 4.882800e+01
 4.101600e+01 3.222700e+01 2.636700e+01 2.148400e+01 1.757800e+01
 1.440400e+01 1.147500e+01 8.593800e+00 6.591801e+00 5.371100e+00
 4.394500e+00 3.601100e+00 2.868700e+00 2.304700e+00 1.914100e+00
 1.601600e+00 1.328100e+00 1.074200e+00 8.789100e-01 6.835900e-01
 5.078100e-01 3.710900e-01 2.880900e-01 2.050800e-01 1.318400e-01
 8.789098e-02 6.835900e-02 5.127000e-02 4.028299e-02 3.295900e-02
 2.685500e-02 2.197300e-02 1.709000e-02 1.281700e-02 1.007100e-02
 8.239700e-03 6.713900e-03 5.493201e-03 4.272499e-03 2.822900e-03
 2.059900e-03 1.678500e-03 1.373300e-03 1.068100e-03 7.629400e-04]
```

```
In [5]: # or to see the impedance tensor (first 4 elements)
        print mt_obj.Z.z[:4]
```

```
[[[  26.58566   -4.302123j  482.4492  +604.7747j  ]
  [-410.0502  -800.4257j      8.994784 +44.07396j ]]

 [[  12.43271   +7.519158j  434.8246  +514.6176j  ]
  [-372.7205  -666.402j      17.64062  +36.09528j ]]

 [[   7.652151  +6.28703j   398.3996  +460.0998j  ]
  [-349.9875  -580.3959j     21.57495  +33.98854j ]]

 [[   3.59474   +1.225811j  362.5121  +413.2823j  ]
  [-328.0029  -501.5329j     25.02421  +33.02813j ]]]
```

```
In [6]: # or the resistivity or phase (first 4 values)
        print mt_obj.Z.resistivity[:4]
        print mt_obj.Z.phase[:4]
```

```
[[[1.15448560e-02 9.52661629e+00]
  [1.28742136e+01 3.22072438e-02]]

 [[4.32975088e-03 9.30931663e+00]
  [1.19572611e+01 3.31035019e-02]]

 [[2.49056438e-03 9.40578869e+00]
  [1.16641228e+01 4.11538240e-02]]

 [[4.66179794e-04 9.76706091e+00]
  [1.16060807e+01 5.54922342e-02]]]
[[[  -9.19198953   51.41945343]
  [-117.1256163    78.46525668]]

 [[  31.16505948   49.80396162]
  [-119.21840697   63.95414249]]

 [[  39.40662667   49.11076951]
  [-121.09061209   57.59379146]]

 [[  18.82944281   48.74426019]
  [-123.18471678   52.85011776]]]
```

As with the MT object, you can explore the object by typing mt_obj.Z.[TAB] to see the available attributes.

2.2 Plot an edi file

In this example we plot MT data from an edi file.

```
In [1]: # import required modules
        from mtpy.core.mt import MT
```

```
        import os

        # Define the path to your edi file and save path
        edi_file = "C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
        savepath = r"C:/tmp"

        # Create an MT object
        mt_obj = MT(edi_file)

        # To plot the edi file we read in in Part 1 & save to file:
        pt_obj = mt_obj.plot_mt_response(plot_num=1, # 1 = yx and xy; 2 = all 4 components
                                                     # 3 = off diagonal + determinant
                                         plot_tipper = 'yri',
                                         plot_pt = 'y' # plot phase tensor 'y' or 'n'
                                        )
        #pt_obj.save_plot(os.path.join(savepath,"Synth00.png"), fig_dpi=400)
```

```
<Figure size 960x720 with 5 Axes>
```

2.3 Make some change to the data and save to a new file

This example demonstrates how to resample the data onto new frequency values and write to a new edi file. In the example below, you can either choose every second frequency or resample onto five periods per decade. To do this we need to make a new Z object, and save it to a file.

```
In [8]: # import required modules
        from mtpy.core.mt import MT
        import os

        # Define the path to your edi file and save path
        edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
        savepath = r"C:/tmp"

        # Create an MT object
        mt_obj = MT(edi_file)

        # First, define a frequency array:
        # Every second frequency:
         new_freq_list = mt_obj.Z.freq[::2]

        # OR 5 periods per decade from 10^-4 to 10^3 seconds
        from mtpy.utils.calculator import get_period_list
        new_freq_list = 1./get_period_list(1e-4,1e3,5)

        # Create new Z and Tipper objects containing interpolated data
        new_Z_obj, new_Tipper_obj = mt_obj.interpolate(new_freq_list)
```

```
        # Write a new edi file using the new data
        mt_obj.write_mt_file(
                    save_dir=savepath,
                    fn_basename='Synth00_5ppd',
                    file_type='edi',
                    new_Z_obj=new_Z_obj, # provide a z object to update the data
                    new_Tipper_obj=new_Tipper_obj, # provide a tipper object
                    longitude_format='LONG', # write longitudes as 'LONG' not 'LON'
                    latlon_format='dd'# write as decimal degrees (any other input
                                     # will write as degrees:minutes:seconds
                    )
```

```
C:\mtpywin\mtpy\mtpy\utils\calculator.py:308: RuntimeWarning: invalid value encountered in doubl
  z_rel_err = error/z_amp
```

```
Out[8]: 'C:\\tmp\\Synth00_resamp.edi'
```

3 Analysis

The analysis modules contain functions to analyse MT data, for example analyse dimensionality or strike angle for either a single edi file or a collection of edi files.

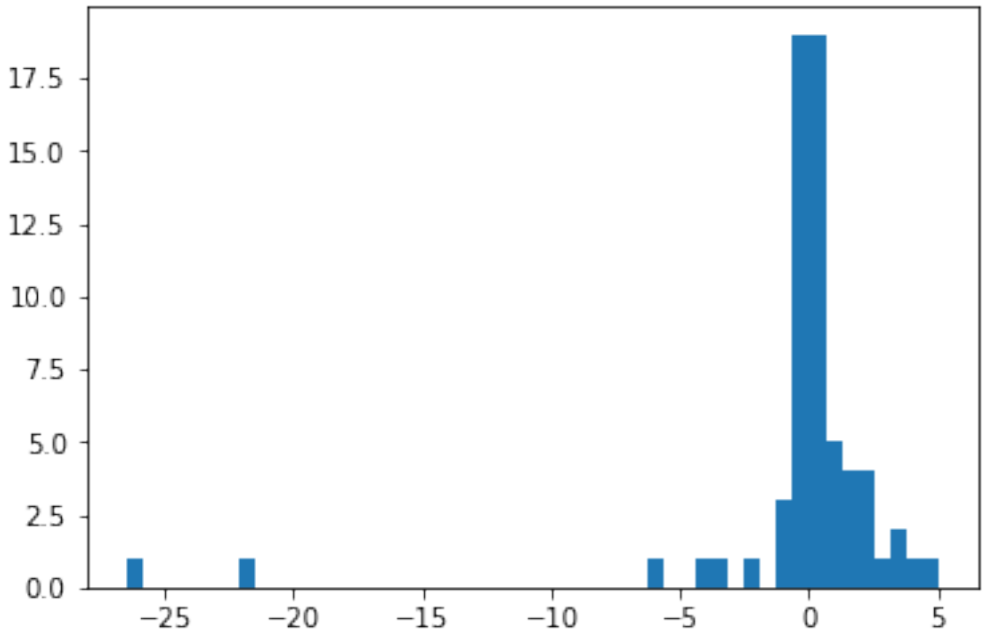
3.1 Look at the Phase Tensor

The phase tensor is an object within the MT object. So when you read in an edi file, it will automatically contain the phase tensor. To look at the attributes of the phase tensor, you can (as before) type mt_obj.[TAB] to see what is available. For example, to look at the skew angle (beta):

```
In [16]: from mtpy.core.mt import MT
         import matplotlib.pyplot as plt

         # Define the path to your edi file and save path
         edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"

         mt_obj = MT(edi_file)

         # look at the skew values as a histogram
         plt.hist(mt_obj.pt.beta,bins=50)
```

```
Out[16]: (array([ 1.,  0.,  0.,  0.,  0.,  0.,  0.,  1.,  0.,  0.,  0.,  0.,  0.,
                  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,  0.,
                  0.,  0.,  0.,  0.,  0.,  0.,  1.,  0.,  0.,  1.,  1.,  0.,  1.,
                  0.,  3., 19., 19.,  5.,  4.,  4.,  1.,  2.,  1.,  1.]),
          array([-2.64957011e+01, -2.58646253e+01, -2.52335496e+01, -2.46024738e+01,
                 -2.39713981e+01, -2.33403223e+01, -2.27092466e+01, -2.20781708e+01,
                 -2.14470951e+01, -2.08160193e+01, -2.01849436e+01, -1.95538678e+01,
                 -1.89227921e+01, -1.82917163e+01, -1.76606406e+01, -1.70295648e+01,
```

```
        -1.63984891e+01, -1.57674133e+01, -1.51363376e+01, -1.45052618e+01,
        -1.38741861e+01, -1.32431104e+01, -1.26120346e+01, -1.19809589e+01,
        -1.13498831e+01, -1.07188074e+01, -1.00877316e+01, -9.45665586e+00,
        -8.82558011e+00, -8.19450436e+00, -7.56342862e+00, -6.93235287e+00,
        -6.30127712e+00, -5.67020137e+00, -5.03912562e+00, -4.40804987e+00,
        -3.77697413e+00, -3.14589838e+00, -2.51482263e+00, -1.88374688e+00,
        -1.25267113e+00, -6.21595384e-01,  9.48036442e-03,  6.40556113e-01,
         1.27163186e+00,  1.90270761e+00,  2.53378336e+00,  3.16485911e+00,
         3.79593485e+00,  4.42701060e+00,  5.05808635e+00]),
 <a list of 50 Patch objects>)
```



3.2 Look at dimensionality

Here, we use the phase tensor to determine which parts of the impedance tensor are 1D, 2D or 3D. The code returns an array with a value (1, 2 or 3) representing the dimensionality

```
In [2]: # Import required modules
        from mtpy.analysis.geometry import dimensionality
        from mtpy.core.mt import MT
        import os

        # Define the path to your edi file and save path
        edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
        savepath = r"C:/tmp"

        # Create an MT object
```

```
        mt_obj = MT(edi_file)

        #Have a look at the dimensionality
        print dimensionality(z_object = mt_obj.Z,
                             skew_threshold = 5, # threshold for 3D
                             eccentricity_threshold=0.1 # threshold for 2D
                             )
```

```
[2 2 2 2 1 2 2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2 2 2 2
 2 2 2 2 2 2 2 2 1 2 1 1 1 1 2 2 2 2 2 2 2 3 2 2 2 3 3 3]
```

3.3 Look at strike angle

Here, we calculate the strike angle for the 2D part of the impedance tensor.

```
In [9]: # Import required modules
        from mtpy.analysis.geometry import strike_angle
        from mtpy.core.mt import MT
        import numpy as np
        import os

        # Define the path to your edi file and save path
        edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
        savepath = r"C:/tmp"

        # Create an MT object
        mt_obj = MT(edi_file)

        # calculate strike
        strike = strike_angle(z_object = mt_obj.Z,
                              skew_threshold = 5, # threshold for 3D
                              eccentricity_threshold=0.1 # threshold for 2D
                             )

        # display the median strike angle for this station
        # two values because of 90 degree ambiguity in strike
        print np.nanmedian(strike,axis=0)
```

```
[-3.98292164 86.01707836]
```

3.4 Use dimensionality to mask an edi file

Here, we use the dimensionality calculated in Part 1 to mask all 3D parts of the impedance tensor and write to a new edi file.

```
In [3]: # Import required modules
        from mtpy.core.z import Z, Tipper
```

```
from mtpy.analysis.geometry import dimensionality
from mtpy.core.mt import MT
import os

# Define the path to your edi file and save path
edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
savepath = r"C:/tmp"

# Create an MT object
mt_obj = MT(edi_file)

# Create an array (mask) with value True where the data are 1D or 2D and
# False where the data are 3D
dim = dimensionality(z_object = mt_obj.Z,
                     skew_threshold = 5,
                     eccentricity_threshold=0.1)
mask = dim < 3

# Apply masking. The new arrays z_array, z_err_array, and freq will
# exclude values where mask is False (i.e. the 3D parts)
new_Z_obj = Z(z_array=mt_obj.Z.z[mask],
              z_err_array=mt_obj.Z.z_err[mask],
              freq=mt_obj.Z.freq[mask])
new_Tipper_obj = Tipper(tipper_array=mt_obj.Tipper.tipper[mask],
                        tipper_err_array=mt_obj.Tipper.tipper_err[mask],
                        freq = mt_obj.Tipper.freq[mask])

# Write a new edi file (as before)
mt_obj.write_mt_file(save_dir=savepath,
                     fn_basename='Synth00_mask3d',
                     file_type='edi',
                     new_Z_obj=new_Z_obj,
                     new_Tipper_obj=new_Tipper_obj,
                     longitude_format='LONG',
                     latlon_format='dd')
```

```
Out[3]: 'C:\\tmp\\Synth00_mask3d_1.edi'
```

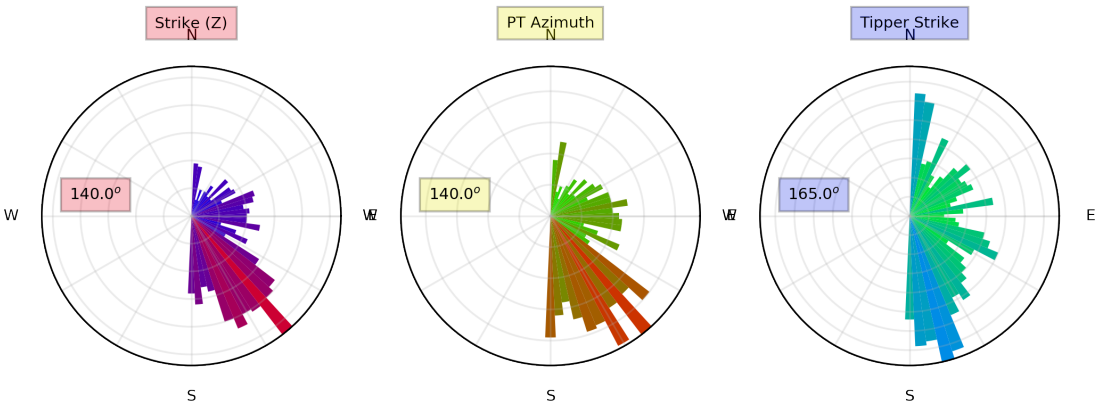
3.5 Plot strike for a collection of files

In this example, we plot the strike as a rose plot for a collection of edi files. Strike is calculated from the Z invariants (after Weaver et al., 2000; 2003), the phase tensor (Caldwell et al. 2004) and the tipper. Plots can include all frequencies or be separated according to decade if you set plot_type = 1.

```
In [26]: # Import required modules
         from mtpy.imaging.plotstrike import PlotStrike
         import os
```

```
        # Path containing edi files
        edi_path = r'C:/mtpywin/mtpy/examples/data/edi_files_2'

        # Full path to save path if you want to save the image
        savepath = r'C:/tmp'

        # Get full path to all files with the extension '.edi' in edi_path
        edi_list = [os.path.join(edi_path,ff) for ff in os.listdir(edi_path) \
                    if ff.endswith('.edi')]

        # make a plot (try also plot_type = 1 to plot by decade)
        strikeplot = PlotStrike(fn_list=edi_list,
                                plot_type=2,
                               plot_tipper='y')

        # save to file
        strikeplot.save_plot(savepath,
                             file_format='.png',
                             fig_dpi=400)
```

```
Reading 28 stations
-----Period Range 1e-05 to 1e+03 (s)-----
   *Z-Invariants:  median=125.2 mode=140.0 mean=140.0
   *PT Strike:     median=125.8 mode=140.0 mean=109.6
   *Tipper Stike:  median=109.5 mode=165.0 mean=99.9

Note: North is assumed to be 0 and the strike angle is measured clockwise positive.
```




```
Saved figure to: C:/tmp\StrikeAnalysis.png

<Figure size 432x288 with 0 Axes>
```

3.6 Rotating an edi file to strike and save to a new file

In the example below, we read an edi file, rotate it to a pre-defined strike and save it to a new file. Before saving the new edi file, we display the new rotation angle. This step can be omitted, but it is useful to check that the final rotation angle for the edi file is what you expect. Note there are multiple values for rotation angle representing each frequency contained in the edi file.

```
In [4]: # Import required modules
        from mtpy.core.z import Z, Tipper
        from mtpy.analysis.geometry import strike_angle
        from mtpy.core.mt import MT
        import os

        # Define the path to your edi file and save path
        edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"
        savepath = r"C:/tmp"

        # Create an MT object
        mt_obj = MT(edi_file)

        # From 3.3; we determine strike angle is -4 or 86 degrees
        # based on other geological information we determine it to be
        # -4 degres.
        strike = -4
        mt_obj.Z.rotate(strike)
        mt_obj.Tipper.rotate(strike)

        # check the rotation angle
        print mt_obj.Z.rotation_angle

        # Write a new edi file (as before)
        mt_obj.write_mt_file(save_dir=savepath,
                             fn_basename='Synth00_rotate%1i'%strike,
                             file_type='edi',
                             longitude_format='LONG',
                             latlon_format='dd')
```

```
[356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356.
 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356.
 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356.
 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356. 356.
 356. 356. 356. 356. 356. 356. 356. 356. 356.]
```

```
Out[4]: 'C:\\tmp\\Synth00_rotate-4.edi'
```

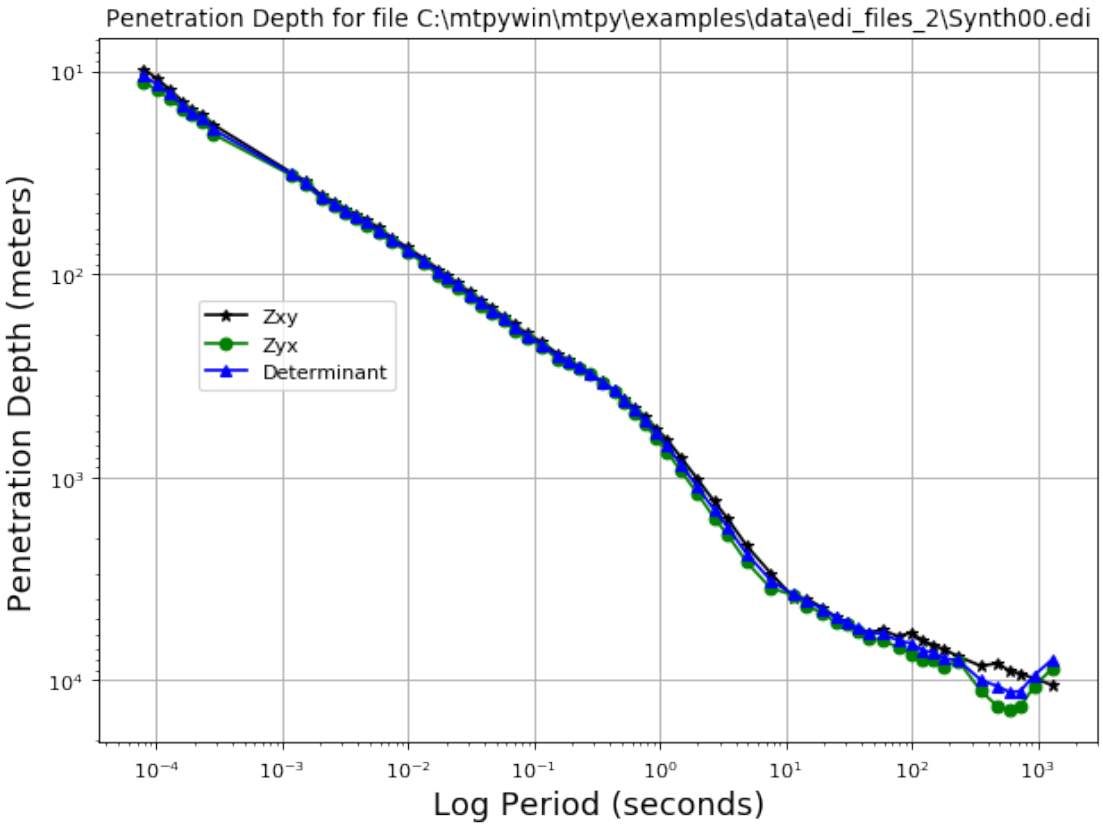
4 Imaging

4.1 Plotting penetration depth using the Niblett-Bostick transform

4.1.1 Penetration depth as a function of period for 1 site

Here, we plot the Niblett-Bostick depth as a function of period/frequency for one site.

```
In [7]: # Import required modules
        import os
        from mtpy.imaging import penetration_depth1d as pd1d

        # Define edi file
        edi_file = r"C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi"

        # Define file to save to
        save_file = r"C:/tmp/penetration_depth1d.png"

        # Create a plot of penetration depth and save to file
        pd1d.plot_edi_file(edi_file, savefile=save_file, fig_dpi=400)
```

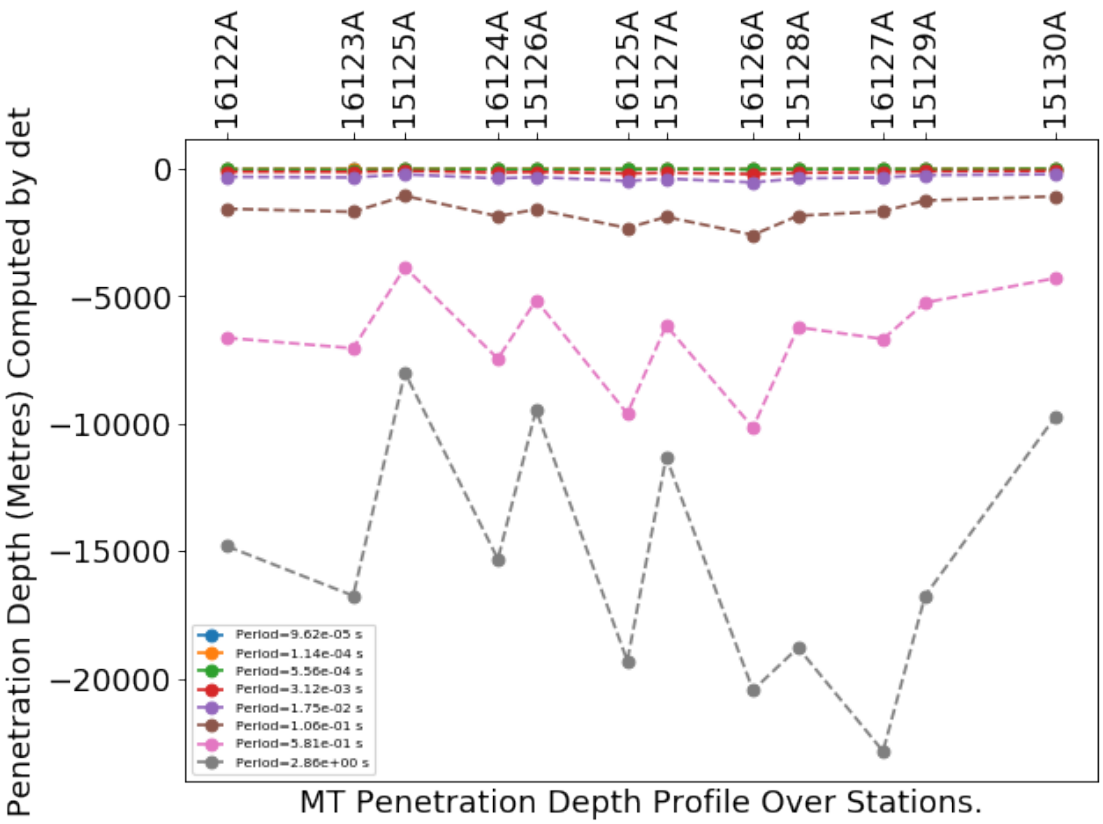


4.1.2 Penetration depth for selected periods along a profile

Here, we plot the Niblett-Bostick depth as a function of distance along a profile, for selected periods

In [15]:
```
#Import required modules
from mtpy.imaging import penetration_depth2d as pen2d

#Define a path containing all the edi files in the profile & a savepath
edi_path = r'C:/mtpywin/mtpy/data/edifiles'
savepath = r'C:/tmp'

# Choose indices of periods to plot
period_index_list = [0, 1, 10, 20, 30, 40, 50, 59]

# Plot profiles for different modes ('det','zxy' or 'zyx')
pen2d.plot2Dprofile(edi_path, period_index_list,
                    'det', marker='o',
                    tick_params={'rotation':'vertical'})

# To save any of these figures:
#plt.savefig(os.path.join(savepath,'penetration_depth_profile.png'), dpi=400)
```

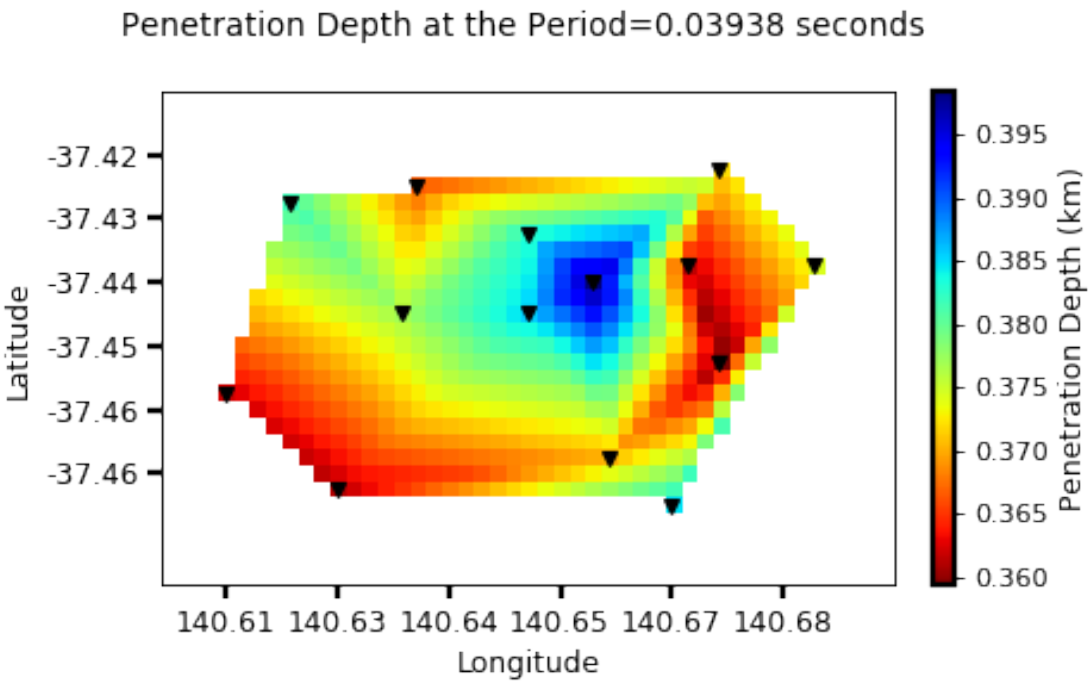
```
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
Should input a freq array to know which index of the PT array corresponds to which freq.
========================================================================
Rotated Z and Tipper to align with +171.89 degrees E of N
Profile angle is +261.89 degrees E of N
========================================================================
```



4.1.3 Penetration depth for a selected period as a map

Here, we plot the Niblett-Bostick depth for one period, and interpolate between stations on a map.

```
In [6]: #Import required modules
        from mtpy.imaging import penetration_depth3d as pen3d

        # Set path to edi files to include in the plot and define savepath
        edi_path = r'C:/mtpywin/mtpy/examples/data/edi2'
        savepath = r'C:/tmp'

        # Create plot for period index number 10 for determinant
        pen3d.plot_latlon_depth_profile(edi_path, 10, 'det', showfig=True,
                                        savefig=True, savepath=savepath,
                                        fontsize=11, fig_dpi=400)
```




```
C:\mtpywin\mtpy\mtpy\imaging\penetration.py:474: DeprecationWarning: Call to deprecated function
  def get_period_fmt(self):
```

4.2 Phase tensor plotting

In the next examples we will plot phase tensor maps (after Caldwell et al., 2004 & Bibby et al. 2005) and induction vectors. In these and later maps, there are many different parameters that can be varied, and generally there will be some tweaking that will need to be done to get the parameters (e.g. ellipse scaling) perfect for publication-quality plots. Note that some parameter tweaks can be done later (e.g. in Adobe Illustrator or Inkscape) if you save the plot to a vector graphic format like .eps and we recommend this as it can take hours to get all the parameters perfect!

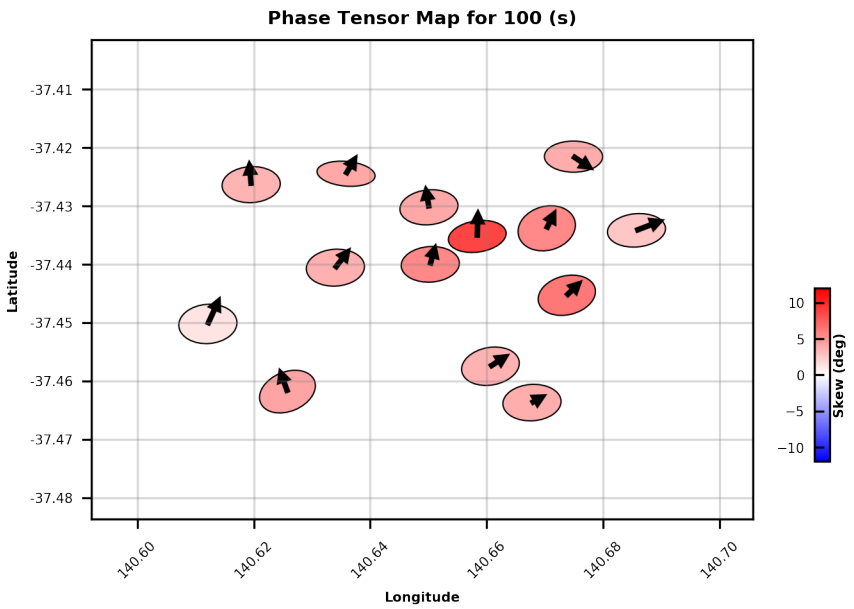
4.2.1 Phase tensor maps

In this example we plot all edi files from a directory as a phase tensor map for a selected frequency, with real induction vectors (Parkinson convention) overlain. There are quite a few parameters you can adjust, feel free to spend some time with this example updating them and viewing the result.

```
In [20]: # Import required modules
         from mtpy.imaging.phase_tensor_maps import PlotPhaseTensorMaps
         import os

         import matplotlib.pyplot as plt
```

```
# directory containing edis
edi_path = r'C:/mtpywin/mtpy/examples/data/edi2'

# full path to file to save to
savepath = r'C:/tmp'

# frequency to plot
plot_freq = 1e-2

# name image according to plot frequency
image_fn = 'phase_tensor_map%1is'%(int(1./plot_freq))+'.png'

# gets edi file names as a list
edi_list = [os.path.join(edi_path,ff) for ff in os.listdir(edi_path) \
            if ff.endswith('.edi')]

# generate plot
ptmap = PlotPhaseTensorMaps(fn_list = edi_list,
                plot_freq = plot_freq , # frequency to plot
                fig_size = (4,3), # x, y dimensions of figure
                xpad = 0.02, ypad = 0.02, # pad around stations
                plot_tipper = 'yr', # 'y' + 'r' and/or 'i' to plot
                                    # real and/or imaginary
                edgecolor='k', # a matplotlib colour or None for no borders
                lw=0.5, # linewidth for the ellipses
                minorticks_on=False, # whether or not to turn on minor ticks
                ellipse_colorby='skew', # 'phimin', 'phimax', or 'skew'
                ellipse_range = [-12,12,2], # [min,max,step]
                ellipse_size=0.01, # scaling factor for the ellipses
                arrow_size=0.1,
                arrow_head_width=0.002, # scaling for arrows (head width)
                arrow_head_length=0.002, # scaling for arrows (head length)
                ellipse_cmap='bwr', # matplotlib colormap
                station_dict={'id':(5,7)} ,
                cb_dict = {'position':
                           [1.05,0.2,0.02,0.3]}, # colorbar position [x,y,dx,dy]
                font_size=5
                )

# save the plot
ptmap.save_figure(os.path.join(savepath,image_fn))
```

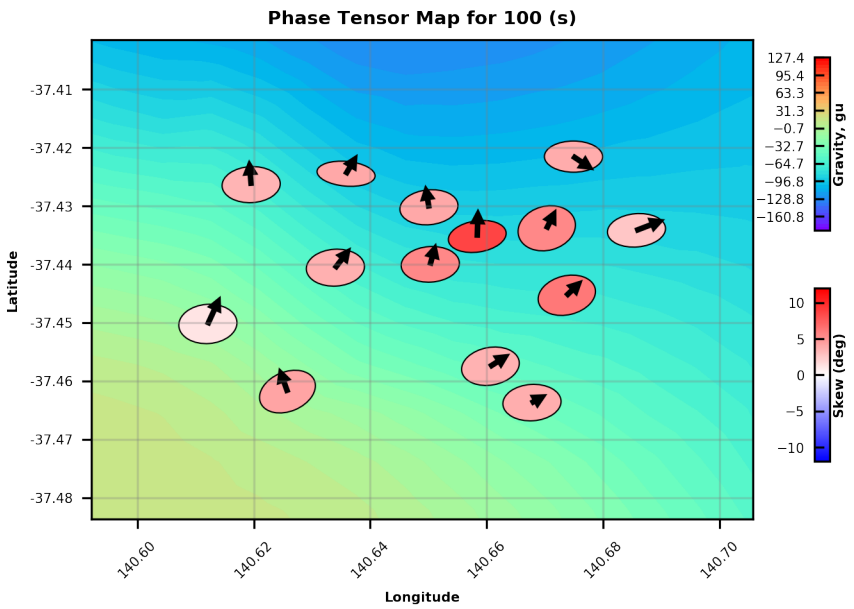
```
Reading 14 stations
```




```
<Figure size 432x288 with 0 Axes>
```

If you want to plot some other image in the background (e.g. gravity) you can load it as follows & plot (the example below uses a Bouguer anomaly grid in netCDF format)

```
In [21]: # Import the netCDF4 module
         from netCDF4 import Dataset
         import numpy as np

         # load a netcdf file
         grav = Dataset(r'C:/mtpywin/mtpy/examples/data/gravity/gravity.nc')
         glon, glat = np.meshgrid(grav.variables['lon'],grav.variables['lat'])
         vals = grav.variables['Band1'][:]


         ptmap.plot(show=True,
                    raster_dict={'lons':glon.flatten(),
                                 'lats':glat.flatten(),
                                 'vals':vals.flatten(),
                                 'levels':50,
                                 'cmap':'rainbow',
                                 'cbar_title':'Gravity, gu',
                                 'cbar_position':[1.05,0.6,0.02,0.3]}  )
```



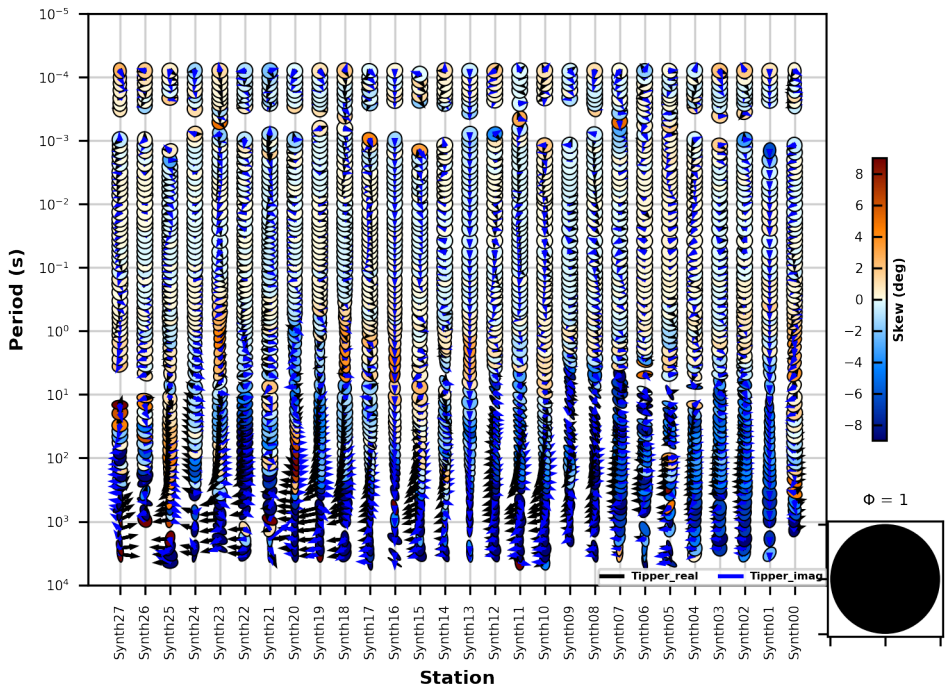
4.2.2 Phase tensor sections

In this example we plot phase tensors for all frequencies from some edi files located along a transect.

```
In [33]: # import required modules
         from mtpy.imaging.phase_tensor_pseudosection import PlotPhaseTensorPseudoSection
         import os

         # path to edis
         edi_path = r'C:/mtpywin/mtpy/examples/data/edi_files_2'

         # save path
         savepath = r'C:/tmp'

         # edi list
         edi_list=[os.path.join(edi_path,edi) for edi in os.listdir(edi_path) \
                   if ((edi.endswith('.edi')))]

         # dictionary containing ellipse properties
         ellipse_dict = {'ellipse_colorby':'phimin', # phimin, phimax, skew,
                                                     # skew_seg
                         'ellipse_range':[0,90]} # Color limits. If plotting
                                                 # skew_seg need to provide
                                                 # 3 numbers, the 3rd indicates
                                                 # interval, e.g. [-12,12,3]
```

```
        # create a plot object
        ptsection = PlotPhaseTensorPseudoSection(fn_list = edi_list,
                        linedir='ns', # 'ns' if the line is closer to north-south,
                                      # 'ew' if line is closer to east-west
                        stretch=(17,8), # determines (x,y) aspect ratio of plot
                        station_id=(0,10), # indices for showing station names
                        plot_tipper = 'yri', # plot tipper ('y') + 'ri' for real+imag
                        font_size=5,
                        lw=0.5,

                                            )
        ptsection.ellipse_size = 2.
        ptsection.plot()

        ptsection.save_figure(save_fn = os.path.join(savepath,'PhaseTensorSection.pdf'),
                              fig_dpi=400)
```

```
Reading 28 stations
-------------------------
skew min = -76.25
skew max = 76.64
-------------------------
```




```
Saved figure to: C:/tmp\PhaseTensorSection.pdf
```

```
<Figure size 432x288 with 0 Axes>
```

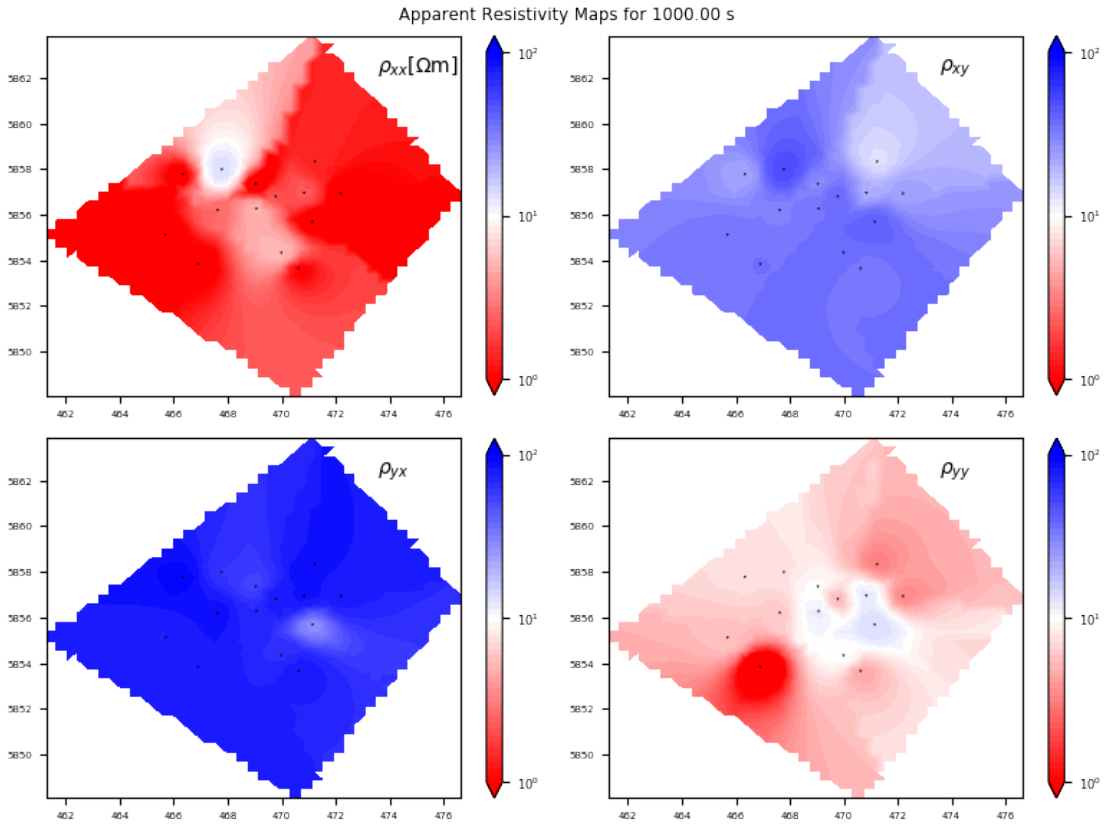
4.3 Apparent resistivity and phase sections and maps

4.3.1 Apparent resistivity maps

Plot apparent resitivity for a selected period, for an array of sites. Resistivity values are interpolated between sites

```
In [61]: # Import required modules
         from mtpy.imaging.plot_resphase_maps import PlotResPhaseMaps
         import os

         # Define edi path and save path
         edipath = r'C:/mtpywin/mtpy/examples/data/edi2'
         savepath = r'C:/tmp'

         # Make an edi list
         edi_list = [os.path.join(edipath,ff) for ff in os.listdir(edipath) \
                     if ff.endswith('.edi')]

         # Define plot frequency
         freq = 0.001

         # Initialise a plot object
         prp = PlotResPhaseMaps(fn_list=edi_list,
                                mapscale='km')

         # plot resistivity
         f = prp.plot(freq,
                      'res',
                      1, 100, # limits in resistivity. Can be provided as a number
                              # or a 2x2 array to give different limits for
                              # different components
                      nn=3, p=3,
                      extrapolation_buffer_degrees=0.05, # how far to extrapolate
                      regular_grid_nx=40, # number of x grid points
                      regular_grid_ny=40, # number of x grid points
                      cmap='bwr_r', # colour map
                      show=True)

         # save plot
         prp.fig.savefig(os.path.join(savepath,'Resistivity_%1is.png'%(1./freq)),
                         dpi=300)
```

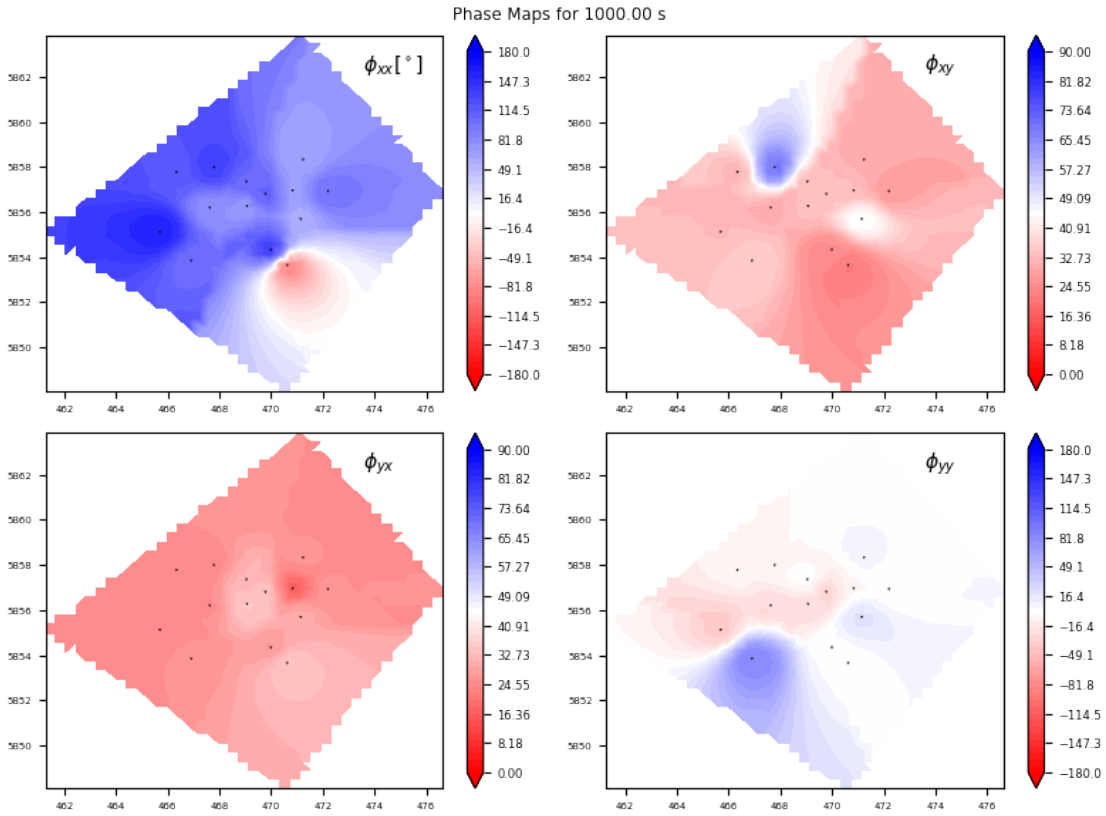
```
Reading 14 stations
```



4.3.2 Phase maps

Similarly, you can plot phase as an interpolated map.

```
In [62]: # plot phase
         f = prp.plot(freq, # frequency to plot
                      'phase', # phase or res
                      np.array([[-180,0],   # minimum phase
                                [0,-180]]), # for colour stretch
                      np.array([[180,90],   # maximum phase
                                [90,180]]), # for colour stretch
                      nn=3, p=3,
                      extrapolation_buffer_degrees=0.05, # how far to extrapolate
                      regular_grid_nx=40, # number of x grid points
                      regular_grid_ny=40, # number of y grid points
                      cmap='bwr_r', # colour map
                      show=True)

         # save plot
         prp.fig.savefig(os.path.join(savepath,'Phase_%1is.png'%(1./freq)),dpi=300)
```



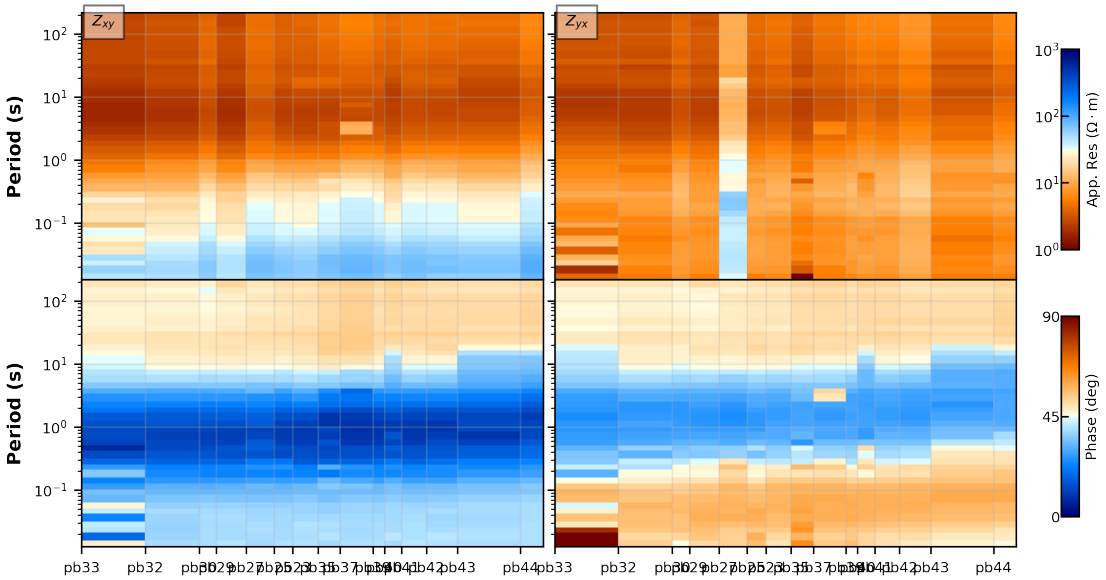
4.4 Apparent resistivity and phase pseudosections

Plot apparent resistivity and phase as a function of period for several sites located along a transect

```
In [63]: # Import required modules
         import os
         import mtpy.imaging.plotpseudosection as pps

         # define edi path and savepath
         edi_path = r'C:/mtpywin/mtpy/examples/data/edi_files'
         savepath = r'C:/tmp'

         # list all edi files in directory
         edi_list = [os.path.join(edi_path,ff) for ff in os.listdir(edi_path) \
                     if (ff.endswith('.edi'))]

         # make a plot
         pps.PlotResPhasePseudoSection(fn_list = edi_list,
                                       linedir='ns', # 'ns' or 'ew' - approximate line
                                                     # orientation
                                       plot_xx = 'n', # plot xx component 'y' or 'n'
```

```
    plot_xy = 'y', # plot xy component 'y' or 'n'
    plot_yx = 'y', # plot yx component 'y' or 'n'
    plot_yy = 'n', # plot yy component 'y' or 'n'
    res_limits=[0,3], # log resistivity limits
    phase_limits=[0,90], # log phase limits
    shift_yx_phase = True, # True or False
    plot_style='pcolormesh' # 'pcolormesh' or 'imshow'
)
```

```
Reading 15 stations
```



Out[63]: <mtpy.imaging.plotpseudosection.PlotResPhasePseudoSection at 0x36d08400>

5 Modeling

The modeling modules in MTPy are designed to support third party software. I.e. they assist with input file generation and then analysis and visualisation of the results. Here, we give examples the three more commonly used software packages. Occam 1d, Occam 2d and ModEM.

5.1 Occam 1D

This first example demonstrates how to create input files for inversion of MT data using the Occam 1D code (Key 2009, Constable et al 1987) - http://marineemlab.ucsd.edu/Projects/Occam/1DCSEM/.

There are three input files. * Data file, containing the data for inversion * Model file (which contains the model mesh) * Startup file - called by Occam1d and contains the data and model file names together with some control parameters for the inversion.

```
In [3]: # import required modules
        import os
        import mtpy.modeling.occam1d as mtoc1d

        # full path to edi file and save path
        edi_file = r'C:/mtpywin/mtpy/examples/data/edi_files_2/Synth00.edi'
        savepath = r'C:/tmp/Occam1D_inv'

        # make the save path if it doesn't exist
        if not os.path.exists(savepath):
            os.mkdir(savepath)

        # create data file
        ocd = mtoc1d.Data()   #create an object and assign values to arguments
        ocd.write_data_file(edi_file=edi_file,
                            mode='det',  # 'te', 'tm', or 'det'
                            save_path=savepath, # path to save to
                            res_errorfloor=4, # error floor in percentage
                            phase_errorfloor=2, # error floor in degrees
                            remove_outofquadrant=True)

        # create model file
        ocm = mtoc1d.Model(n_layers = 100, # number of layers
                           target_depth = 40000,# target depth in metres,
                                                # before padding
                           bottom_layer = 100000, # total depth of model
                           z1_layer=10  # first layer thickness in metres
                           )
        ocm.write_model_file(save_path=savepath)

        # create startup file
        ocs = mtoc1d.Startup(data_fn=ocd.data_fn,   # basename of data file
                             model_fn=ocm.model_fn,   # basename for model file
                             max_iter=200, # maximum number of iterations to run
                             target_rms=1.0
                            )
        ocs.write_startup_file()
```

```
Wrote Data File to : C:/tmp\Occam1d_DataFile_DET.dat
Wrote Model file: C:/tmp\Model1D
Wrote Input File: C:/tmp\OccamStartup1D
```

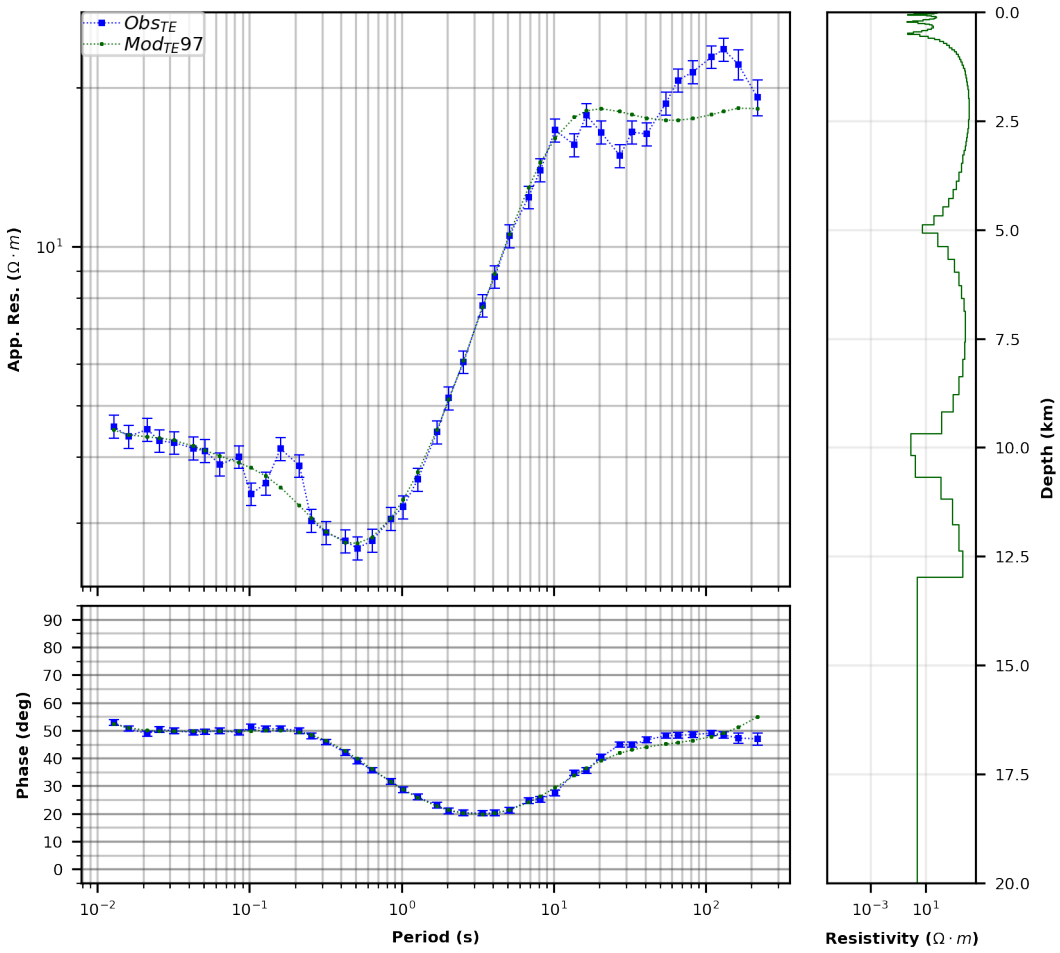
5.1.1 Viewing the outputs

Now that you have created the required inputs, you can run Occam1d on your files. Once you have done this, the following script can then be used to visualise the outputs as modelled and measured resistivity and phase, together with the 1D model. For this example below, we will use

some example Occam 1D outputs from the mtpy examples directory.

```
In [4]: import mtpy.modeling.occam1d as mtoc1d
        import os.path as op

        # working directory
        wd = r'C:\mtpywin\mtpy\examples\model_files\Occam1d'

        # model and data file names
        modelfn=op.join(wd,'Model1D')
        datafn=op.join(wd,'Occam1d_DataFile_DET.dat')

        iterfn  = op.join(wd,'ITER_97.iter')
        respfn  = op.join(wd,'ITER_97.resp')

        # read in the model, don't need these lines to view the model
        # but useful if you want to analyse the data
        oc1m = mtoc1d.Model(model_fn=modelfn)
        oc1m.read_iter_file(iterfn)

        # read in the data file
        oc1d = mtoc1d.Data(data_fn=datafn)
        oc1d.read_data_file(data_fn=datafn)
        oc1d.read_resp_file(resp_fn=respfn,data_fn=datafn)

        # plot the model and response
        pr = mtoc1d.Plot1DResponse(data_te_fn = datafn,
                                   model_fn = modelfn,
                                   resp_te_fn = respfn,
                                   iter_te_fn = iterfn,
                                   depth_limits = (0,20)
                                   )
```

```
C:\mtpywin\Anaconda2\lib\site-packages\matplotlib\cbook\deprecation.py:107: MatplotlibDeprecatio
  warnings.warn(message, mplDeprecation, stacklevel=1)
```



5.2 Occam 2D

5.2.1 Creating inputs

The example below shows how to set up input files for modelling using the Occam 2D software (Constable et al. 1987, deGroot-Hedlin and Constable, 1990, http://marineemlab.ucsd.edu/Projects/Occam/2DMT/index.html).

For more details on the specifics of the Occam 2D inversion code and input options, please refer to the Occam 2D user manual (Occam2DMT_FilesAndOptions.pdf) contained in the zip file from the above website. The input files required for modelling are described below.

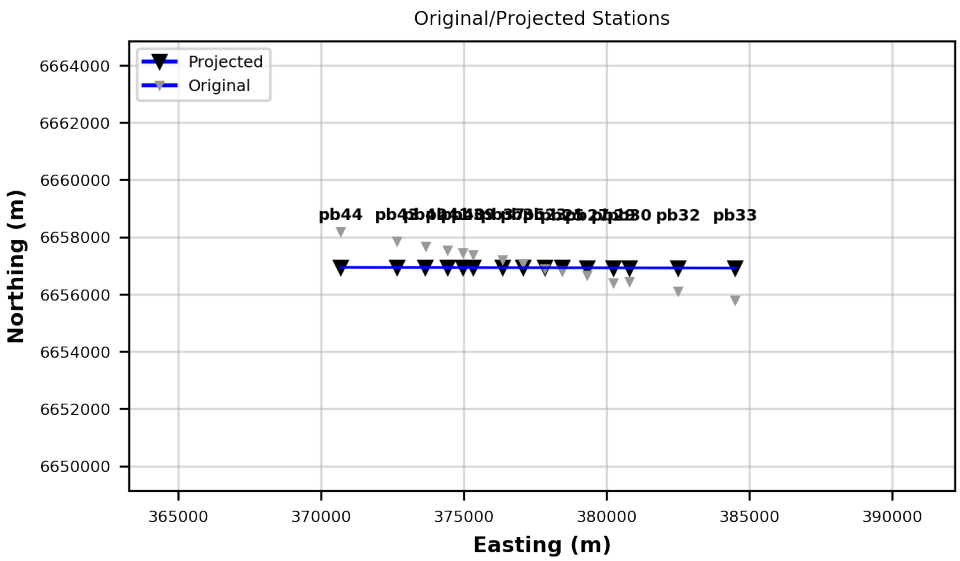
There are four input files that are created.

- Data file - contains data for the inversions and relative station locations along the 2D profile used for the inversion
- Mesh file - contains mesh geometry information and information on which parameters are fixed/free

- Model file - details how mesh blocks are divided into model blocks (see Occam2D user manual)
- Startup file - contains control parameters for the inversion and the Data, Mesh, and Model file names

In [7]:
```
import mtpy.modeling.occam2d_rewrite as occam2d
import os
import numpy as np


# path where edi files are located
edipath = r"C:/mtpywin/mtpy/examples/data/edi_files"

# path to save to
savepath = r'C:/tmp/Occam2D_inv'

# make the save path if it doesn't exist
if not os.path.exists(savepath):
    os.mkdir(savepath)

# list of stations
slst=[edi[0:-4] for edi in os.listdir(edipath) if edi.find('.edi')>0]

# create an occam data object
ocd = occam2d.Data(edi_path=edipath,
                   station_list=slst,
                   interpolate_freq=True, # interpolate frequencies
                   freq=np.logspace(-3,3,37) # frequency list to invert for
                   )
ocd.save_path = savepath

#### make data file
# geoelectric strike for rotation
# if not specified will calculate from the data
ocd.geoelectric_strike = 0.1

# error floors
ocd.res_te_err = 10 # error floor
ocd.res_tm_err = 10
ocd.phase_te_err = 5
ocd.phase_tm_err = 5
ocd.model_mode = '1' # modes to invert for - see
# https://mtpy2.readthedocs.io/en/develop/modeling.html#module-occam-2d
# for options
ocd.write_data_file()

# make model and mesh files
```

```
        ocr = occam2d.Regularization(ocd.station_locations)
        ocr.n_layers = 60 # number of layers
        ocr.cell_width = 1250 # cell width to aim for, note this is the
                              # mesh size (2 mesh blocks across per model block)
        ocr.x_pad_multiplier = 1.9 # controls size of padding
        ocr.trigger= 0.25 # controls aspect ratio of blocks
        ocr.z_bottom = 200000 # bottom of model
        ocr.z1_layer = 50 # z1 layer and target depth in metres
        ocr.z_target_depth = 80000 # target depth for inversion
        ocr.save_path=ocd.save_path
        ocr.build_mesh()
        ocr.build_regularization()
        ocr.write_mesh_file()
        ocr.write_regularization_file()
        #ocr.plot_mesh() # uncomment to plot the mesh

        # make startup file
        ocs=occam2d.Startup()
        ocs.iterations_to_run=100
        ocs.resistivity_start=2.0 # log10(starting resistivity)
        ocs.target_misfit = 1.2
        ocs.data_fn=op.join(ocd.data_fn)
        ocr.get_num_free_params()
        ocs.param_count=ocr.num_free_param
        ocs.save_path=ocd.save_path
        ocs.model_fn=ocr.reg_fn
        ocs.write_startup_file()

==========================================================================
Rotated Z and Tipper to align with +0.10 degrees E of N
Profile angle is +90.10 degrees E of N
==========================================================================
```




```
Wrote Occam2D data file to C:/tmp/Occam2D_inv\OccamDataFile.dat
============================================================
                    MESH PARAMETERS
============================================================
  number of horizontal nodes = 160
  number of vertical nodes   = 90
  Total Horizontal Distance  = 28594.665131
  Total Vertical Distance    = 293170.000000
============================================================
============================================================
               REGULARIZATION PARAMETERS
============================================================
   binding offset       = 0.0
   number layers        = 85
   number of parameters = 4267
   number of free param = 4267
============================================================
============================================================
                    MESH PARAMETERS
============================================================
  number of horizontal nodes = 33
  number of vertical nodes   = 60
  Total Horizontal Distance  = 904894.259656
  Total Vertical Distance    = 358330.000000
============================================================
============================================================
               REGULARIZATION PARAMETERS
============================================================
```

```
   binding offset       = 0.0
   number layers        = 55
   number of parameters = 498
   number of free param = 498
=====================================================
Wrote Mesh file to C:/tmp/Occam2D_inv\Occam2DMesh
Wrote Regularization file to C:/tmp/Occam2D_inv\Occam2DModel
Wrote Occam2D startup file to C:/tmp/Occam2D_inv\Occam2DStartup
```

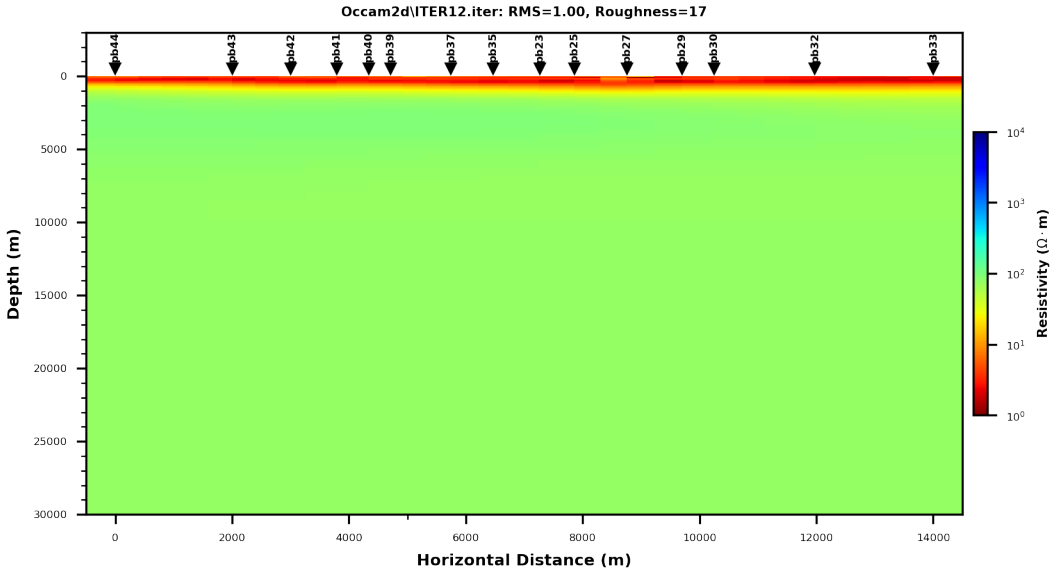
Now that you have created the required inputs, you can run Occam2d on your files. Once you have done this, the following script can then be used to visualise the outputs as modelled and measured resistivity and phase, together with the 2D model. For this example below, we use some example Occam 2D outputs from the mtpy examples directory.

5.2.2 Viewing the model

```
In [18]: # Import required modules
         from mtpy.modeling.occam2d_rewrite import PlotModel
         import os

         # path to directory containing inversion files
         idir = r'C:/mtpywin/mtpy/examples/model_files/Occam2d'
         savepath = r'C:/tmp'

         # iteration and response files
         iterfile = 'ITER12.iter'
         datafn = 'OccamDataFile.dat'

         # define file paths
         pltm = PlotModel(iter_fn=os.path.join(idir,iterfile),
                     data_fn=os.path.join(idir,datafn),
                     station_font_pad = 2.5, # pad (in plot units) between station
                                             # symbol and station label
                     station_font_size = 4, # station font size
                     station_font_rotation = 90, # rotation of the station font
                     font_size=4, # font size to use
                     climits=(0,4), # colour scale limits
                     cb_shrink= 0.3, # controls the size of the colorbar
                     xpad=0.5, # pad (in km) either side of profile
                     yscale = 'm', # 'm' or 'km'
                     yminorticks = 1.,
                     dpi=300, # resolution of figure
                     fig_aspect = 0.25,    # aspect ratio between horizontal
                                           # and vertical scale
                     ylimits = (-2,30), # depth limits
                     stationid=(-1,3)) # index of station name to plot
```

```
        # save the model
        pltm.save_figure(os.path.join(savepath,'model.png'))
```

```
Reading from C:/mtpywin/mtpy/examples/model_files/Occam2d\OccamDataFile.dat
    profile_angle = 97.0
    geoelectric_strike = 7.0
    number of sites = 15
    number of frequencies = 19
```




```
Saved figure to: C:/tmp\model.png
```

```
<Figure size 432x288 with 0 Axes>
```

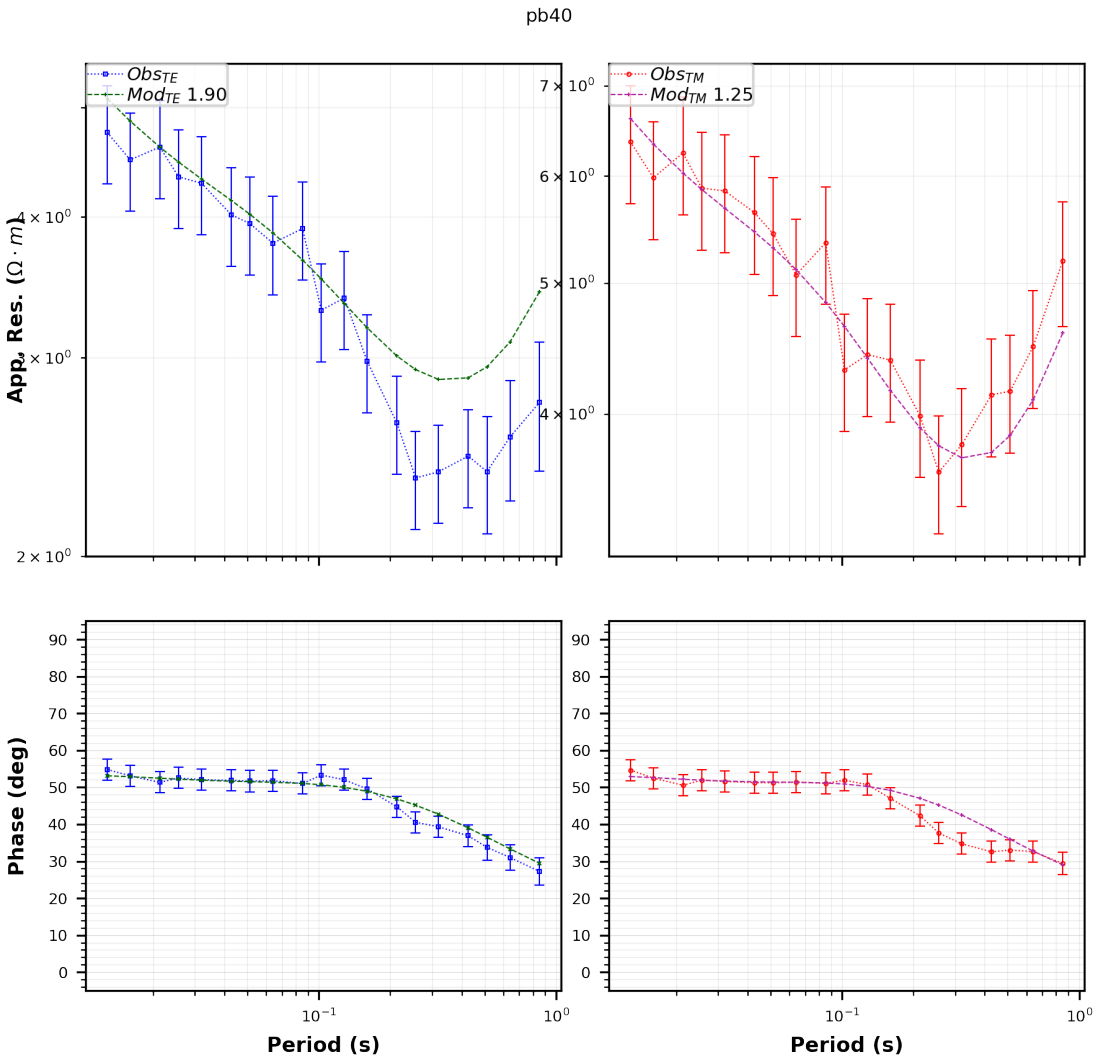
5.2.3 Viewing the responses

Below is a simple example of plotting a response from a single station from an Occam 2D inversion. See the documentation pages for the Occam 2d mtpy modules for more details.

```
In [27]: # Import required modules
         from mtpy.modeling.occam2d_rewrite import PlotResponse
         import os

         # path to directory containing inversion files
         idir = r'C:/mtpywin/mtpy/examples/model_files/Occam2d'
```

```
        # data and response files
        datafn = 'OccamDataFile.dat'
        respfile = 'RESP12.resp'

        # plot response
        pr = PlotResponse(os.path.join(idir,datafn),
                          resp_fn = os.path.join(idir,respfile),
                          plot_type=['pb40'] # either a list of stations to plot
                                             # or '1' to plot all stations
                          )
        pr.save_figures(os.path.join(savepath,'Occam2dresponses'),
                        fig_fmt='png')
```

```
Reading from C:/mtpywin/mtpy/examples/model_files/Occam2d\OccamDataFile.dat
    profile_angle = 97.0
    geoelectric_strike = 7.0
    number of sites = 15
    number of frequencies = 19
```




```
saved figure to C:/tmp\Occam2dresponses\pb40_resp.png
```

5.3 ModEM

5.3.1 Creating Inputs

The example below demonstrates how to set up input files for 3D inversion using the ModEM inversion code (Egbert and Kelbert 2012; Kelbert et al. 2014; http://blogs.oregonstate.edu/modem3dmt/).

The ModEM code has three compulsory input files:

- Model file - contains information on the mesh size and starting resistivity
- Data file - contains the impedance tensor and tipper data at each frequency and station locations

- Covariance file - contains model covariance parameters, which control smoothing

Data file The data file needs to be created before any of the other files can be made. This is because the data file reads the station locations, and these are then used to create a grid centred on the stations. There are a number of different parameters you can vary - see the comments next to each line when creating the data object. You need to check these are correct - MTPy assumes you know what you are doing and will not give you an error if you choose the wrong projection, for example.

```
In [2]: import os
        from mtpy.modeling.modem import Data
        from mtpy.core.edi import Edi
        from mtpy.utils.calculator import get_period_list
        import numpy as np

        # path to save to
        workdir = r'C:/tmp/ModEM_inv'

        # make the save path if it doesn't exist
        if not os.path.exists(workdir):
            os.mkdir(workdir)

        # path containing edi files
        edipath = r'C:/mtpywin/mtpy/examples/data/edi_files_2'

        # find all files in edipath
        edi_list = [os.path.join(edipath,ff) for ff in os.listdir(edipath) if \
                    (ff.endswith('.edi'))]

        # define period list to interpolate data onto
        # MTPy will not extrapolate outside the data period range
        # this code gets 4 periods per decade
        period_list = get_period_list(1e-4,3e3,4)

        # create a data object
        do = Data(edi_list=edi_list,
                  inv_mode = '1', # invert for Z + tipper ('2' means Z only)
                  save_path=workdir,
                  period_list=period_list,
                  period_buffer=2., # buffer factor to determine how far to interpolate
                                    # between points. 2 means interpolate by a factor of
                                    # 2. e.g. if the data is at 10s the code will
                                    # interpolate only from 5 to 20 s.
                  error_type_z='floor_egbert', # error type (egbert is % of sqrt(zxy*zyx))
                  error_value_z=5., # error floor in percent
                  error_type_tipper = 'floor_abs', # type of error to set in tipper,

                                                   # floor_abs is an absolute value set
```

```
                                                # as a floor
                    error_value_tipper=0.01,
                    model_epsg=28354 # model epsg, currently set to utm zone 54.
                                     # See http://spatialreference.org/ to
                                     # find the epsg code for your projection
                         )
        # write data file, setting elevation to zero as we haven't added topography
        do.write_data_file()

        # save epsg code and centre position to a text file
        np.savetxt(os.path.join(workdir,'center_position.txt'),
                   np.array([do.center_point['east'],
                             do.center_point['north']]))
        np.savetxt(os.path.join(workdir,'epsg.txt'),[do.model_epsg])

If you want to write a vtk file for 3d viewing, you need download and install evtk from https://
Note: if you are using Windows you should build evtk first witheither MinGW or cygwin using the
    python setup.py build -compiler=mingw32  or
    python setup.py build -compiler=cygwin
If you want to write a vtk file for 3d viewing, you need to install pyevtk
Note: if you are using Windows you should build evtk first witheither MinGW or cygwin using the
    python setup.py build -compiler=mingw32  or
    python setup.py build -compiler=cygwin
If you want to write a vtk file for 3d viewing, you need download and install evtk from https://


If you want to write a vtk file for 3d viewing, you need download and install evtk from https://


If you want to write a vtk file for 3d viewing, you need to pip install PyEVTK: https://bitbucke
Note: if you are using Windows you should build evtk first witheither MinGW or cygwin using the
    python setup.py build -compiler=mingw32  or
    python setup.py build -compiler=cygwin
-------------------------------------------------
Inverting for periods:
     0.000100
     0.000178
     0.000316
     0.000562
     0.001000
     0.001778
     0.003162
     0.005623
     0.010000
     0.017783
     0.031623
     0.056234
     0.100000
```

```
     0.177828
     0.316228
     0.562341
     1.000000
     1.778279
     3.162278
     5.623413
     10.000000
     17.782794
     31.622777
     56.234133
     100.000000
     177.827941
     316.227766
     562.341325
     1000.000000
     1778.279410
     3162.277660
--------------------------------------------------


C:\mtpywin\mtpy\mtpy\utils\calculator.py:308: RuntimeWarning: invalid value encountered in doubl
  z_rel_err = error/z_amp


2018-09-21T13:56:31 - Data - INFO - Wrote ModEM data file to C:/tmp\ModEM_Data.dat
```

Model file Once the data file has been created, we now create the model file. MTPy creates a grid that covers the stations with the provided cell size. You can update parameters like cell size, target depth, padding parameters, and first layer thickness as described below.

Once the model is created, we then add topography. In the example below we will use etopo1 topography/bathymetry data downloaded from https://www.ngdc.noaa.gov/mgg/global/.

After topography is added to the model, we then need to change the station elevations so that the stations sit on the topography.

```
In [3]: from mtpy.modeling.modem import Model

        # create a Model object
        mo = Model(station_locations=do.station_locations,
                       cell_size_east=8000,
                       cell_size_north=8000,
                       pad_north=7, # number of padding cells N and S
                       pad_east=7,# number of padding cells E and W
                       pad_z=6, # number of vertical padding cells
                       pad_num=6, # number of cells outside station area before padding
                       pad_stretch_v=1.6, # increase factor in padding cells (vertical)
                       pad_stretch_h=1.9, # increase factor in padding cells (horizontal)
```

```
                        n_air_layers = 10, # number of air layers
                        res_initial_value=100, # halfspace resistivity value
                                               # for reference model (ohm-m)
                        n_layers=100, # total number of z layers, including air
                        z1_layer=50, # first layer thickness
                        pad_method='stretch', # method for calculating padding
                        z_target_depth=300000 # approx. depth to bottom of core model
                                              # (padding after this depth)
                        )

        mo.make_mesh()
        mo.write_model_file(save_path=workdir)

        ## add topography to the model and rewrite
        topo_file = r'C:/mtpywin/mtpy/examples/data/AussieContinent_etopo1.asc'
        mo.add_topography_to_model2(topo_file)
        mo.write_model_file(save_path=workdir)

        # project the stations on the topography
        do.project_stations_on_topography(mo)

---------------
        Number of stations = 28
        Dimensions:
                e-w = 87
                n-s = 73
                z  = 101 (without 7 air layers)
        Extensions:
                e-w = 2147600.0 (m)
                n-s = 2035600.0 (m)
                0-z = 1188110.0 (m)
        Stations rotated by: 0.0 deg clockwise positive from N

 ** Note ModEM does not accommodate mesh rotations, it assumes
    all coordinates are aligned to geographic N, E
    therefore rotating the stations will have a similar effect
    as rotating the mesh.
---------------
 Elevation data type and shape  ***  <type 'numpy.ndarray'> (72L, 86L) 72 72
---------------------------------------------------
Inverting for periods:
     0.000100
     0.000178
     0.000316
     0.000562
     0.001000
     0.001778
     0.003162
```

```
      0.005623
      0.010000
      0.017783
      0.031623
      0.056234
      0.100000
      0.177828
      0.316228
      0.562341
      1.000000
      1.778279
      3.162278
      5.623413
      10.000000
      17.782794
      31.622777
      56.234133
      100.000000
      177.827941
      316.227766
      562.341325
      1000.000000
      1778.279410
      3162.277660
--------------------------------------------------
2018-09-21T13:56:59 - Data - INFO - Wrote ModEM data file to C:/tmp\ModEM_Data.dat


Out[3]: ([16,
          18,
          20,
          22,
          24,
          26,
          28,
          30,
          32,
          34,
          36,
          38,
          40,
          42,
          44,
          46,
          48,
          50,
          52,
          54,
```

```
 55,
 57,
 59,
 61,
 63,
 65,
 67,
 69],
[55,
 53,
 52,
 50,
 49,
 47,
 46,
 44,
 43,
 41,
 40,
 38,
 37,
 35,
 34,
 32,
 31,
 29,
 28,
 26,
 25,
 23,
 22,
 20,
 19,
 17,
 16,
 14])
```

The final step is to create a covariance file, which provides information on the location of free vs fixed parameters, and smoothing. The covariance file is created based on the model file we generated in the previous step.

```
In [4]: from mtpy.modeling.modem import Covariance

        # create a covariance file
        co = Covariance()
        co.smoothing_east = 0.6
        co.smoothing_north = 0.6
        co.smoothing_z = 0.6
        co.write_covariance_file(model_fn=mo.model_fn)
```

```
    -1017800.000     -1073800.000         -473.000

    0.000

Reading C:/tmp\ModEM_Model_File.rho
```

5.3.2 Viewing outputs

Once you've run ModEM there are quite a few functions available to look at model outputs. Alternatively, you can use MTPy to write the model to a Gocad sgrid format and use Gocad to interrogate the model.

Resistivity model slice The first function we demonstrate is how to plot a ModEM depth slice. Note that this function has an option for interactive plotting if you run it as a script and set plot_yn to 'y'. Here we will just use static plotting.

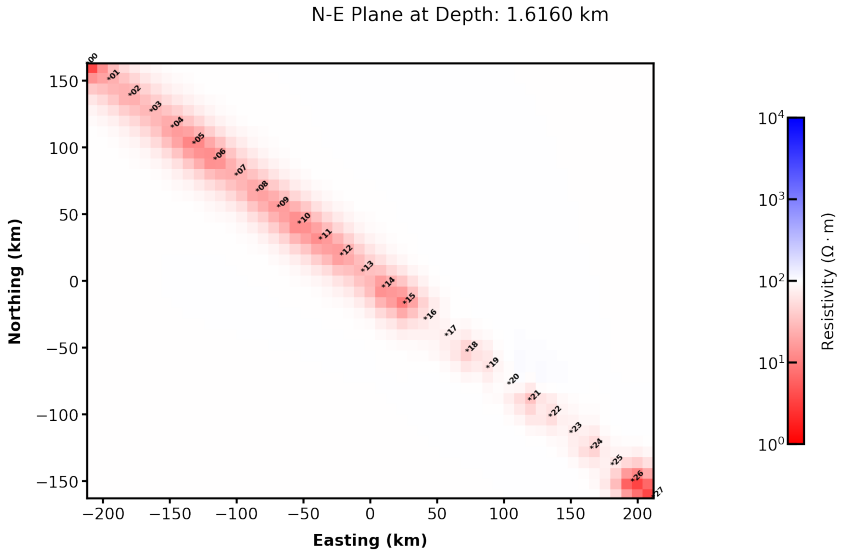
```
In [9]: import os
        from mtpy.modeling.modem import PlotSlices

        wd = r'C:/mtpywin/mtpy/examples/model_files/ModEM_2'

        savepath = r'C:/tmp'

        model_fn = os.path.join(wd,'Modular_MPI_NLCG_004.rho')
        data_fn = os.path.join(wd,'ModEM_Data.dat')

        pObj = PlotSlices(model_fn=model_fn,
                data_fn=data_fn,
                save_path=wd,
        #        climits  = [0,2], # log10(colour limits)
                cmap='bwr_r', # colour map
                plot_stations=True, # True/False - show station locations or not
                station_id=[5,8], # indices (start,finish) of station label to plot
        #        ew_limits=[-220,220], # east-west limits, if not provided
        #                              # will auto calculate from data
        #        ns_limits=[-170,170], # north-south limits, if not provided
        #                              # will auto calculate from data
                font_size=6, # font size on plots
                fig_size=(6,3), # figure size
                plot_yn='n', # whether to load interactive plotting
                fig_dpi = 400 # change to your preferred file resolution
                          )

        pObj.save_path = savepath
        pObj.export_slices(plane='N-E', # options are 'N-Z', 'E-Z', and 'N-E'
                           indexlist=[32], # slice indices to plot
                           station_buffer=20e3, # distance threshold for plotting
```

```
                                                    # stations on vertical slice
                          save=True,
                          )
```

```
     -386800.000      -442800.000           0.000

    0.000
```

```
2018-10-02T10:29:12 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
=============== ================================================
    Buttons                  Description
=============== ================================================
     'e'          moves n-s slice east by one model block
     'w'          moves n-s slice west by one model block
     'n'          moves e-w slice north by one model block
     'm'          moves e-w slice south by one model block
     'd'          moves depth slice down by one model block
     'u'          moves depth slice up by one model block
=============== ================================================
Exporting C:/tmp\N-E-plane-at-Depth032.1.616.km.png..
```

```
Out[9]: ([<Figure size 2400x1200 with 2 Axes>],
         ['C:/tmp\\N-E-plane-at-Depth032.1.616.km.png'])
```



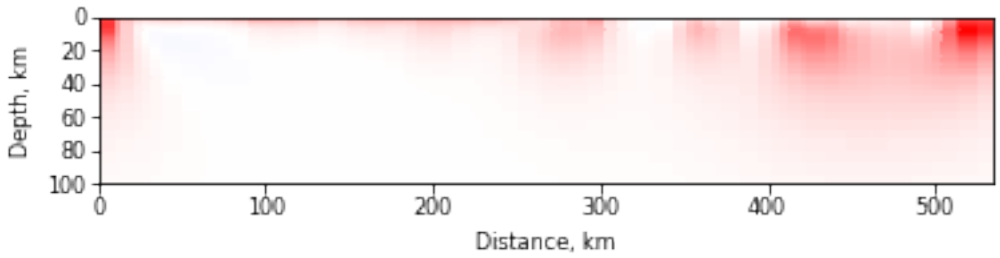
Plot model along arbitrary profile The example below shows how to plot stations along an arbitrary profile, which is particularly useful in the case where you may have run a 3D model on 2D profile data. Please see the code below for parameters that can be varied.

In [17]:
```
import os

import matplotlib.pyplot as plt
from matplotlib import colors
import numpy as np

from mtpy.modeling.modem import PlotSlices

# working directory and save path
wd = r'C:/mtpywin/mtpy/examples/model_files/ModEM_2'
savepath = r'C:/tmp'

# model and data file names
model_fn = os.path.join(wd,'Modular_MPI_NLCG_004.rho')
data_fn = os.path.join(wd,'ModEM_Data.dat')
fs = 8 # fontsize on plot

# create a PlotSlices object
ps = PlotSlices(model_fn=model_fn,
                data_fn=data_fn,
                save_path=wd,
                plot_yn='n')

# create a new figure
fig = plt.figure(figsize=[6,3])
ax = plt.subplot(111)

# get resistivity data along a slice defined by the stations
gd, gz, gv = ps.get_slice("STA",
                          nsteps=200 # total number of cells across
                         )
## to get resistivity along an arbitrary profile
## (in this case stations 5 to 9)
## xy locations
#coords = np.vstack([ps.station_east[5:10],ps.station_north[5:10]]).T
#gd, gz, gv = ps.get_slice("XY", nsteps=50, coords=coords)

ci = ax.pcolormesh(gd, gz, gv,
                vmin=1,vmax=1e4, # min & max resistivity on colour map
                norm=colors.LogNorm(), # plot colours on a log scale
                 cmap='bwr_r', # colour map
                 rasterized=True)

# set some plot parameters and add labels
ax.invert_yaxis()
ax.set_aspect(1)
ax.set_ylim(1e2)
plt.setp(ax.get_xticklabels(),fontsize=fs)
```

```
        plt.setp(ax.get_yticklabels(),fontsize=fs)
        plt.xlabel('Distance, km',fontsize=fs)
        plt.ylabel('Depth, km',fontsize=fs)

        plt.savefig(os.path.join(savepath,'DepthSlice.png'),
                    dpi=400) # change to your desired figure resolution
```

```
     -386800.000      -442800.000           0.000

    0.000
```

```
2018-10-02T10:56:38 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
============== ================================================
    Buttons                  Description
============== ================================================
     'e'          moves n-s slice east by one model block
     'w'          moves n-s slice west by one model block
     'n'          moves e-w slice north by one model block
     'm'          moves e-w slice south by one model block
     'd'          moves depth slice down by one model block
     'u'          moves depth slice up by one model block
============== ================================================
```

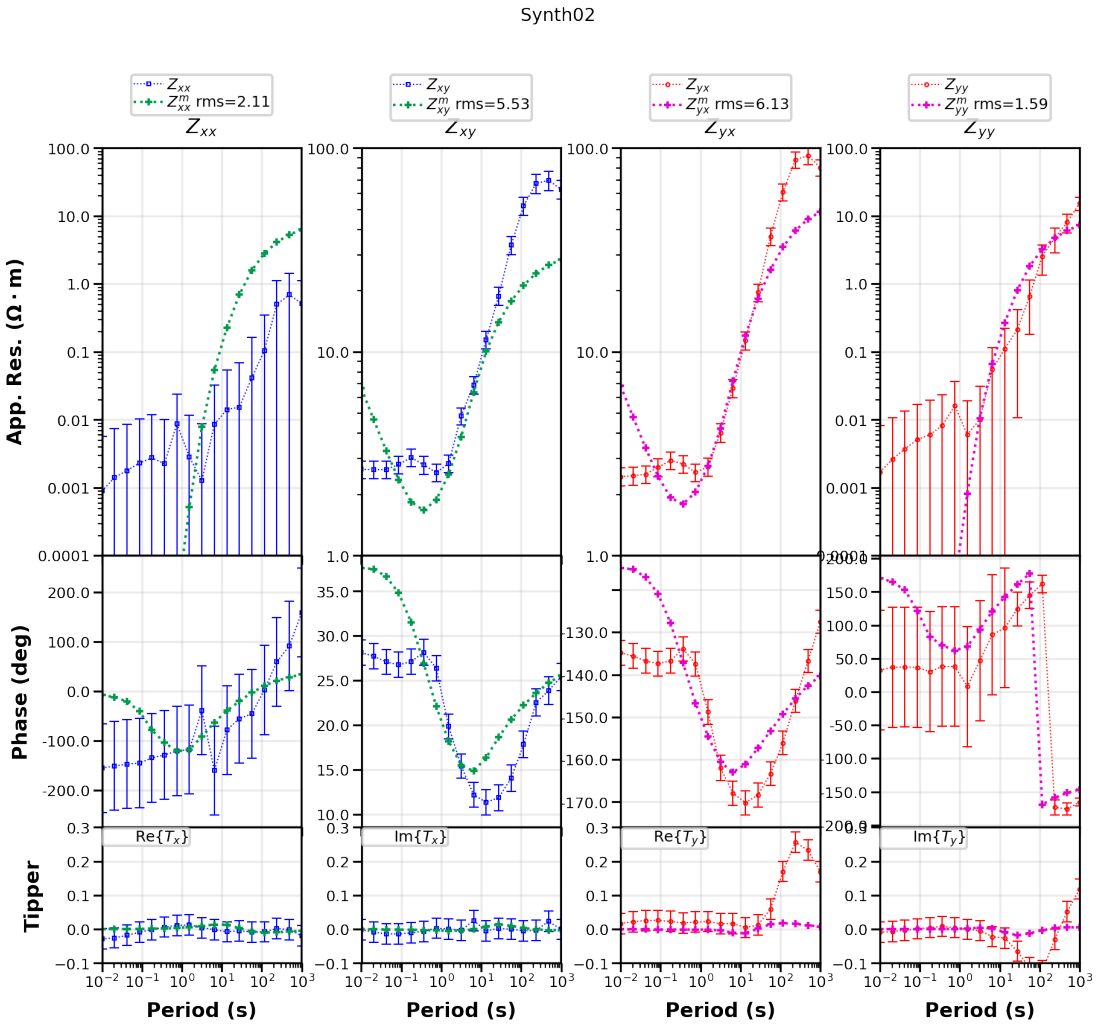


Data and model response The example below shows how to plot the data together with the model response at one or more stations.

```
In [27]: import os
         from mtpy.modeling.modem import PlotResponse

         # working directory and save path
         wd = r'C:/mtpywin/mtpy/examples/model_files/ModEM_2'
         savepath = r'C:/tmp'

         # response and data files
         respfn = 'Modular_MPI_NLCG_004.dat'
```

```
datafn = 'ModEM_Data.dat'

# make a plot object
ro = PlotResponse(data_fn=os.path.join(wd,datafn),
                  resp_fn=os.path.join(wd,respfn),
                  plot_type=['Synth02'], # provide a list of station names
                                         # or '1' to plot all stations
                  plot_style=1,  # 1 for 4-colums; 2 for 2-columns
                  plot_z=False,
                  )
ro.plot()

ro.save_figure(os.path.join(savepath,'response.png'),
               fig_dpi=400) # change fig_dpi to your desired resolution
```

```
2018-10-02T11:39:29 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
2018-10-02T11:39:30 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
Plotting: Synth02
self.plot_tipper = True
```



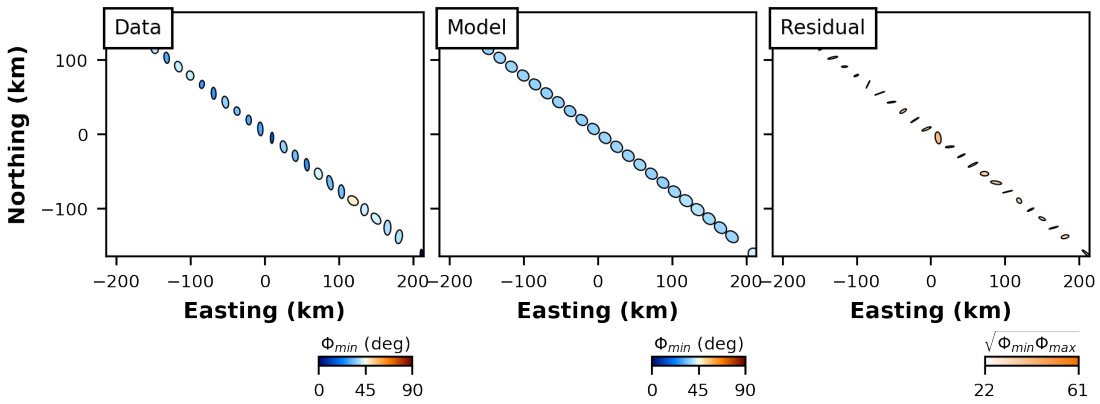
Saved figure to: C:/tmp\response.png

Phase tensor plots This example shows how to plot model and response phase tensors for a specified frequency, as a map. Depending on what inputs you provide, you can plot the data, model response, and the residual phase tensor, which is a measure of the difference between the data and model response.

```
In [3]: import os
        from mtpy.modeling.modem.phase_tensor_maps import PlotPTMaps


        workdir = r'C:/mtpywin/mtpy/examples/model_files/ModEM_2'
        savepath= r'C:/tmp'
```

```
ptmap = PlotPTMaps(data_fn=os.path.join(workdir, 'ModEM_Data.dat'),
            resp_fn=os.path.join(workdir, 'Modular_MPI_NLCG_004.dat'),
            cb_pt_pad=0.0, # y position of colorbar on plot
            fig_size=(6,2.5),
            ellipse_dict =  {'size': 20,
                             'ellipse_range':[0, 90],
                             'ellipse_colorby':'phimin',
                             'ellipse_cmap':'mt_bl2gr2rd'},
            residual_cmap='mt_wh2or'
            )

for period_index in [16]: # customise which periods to plot
    ptmap.plot(period=period_index, # index of period to plot
               edgecolor='k', # colour for edge of ellipses
               lw = 0.5 # linewidth of edge of ellipses
               )

# save all plots to file
ptmap.save_figure(save_path=savepath,
                  file_format='png',
                  fig_dpi=400) # change to your desired resolution
```

```
('The input parameter period is', 16)
2018-10-02T15:34:07 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
2018-10-02T15:34:08 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N
Plotting Period: 1000
{'edgecolor': 'k', 'lw': 0.5}
```

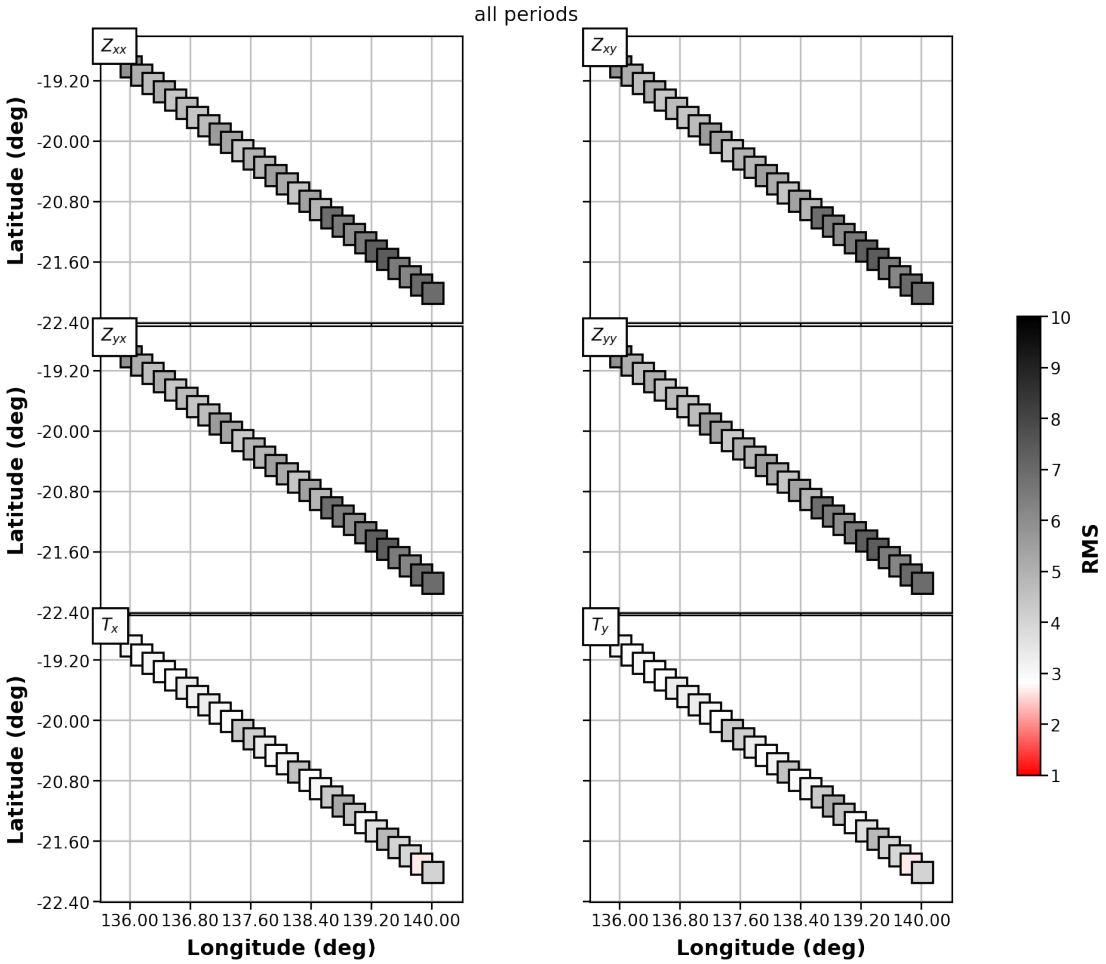



```
Saved figure to: C:/tmp\PT_DepthSlice_images.png
```

RMS maps These functions plot the (normalised) data-model misfit. You can choose an integer value for period_index to plot a particular period, or just specify 'all' to plot the root-mean-square misfit over all periods. The plots are broken up according to component - Z_{XX}, Z_{XY}, Z_{YX}, Z_{YY}, T_X, T_Y.

```
In [38]: import os
         import numpy as np
         from mtpy.modeling.modem import PlotRMSMaps

         wd = r'C:/mtpywin/mtpy/examples/model_files/ModEM_2'
         savepath = r'C:/tmp'

         resid_fn = os.path.join(wd,'Modular_MPI_NLCG_004.res')

         # create a RMS plot object
         probj = PlotRMSMaps(resid_fn,
                             rms_min=1, # min rms for colorbar
                             rms_max=10, # max rms for colorbar
                             period_index='all' # 'all' or integer value
                            )

         # save figure
         probj.save_figure(save_path=savepath,
                           fig_close=False, # whether or not to close figure
                           save_fig_dpi = 400 # change to your preferred figure resolution
                           )
```

```
2018-09-19T12:13:51 - Data - INFO - Set rotation angle to 0.0 deg clockwise from N


C:\mtpywin\mtpy\mtpy\modeling\modem\residual.py:197: RuntimeWarning: invalid value encountered i
  z_norm = np.abs(res_vals['z']) / (np.real(res_vals['z_err']) * 2. ** 0.5)
C:\mtpywin\mtpy\mtpy\modeling\modem\residual.py:211: RuntimeWarning: invalid value encountered i
  tip_norm = np.abs(res_vals['tip']) / (np.real(res_vals['tip_err']) * 2. ** 0.5)
C:\mtpywin\Anaconda2\lib\site-packages\matplotlib\figure.py:459: UserWarning: matplotlib is curr
  "matplotlib is currently using a non-GUI backend, "


saved file to C:/tmp\RMS_AllPeriods.png
```


all periods
Z_{xx}
Z_{xy}
Z_{yx}
Z_{yy}
T_x
T_y
Latitude (deg)
-19.20
-20.00
-20.80
-21.60
-22.40
136.00
136.80
137.60
138.40
139.20
140.00
Longitude (deg)
RMS
10
9
8
7
6
5
4
3
2
1