ModEM Geophysics

Innovating solutions in EM Geophysics

Oregon State University OSU College of Earth, Ocean, and Atmospheric Sciences

Observatório Nacional

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ModEM: A user's guide

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ModEM-Geophysics Inc., OR, USA

Online Eminar talk: 15th May 2021

GFZ Helmholtz-Zentrum Potsdam

Outlines

- Brief introduction on ModEM's structure and the modularity idea
- How to setup ModEM on your server/cluster.
- How to call ModEM with basic options (Forward modelling, Inversion).
- Advanced inversion setting.
- How to perform model resolution studies on your preferred model(s).
- Some examples from few projects on various scales.
- How to control the inversion run (NOT only RMS values) Taking about 3D targets, it is might be NOT appropriate to 2D inversion!

Introduction on ModEM and the Modularity idea

- The modularity idea is already presented in the name: ModEM
- Name Definition: **Mod**ular system for **E**lectro**M**agnetics

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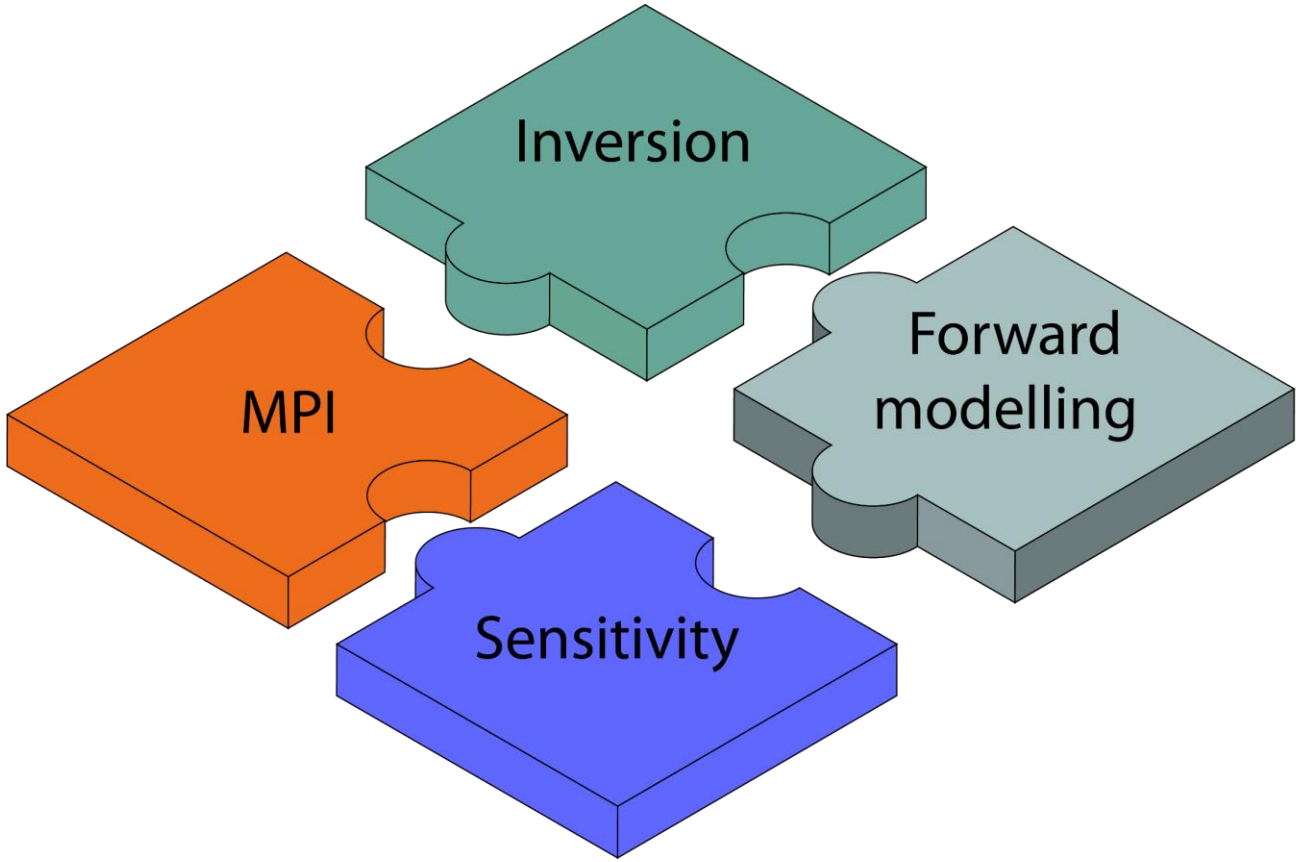
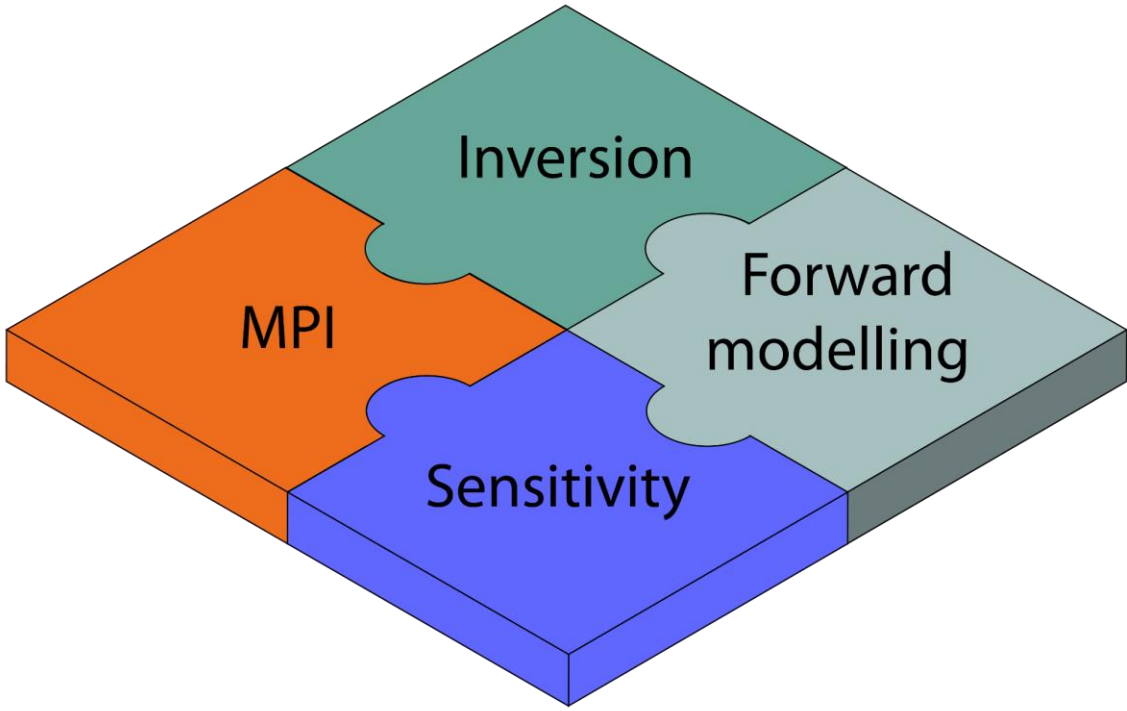
Introduction on ModEM and the Modularity idea



Connect the pieces



Functional code

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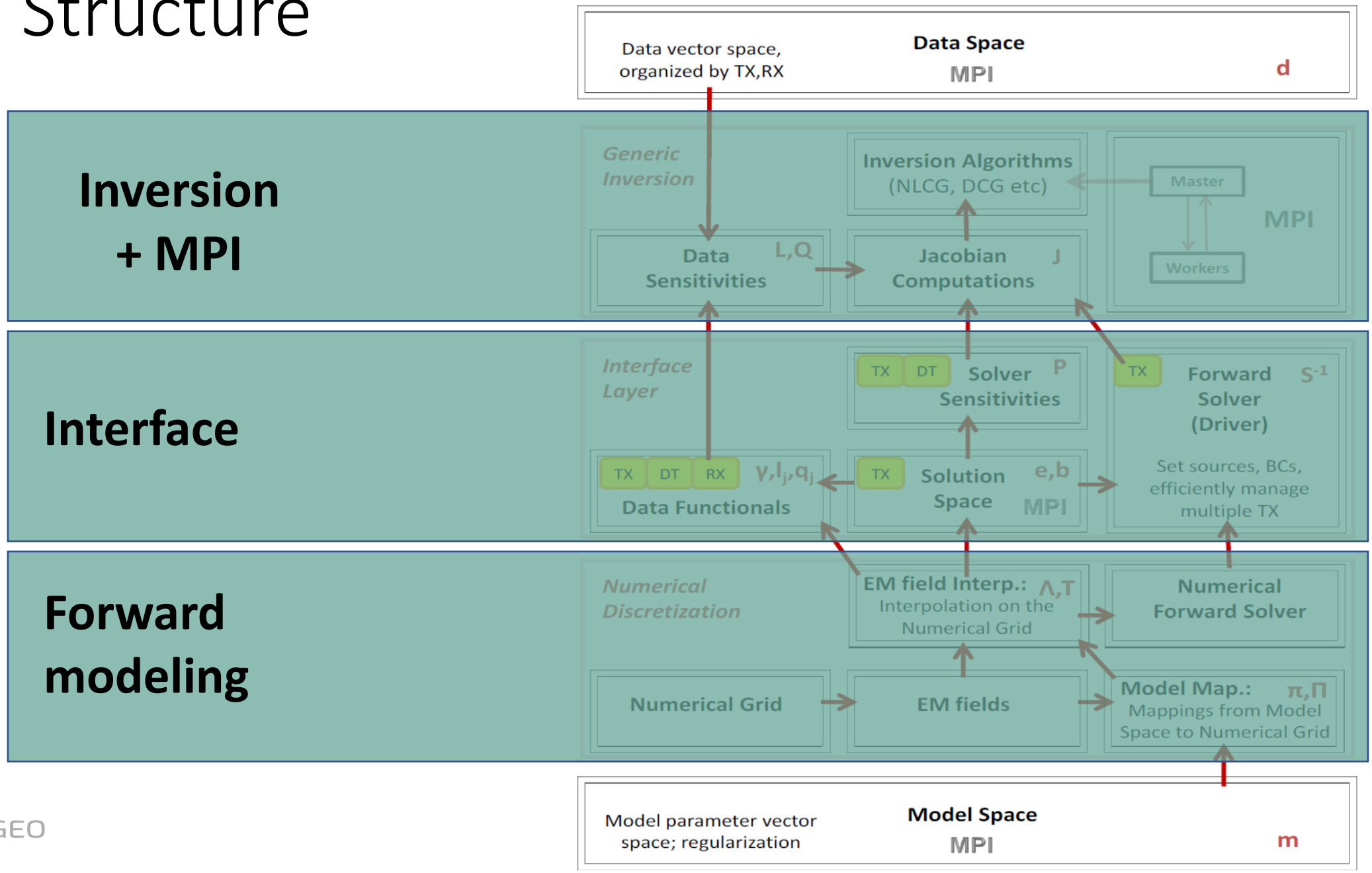
ModEM Structure



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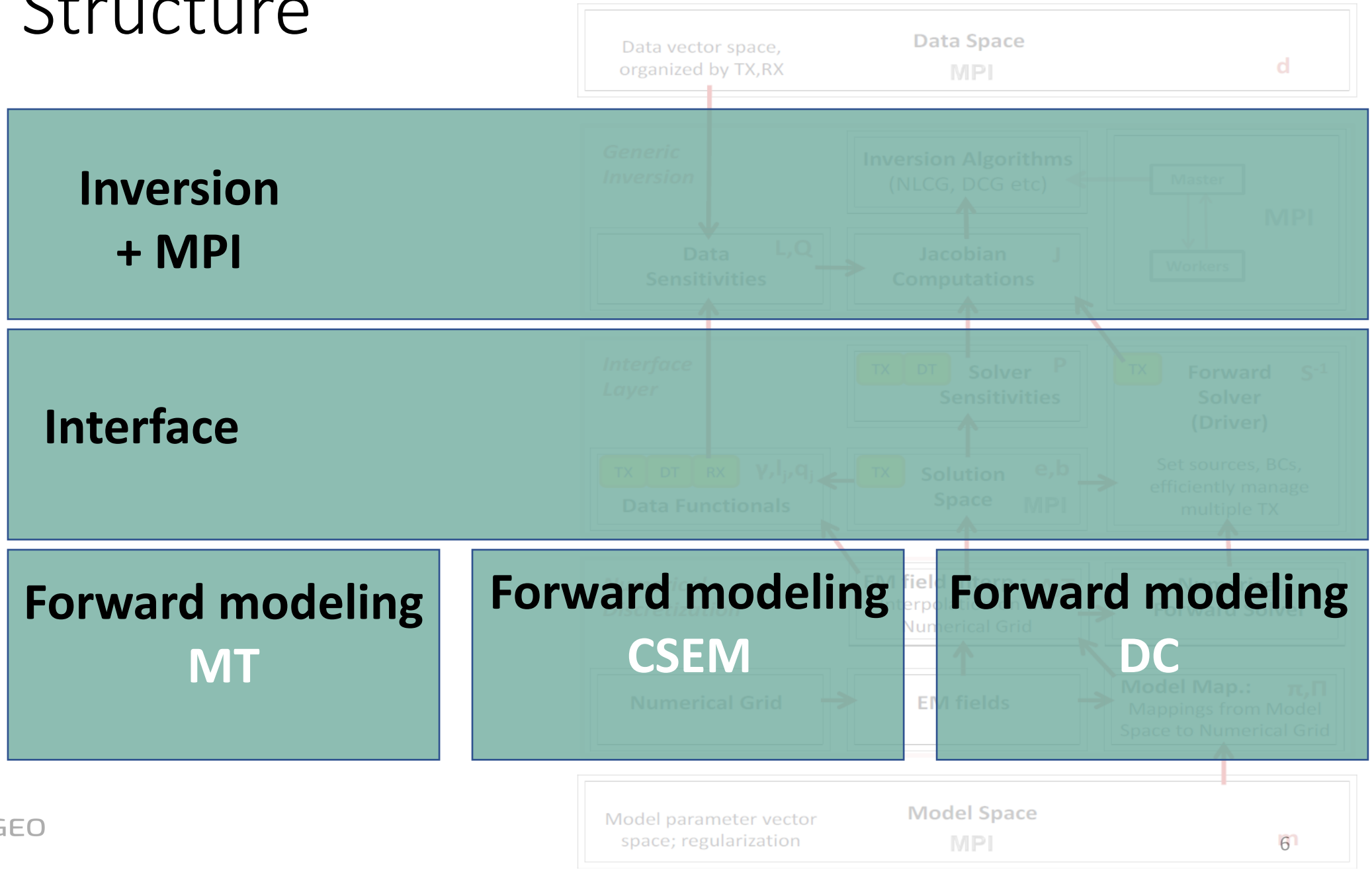
ModEM Structure



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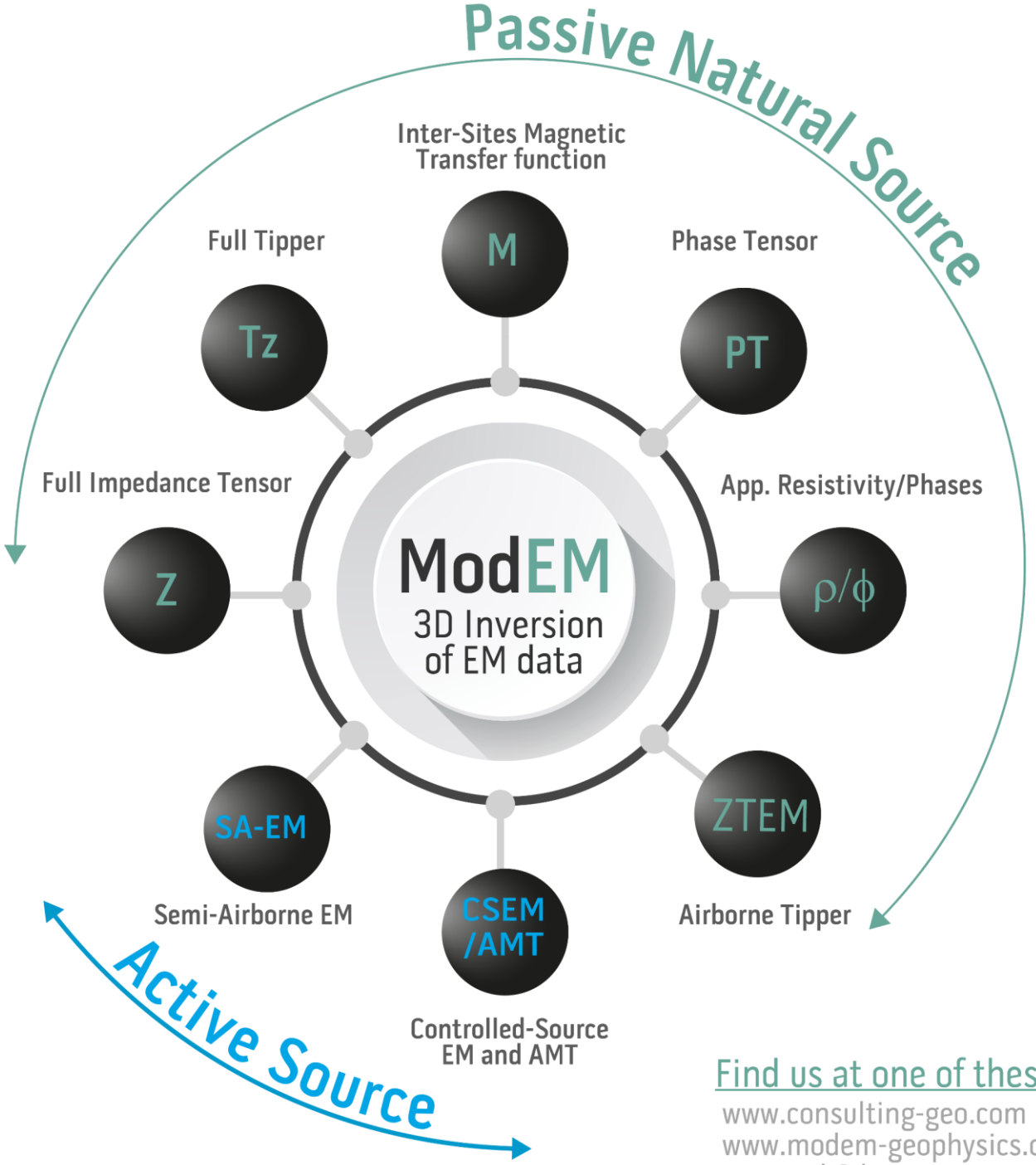
The Modularity of ModEM at a Glance

Further developments include, but limited to:

- Multi-Resolution Grid
- Modified system of Eqs.
- Simple Anisotropy (VTI)
- Joint inversion (EM methods)

Contributions by others:

- General Anisotropy
- Apparent Resistivity Tensors
- … and much more



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Find us at one of these links:
www.consulting-geo.com
www.modem-geophysics.com
www.web3dmt.com

The Modularity of ModEM at a Glance

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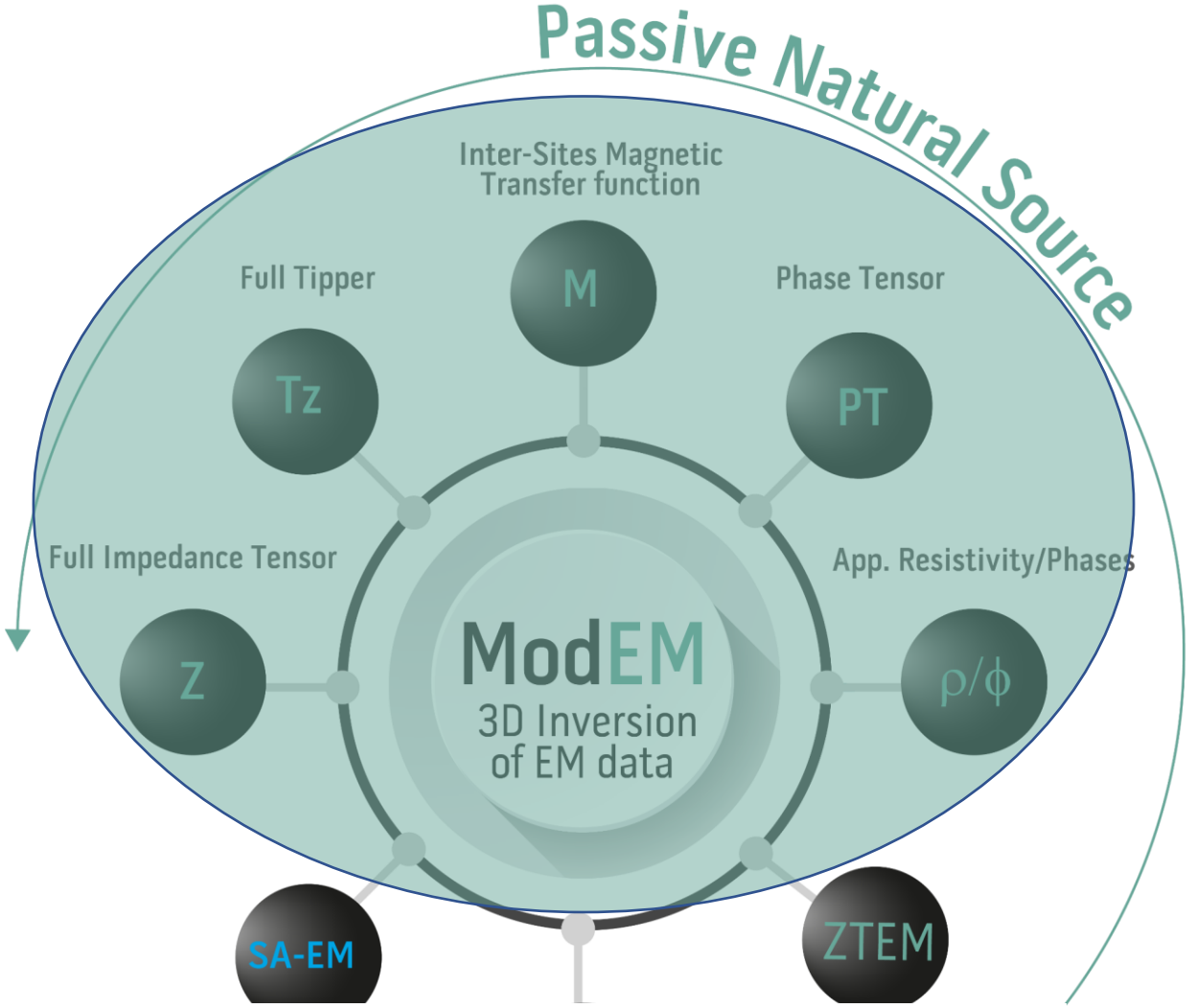

Methods available in the academic version

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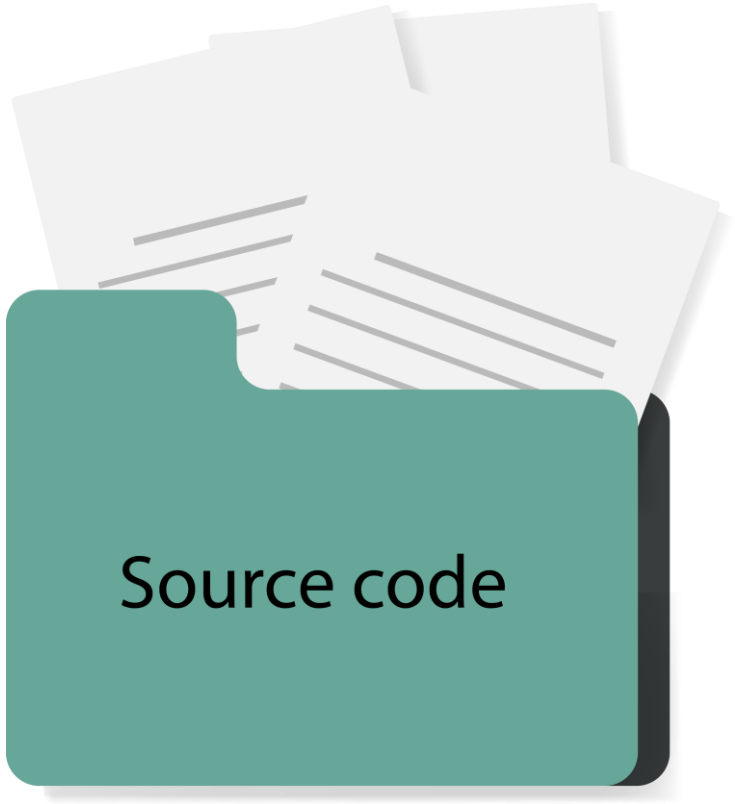
www.web3dmt.com

How to setup ModEM on your server/cluster



Makefile for **GFortran**

Makefile for **PGI**

Makefile for **Intel**

- **Some adjustments might be required to fit within the Linux architect/compiler you have.**
- **Make sure you have MPI installed on your machine**

```
$ make –f MAKEFILE_FOR_YOUR_COMPLIER
```

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How to setup ModEM on your server/cluster

```
# ------------------Macro-Defs----------------------
include Makefile.local
OBJDIR = ./objs/3D_MT/IFortReleaseMPI
F90 = mpif90
FFLAGS =   -O2  -ffree-form -ffree-line-length-300 -m64
MPIFLAGS = -x f95-cpp-input -DMPI
#MODULE = -dir $(OBJDIR)
#LIBS = -llapack -lblas
#LIBS= -L/usr/lib/gcc/x86_64-linux-gnu/4.8/ -lgomp
```

Compiles for MPI version (parallel computing)

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How to setup ModEM on your server/cluster

```
# ------------------Macro-Defs----------------------
include Makefile.local
OBJDIR = ./objs/3D_MT/IFortReleaseMPI
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FFLAGS =   -O2  -ffree-form -ffree-line-length-300 -m64
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#LIBS = -llapack -lblas
#LIBS= -L/usr/lib/gcc/x86_64-linux-gnu/4.8/ -lgomp
```

Compiles for MPI version (parallel computing)

Compiles for serial version

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How to setup ModEM on your server/cluster

The files we share with you include also

- User's manual
- **„Copyrights" agreement**

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How to setup ModEM on your server/cluster

With this you have an executable which you can call:

$ ModEM COMMMAND_LINE

Serial run

$ mpirun –n 10 ModEM COMMMAND_LINE

Parallel run

$$n(number\ of\ CPU's) = \begin{cases} min = 2 \\ max = (2 * \mathbf{Num\_Of\_Per}) + 1 \end{cases}$$

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COMMMAND_LINE

- Flags passed to ModEM to perform a specific task:

- -F → To run the forward modelling on a specific model for a given set of sites positions and periods.
- -I → To run an inversion for a given dataset.
- -C → To apply smoothing (INV/FWD) on a given model.
- -J → To compute the sensitivity matrix.

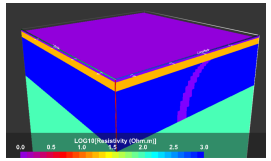
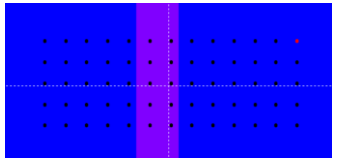
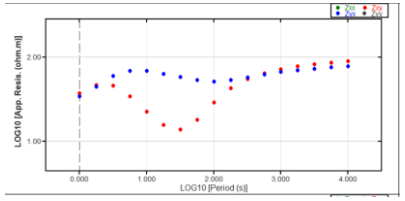
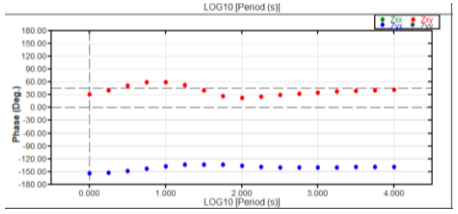
Forward modeling -F

- The command line for calling the forward modeling is:

$ModEM –F

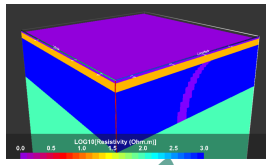
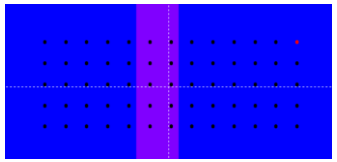
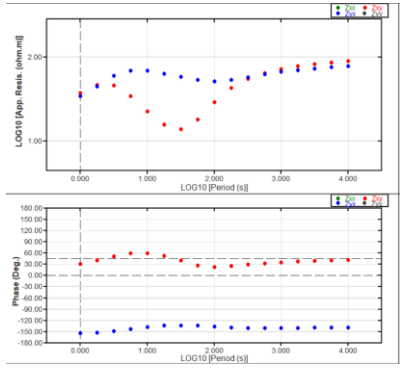
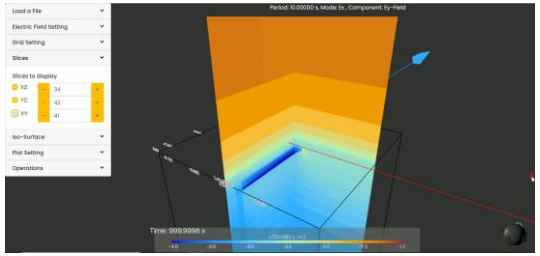
„Basic Input/Output“

Input_Model Input_Data Output_Model_Resp

„Advanced Output“

Input_Model Input_Data Output_Model_Resp [Output_E_solution FWD_para]

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Files formats

- Before start discussing the advanced input/output files, let us take a look at the basic input files used for running the forward modelling and later the inversion.

The model and data files formats

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ModEM (Input/Output)

- **Input_Model** Input_Data

Example: Model file

# of cells in x, y and z directions, and if the resistivity values are LIN or LOGE

```
1   # 3D MT model written by ModEM in WS format
2     78    67    65     0 LOGE
3     12000.000    12000.000
4     17280.000    17280.000
5       200.000      200.000
6
7   3.91439E+01  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E
8   3.91439E+01  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E
9   3.91439E+01  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E
10  3.91439E+01  3.91439E
11  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E
12  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E+01  3.91439E
```

Comments line

Cell dimension (in m) in x direction

Cell dimension (in m) in y direction

Cell dimension (in m) in z direction

LOGE (Resistivity values) for the first z slice

ModEM (Input/Output)

- Input_Model **Input_Data**

Example: Data file

First well know user's problem

Full Impedances data block

```
1  # Description:
2  # Period(s) Code GG_Lat GG_Lon X(m) Y(m) Z(m) Component Real Imag Error
3  > Full_Impedance
4  > exp(+i\omega t)
5  > [mV/km]/[nT]
6  > 0.00
7  > -0.090470 0.035964
8  > 24 420
9  7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  ZXX  -2.484316E-2  -1.913996E-2  8.540510E+0
10 7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  ZXY   6.244343E+1   6.274428E+1  4.270255E+0
11 7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  ZYX  -5.466960E+1  -6.165030E+1  4.270255E+0
12 7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  ZYY   9.671964E-3   3.555606E-2  8.540510E+0
13 1.264910E-01  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  ZXX  -3.710875E-2   3.084892E-2  6.367315E+0
```

Comments lines

Define the data type, sign convention and units

Rotation angle and the Lat/Long of Refe. point

# of periods (max.) and sites

Full vertical magnetic transfer functions data block

```
40329  # Description:
40330  # Period(s) Code GG_Lat GG_Lon X(m) Y(m) Z(m) Component Real Imag Error
40331  > Full_Vertical_Components
40332  > exp(+i\omega t)
40333  > []
40334  > 0.00
40335  > -0.090470 0.035964
40336  > 24 420
40337  7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  TX  3.765835E-02  4.576977E-02  3.000000E-2
40338  7.113100E-02  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  TY  2.501445E-02  -1.148927E-02  3.000000E-2
40339  1.264910E-01  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  TX  2.429581E-02  1.860053E-05  3.000000E-2
40340  1.264910E-01  A01  3.432900  -3.095455  392219.800  -348587.500  0.000  TY  -1.814399E-02  -3.279436E-02  3.000000E-2
```

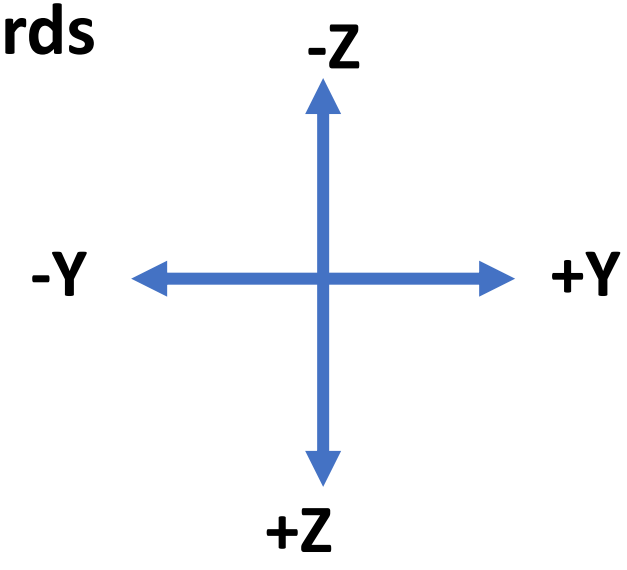
Inversion (Input/Output)

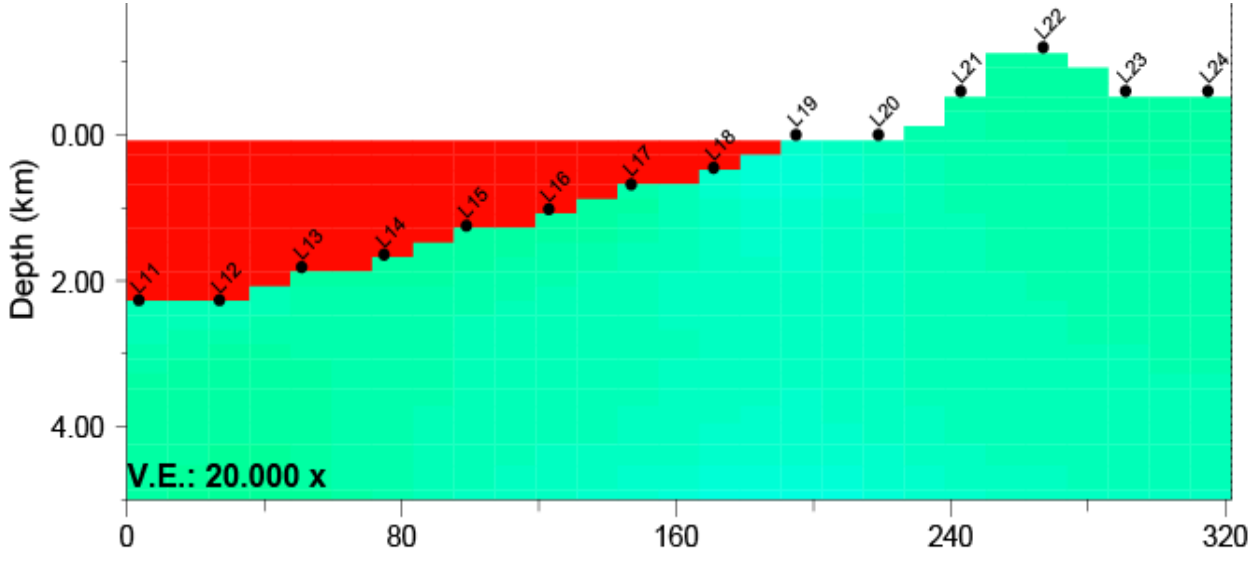
- Input_Model **Input_Data**

Example: Data file

VERY IMPORTANT NOTICE WHEN WORKING WITH TOPO. and/or BATH.

Please keep in mind that the Z-axis is POSITIVE downwards and NEGATIVE upwards





Z position of the site

4.000000E+04	L10	-2.500600	-1.148700	-270004.500	-137999.600	2578.507	ZYY	2.902060E-4	-2.080590E-3	4.449430E-3
1.300000E+01	L11	-2.500400	0.935500	-270004.500	-113999.600	2378.507	ZXX	1.352560E-3	9.605990E-4	4.844900E-1
1.300000E+01	L11	-2.500400	0.935500	-270004.500	-113999.600	2378.507	ZXY	3.176590E+0	3.211830E+0	2.422450E-1
1.300000E+01	L11	-2.500400	0.935500	-270004.500	-113999.600	2378.507	ZYX	-3.558610E+0	-3.786370E+0	2.422450E-1
1.300000E+01	L11	-2.500400	0.935500	-270004.500	-113999.600	2378.507	ZYY	-1.305590E-3	2.974470E-3	4.844900E-1
2.200000E+01	L11	-2.500400	0.935500	-270004.500	-113999.600	2378.507	ZXX	1.931290E-3	4.984020E-4	3.755830E-1

Forward modeling -F

„Advanced Input/Output“

Input_Model Input_Data Output_Model_Resp [Output_E_solution FWD_para]

Output_E_solution (Binary format)

- Is a file in which we store the electric field components (E_x, E_y, E_z) at **all cell edges** for **all periods** and **both polarization**,
- is necessary to perform later e.g., the **nested modeling**.

FWD_para (ASCII format)

- An Ascii file in which we define parameters that control the
- It contains the name of **Output_E_solution** which will be used for the **nested modeling**.

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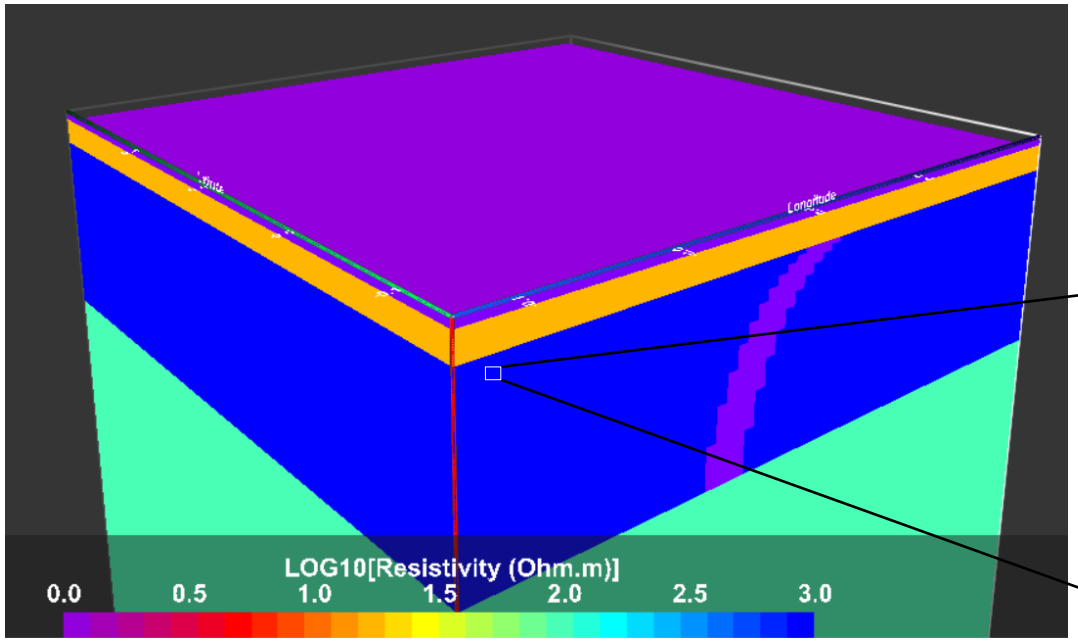
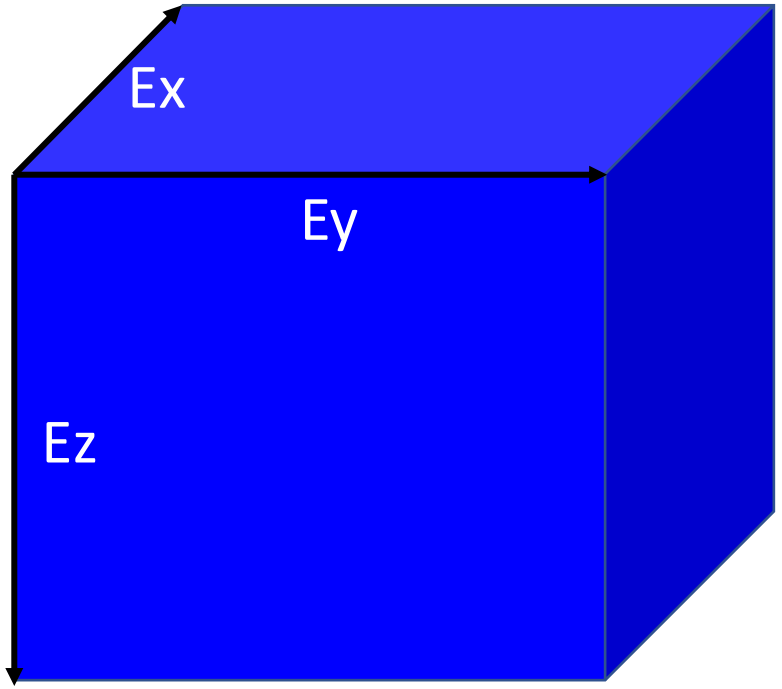
Why the size of E_solution file is too large





Electric field components defined on edges

$$\nabla \times \nabla \times \vec{E} + i\omega\mu\sigma\vec{E} = 0$$

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COMMMAND_LINE

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Inversion -I

- The command line for calling the Inversion is:

$ModEM –I NLCG|DCG| etc.

Basic Input/Output
Input_Model Input_Data

Advanced-level1
Input_Model Input_data Input_INV_para.

Advanced-level2
Input_Model Input_data Input_INV_para. FWD_para.

Advanced-level3
Input_Model Input_data Input_INV_para. FWD_para. Model_Cov

Advanced-level4
Input_Model Input_data Input_INV_para. FWD_para. Model_Cov model_prm

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Inversion process

- Objective function:

$$\varphi = \overbrace{\varphi_d}^{Data\ misfit\ term} + \lambda \underbrace{\varphi_m}_{Constraint\ term}$$

$$\varphi \xrightarrow{minimized} \Delta\mathbf{m}_k$$

$$\mathbf{m}_k = \mathbf{C}_{\boldsymbol{m}}^{-\mathbf{1}}\,\Delta\mathbf{m}_k + \mathbf{m}^{\mathbf{0}} \qquad at\ k^{th}\ NLCG\ iteration$$

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Inversion process

- Objective function:

$$\varphi = \overbrace{\varphi_d}^{Data\ misfit\ term} + \lambda \underbrace{\varphi_m}_{Constraint\ term}$$

$$\varphi \xrightarrow{minimized} \Delta \mathbf{m}_k$$

$$\mathbf{m}_k = \mathbf{C}_{\boldsymbol{m}}^{-\mathbf{1}}\, \Delta \mathbf{m}_k + \mathbf{m}^{\boldsymbol{pre}} \qquad at\ k^{th}\ NLCG\ iteration$$

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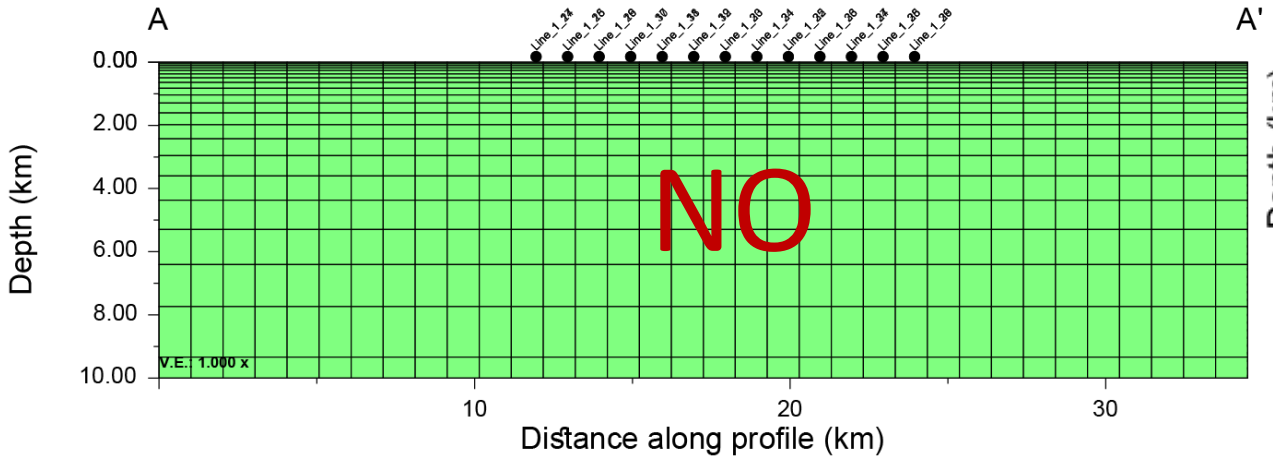
Inversion (Input/Output) → Level 3

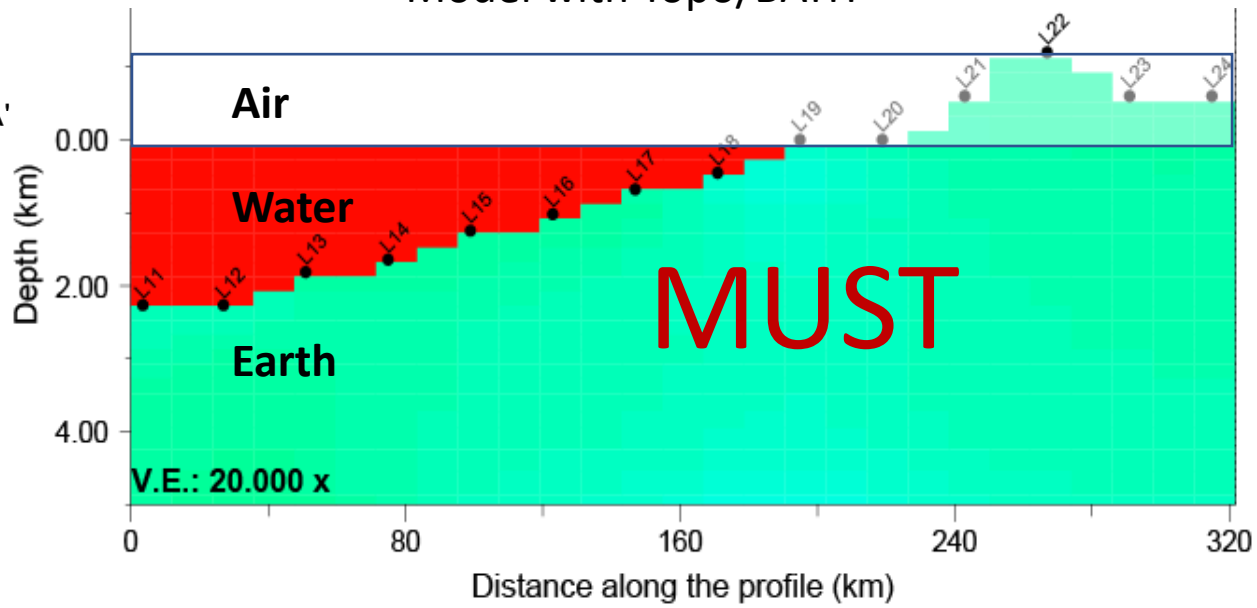
Input_Model Input_data Input_INV_para. FWD_para. **Model_Cov**

The basic question is: **Do I need to use the model covariances file?**

Simple model: No Topo/BATH



Model with Topo/BATH



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Inversion (Input/Output) → Level 3

Input_Model Input_data Input_INV_para. FWD_para. **Model_Cov**

Example: Model_Cov (ASCII Format)

Basically, the model covariance file contains the **indices of each model parameter**. You can index the model parameters by any number; Model parameter with an index of **0 or 9** will be fixed automatically during the inversion, e.g., Air and Water

16 lines header explain the format for the model covariance file.

```
+-----------------------------------------------------------------------------+
| This file defines model covariance for a recursive autoregression scheme.   |
| The model space may be divided into distinct areas using integer masks.     |
| Mask 0 is reserved for air; mask 9 is reserved for ocean. Smoothing between |
| air  ocean and the rest of the model is turned off automatically. You can   |
| also define exceptions to override smoothing between any two model areas.   |
| To turn off smoothing set it to zero. This header is 16 lines long          |
| 1. Grid dimensions excluding air layers (Nx  Ny  NzEarth)                   |
| 2. Smoothing in the X direction (NzEarth real values)                       |
| 3. Smoothing in the Y direction (NzEarth real values)                       |
| 4. Vertical smoothing (1 real value)                                        |
| 5. Number of times the smoothing should be applied (1 integer >= 0)         |
| 6. Number of exceptions (1 integer >= 0)                                    |
| 7. Exceptions in the form e.g. 2 3 0. (to turn off smoothing between 2 & 3) |
| 8. Two integer layer indices and Nx x Ny block of masks  repeated as needed.|
+-----------------------------------------------------------------------------+

88 82 65

0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3
0.3

2

0


1 1
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

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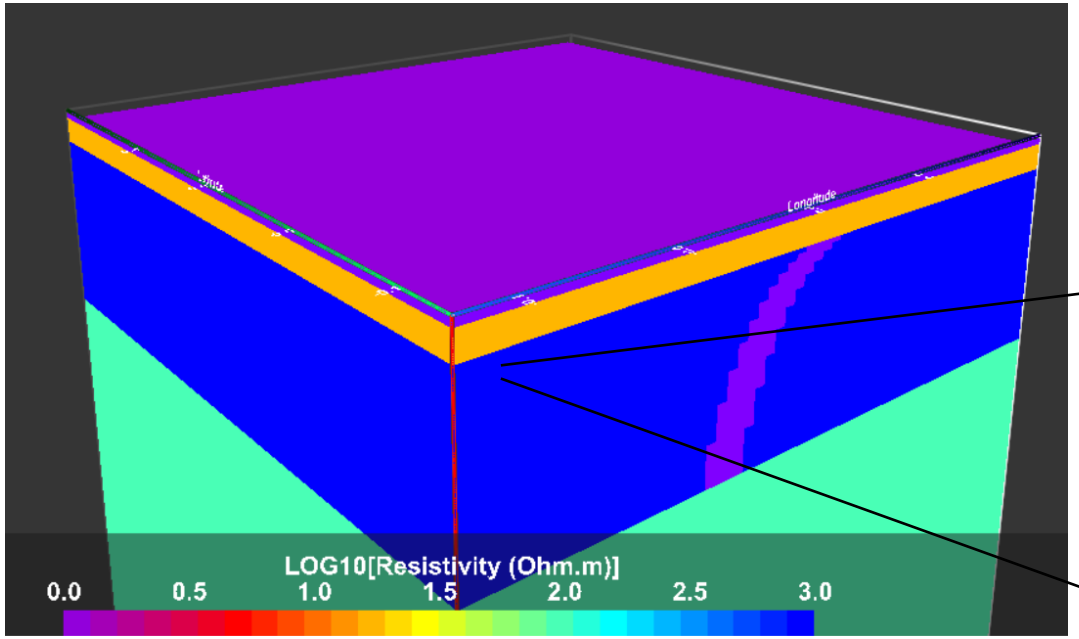
Inversion (Input/Output) → Level 3

Indices and electrical conductivity of each model parameter



Each model parameter has 2 attributes:

- Electrical conductivity value (sigma)
- An index (0 to 9)

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Inversion (Input/Output) → Level 3

Input_Model Input_data Input_INV_para. FWD_para. **Model_Cov**

Example: Model_Cov (ASCII Format)

An important option is located at line # 6 after in the header (line # 26 in this example file).
With this option you can switch off or define a specific smoothing between any two regions in the model domain (key word: **tear zone**)

```
1  +------------------------------------------------------------------------------+
2  | This file defines model covariance for a recursive autoregression scheme.    |
3  | The model space may be divided into distinct areas using integer masks.      |
4  | Mask 0 is reserved for air; mask 9 is reserved for ocean. Smoothing between |
5  | air  ocean and the rest of the model is turned off automatically. You can    |
6  | also define exceptions to override smoothing between any two model areas.    |
7  | To turn off smoothing set it to zero. This header is 16 lines long.          |
8  | 1. Grid dimensions excluding air layers (Nx  Ny  NzEarth)                    |
9  | 2. Smoothing in the X direction (NzEarth real values)                        |
10 | 3. Smoothing in the Y direction (NzEarth real values)                        |
11 | 4. Vertical smoothing (1 real value)                                         |
12 | 5. Number of times the smoothing should be applied (1 integer >= 0)          |
13 | 6. Number of exceptions (1 integer >= 0)                                     |
14 | 7. Exceptions in the form e.g. 2 3 0. (to turn off smoothing between 2 & 3) |
15 | 8. Two integer layer indices and Nx x Ny block of masks  repeated as needed.|
16 +------------------------------------------------------------------------------+
17
18 88 82 65
19
20 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.
21 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.3 0.
22 0.3
23
24 2
25
26 0
27
28
29 1 1
30 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
31 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

Example

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Inversion (Input/Output) → Level 3

Input_Model Input_data Input_INV_para. FWD_para. **Model_Cov**

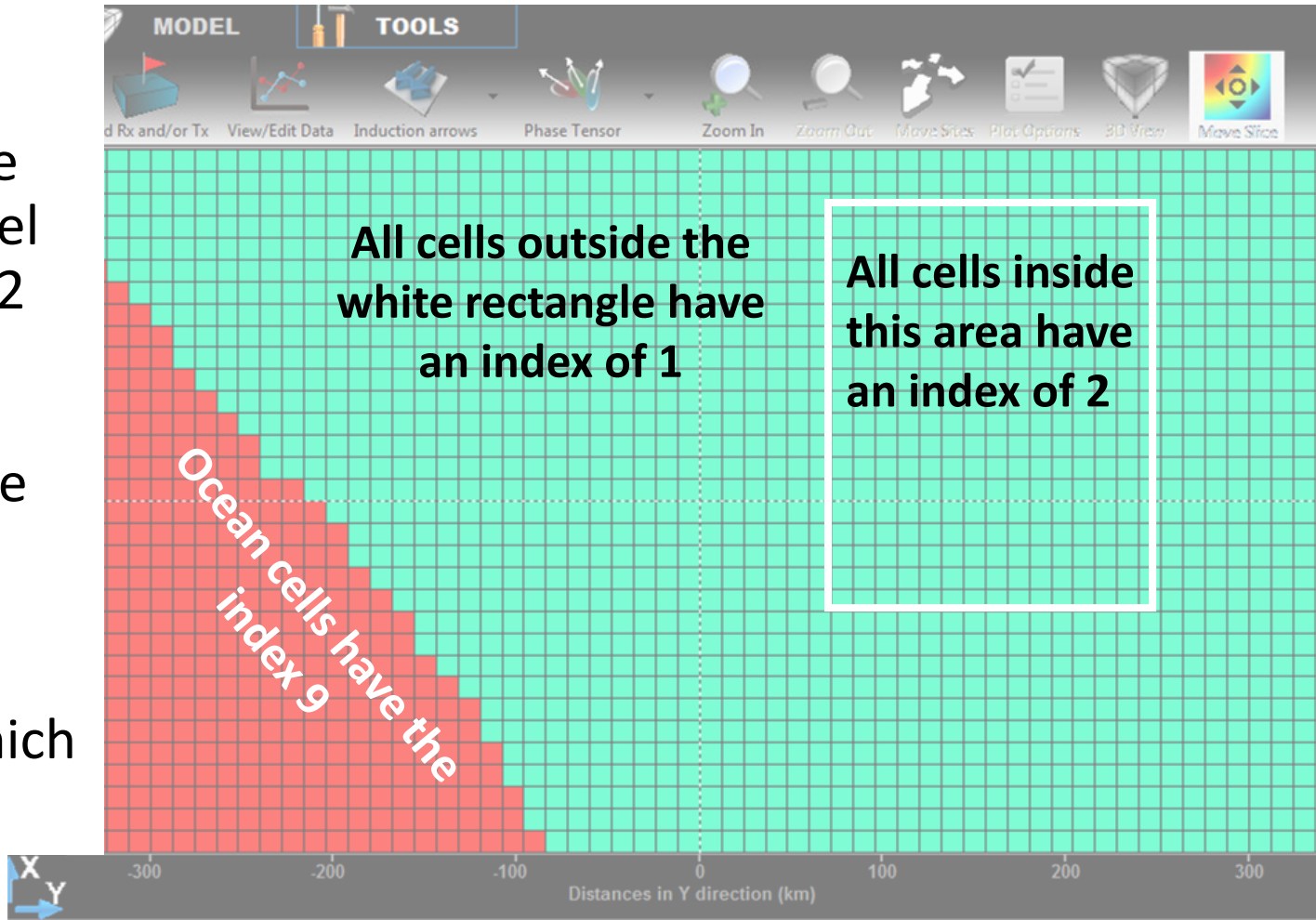
Example: Model_Cov (ASCII Format)

- The ocean cells with an index of 9 are automatically fixed.
- Switching off the smoothing between the highlighted area and the rest of the model parameters. To do that assign the index 2 for all cells located inside the white rectangle.
- At line # 6 in the model covariance file we need to write:

1

1 2 0

This means that we have ONE exception which is switching off smoothing between **1** and **2**



Inversion (Input/Output) → Level 4

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov **model_prm**

To use the optional model perturbation file (**model_prm) as an input** we need first to understand few things:

- **The output files after each iteration are:**

***_NLCG_060.rho → **Inverted model**
***_NLCG_060.dat → **Predicted data**
***_NLCG_060.prm → **Transformed model parameter (rough)**
***_NLCG_060.res → Data residuals

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Inversion (Input/Output) → Level 4

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov **model_prm**

The most obvious use of the *.prm file is the following case:
For some technical reasons, the inversion stops after 60 iterations while the inversion's stopping criteria still didn't reach! **What to do?**

***_NLCG_060.rho → **Inverted model**
***_NLCG_060.dat → **Predicted data**
*****_NLCG_060.prm → Transformed model parameter (rough)**
***_NLCG_060.res → Data residuals

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov *****_NLCG_060.prm**

Prior model

Starting model

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Inversion (Input/Output) → Level 4

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov **model_prm**

This command line is used when want to perform Model Resolution Studies

Best explained using a real world example

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Model Resolution studies (Example)

3D inversion of 164 MT sites

Data:

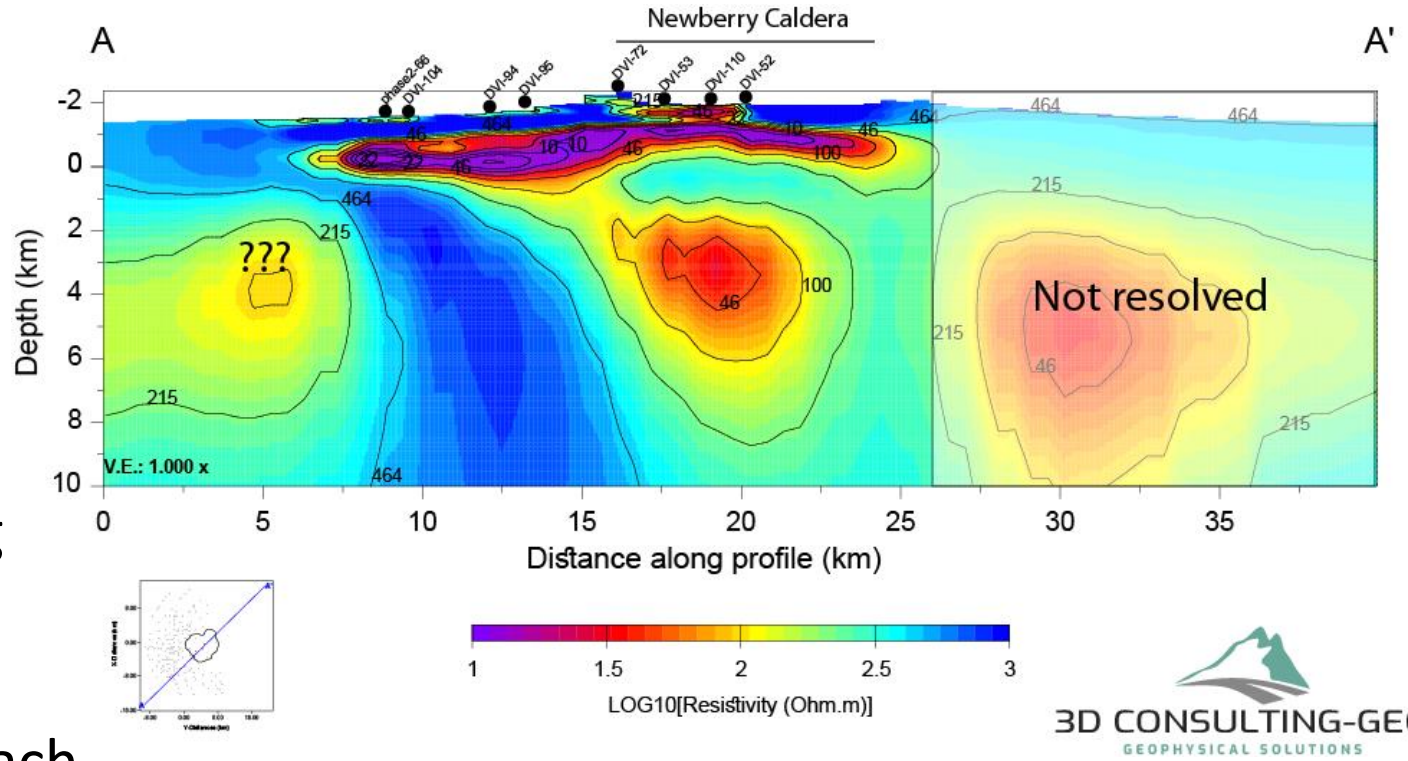
- Broad Band from 100 Hz to ~0.001 Hz
- Full Impedance tensor
- Min. site spacing, ~ 500 m

Model:

- 75 x 60 x 83 cells in X, Y and Z
- Min. cell size in X and Y, 500 m
- Topography included→ carful Z gridding

Inversion:

- Prior model: 500 ohm.m
- Error setting: Gradual decreasing approach
- 130 NLCG iterations in total



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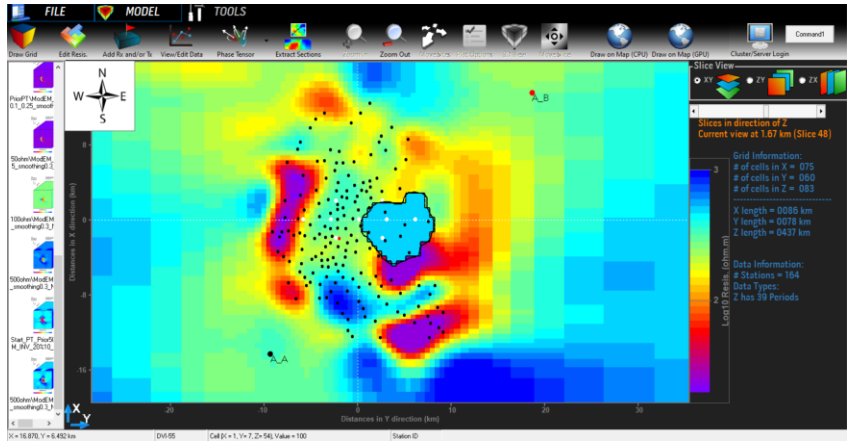
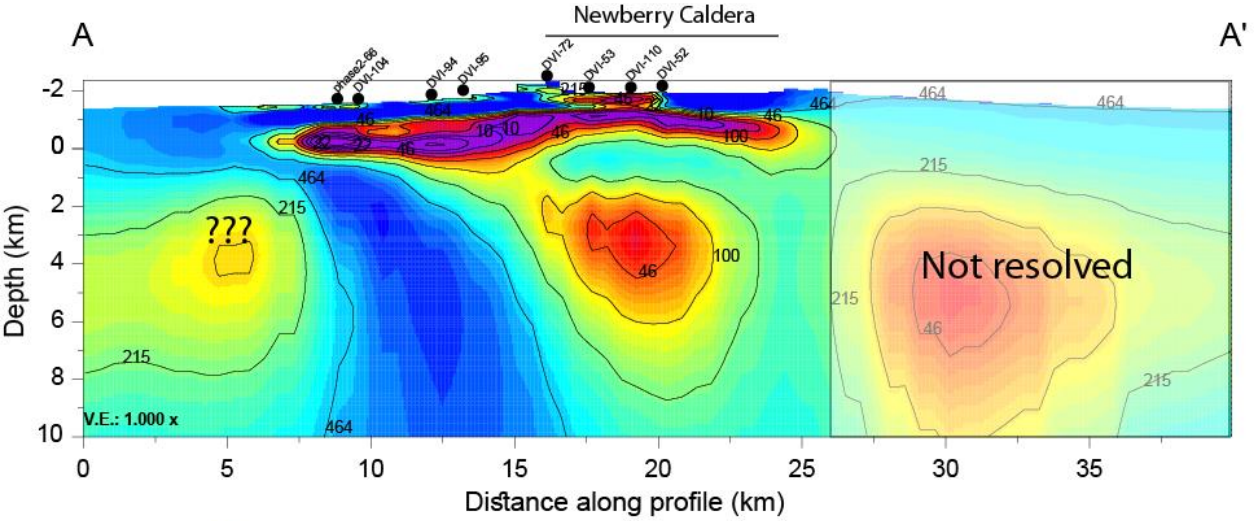
Model Resolution studies (Example)

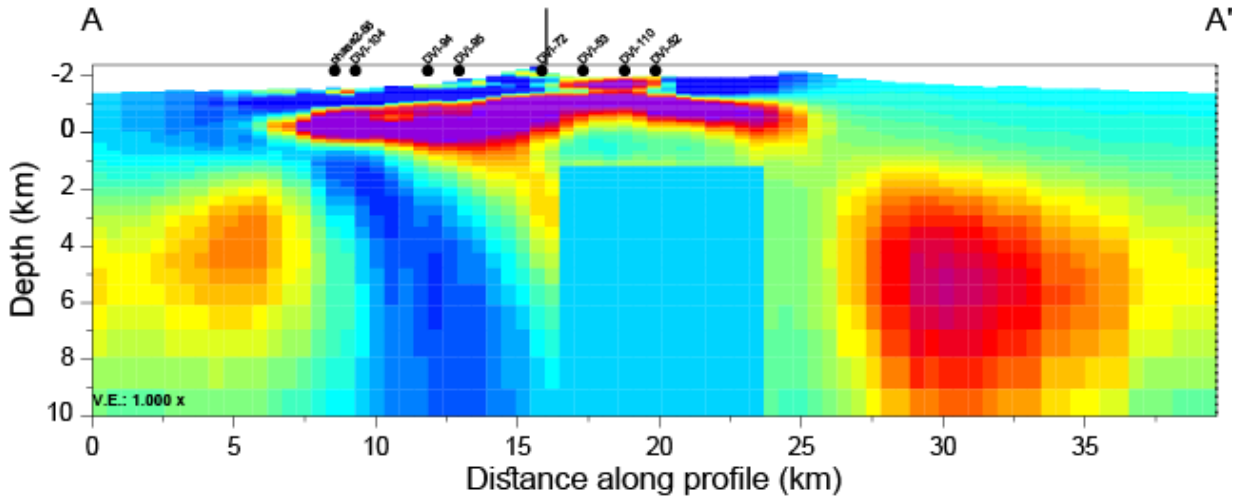
- Use appropriate tools to modify the resistivity values in your preferred model.
- “Reset” the resistivity values of your target feature(s) with the resistive value of the prior model

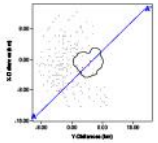


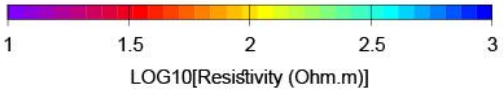
Preferred model



Modified model







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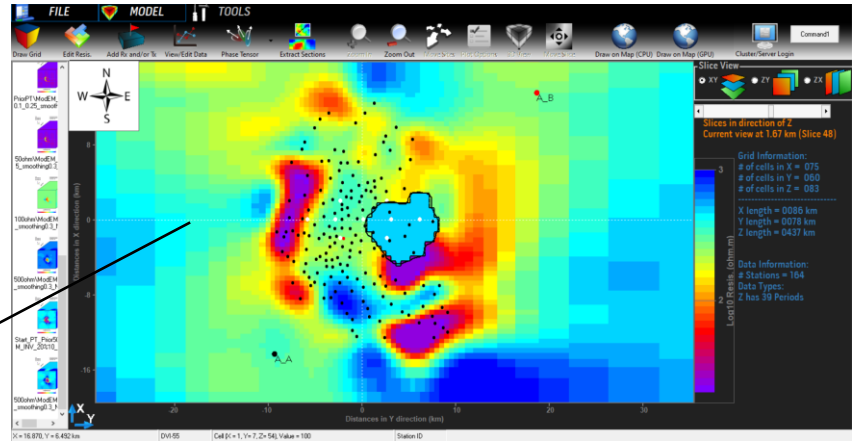
Inversion (Input/Output) → Level 4

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov **model_prm**

We have a Modified model and we want to re-run the inversion



Modified_Model Input_data Input_INV_para. FWD_para. Model_Cov

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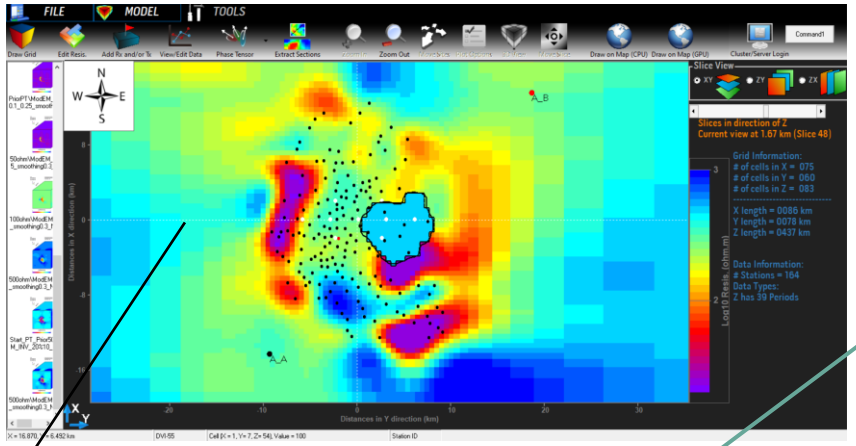
GEOPHYSICAL SOLUTIONS

Inversion (Input/Output) → Level 4

Input_Model Input_data Input_INV_para. FWD_para. Model_Cov **model_prm**

We have a Modified model and we want to re-run the inversion



$ModEM –C INV **Modified_Model** **rough_pertur.prm** Model_Cov Input_Model

What is the mathematical meaning of this operation?

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Mathematical meaning of –C INV flag

$$\mathbf{m}_k = \mathbf{C}_m^{1/2}\,\Delta\mathbf{m}_k + \mathbf{m}^{pre}$$

$$\Delta\mathbf{m}_k = \mathbf{C}_m^{-1/2}(\mathbf{m}_k - \mathbf{m}^{pre})$$

$ModEM –C INV **modified_preferred.rho** **rough_pertur.prm** Model_Cov Input_Model

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Some practical remarks

The RMS or nRMS

$$\mathbf{nRMS} = \sqrt{\frac{\mathbf{1}}{N}\sum_{N}\left(\frac{(d - f(\mathbf{m})}{err}\right)^{2}}$$

→ **This is ONE single number (the overall RMS) which is computed over:**

- **All sites**
- **All periods**
- **All components**

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Some practical remarks

The overall RMS during the inversion run

→ info. are found in *.log file

```
The initial damping parameter lambda is  1.0E+00
The initial line search step size (in model units) is     1.000000
   START: f=2.569494E+02 m2=0.000000E+00 rms=  16.029641 lambda=1.000000E+00 alpha=2.000000E+01
    GRAD: initial norm of the gradient is 1.92105E+00
The initial value of alpha updated to  5.20549E-01
Starting line search...
  STARTLS: f=2.550518E+02 m2=2.677376E-06 rms=  15.970340 lambda=1.000000E+00 alpha=5.205487E-01
   QUADLS: f=1.946348E+02 m2=4.500683E-03 rms=  13.950998 lambda=1.000000E+00 alpha=2.134253E+01
Sufficient decrease condition satisfied, exiting line search
Completed NLCG iteration     1
    with: f=1.946348E+02 m2=4.500683E-03 rms=  13.950998 lambda=1.000000E+00 alpha=3.410858E+01
Starting line search...
  STARTLS: f=1.583420E+02 m2=1.359147E-02 rms=  12.582861 lambda=1.000000E+00 alpha=3.410858E+01
   QUADLS: f=7.160089E+01 m2=9.994167E-02 rms=   8.455823 lambda=1.000000E+00 alpha=1.660742E+02
Sufficient decrease condition satisfied, exiting line search
Completed NLCG iteration     2
    with: f=7.160089E+01 m2=9.994167E-02 rms=   8.455823 lambda=1.000000E+00 alpha=2.095854E+02
Starting line search...
  STARTLS: f=4.589573E+01 m2=1.674052E-01 rms=   6.762272 lambda=1.000000E+00 alpha=2.095854E+02
   QUADLS: f=1.869711E+01 m2=3.612538E-01 rms=   4.282039 lambda=1.000000E+00 alpha=6.121357E+02
Sufficient decrease condition satisfied, exiting line search
Completed NLCG iteration     3
    with: f=1.869711E+01 m2=3.612538E-01 rms=   4.282039 lambda=1.000000E+00 alpha=7.221589E+02
Starting line search...
  STARTLS: f=1.186647E+01 m2=4.838602E-01 rms=   3.373812 lambda=1.000000E+00 alpha=7.221589E+02
   QUADLS: f=8.780962E+00 m2=6.159943E-01 rms=   2.857441 lambda=1.000000E+00 alpha=1.378442E+03
Sufficient decrease condition satisfied, exiting line search
Completed NLCG iteration     4
    with: f=8.780962E+00 m2=6.159943E-01 rms=   2.857441 lambda=1.000000E+00 alpha=1.562978E+03
Starting line search...
  STARTLS: f=6.124809E+00 m2=7.390348E-01 rms=   2.320727 lambda=1.000000E+00 alpha=1.562978E+03
   QUADLS: f=5.759886E+00 m2=7.965438E-01 rms=   2.227856 lambda=1.000000E+00 alpha=2.183524E+03
Sufficient decrease condition satisfied, exiting line search
Completed NLCG iteration     5
    with: f=5.759886E+00 m2=7.965438E-01 rms=   2.227856 lambda=1.000000E+00 alpha=2.305757E+03
```

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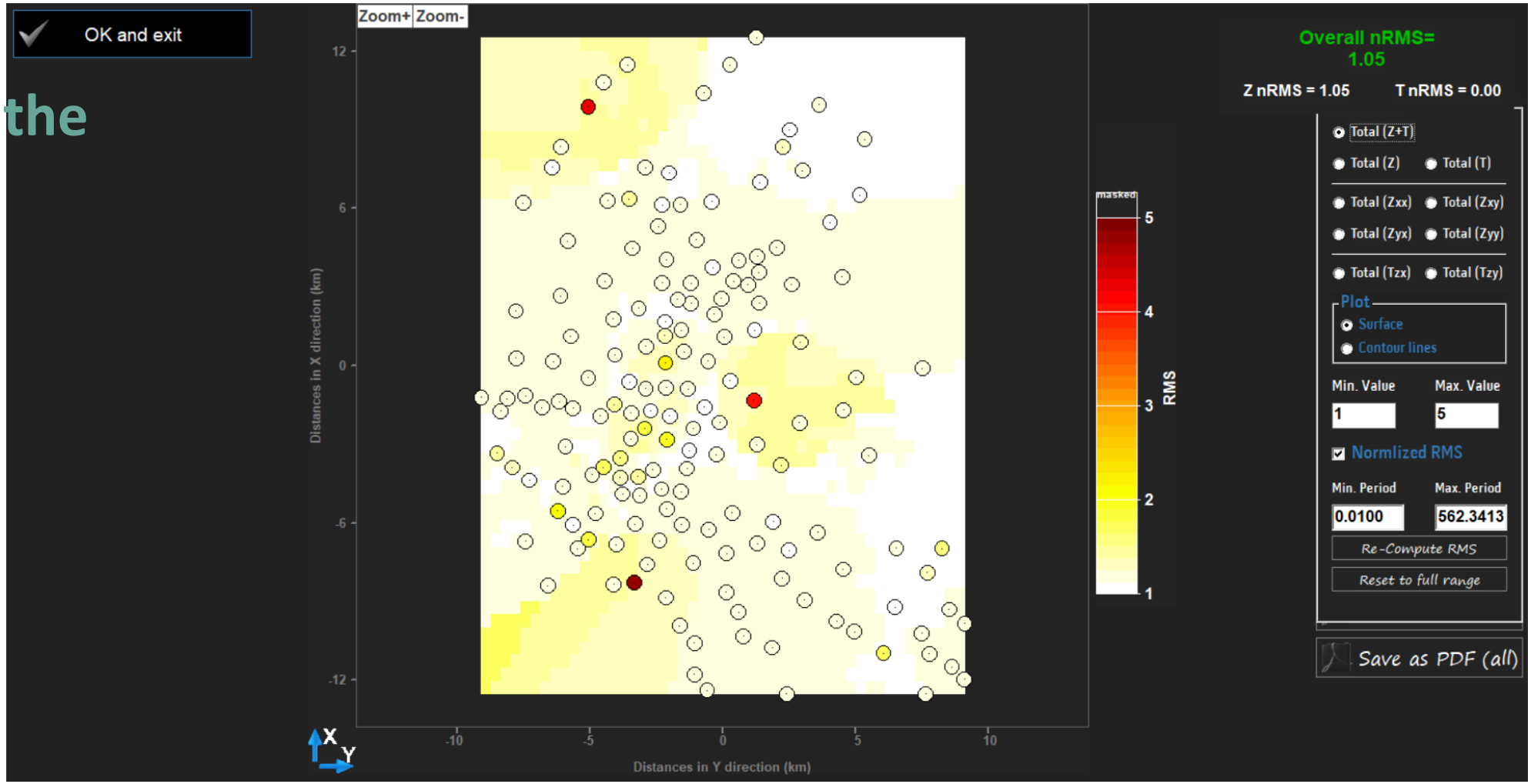
Some practical remarks

Better to look at the RMS at:

- each site
- Component
- Period range

RMS Maps



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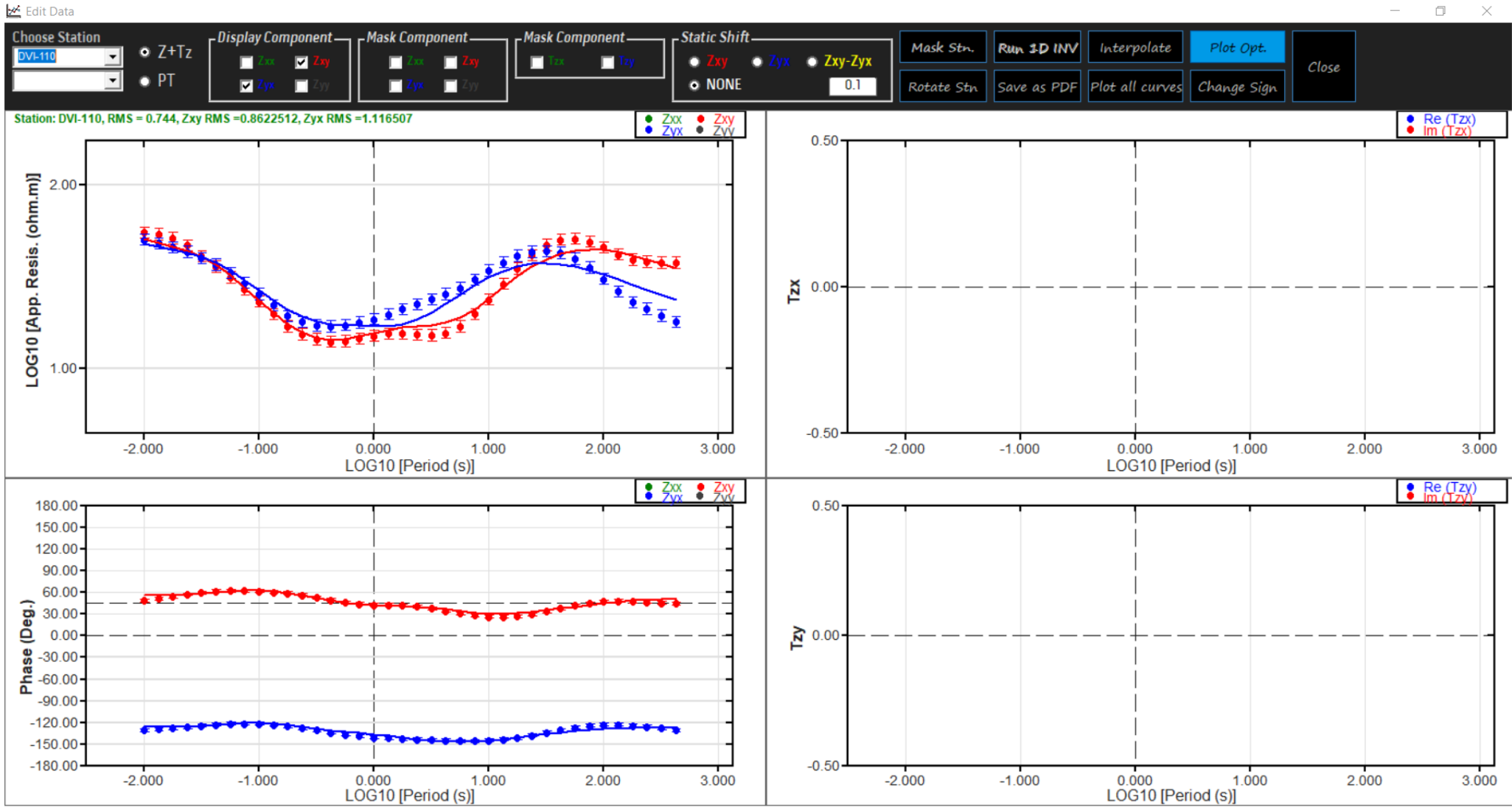
Some practical remarks

Much better, Looking at the sounding curves and analyse what is fitted and what is NOT



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Some practical remarks

- When running ModEM, several outputs are printed on the screen. Among others, the solver's convergence.

This part shows to which tolerance the divergence correction is converged

Solver (QMR) tolerance

```
385   node[002]:   finished divergence correction:   34   0.9141071E-07
386   node[007]:   finished divergence correction:   52   0.5182069E-07
387   node[003]:   finished divergence correction:   45   0.9712197E-07
388   node[011]:   finished divergence correction:   44   0.5198138E-07
389   node[006]:   finished divergence correction:   47   0.6373914E-07
390   node[010]:   finished divergence correction:   47   0.5125431E-07
391   node[009]:   finished divergence correction:   45   0.7901899E-07
392   node[020]:   finished divergence correction:   44   0.8510626E-07
393   node[020]:     finished solving:     158   0.9794737E-07
394   node[020]:      time taken (mins)     1.414193
395   node[020]:    Waiting for a message from Master
      nished divergence correction:   42   0.7204920E-07
      finished solving:     158   0.9159841E-07
       time taken (mins)     1.439974
      aiting for a message from Master
      nished divergence correction:   48   0.5907255E-07
      nished divergence correction:   44   0.8513982E-07
      nished divergence correction:   41   0.9407652E-07
      finished solving:     174   0.7914782E-07
       time taken (mins)     1.538411
```

If you observe large numbers for the errors, please check the model and/or data files!

→ Large solver's error means that the E solution is not well computed → The whole process (FWD and/or INV) will fail.

Take Home messages

- You only have the measured data when you start any kind of inversion→ **understanding and analysing the data is the key point to understand your inversion results and models later.**
- There is NO a ready to use recipe to run the inversion → **each dataset has its own characteristic and needs to be handled with some attentions.**
- PLEASE KEEP IN MIND: At the end of the day, any code works with what you provide and it doesn't do MAGIC→ **If you feed it with noisy and/or physically meaningless data you will get meaningless models.**

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Summary

A modular system for regularized inversion of frequency domain EM data has been developed. In principle this:

→ Supports multiple inversion algorithms

→ Is adaptable to a wide range of EM geophysical problems (different sources/receivers; joint inversion)

and is designed to make it easy to

→ Change model parameterization, regularization

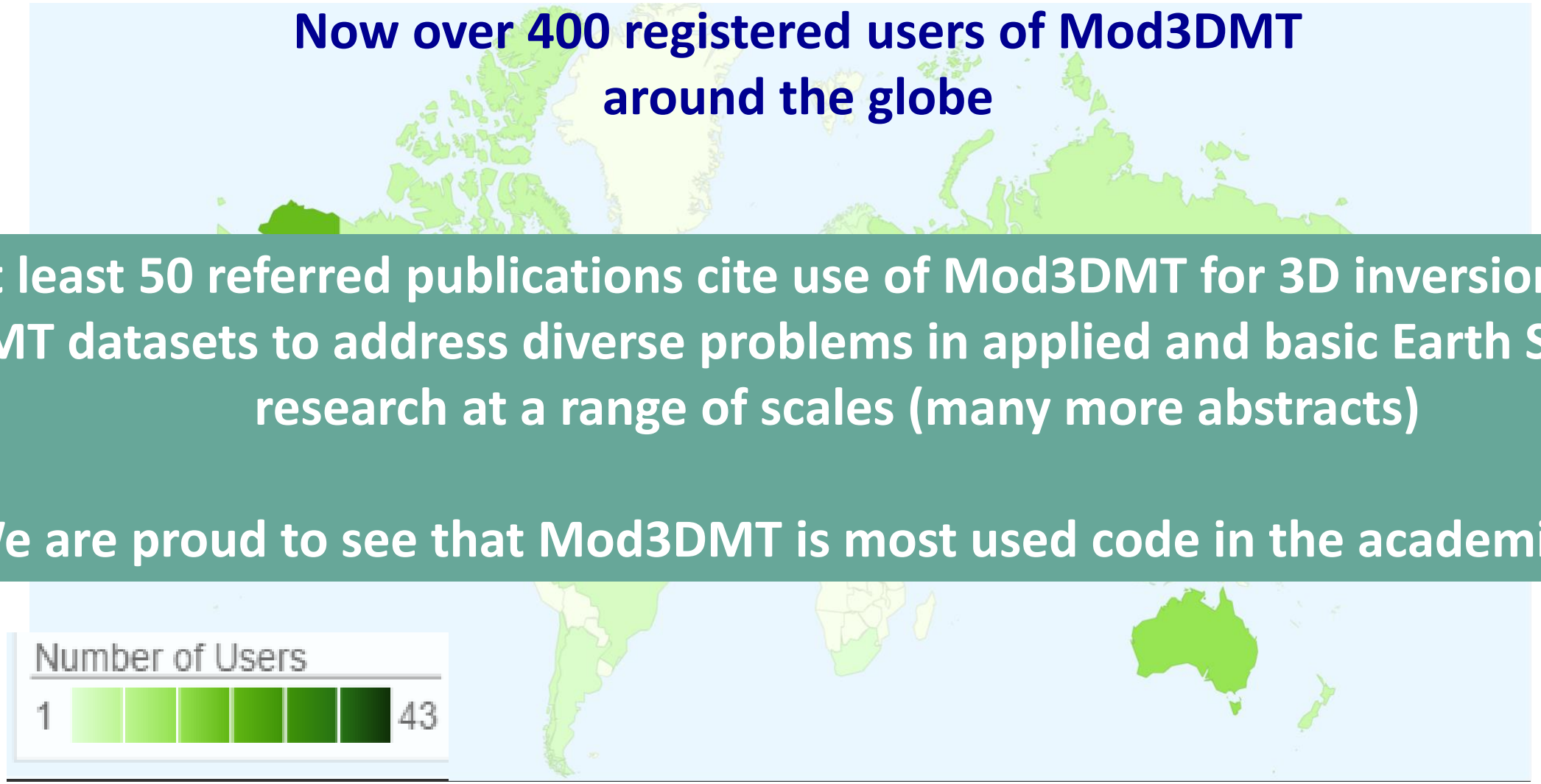
→ Add new data types

→ … etc

A stable version with basic capabilities is freely available for non-commercial use

Mod3DMT: Version of ModEM suitable for 3D inversion of MT data was made available for academic use

Now over 400 registered users of Mod3DMT around the globe



At least 50 referred publications cite use of Mod3DMT for 3D inversion of real MT datasets to address diverse problems in applied and basic Earth Science research at a range of scales (many more abstracts)

We are proud to see that Mod3DMT is most used code in the academic world

Thank you for your attention

Iso-Surface from the 3D conductivity model in Clouncurry mining area in Australia together with some interfaces from the 3D geological model