Point and kinematic source inversion with the KiWI tools, MESS 2012

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Outline

What and where?

- **Data**
- **GFDB**
- **Inversion tools**

Kiwi tools internals

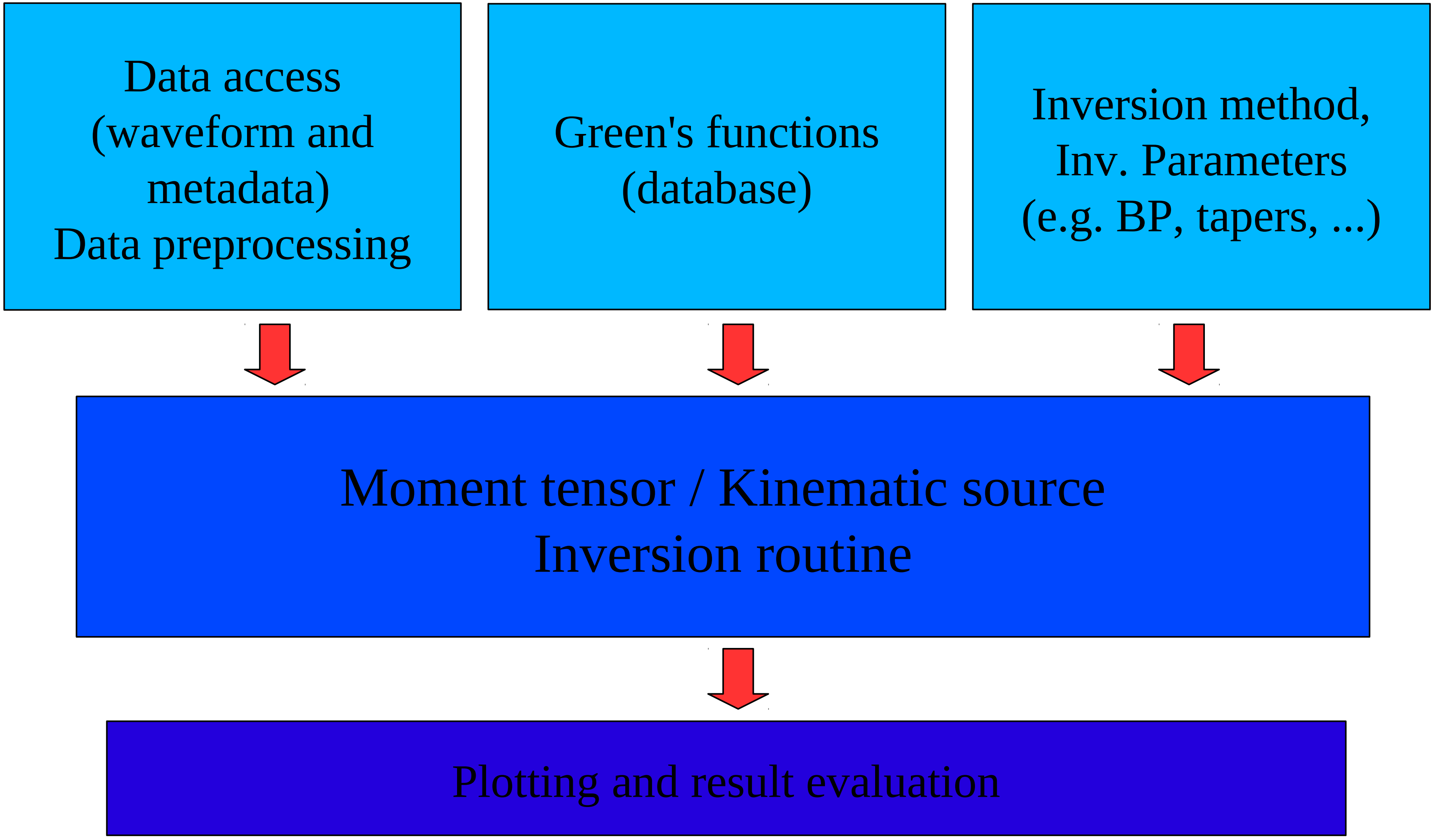
Rapidinv (1/2)

- **Workflow**
- **Point source inversion**

Rapidinv (2/2)

- **Kinematic source inversion**
- **Fast directivity inversion**

Source inversion in seismology, what do we need?



… and where to find it!

What and where?	**local/kiwimess2012**
Data	**RAPIDINV/DATA/<eventdir>**
	META

data are also described in the printed documentation

GFDB	**GFDB**
Inversion tools	**RAPIDINV/WORK**

a rapidinv manual is also provided as printed documentation

Results	**RAPIDINV/RESULTS/<eventdir>**

Available data

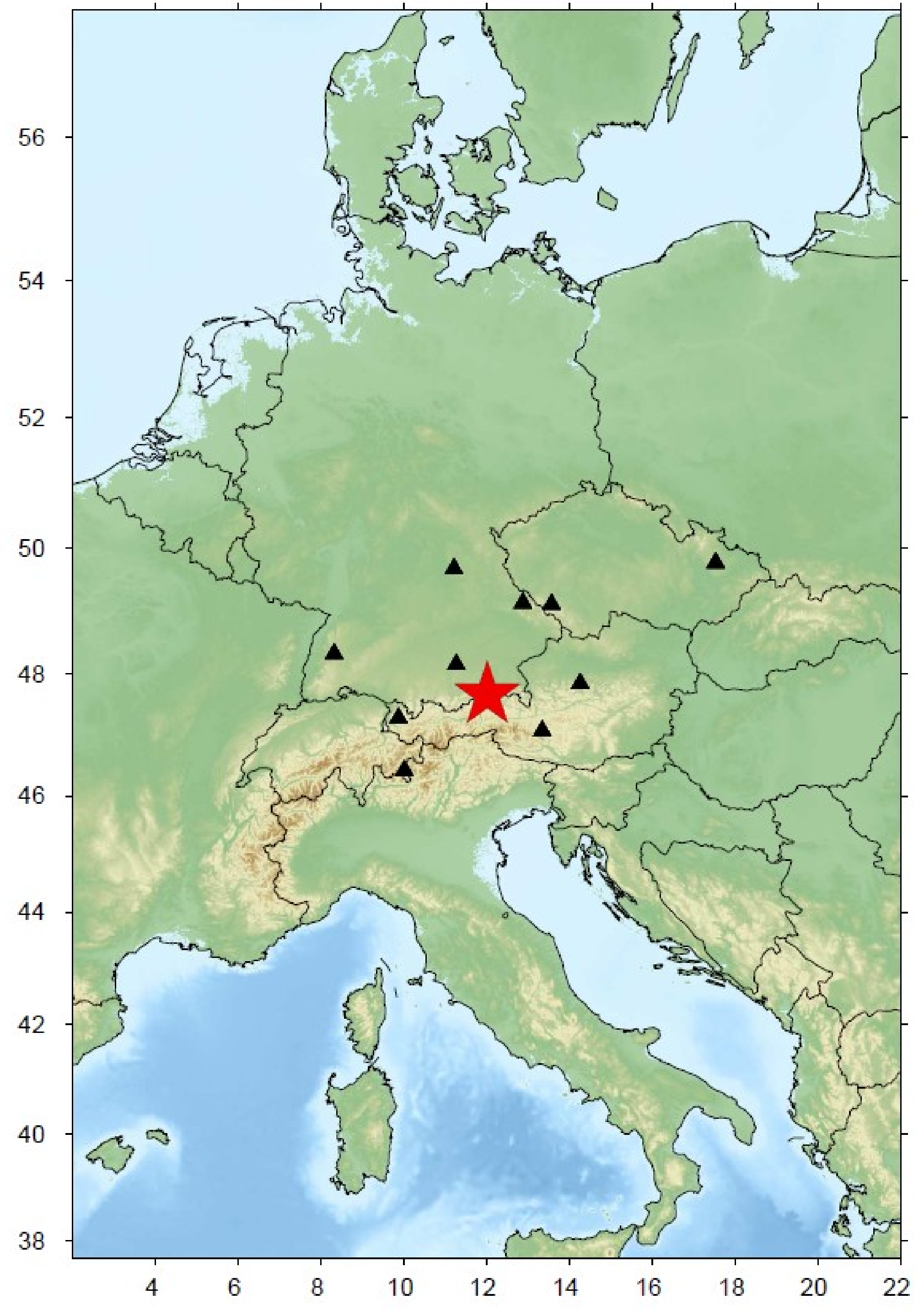
The 15.3.2012 Bayrischzell event

Realistic synthetic datasets

SYNTH1	**DC point source**
SYNTH2	**MT point source**
SYNTH3	**Kinematic model 1**
SYNTH4	**Kinematic model 2**

Synthetic data for different velocity model (Stich et al. JGR 2005)

SYNTH5	**~SYNTH1**
SYNTH6	**~SYNTH2**
SYNTH7	**~SYNTH3**
SYNTH8	**~SYNTH4**



Available data

Real data

Shallow events (depths 1-30km)

Local distances (up to 200/400km)

Regional distances (up to 1000km)

Mw 4-7

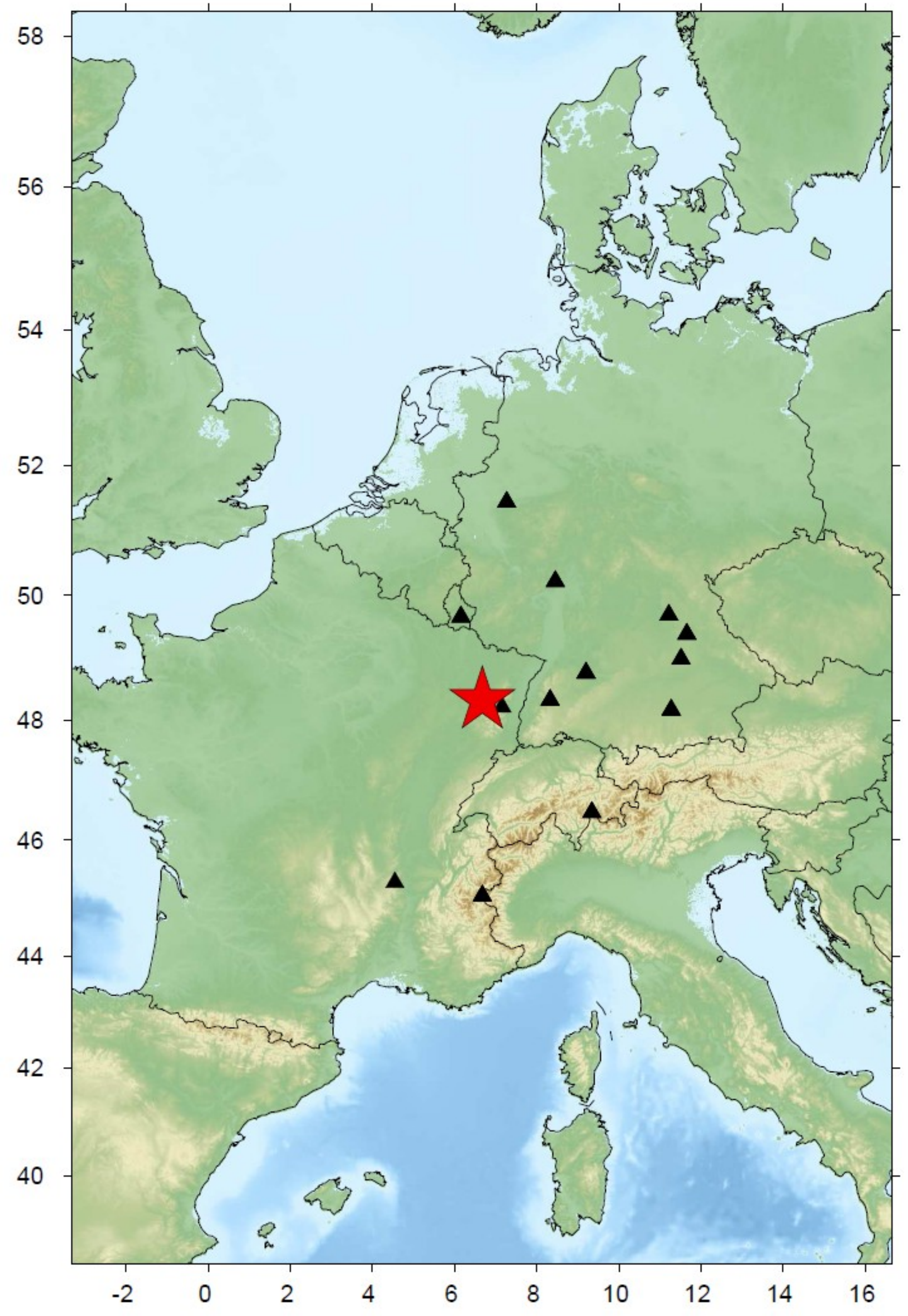
Old (Teutschenthal 11.9.1996)

New (Emilia, Italy, 24.12012)

Natural (most)

Induced (Rotenburg, Teutschenthal)

Europe (Italy, France, Greece, Turkey, Germany)



Available data

General info:

go to RAPIDINV/DATA/<eventdir>

inside you find:

DISPL.XXX.BH?

displacements (0.5s)

station XXX

spatial component ? (N, E, Z=upward)

miniSEED format

stations.dat

station text file

format = id_stat name lat lon

Available data

General info:

go to RAPIDINV/META

inside you find:

events.txt	**info on event location/time**
events_w_solutions.txt	**also include rough foc.mec.**
stations.txt	**info on station locations**

Looking at the waveforms:

snuffler DATA/<eventdir> --stations=”META/stations.dat” --event=META/events.txt”

Select event + sort for epicentral distance

snuffler DATA/<eventdir> --stations=”META/stations.dat” --event=META/events_w_solutions.txt”

Check waveform fit (e.g. at different frequency ranges)

Available GFDB

General info:

go to GFDB

inside you find a database (chunks + index)

Query the database (gfdb_info, gfdb_extract)

On the database

IASP91 model

Source depths: 0-40km, step 1km

Epicentral distances: up to 1000k, step 1km

Working and results directory

General info:

go to RAPIDINV/WORK

rapidinv.py (and mopad.py)

rapidinv.defaults, rapidinv.acceptables

rapidinv.inp.*

go to RAPIDINV/RESULTS

(should be empty)

here you will have subdirectories with inversion results

minimizer **and** ***rapidinv***

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The ***minimizer*** KiWI tool

http://kinherd.org/power/trac/wiki/MinimizerTool

Synthetic seismogram generator for extended earthquake sources and misfit calculation engine

Some commands:

- set_database dbpath [nipx nipz]
- set_receivers filename
- set_ref_seismograms filenamebase format
- set_source_location latitude longitude reference-time
- set_source_params source-type source-params ...
- set_source_params_mask mask
- set_misfit_method (l2norm | l1norm | ampspec_l2norm | ampspec_l1norm | scalar_product | peak)
- set_misfit_filter x0 y0 x1 y1 ...
- set_misfit_taper ireceiver x0 y0 x1 y1 ...
- minimize_lm
- get_global_misfit
- output_seismograms filenamebase fileformat (synthetics|references) (plain|tapered|filtered)

Simply using the KiWI tool, ***rapidinv12***

Rapidinv is a python script which has been developed at Hamburg University with the goal of simplifying the process of kinematic inversion using the Kiwi tools (kinherd.org).

The inversion procedure adopt the eikonal source model (Heimann et al. 2008) and a multi-step inversion strategy, as explained in Cesca et al. (2009).

The inversion is carried out in the following three main steps:

Step 1 Focal mechanism inversion DC/MT

This is expected to be done in the frequency domain, by fitting amplitude spectra.

Source parameters retrieved after this inversion steps are: strike, dip, rake (4 possible configurations), scalar moment, source depth.

Step 2 Centroid location inversion DC/MT

This is expected to be done in the time domain, by fitting displacements time traces.

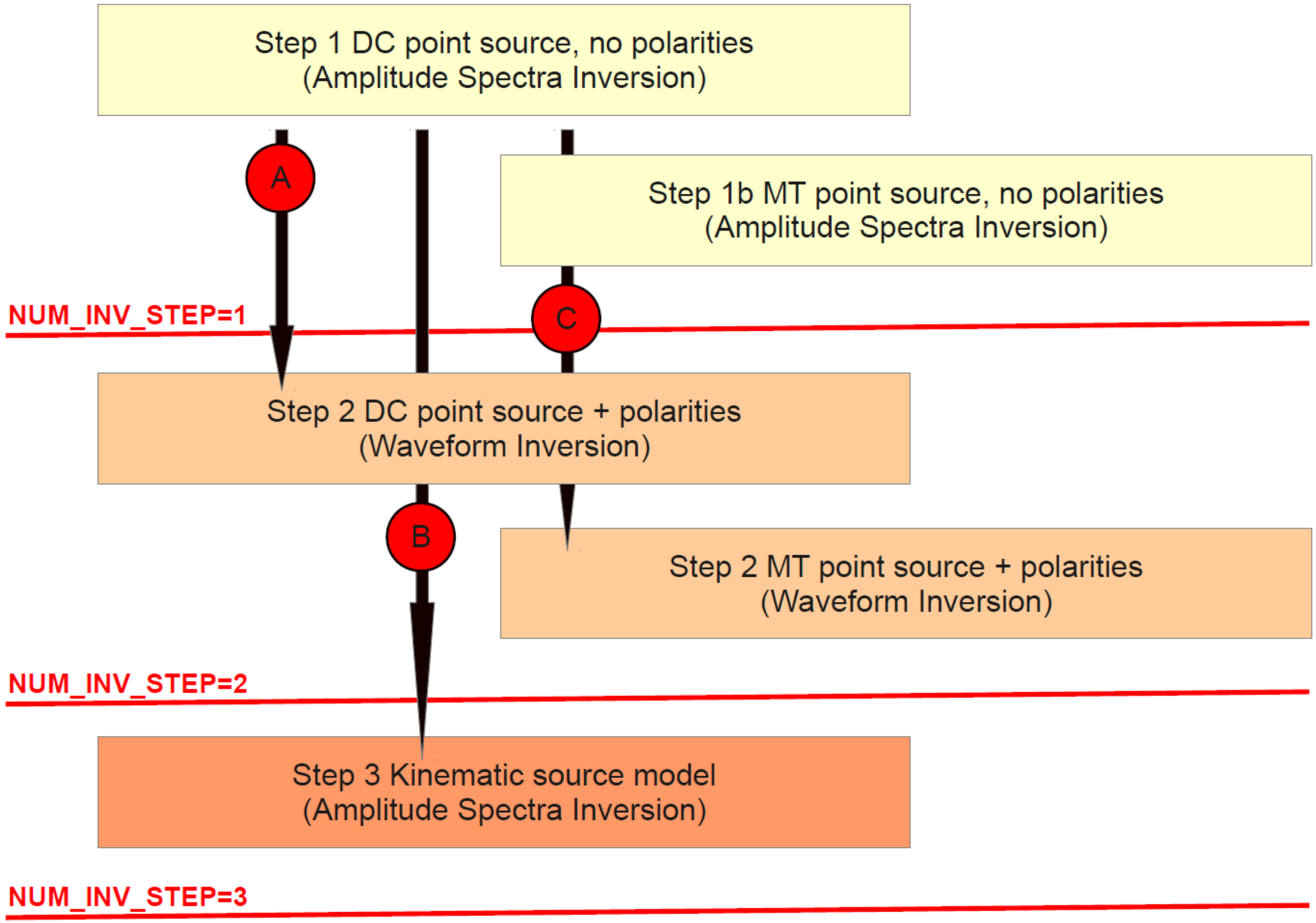
Source parameters retrieved after this inversion steps are: strike, dip, rake (2 possible configurations), centroid relative location (North, East, Time offset).

Step 3 Kinematic inversion

This can be done both in the time or frequency domain.

Source parameters retrieved after this inversion step are: strike, dip, rake (1 configuration corresponding to true fault plane orientation), radius, area, rupture velocity, nucleation point coordinates (along-strike, down-dip), rupture time, average slip.

Simply using the KiWI tool, ***rapidinv***



Rapidinv, getting started

The following steps are required prior to the inversion:

The Kiwi tools

Kiwi tools do the internal job of seismogram generation, misfit calculation and inversion. The user should at first install the Kiwi package following instructions at kinherd.org.

Data

Data have to be processed in advance and be saved using the expected naming (e.g. DISPL.STAT.BHZ, note that this differs from internal Kinherd data file naming) and formats (currently Kiwi tools handle sac, ascii and miniSEED, but rapidinv is not accepting this last format yet). Data processing tools exist within the Kiwi tools, but the data file which are produced as output of this tools have currently a different naming. Additional short processing is thus requried to prepare data files.

A text file with station information must be saved in the data directory (for file format, see variable STAT_INP_FILE in the paragraph 3 of this guide).

Green's functions database

Green's functions have to be generated in advance (using e.g. GEMINI or QSEIS code for 1D layered Earth models). They have to be stored into a database structure.

Green's functions database handling tools exist within the Kiwi tools.

Moment tensor decomposition

Mopad.py (Krieger and Heimann, submitted) is used for moment tensor decomposition and plotting purposes. The code should be available.

Rapidinv, starting...

When ready, the inversion can be prepared and executed, following these steps:

1) Copy to your working directory the files:

rapidinv12.py (python script)

rapidinv.defaults (default values of inversion variables)

rapidinv.acceptables (acceptable formats of inversion variables)

2) Build your specific input file, <rapidinv.inputfile>

This should have a similar format as rapidinv.defaults, but only with variables (see next paragraph) with different values than the default ones.

Empty and commented lines (starting with #) are neglected

All variables are described later and in the manual (see appendix).

3) Run the python script

python rapidinv12.py <rapidinv.inputfile>

4) Plot results

If the inversion was successful (“Ho finito!”), postscript and text files with results will be saved in the result directory (see variable INVERSION_DIR in the paragraph 3 of this guide).

Rapidinv, workflow

rapidinv.defaults is first read	variables assigned by default values
Specific input file is read	variables updated
rapidinv.acceptables is read	variables format checked

Variable/values are internally structured into a python dictionary

Several minimizer input files are created

    Minimizer <mininmizer.inp.* >minimizer.out.*

All steps can be checked

    ls RESULTS/minimizer.inp* RESULTS/minimizer.out*

Results files are generated

*dat	information
*ps	plots

Rapidinv, starting...

One example:

COMP_2_USE

Default: *ned*

Acceptable: *string*

The string should include one letter for each spatial component to consider. Letter follow the convention from kinherd.org:

d: down

u: up

n: North

s: South

e: East

w: West

r: transversal, rightward as seen from source to receiver

l: transversal, leftward as seen from source to receiver

a: radial, away from source

c: radial, backward to source

Rapidinv, useful variables (general)

DATA_DIR

Path to the directory containing all data and station information.

DATA_FORMAT

Expected format of input displacement data (see kinherd.org for more details).

STAT_INP_FILE

Default: *stations.dat*

Name of the input file with list of stations to be used. This file, with the proper format, should exist and be saved in the data directory (see DATA_DIR). Specific file format (manual).

All stations here indicated will be considered. If data are missing, station will be excluded. If data are partially missing, only existing components will be used. If data files exist, but the station name is not included in the list, data will not be used.

INVERSION_DIR

Path to the directory where all output files will be saved.

NUM_INV_STEPS

Number of inversion steps to realize (1=only focal mechanism, 2= focal mechanism and centroid location, 3=full point and kinematic inversion).

Rapidinv, useful variables (general)

EPIC_DIST_MIN, EPIC_DIST_MAX

Minimum and maximum epicentral distance to consider for all steps.

LATITUDE_NORTH, LONGITUDE_EAST

Original latitude and longitude (deg) of the epicenter. Further relocation will be relative to this value.

YEAR, MONTH, DAY, HOUR, MIN, SEC

Event origin time.

SW_FILTERNOISY

Switch to detect and remove noisy traces.

SW_WEIGHT_DIST

Apply a distance-dependent weight, w: w = station_epicentral_distance / maximal_epic_distance.

SW_FULLMT

Switch to additionally run full moment tensor inversion

Rapidinv, useful variables (step 1)

DEPTH_1, DEPTH_2, DEPTH_STEP

SCAL_MOM_1, SCAL_MOM_2, SCAL_MOM_STEP

STRIKE_1, STRIKE_2, STRIKE_STEP

DIP_1, DIP_2, DIP_STEP

RAKE_1, RAKE_2, RAKE_STEP

Min, Max, Increment of depth (km), moment (Nm) and fault angles (deg) to define starting configurations, during inversion step 1.

SW_RAPIDSTEP1

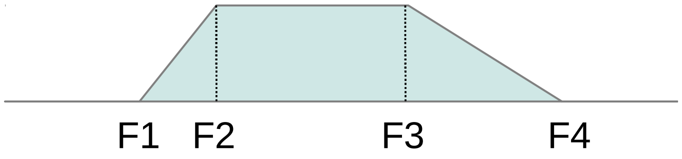
Ignore STRIKE_1, STRIKE_2, … and test 10 default configurations of strike-dip-rake.

DEPTH_BOTTOMLIM, DEPTH_UPPERLIM

Minimum and maximum accepted depth (km) after inv. step 1 (all other solutions will be removed)

BP_F1_STEP1, BP_F2_STEP1, BP_F3_STEP1, BP_F4_STEP1

Bandpass frequency (e.g. 0.009 0.01 0.1 0.11) at inversion step 1.



Rapidinv, useful variables (step 1)

INV_MODE_STEP1

Defines the strategy to carry out inversion step 1. The following possibilities are allowed:

invert_dmsdst: gradient inversion of invert strike, dip, rake, moment, depth

MISFIT_MET_STEP1

ampspec_l1norm: amplitude spectra will be compared, using L1 norm

ampspec_l2norm: amplitude spectra will be compared, using L2 norm

(l1norm: time traces will be compared, using L1 norm)

(l2norm: time traces will be compared, using L2 norm)

PHASES_TO_USE_ST1

Seismic phases to be used for inv. step 1:

p: P phases (on all used components, as defined in COMP_2_USE)

b: Bodywaves (P on vertical component, S on remaining components)

a: Full waveform (on all used components, as defined in COMP_2_USE)

Rapidinv, useful variables (step 1)

WEIGHT_A_ST1, WEIGHT_P_ST1, ...

Defines a weight for the time window for phase ***a (p, ...)*** during inversion step 1.

It is used only if the phase is activated in PHASES_TO_USE_ST1.

WIN_LENGTH_A_ST1, WIN_LENGTH_P_ST1, ...

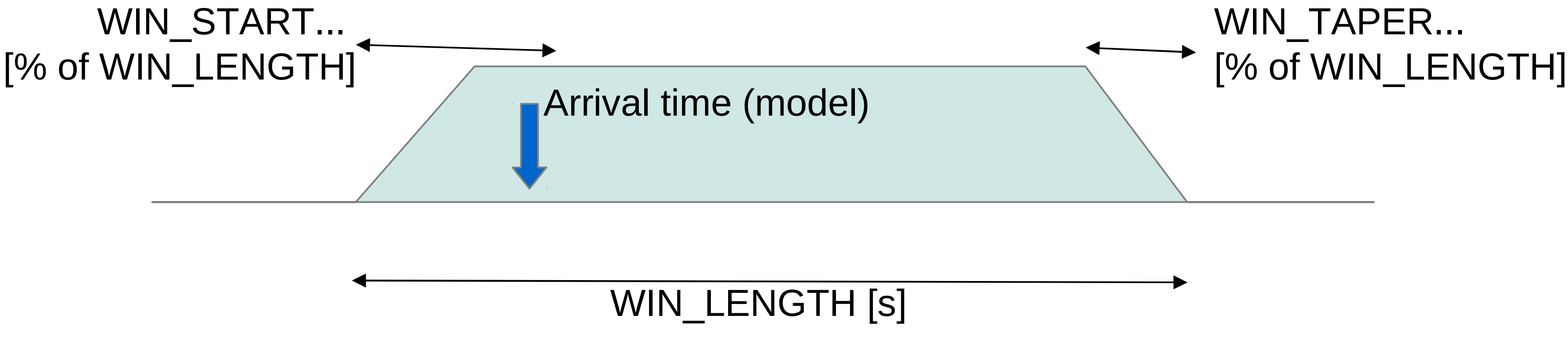
Defines the length (s) of the time window for phase ***a (p, ...)*** during inversion step 1.

WIN_START_A_ST1, WIN_START_P_ST1, ...

Defines the starting time of the time window for phase ***a (p, ...)*** during inversion step 1. The value indicates the position of theoretical first P (or S) phase within the time window, defined as percentage of the window length (e.g. 0.02 for a window length of 100s, indicates that the window will start to have the theoretical first P phase arrival time at 2% of the window length).

WIN_TAPER_A_ST1, WIN_TAPER_P_ST1, ...

Defines the tapering of the time window for phase ***a (p, ...)*** during inversion step 1. A taper is applied in the time domain, smoothing the time window at both sides. The length of the smoothed part of each side is defined by the given real value, which is defined as a percentage of the time window length



Rapidinv, useful variables (step 1 - plotting)

DATA_PLOT_STEP1

Acceptable: *amsp*|*seis*

Define if data format for plotting result after inversion step 1 is amplitude spectra or displacements)

AMPL_PLOT_STEP1

amax: amplitudes of different traces have the same scale (true amplitudes can be better seen).

norm: amplitudes are normalized, they are enlarged to the maximal possible scale (fit).

FILT_PLOT_STEP1

Acceptables: *plain*|*filtered*|*tapered*

Defines the format of time series for plotting results after inversion step 1.

START_PLOT_STEP1, LEN_PLOT_STEP1, TICK_PLOT_STEP1

Defines the start, length and tick interval (s) of time series for plotting results after inversion step 1.

These are used only if DATA_PLOT_STEP1 is ***seis*.**

Rapidinv, useful variables (step 2)

EPIC_DIST_MAXLOC

Additional constraint on maximum epicentral distance to consider for inversion step 2 (where maximum distance will be the minimum between EPIC_DIST_MAX and EPIC_DIST_MAXLOC).

GFDB_STEP2

GFDB used to calculate synthetic seismogram during inversion step 2.

MISFIT_MET_STEP2

l1norm: time traces will be compared, using L1 norm

l2norm: time traces will be compared, using L2 norm

REL_EAST_1, REL_EAST_2, REL_EAST_STEP

REL_NORTH_1, REL_NORTH_2, REL_NORTH_STEP

Min, max and increment of relative location along East and North direction (meters) to define the group of starting configuration, during inversion step 2.

REL_TIME1, REL_TIME_2, REL_TIME_STEP

Min, max and increment of relative time offset (seconds) to define the group of starting configuration, during inversion step 2.

Rapidinv, useful variables (step 2, similar to step 1)

PHASES_TO_USE_ST2

WEIGHT_*_ST2, WIN_LENGTH_*_ST2, WIN_START_*_ST2, WIN_TAPER_*_ST2

As for inversion step 1 (use of bodywaves may work better for location)

BP_F1_STEP2, BP_F2_STEP2, BP_F3_STEP2, BP_F4_STEP2,

Bandpass inversion step 2.

DATA_PLOT_STEP2

Acceptable: *amsp*|*seis*

Define if data format for plotting result after inversion step 2 (amplitude spectra/displacements)

CHECK YOUR RESULTS

- ***step1.ptsolution.ps***
- ***step1.mtsolution.ps***
- ***step2.ptsolution.ps***
- ***step2.mtsolution.ps***

Practical 1

SYNTHETIC DATA

1) Run a point source inversion (DC and full MT) for Bayrischzell synthetic event 1 (SYNTH1)

2) Test SYNTH2. Is there a significant improvement in the MT solution respect to the DC one?

3) Try now SYNTH5 and SYNTH6. Play around with the BP frequency range and check, the quality of your misfit when including higher frequencies.

REAL DATA

4) Choose a real dataset. GER220203, GER051204 and GER201004 are easier cases. Perform the point source inversion (DC and MT). Is there a significant non-DC term? Does the misfit significantly improve from DC to MT?

5) Can you resolve a better source location in inversion step2?

6) Use bodywave phases instead of full waveform and compare the inversion results

7) Try the inversion for some other larger events (Greece, Turkey)

Kinematic inversions with *rapidinv*

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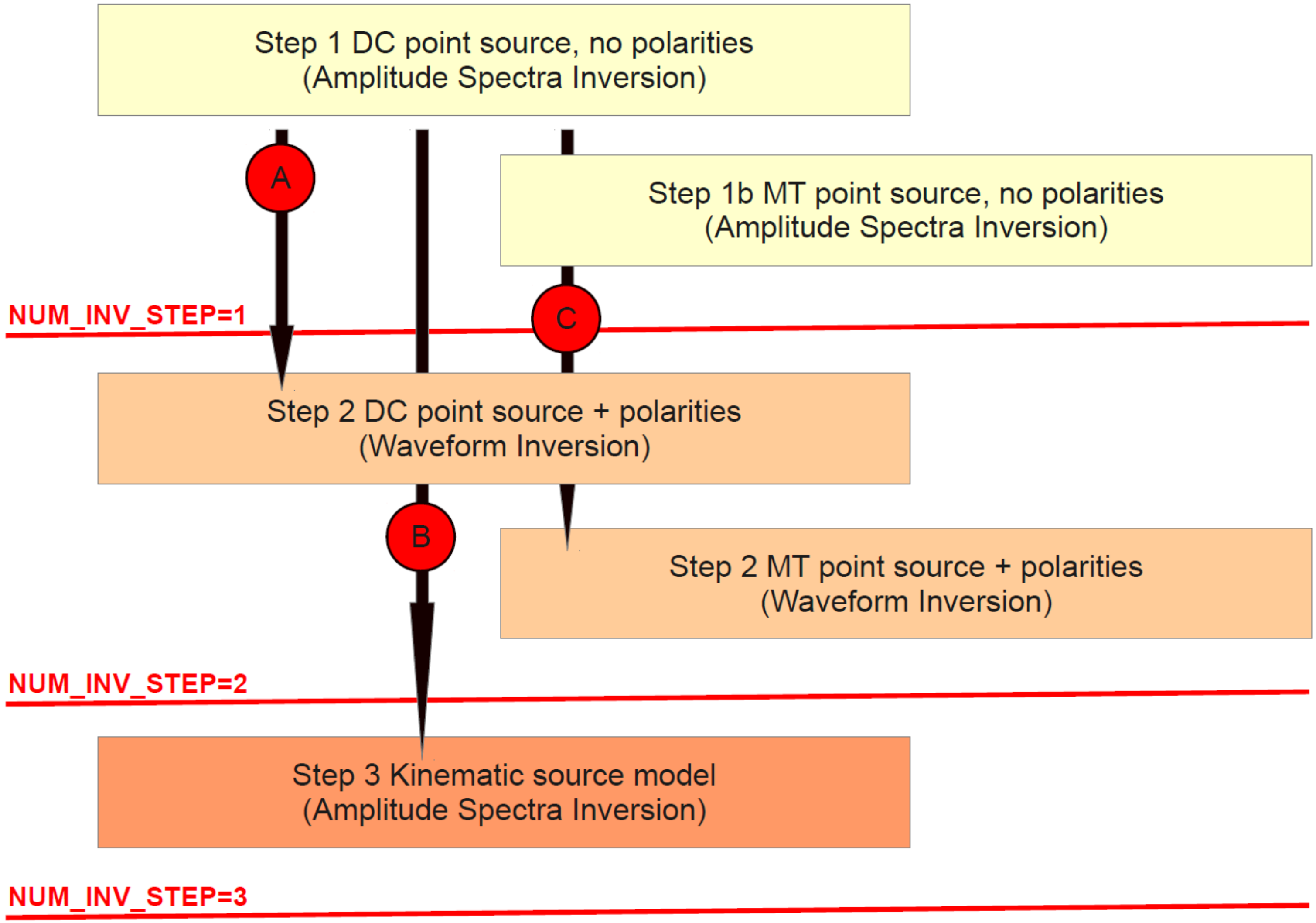
Simply using the KiWI tool, ***rapidinv***



Rapidinv, useful variables (step 3)

EPIC_DIST_MAXKIN

Additional constraint on maximum epicentral distance to consider for inversion step 3 (where maximum distance will be the minimum between EPIC_DIST_MAX and EPIC_DIST_MAXKIN).

GFDB_STEP3

Defines the GFDB used to calculate synthetic seismogram during the inversion step 3.

MISFIT_MET_STEP3

ampspec_l1norm: amplitude spectra will be compared, using L1 norm

ampspec_l2norm: amplitude spectra will be compared, using L2 norm

l1norm: time traces will be compared, using L1 norm

l2norm: time traces will be compared, using L2 norm

REL_RUPT_VEL_1, REL_RUPT_VEL_2, REL_RUPT_VEL_S

Min, max, increment of relative rupture velocity for starting configurations of inv. Step 3.

Better keep it fix to e.g. 0.7

Rapidinv, useful variables (step 3, similar to step 1 & 2)

PHASES_TO_USE_ST3

WEIGHT_*_ST3, WIN_LENGTH_*_ST3, WIN_START_*_ST3, WIN_TAPER_*_ST3

As for inversion step 1 (use of bodywaves may work better for location)

BP_F1_STEP3, BP_F2_STEP3, BP_F3_STEP3, BP_F4_STEP3,

Bandpass inversion step 2.

DATA_PLOT_STEP3

Acceptable: *amsp***|***seis*

Define if data format for plotting result after inversion step 2 (amplitude spectra/displacements)

SW_APPDURATION

Activate fast directivity inversion (uses BP and taper from inversion step 3)

CHECK YOUR RESULTS

step3.eiksolution.ps

apparentduration.ps

Practical 2

SYNTHETIC DATA

1) Run a point source and kinematic inversion (DC and full MT) for Bayrischzell synthetic event 3 and 4 (SYNTH3, SYNTH4)

2) Can you resolve some directivity effects? Check resolution using apparent duration, are this consistent with the results of eikonal inversion?

3) Is the point source solution affected. Does this change when including high frequencies?

REAL DATA

4) Choose a real dataset. GRE080608A, GRE110406A and GRE120406A are easier cases. Perform point and kinematic inversion. Compare your solution with Global CMT solution (www.globalcmt.org).

5) Can you resolve a centroid location in inversion step2?

6) Compare eikonal and apparent duration solutions.

7) Check the misfits for all tested rupture models (step3-eiksolutions.dat). Is there a significant improvement between the best solutions for the two fault planes?

8) Try with other events.