Release Notes for Leroi – Version 8.0.0 – 17 January 2008

Leroi has undergone fundamental change since the last release. It can now model the response of plates in any layer by setting DO3D = 3. However, plates cannot cross layer boundaries because of the inherent conflict in boundary conditions between the layered earth (where normal current is discontinuous) and the plate (where down dip current is continuous.) When DO3D = 3, plunge for all plates must be zero. Inversion has not been enabled for cases where all plates are not in the basement.

The new features required a major revision in several modules, in particular, those used to compute Green's functions for the primary field on target, the intra and inter plate functions used for computing scattering current, and those relating plate currents to the receivers. A major error that had been in Leroi for years was found and corrected during this process. Thus in running Leroi for the normal case of all plates in the basement, differences in the new response compared to the old response may on rare occasions exceed 10 percent. Commonly, they are less for the test examples provided.

The directory Modelling 1 contains the new results for previously distributed examples. The model is two plates in the basement of a three-layered model where one of them has a 15 degree plunge.

The directory Modelling 2 contains results for a new model with a three-layered host where one plate is in the layer above basement and one is in the basement. These have the same names as those in Modelling 1 except for the suffix V; eg CamV.cfl instead of Cam.cfl.

Leroi.f90 can be compiled using any ANSII standard Fortran compiler. Not all compilers are equal, however. For development, we rely heavily on the Lahey compiler, because it has excellent traceback that can identify the location of a problem that arises either through erroneous data input or a problem in the program itself. The Intel compiler generates executables that can run up to fifty percent faster than those generated by Lahey but when there is a crash, the output is gibberish rather than a useful traceback. Thus in this release, Leroi.exe is generated using the Intel compiler and can be used effectively given correct data input. When a crash occurs, re-running the same files using LeroiL.exe will generate useful information that can be used to solve the problem.

Serious users are urged to look through Leroi_8.txt or the header of Leroi.f90. These contain complete instructions for setting up the control and inversion files as well as giving information on options that may not be activated in the Maxwell version. In that case, Maxwell can be used to generate the control file and a text editor can be used to access non-standard options during runtime.

Tasks: Modelling and Inversion for time-domain and frequency domain ground and downhole systems. Leroi is designed to simulate almost any extant system through the different survey, source and receiver options.

Model: Thin plates, each of which constrained to be entirely contained in a single layer of a horizontally-layered halfspace. There is no restriction on the number of plates or layers.

Package:

Leroi.f90 – ANSI standard Fortran 90 source code documented throughout.

Leroi_8.txt – description of the program plus detailed instructions on constructing the control files for the various options. It is simply the 1800 line header of Leroi.f90

Leroi.exe and LeroiL.exe – Windows executable

F2.bat – Windows batch file to initiate stand-alone modelling tasks

V2.bat - Windows batch file to initiate stand-alone inversion tasks

X.cfl – examples of control files for modelling and inversion

X.inv – examples of files containing data to be inverted

X.out – examples of verbose output files from modelling tasks

X.mf1 – examples of modelling output files in a plot format

Model Description:

The plates are of infinitesimal thickness and in fact are conductances superposed on a horizontally-layered halfspace. Electrically, each plate is represented as a conductivity-thickness product augmented with Cole-Cole parameters giving it a frequency-dependent, complex conductance. Similarly, the layers have a frequency-dependent, complex resistivity including relative magnetic permeability, relative dielectric constant and the Cole-Cole parameters used to simulate induced polarisation responses.

An N-layer model consists of N-1 layers of uniform thickness over basement. Each layer can have an individual thickness.

Each plate is described by a conductance, length, dip width, east, north and depth of the plate reference point, and the orientation angles: dip azimuth, dip and plunge. For zero plunge, plate-length and strike-length are synonymous.

Each plate modelled by Leroi starts as a horizontal rectangular plate whose strike edge runs east-west; ie, the dip azimuth points north. The southern edge is designated as the ξ axis and the PRE or plate reference edge. Initially ξ points west. The down-dip coordinate, η, initially points north. The midpoint of the ξ axis, or PRE, is designated as the PRP or plate reference point. All rotations are performed about axes that pass through the PRP.

The plate orientation is described in terms of dip azimuth, dip and plunge. From the observer standpoint, the plate orientation is achieved by first applying an azimuthal rotation (clockwise looking down) about the vertical axis, followed by a clockwise dip rotation about the rotated ξ axis (PRE) followed by a clockwise plunge rotation about the plate normal. (In practice, Leroi uses a mathematical equivalent based on rotations about fixed axes in reverse order.

If the depth of the PRP is insufficient to keep the plate in the basement and DO3D /= 3, Leroi will push the plate down such that the highest corner is 1 cm below the basement boundary. This is usually the result of applying a non-zero plunge.

Model Validity and Accuracy

The thin plate model superposes a plate-shaped conductance on the layered earth host. This implies that the electric field normal to the plate is the same on each side of the plate. This is valid when the thickness of target being modelled is a fraction of the skin depth wavelength of the incident radiation. Skin depth is inversely proportional to the square root of target conductivity and source frequency. Thus, in time domain, Leroi may not yield correct results at very early delay times for very conductive targets. On the other hand, Leroi can be used to model rather thick targets of moderate conductivity; eg, palaeochannels.

Except for the limits imposed by thickness, conductivity contrast is not an issue for Leroi. The plate may have any conductance and the host any resistivity, allowing "contrasts" of 1,000,000 to 1 to be modelled accurately.

Leroi divides each plate into a number of cells whose linear dimensions are governed by the variable CELLW (See Leroi_8.txt). The electric field is assumed to be constant in each cell. Thus the smaller CELLW is chosen to be, the more accurate the result, depending upon the conductivity structure and geometry of the situation being modelled. When the number of cells exceeds 1000, computation times can increase rather dramatically. In most applications, setting CELLW = 25 is a good compromise. However, for some situations, cell sizes of 40 and even 100 metres have yielded acceptable results. For very large plates, one might have no choice but to use larger cell sizes. As with all the P223 programs, there is no substitute for experimentation prior to serious use.

Survey Options Survey Type =

1. General option for separate setup of transmitter and receiver arrays. Open and closed loops are not shape restricted. Inductive and galvanic sources & receivers are permitted. This would be the correct choice for downhole surveys using surface loop transmitters or for CSAMT.
2. Moving Loop Survey with one or more magnetic dipole receivers moving at fixed horizontal offsets with respect to rectangular loop. (Central loop = 1 receiver at zero offset)
3. Surface Magnetic Dipole-Dipole Survey with one or more magnetic dipole receivers moving at fixed horizontal offsets with respect to magnetic dipole transmitter on or above ground

4. Coincident Loop Survey with rectangular loop
5. Borehole Magnetic Dipole-Dipole **Survey** with single magnetic dipole receiver moving downhole at fixed offset with a magnetic dipole transmitter

Source Options for Survey Type 1

1. Closed Loop. This can have 3 or more vertices and can be anywhere above on or below surface. The loop must be horizontal, ie, all vertices at the same vertical level.
2. Open Loop. This can have 2 or more vertices where the open side is determined by grounded electrodes. The vertices and electrodes can be anywhere but must all be on the same vertical level
3. Magnetic Dipole. This can be anywhere and can have any orientation.

Receiver Options for Survey Type 1

1. Magnetic Dipole. (B, dB/dt or normalised output) This can be anywhere. Three components are computed (X,Y,Z) where the direction of X with respect to north is specified by the user. There are two options for downhole surveys: U-V-A for normal people and S-N-W for Utem.
2. Electric Dipole. (voltage output) Both electrodes must be at the same vertical level.
3. Point electric field

Special System Options

1. Sampo – frequency domain moving loop system.
   Output is ABS (Bz/Bx) (ISYS = 2)
2. Utem – Utem normalisation scheme, delay times and reversed channel designation. (S-N-W output for downhole systems) (ISYS = 4)

Time-Domain Modelling & Inversion

All computations are performed in frequency domain. The default 3D spectrum is from 0.1 Hz to 10 Hz at three points per decade and from 10 Hz to 100 kHz at 6 points per decade. This can be altered by setting TDFD = 0 (See Leroi_8.txt)

For each receiver position, the spectrum is splined and extrapolated back to DC. A custom-designed Hankel filter is used to transform this into the time domain. The result is computed to 5 full pulses, folded back into a single pulse, convolved with the time-domain waveform and integrated over the receiver windows.

Modelling with Leroi

Set up a control file appropriate to the desired option using the instructions in Leroi_8.txt or in the header in Leroi.f90. Give it an appropriate name with the extension .cfl ; eg A7900.cfl. In a windows command window, typing in

F2 A7900 B7900

will result in

A7900 being copied to Leroi.cfl, running Leroi and producing Leroi.out and Leroi.mf1

These output files are copied to B7900.out and B7900.mf1 respectively.

In the ***Modelling*** directory, there are examples of using several systems over the same model.

Layered Earth Parameters

	Lyr 1	Lyr 2	Basement
Resistivity:	50	200	1300
Thickness:	18	20	

Plate Parameters

	SIG_T	Depth RL	Centre East	Centre North	Plate Length	Plate Width	Dip Azimuth	Dip	Plunge
Plate 1:	150.	-60	4000	2000	200	180	45	55	0
Plate 2:	200	-70	3900	2150	300	200	60	65	15

Time Domain

Cam.cfl – Cameco moving loop system with three receivers per loop position
Cdnt.cfl – Coincident loop survey
Cntrl.cfl – Central loop survey
FxLptd.cfl - 3 Fixed Loop positions with surface & downhole receivers
Utem.cfl - 3 Fixed Loop positions with surface & downhole receivers

Frequency Domain
Csamt.cfl – Electric dipole transmitter with magnetic and electric dipole receivers
HCP.cfl and VCA.cfl – horizontal coplanar and vertical coaxial systems
Sampo.cfl – GTK system
SlimBoris.cfl – drill hole probe

Inversion with Leroi

Set up a control file appropriate to the desired option using the instructions in Leroi_8.txt or in the header in Leroi.f90. Give it an appropriate name with the extension .cfl ; eg A7900.cfl. Using the same documentation, create a file containing the data to be inverted with the .inv extension, say C7900.inv. In a Windows command window, typing in

V2 A7900 B7900 C7900

will result in

A7900 being copied to Leroi.cfl, C7900.inv being copied to Leroi.inv running Leroi and producing Leroi.out and Leroi.mv1

These output files are copied to B7900.out and B7900.mv1 respectively

In the ***Inversion*** directory, there are examples using several systems to invert data generated by the same two models, one with plunge = 0 and one with plunge = 15.

Layered Earth Parameters

	Lyr 1	Basement
Resistivity:	100	1000
Thickness:	10	

Plate Parameters

	SIG_T	Depth RL	Centre East	Centre North	Plate Length	Plate Width	Dip Azimuth	Dip	Plunge
Model 1:	30.	-25	6250	8000	400	200	140	60	0
Model 2:	30	-70	6240	8000	400	200	140	60	15

As with the other P223F programs, Leroi allows the user four different constraint choices: none, fixed, frictional and buffered bounds. The additional implicit Leroi constraint that plates are not allowed out of the basement makes inversion with non-zero plunge quite “interesting”. It means that length, dip, plunge and depth are interdependent rather than orthogonal variables. When practical, it is best to fix plunge to zero, at least for an initial inversion or to use a fairly deep initial starting guess.

Sensitivity Computations

In theory, the sensitivity matrix, for each iteration would be computed using the analytic derivatives of the model with respect to each unfixed parameter. In practice, a numerical derivative scheme is faster and more stable. In Leroi, this is done by computing models where each unfixed parameter in turn is increased by a specified percentage and then subtracting the original model data from each result.

Since the inversion is a non-linear process, the exact derivative is not necessarily the most efficient choice. The inversion path (but not always the result) will be guided by the size of the difference step. The default step regime in Leroi computes sensitivities initially using a 5 percent difference. When subsequent iterations can no longer reduce the error significantly, a 3 percent difference scheme is tested. If the error is reduced, it is used for the rest of the inversion.

If in RECORD 16, CNVRG is set to 10 or 20, the user can change this by specifying the number and value of the difference steps to be tested during the inversion. The first KPCT value will be used until the error can no longer be reduced and then the next values will be used similarly. Thus the time required by the inversion will be increased according to how many KPCT values are specified.

At least 1 value is required (NDSTP = 1) The suggested maximum value of NDSTP is 3. The values for KPCT should be in the interval from 2 to 15. A KPCT value can be used more than once but it would be silly to use the same values sequentially.

Example (Default scheme)

NDSTP = 2
KPCT (1:NDSTP) = 3, 5

Three step scheme

NDSTP = 3
KPCT (1:NDSTP) = 3, 5, 8

Experiments with various schemes were part of the inversion testing process. In most cases, the chosen default performed best.