The new release of the database of Earthquake Mechanisms of the Mediterranean Area (EMMA Version 2)

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1. Introduction

The motivation of this work originates from the difficulties that any investigator, interested in seismotectonics and seismic hazard analysis of Italy and surrounding regions, encounters when collecting fault plane solutions from the literature. Italy is in fact a region with a relatively moderate seismicity, where the earthquakes above the magnitude threshold of the Harvard CMT catalog (about Mw>5.5) are only few dozens since 1976, hence the contribution given by first pulse mechanisms published in the literature is also necessary to well characterize the tectonic styles of the various seismic source areas. The difficulties in using such data mainly come from the fact the they were very dispersed over a large number of papers as well as that, due to the papery format, they were not easily available for analyses by computer codes. Moreover, a number of mistakes can be occasionally found on some of them, going from the incorrect use of terms (*i.e.* strike instead of dip-direction) to inconsistencies of the reported data (*i.e.* non-orthogonality of fault planes and deformation axes, inconsistency between plane and axes, etc.).

Therefore, taking advantage of a call for proposals within the Framework Project 2000/2002 of the Italian *Gruppo Nazionale Difesa dai Terremoti* (GNDT), our group submitted a Coordinate Project ("Revision of the theoretical and observational grounds of seismic hazard estimates at a national scale") where one of the tasks was concerned to the development of a reliable catalog of focal mechanisms to be used in new hazard estimates. We thus started to collect focal solutions, from the national and international literature. Initially our interest was limited to Italy and surrounding region, but later the area has been extended to include the whole Mediterranean Sea and surrounding regions, from the Atlantic Ocean to Iran. The first version of the database, published more than one year ago (Vannucci and Gasperini, 2003), contains more than 6000 mechanisms taken from 193 directly examined papers, some of which refer to 175 other works (mostly thesis or technical reports) which was not possible to find (see the complete lists in Appendix B and C respectively). Such version was recently used to constrain the tectonic styles of the seismogenic source areas of the new seismic zonation ZS9 (Working Group, 2004) which has been developed within the framework of the INGV initiative following the Italian Prime Minister Ordinance of March 20, 2003 for the assessment of the new seismic hazard map of Italy

The database is embedded in a MS-Access application allowing the visual comparison between original and recomputed focal mechanisms data, the importing of the data from the on-line Global

CMT Harvard catalog and from two regional RCMT catalogs (INGV and ETH), the selection of mechanisms on the basis of various criteria as well as the exporting onto ASCII files of the data to be used in further computations.

An added value of the EMMA database is the checking for consistency of all the mechanism parameters and, in case of problems, their correction so that the mechanisms are immediately usable for drawing maps or making further computations like the ones shown in the previous article of this issue. We checked the angles between planes and between axes to not differ from 90° by more than three degrees. Also, we checked the consistency between fault planes and axes and between moment tensor components and planes and/or axes. To make all of these checks as well as to homogeneously re-compute all relevant parameters (fault planes and deformation axes angles, moment tensor components) for each mechanism, we have developed a structured package of Fortran 77 subroutines (FPSPACK, Gasperini and Vannucci, 2003) performing the most common computations and checks on focal mechanism data. This package is freely available from the ftp server of Computers & Geosciences journal: ftp://ftp.iamg.org/VOL29/v29-07-08.zip and includes, among the others, routines to compute nodal planes from P and T axes and vice versa as well as to compute moment tensor components from planes or axes or best double couple parameters from moment tensor components. All definitions conventions and formulas we have used are reported in Appendix A.

To make reliable selections on the basis of the earthquake size as well as to compute the seismic moment tensor, we uniformly computed the scalar seismic moment, using empirical regressions with available magnitude estimates, for all of the mechanisms for which this parameter is not reported on the original paper.

Another feature of the EMMA database is the choice of the best mechanism among the available duplicates. We weighted each solution on the basis of a series of objective criteria based on: i) the correctness of the solution (presence or absence of errors in the published FPS parameters), ii) the originality of the source (original sources are preferred with respect to indirect ones), iii) the "authoritativeness" of the source (chosen roughly proportional to the impact factor of the journal where the mechanism is published), iv) the recentness of the publication (most recent papers override previous ones). We did not consider any kind of quality estimators (solution quality factor, number of stations, etc) as these are only given by a minority of the published solutions. The "best solution" is the one with higher weight and is marked in the database by a specific flag that can be included in selection.

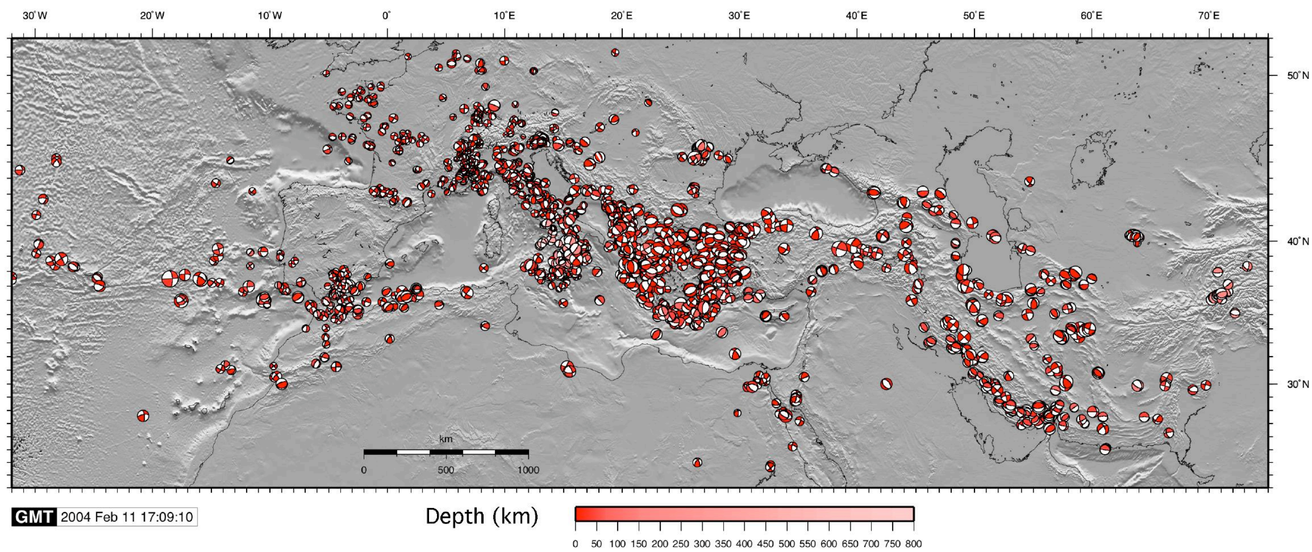

Figure 1 - Spatial distribution of fault plane solutions taken from the literature (on-line CMT catalogs excluded).

2. The new version of EMMA database

This second version of the database is released about one year after the first one, taking advantage of this Special Issue of Annals of Geophysics to disseminate it among the scientific community. All files required to run the MS-Access application are included in a CD-ROM attached to the journal (see instructions below to install and use the MS-Access application). The spatial coverage is similar to previous version (see Fig. 1) as well as the consistency of the data was only slightly improved (see Table 1). The present one however is the first release that is available to a wide community of potential users as the initial release only had a circulation among a restricted ambit. The origin time year ranges from 1905 to 2003 while the moment magnitude Mw from 1.4 to 8.7.

Although we made our best, we can easily predict that at least some mistakes are still present in our work. As well we certainly missed some published papers (see below the complete list of contributing papers). So we explicitly request the collaboration of all investigators that are interested in the improvement of this database to indicate us any kind of mistakes and malfunctioning of the procedure they could find or the omission of interesting papers they know had been published.

We also want to clearly state that our contribution only represents an added value to the work done by the authors of original papers and thus the database must not be cited as the source of data alone but only as a tool to easily access them. We thus strongly recommend the users to insert in their references the complete list of original works that really computed the focal plane solutions they use. As noted above a specific option is available to simplify this task in our MS-ACCESS application.

Type of data	**Number**	**%**
All examined	**6156**	**100.0**
Correct FPS parameters	3761	61.1
FPS parameters with some defects	2395	38.9
Recoverable	**2090**	**34.0**
Wrong axes, correct planes and rakes	126	2.0
Wrong planes or rakes, correct axes	1459	23.7
Only strike and dip of two planes (polarity determined from figures)	505	8.2
Unrecoverable	**305**	**4.9**
Axes and/or planes not perpendicular	205	3.3
Undetermined	100	1.6
Correct+recovered	**5851**	**95.1**
Lacking of earthquake identification parameters (date, location, magnitude)	300	4.9
Usable solutions	5551	90.2
Duplicate solutions	2316	
Distinct earthquakes	**3840**	**100.0**
Earthquakes with only one mechanism	2906	75.7
Earthquakes with more than one mechanism	934	24.3

Table 1 – Summary of the results of the checks performed on the focal mechanisms found in papery literature

3. Hardware and Software prerequisites

The installation requires about 130 Mb of free disk space and the availability of Microsoft Access (Version 97, 2000 or 2003). The disk occupation may increase significantly (up to some hundreds of Mb) as a consequence of the importing of external data and the execution of queries. To reduce this occupation as well as to improve the performances, it is useful to periodically “compact” the database by selecting the appropriate option from the MS-Access Tools menu.

The plotting of the mechanism (beach-ball) in the “Summary and Plot” window also requires the installation of the Generic Mapping Tool (GMT) with *meca* extensions (Wessel and Smith,

1991) and of Ghostscript. These software packages are freely available at the web sites: http://gmt.soest.hawaii.edu/ for GMT and http://www.cs.wisc.edu/~ghost/ for Ghostscript. We have verified that GMT version 3.4.1 and later as well as GNU Ghostscript versions 7.05 and 8.14 work fine. We have not made an exhaustive analysis of compatible operating systems and minimum resources, but satisfying performances can be obtained using a 400 MHz CPU with 128 Mbytes of RAM running Windows 98, 2000 or XP. For an optimal display rendering of windows and menus, the screen resolution must be set to 1024 by 768 or higher.

4. Installation

The folder `\EMMA`, in the attached CD-ROM, contains all the files needed to run the database application and in particular the database files for the three supported MS-Access versions (`EMMA97.MDE`, `EMMA2000.MDE` and `EMMA2003.MDE`) and a folder (`\EMMA\bin`) containing three executables (`Convertk_cmt.exe`, `Convertk_eth.exe`, `Convertk_ingv.exe`) used by the MS-Access application to convert, from original to import formats, the Harvard CMT, the ETH and the INGV RCMT catalogs.

To install the database please follow these steps:

1) Copy (drag-and-drop) the `\EMMA` folder from the CD-Rom onto the hard disk.
2) Select the folder with the right-hand mouse button, choose Properties and then remove the Read-only attribute from `\EMMA` folder and from all included files and folders.
3) Copy the file `GMTENV.BAT` (usually located in the `\SRC` folder of GMT package) to the `\EMMA` folder and rename it as `SETPATH.BAT`
4) Copy the Ghostscript executable (*i.e.* `GSWIN32C.EXE`) to the `\EMMA` folder and rename it as `GS.EXE`
5) From the Start menu select Control Panels and then double click on International. In the Numbers card, set decimal separator as "." (dot), thousands separator as "," (comma) (default setting for English language systems) and 4 decimal digits (default is 2). Do the same settings in the Currency card.
6) Launch the database application (in `\EMMA` folder) by double clicking the .MDE file corresponding to the MS-Access version installed on the host computer (the unnecessary .MDE files can be deleted).
7) From the MS-Access Tools pop-up menu, select Option. In the General card, set the Default Database Directory to the folder containing the .MDE file (for example: `C:\EMMA`).

5. Usage notes

The MS-Access application we have written allows to access mechanism data through a series of menus and masks. The user can display the mechanisms of the entire database or make selections on the basis of earthquake source parameters (date, location, magnitude, etc.) and/or of bibliographic references (authors, journal, etc.). As well, the mechanism data can be exported to ASCII files in order to be plotted by GMT (Wessel and Smith, 1991), or processed by external codes. Another feature of the MS-Access application is the compilation and the exporting of the list of bibliographic references of all of the data or a selection of them. This simplifies the correct citation of all of the contributing papers to investigations making use of the EMMA database.

In these notes, we will give a brief description of the main features of the MS-Access application. They are not to be intended as an exhaustive user manual but rather as a tutorial for a quick access to the database features. However the subdivision in sections might be useful even for a fast finding the needed information at the various levels.

5.1 Main menu

At the start-up, a main menu with four choices is displayed (Fig. 2):

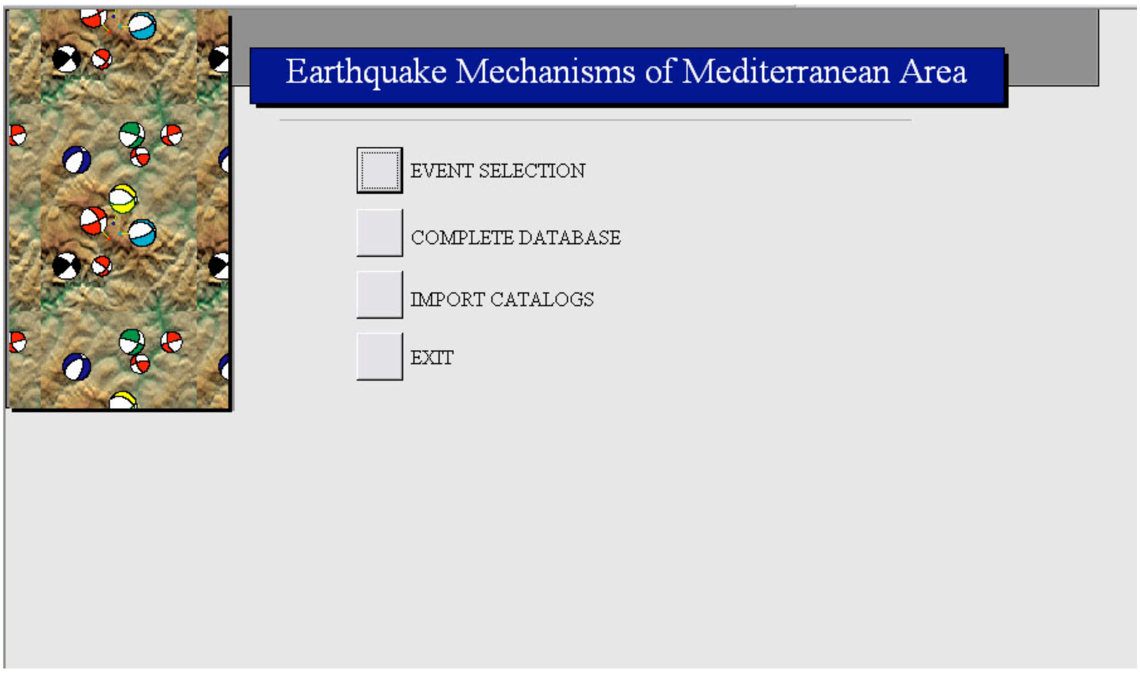

Figure 2 – Main menu of EMMA database.

By clicking the top button (EVENT SELECTION), the **Event Selection Mask** (see section 5.3) is displayed.

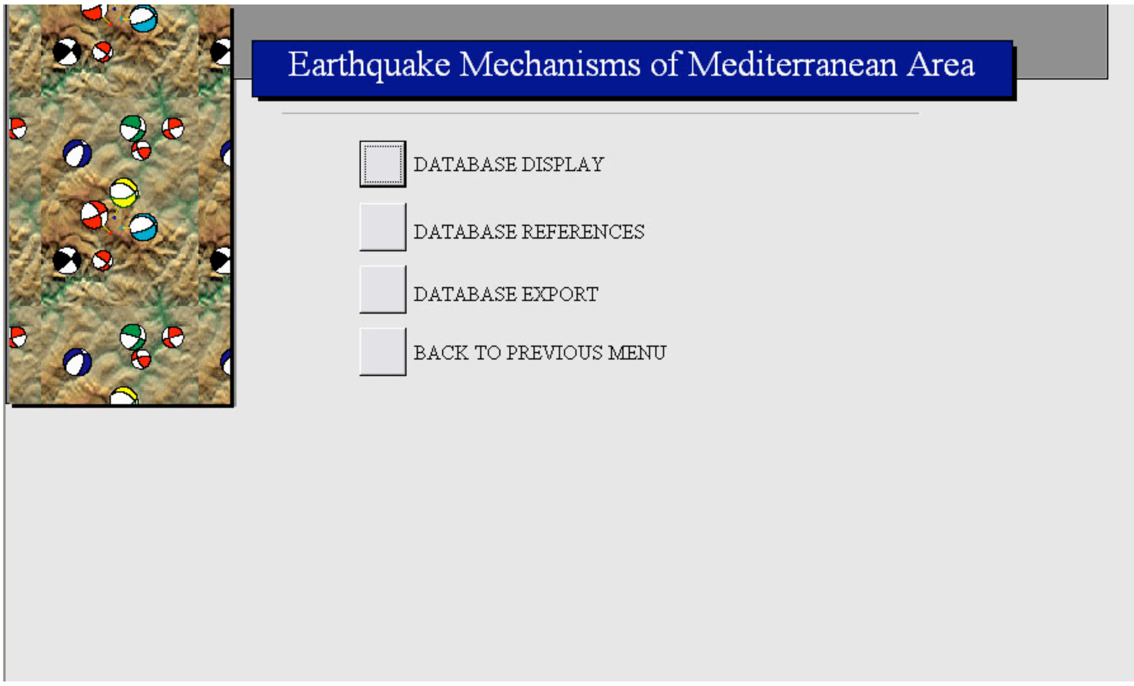

Figure 3 – Complete database menu.

The second button of the main menu (COMPLETE DATABASE) accesses a further menu (Fig. 3) with four choices: the first one (DATABASE DISPLAY) activate the **Mechanism display window** (described in section 5.2), allowing to examine all the events included in the EMMA database, the second one (DATABASE REFERENCES) activate a further menu giving the chance to view and export the complete reference list, the third one (DATABASE EXPORT) starts a menu for exporting the focal mechanism data of the complete set of revised solutions taken from the literature and the fourth one (BACK TO PREVIOUS MENU) return the Main menu

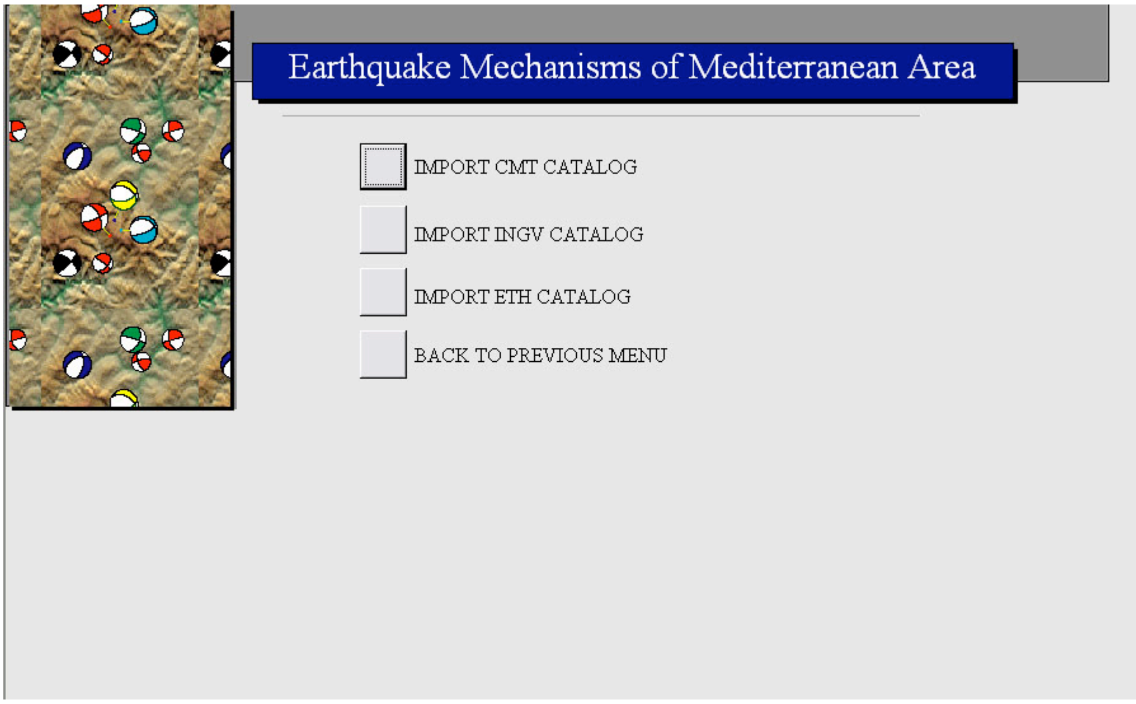

Figure 4 – Import menu.

The third button of the Main menu (IMPORT CATALOGS) accesses another menu (Fig. 4) allowing to import in the database the focal solutions data of three on-line catalogs:

- the global CMT catalog continuously updated by the Harvard Seismology team (Dziewonski et al., 1981 and subsequent papers appeared quarterly on *Phys Earth Plan. Int.*) and available at address: http://www.seismology.harvard.edu/projects/CMT/;
- the Regional CMT (RCMT) catalog of the Mediterranean Region, published by the *Istituto Nazionale di Geofisica e Vulcanologia* (INGV) of Rome (Pondrelli et al, 2002, 2004) and available at address: http://www.ingv.it/seismoglo/RCMT/;
- the Regional CMT (RCMT) catalog of the *Eidgenössische Technische Hochschule* (ETH) of Zürich (Braunmiller et al., 2002), mainly covering the Mediterranean region, available at address: http://seismo.ethz.ch/info/mt.html.

To import the data, the corresponding ASCII input files must be copied in the Default Database Directory (containing the other database files). The names of the input files must be `CMT.DEK`, `INGV.DEK` and `ETH.DEK` respectively and the formats must conform to the standard of each catalog: the four-lines .DEK format (see Fig. 5) for the former two (CMT and INGV) and the ETH specific format for the latter one (see Fig. 6).

The mechanisms data must be sequentially stored into the files without embedded blank lines. A new import execution completely replaced the data previously imported for the same catalog.

```
M010176A 01/01/76 01:29:39.6 -28.61 -177.64  59.06.20.0KERMADEC ISLANDS REGION
MLI BW: 0  0   0 MW:12 30 135 DT=  13.8 0.2 -29.25 0.02 -176.96 0.01  47.8  0.6
 DUR 9.4 EX 26  7.68 0.09  0.09 0.06 -7.77 0.07  1.39 0.16  4.52 0.16 -3.26 0.06
   8.94 75 283   1.26  2  19 -10.19 15 110   9.56 202 30   93  18 60   88
C010576A 01/05/76 02:31:36.3 -13.29  -74.90  95.06.00.0PERU
MLI BW: 6 14  45 MW: 5  8 135 DT=   8.4 0.4 -13.42 0.07  -75.14 0.06  85.4  3.2
 DUR 1.6 EX 24 -1.78 0.21 -0.59 0.28  2.37 0.28 -1.28 0.15  1.97 0.15 -2.90 0.22
   4.97 19 238  -2.35 14 143  -2.62 66  20   3.79 350 28  -60 137 66 -105
C010676A 01/06/76 21:08:19.3  51.60  159.33  33.05.76.0OFF EAST COAST OF KAMCHA
MLI BW: 9 27  45 MW: 9 19 135 DT=   5.8 0.2  51.45 0.02  159.50 0.03  15.0  0.0
 DUR 2.8 EX 25  1.10 0.02 -0.30 0.02 -0.80 0.02  1.05 0.07  1.24 0.08 -0.56 0.02
   1.95 62 315   0.05  4 218  -2.00 27 126   1.98 206 18   78  39 73   94
```

Figure 5 – Sample of .DEK (four lines) input format (CMT and INGV data).

```
|         SED MOMENT TENSOR SOLUTION
|
|   Event: Izmit Earthquake
|
|   Location/Magnitude provided by NEIS:
|     Date/Time: 99/ 8/17  0: 1:38
|     Lat./Lon.:   40.640   29.830
|         mb/Ms:     6.3      7.8
|
|   Moment Tensor Solution:
|   Depth (km):  12.0    Stations Used: 22
|   Moment Tensor: Scale = 10**27 dyn cm
|     Component  Value    Component  Value
|        Mxx     0.555       Myy     0.157
|        Mxy     1.989       Myz     0.444
|        Mxz    -0.284       Mzz    -0.712
|   Source Composition:
|     (Type/%)  DC/ 59  CLVD/ 41   Iso/  0
|   Principal Axes:
|       Axis      Value    Plunge   Azimuth
|         T       2.358         2        42
|         N      -0.482        66       136
|         P      -1.876        24       312
|   Best Fitting Double-Couple:
|       Mo = 2.12E+27 dyn cm     Mw = 7.52
|       Plane   Strike      Rake       Dip
|        NP1       354       -19        74
|        NP2        90      -164        72
|
|
|                 --#####
|           ---------##########
|        ------------#############
|      ---------------############ T
|    ------------------###########   #
|   -----   -----------################
|  ------ P ------------################
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|####--------------------############-----
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| #######################----------------
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|        ################---------
|           ############-------
|                 ######-
|
|   Lower Hemisphere Equal Area Projection
```

Figure 6 – Sample of ETH input format.

The fourth button of the Main menu (EXIT) exits the database application, but not the MS-Access program which, in case, can be manually quitted from the “File” pop-up menu or from the cross button in the window top-right corner.

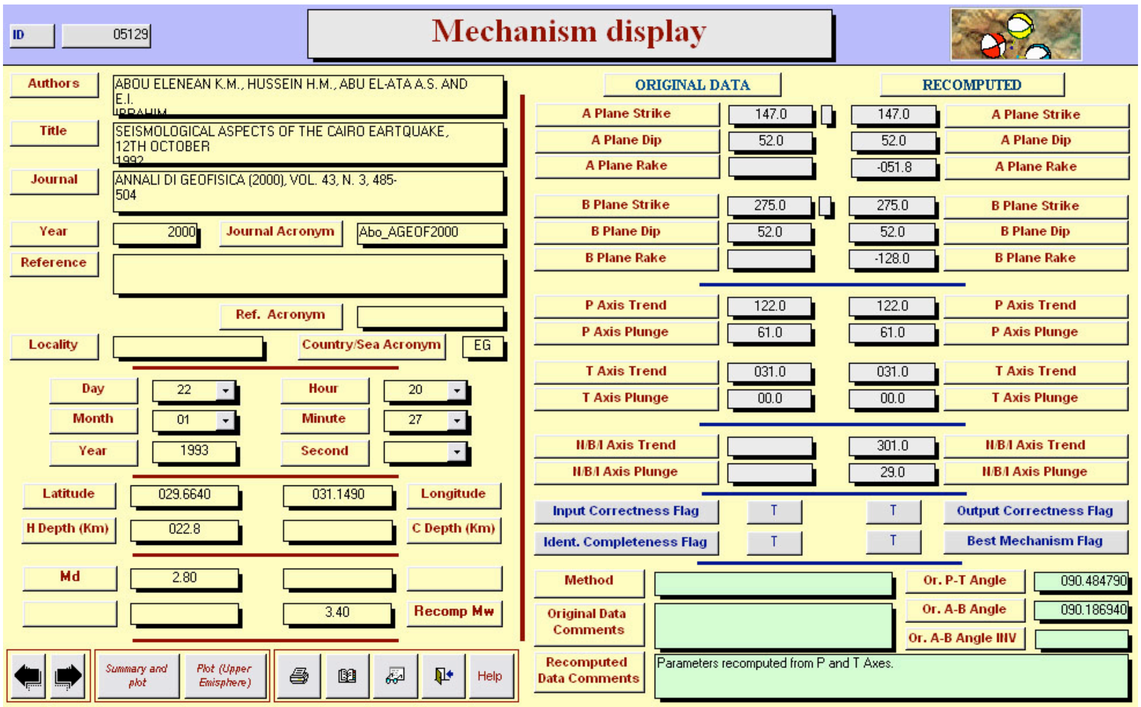

Figure 7 – Mechanism display window.

5.2 Mechanism display window

The Mechanism display window (Fig. 7) can be accessed from the COMPLETE DATABASE button of the Main menu as well as from the **Event Selection mask** described in section 5.3. It allows the scrolling of the mechanisms by the standard MS-Access record search and move arrows located on the window border close to the bottom-left corner. A univocal ID number, displayed on the top-left corner, identifies each focal solution included in the database. The mechanisms can also be scrolled forward and backward by clicking respectively the  and  buttons located close to the bottom-left corner of the window.

The  and  buttons activate the **Summary and plot window** (described in section 5.5) including a beach-ball plot of the mechanism in the lower hemisphere standard representation and in the upper hemisphere alternative representation respectively. The remaining buttons, allow to:  print the layout of the window for the current record,  print the layout of the window for all the selected records (*to use with caution*),  activate the **Additional parameters display**

window (described in section 5.4) showing the values of parameters like moment tensor components, moment tensor decomposition parameters and parameter uncertainties, exit the window and return to the calling menu or mask, Help display a help window with a brief explanation of each button.

The left-hand side of display mask gives, for each fault plane solution, a comprehensive report of the earthquake parameters and of the bibliography of the work from which the data are actually taken as well as of the original reference, when the latter is not directly available and the data were taken from a paper referring it. All earthquake parameters shown in this section exactly reflect those reported on the examined source works, excluding for the moment magnitude reported on left of box Recomp. Mw. This value is uniformly recomputed (see Vannucci and Gasperini, 2003), from the scalar seismic moment or the magnitudes given by the source, in order to make uniform magnitude selections and to determine the seismic moment tensor. It is the result of different possible choices, depending on the parameters available from the source paper. The highest priority is given to direct Mw estimates or ones derived from the reported scalar seismic moment, while in absence of them, Mw is recomputed from other types of magnitude (see details in Vannucci and Gasperini, 2003). Correspondingly, the scalar seismic moment is recomputed, when not available from the paper, from Mw or other types of magnitude.

The right-hand side of display window reports fault planes and/or deformation axes parameters found on the examined source (ORIGINAL DATA) as well as those (RECOMPUTED) resulting from the validation and correction procedure described by Vannucci and Gasperini (2003). The other information displayed in this side of the window gives details on the mechanism estimate method, on the "correctness" of the original data and, in case of problems, on the procedure followed to correct them. In particular, four logical flags (with only two possible values: T = true, F = false) indicate the following focal mechanism properties:

- input correctness flag: if T, the original nodal planes and/or P and T axes were found to be consistent among each other and thus no correction were made to the original data. In this case only the parameters not given by the source are recomputed. If F, some kind of inconsistency was found then, if possible, all the parameters were recomputed consistently.
- ident. completeness flag: if T, all information needed for an univocal identification of the earthquake (epicentral location, origin-time and magnitude or scalar moment) are available from the source. If F, the data reported by the source do not permit the correct identification and thus the mechanism is not "usable" for further analyses.
- output correctness flag: if T, the original or the recomputed nodal planes and P and T axes parameters are correct and usable. If F, the data reported by the source are not consistent

and/or do not allow to re-compute reliable parameters. Even in this case the mechanism is not "usable" for further analyses.

- best mechanism flag; if T, this mechanism is the "best" (in the sense described by Vannucci and Gasperini, 2003) among duplicates for the same earthquake. If F, the mechanism is an alternative solution among duplicates for the same earthquake but not the preferred one.

The green boxes located in lower-right portion of the windows report further details on the mechanism and, in case, on problems encountered in original data and on the choices made to solve them:

- Method gives information on the methods used to compute the mechanism (First motion, CMT, P and S waves, velocity models etc.) when these are clearly declared on the source papers.
- Original Data Comments gives information on evident misprints or terms misuse in the original data.
- Or. P and T Angle reports the angle between P and T axes in degrees, as resulting from the original data (it should be close to 90°).
- Or. A and B Angle gives the angle between nodal planes (A and B) in degrees, as resulting from the original data (it should be close to 90°).
- Or. A and B Angle INV gives, only for defective solutions, the angle in degrees between nodal planes when the strike angle of one of the two is rotated by 180°. If it is close to 90° this represent a clear explanation of the inconsistency found in the original data.
- Recomputed Data Comments reports, for defective solutions, a synthetic description of problems encountered with the original mechanism data and of the procedure followed to solve them and to re-compute consistent parameters.

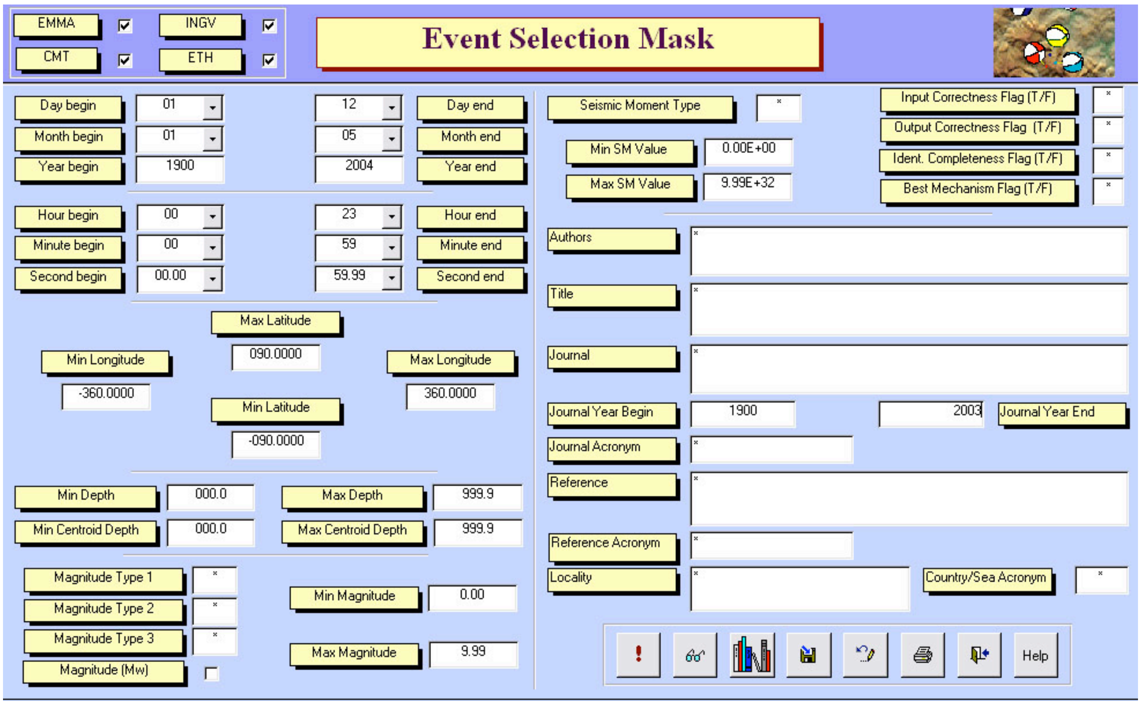

Figure 8 – Mechanism Selection Mask.

5.3 Mechanism Selection Mask

This mask can be accessed by clicking the first button (EVENT SELECTION) of the Main menu. At the top-left corner, the catalog (or catalogs) to be processed can be checked or not by selecting the tick box (or)just on the right of the corresponding yellow boxes: EMMA for the revised mechanisms taken from the literature, CMT for the Harvard CMT Project catalog, ETH and INGV for the Regional CMT catalogs of the ETH of Zurich and INGV of Rome respectively. Note that, different from the literature data (that are already preloaded into the database), the moment tensor catalogs are to be imported by the user (see above).

The Event Selection mask generates a database query that checks in all cases only the earthquake date, location and depths and the Journal Year. The remaining parameters are only considered for selections if the corresponding boxes contain other than an asterisk (*).

To activate a selection in magnitude, the code (or codes) of desired magnitude types (among Ml, Ms, Mb, Mw, Md or M) must be indicated in one or more of the input boxes located on the right of Magnitude Type 1, Magnitude Type 2 or Magnitude Type 3. A given mechanism is selected if at least one of the specified magnitude types is available for the mechanism and its value is between Min Magnitude and Max Magnitude. Another possibility is to check the tick box located on the right of Magnitude (Mw). In this case the selection is made on the homogeneously recomputed moment magnitude described in section 5.2. As well the selection on seismic moment can be activated by selecting a moment code (among M0b, M0, M1) in the input box located on the right of Seismic Moment Type.

The selection on other parameters (Authors, Title, Journal, Journal Acronym, Reference, Reference Acronym, Locality and Country/Sea Acronym) can be activated by indicating the searched alphanumeric strings (or part of it, using the asterisk as wild-card character), in the corresponding input boxes.

The selection query can also include the “correctness” flags described in section 5.2. The desired logical value T (true) or F (false) has to be specified in the corresponding input box.

Warning: *the selections follow a logical “AND” scheme (the mechanism is selected if all the condition are satisfied) for all “active” parameters except for the combination of magnitudes that follows instead a logical “OR” scheme (the mechanism is selected if at least one magnitude type lies within the range).*

The initial limits are set so that to selecting all the events of the chosen catalogs. The changes made to selection limits remain set even after the MS-Access application is exited and restarted. Clicking the “Reset selection” button (fifth from the left in the bottom-right part of the mask), the initial settings are restored and the “end” date limit is updated to the current system time. The other buttons located in the bottom-right side of the mask allow to: execute the selection, enter the **Mechanism display window** (described in section 5.2) allowing to display the selected mechanisms, view or export a list of references (see section 5.6), view and export the selected mechanisms data for various purposes (see section 5.6), print the layout of mask, exit the mask and return to previous menu, display a help window containing a brief description of the function of each button.

Warning: *The change of selection limits does not affects the selected mechanisms until the “execute selection” button is clicked again to execute the selection.*

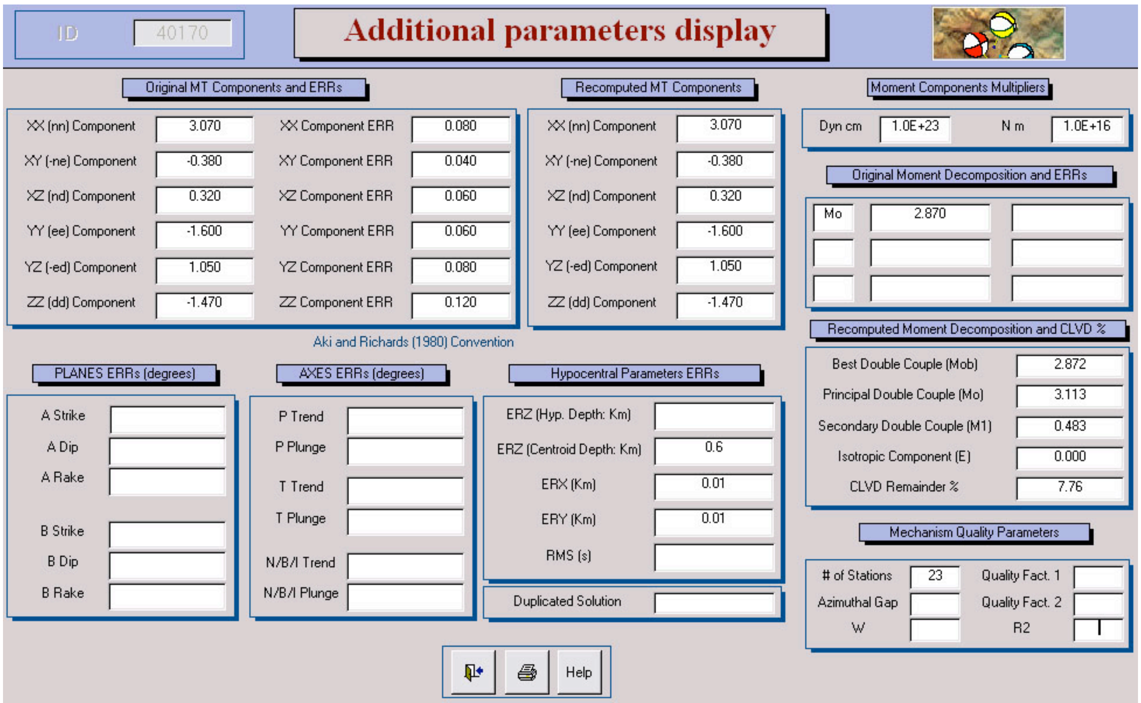

Figure 9 – Additional parameters display window.

5.4 Additional parameters display window

The Additional parameters display window (Fig. 9) can be launched, from button  of the **Mechanism display window** (see section 5.2). In the upper-left section, it reports, when given by the source (mainly for CMT and RCMT catalogs), the original moment tensor components and corresponding errors as well as moment tensor components recomputed from double couple parameters when only the nodal planes and/or deformation axes are given. All of the moment tensor components and errors are multiplied by the exponential factor reported on the top-right corner of the window, both in units of Dyne cm and N m. Independently of the convention used on the source of data, the Aki and Richards (1980) reference frame is used for moment tensor components. Thus in the case of sources (like the CMT and RCMT on-line catalogs) adopting the Harvard CMT convention (see *i.e*. the Appendix A) the sign of the XY (ne) or YZ (ed) components displayed in the window are reversed with respect to the ones found on original sources. On the right-hand side of the window other information, regarding moment tensor decomposition reported by the source (original) or recomputed, are reported. Among the latter ones, the best double couple scalar moment M_{0b} is computed as the average of the two largest moment tensor eigenvectors in modulus, while the percentage of CLVD remainder is determined as one half of the ratio between the smallest and the largest eigenvector (for details see Appendix A). The window also shows parameters that are only sporadically reported by sources (like the errors of fault planes, deformation axes and hypocentral parameters or the quality factors for the first pulse solutions).

Three buttons permits to:  print the current window layout,  exit from the window and return to the Mechanism display window, 

display a window giving a brief explanation of the function of all of the buttons.

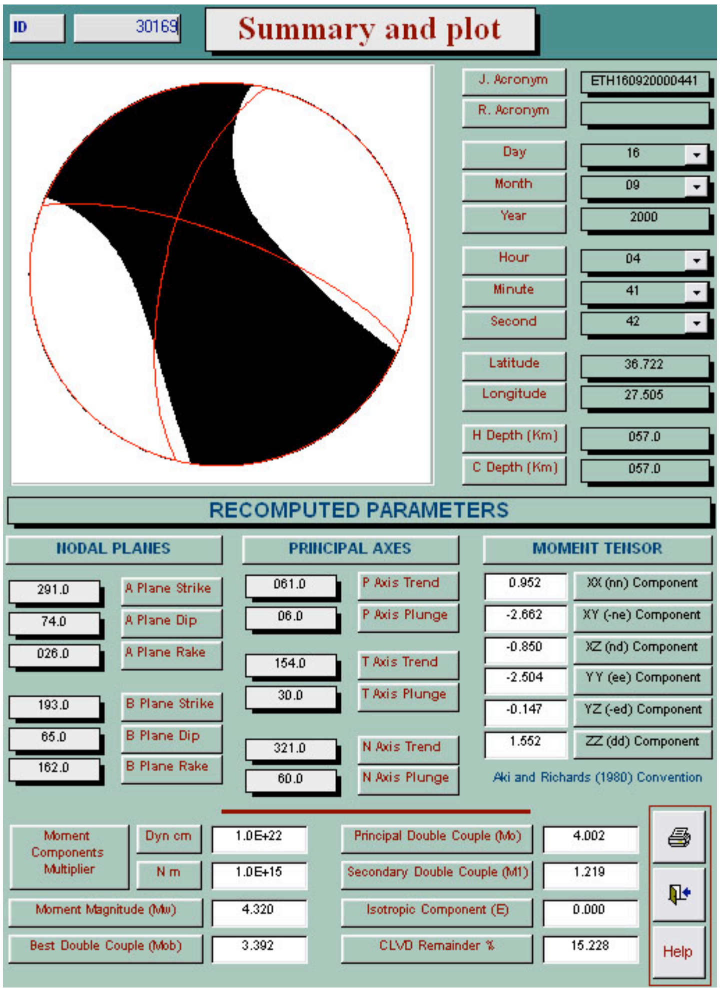

Figure 10 – Summary and Plot window (red lines indicate best double couple nodal planes).

5.5 Summary and Plot window

The Summary and Plot window (Fig. 10) is activated from the **Mechanism Display window** (described in section 5.2) by clicking the buttons 

and 

. While the displayed numerical data are the same in both cases, the beach-ball plots are drawn in the lower hemisphere standard representation fort the first one and in the upper hemisphere alternative representation for the second one. Such plots are correctly drawn only if both GMT and Ghostscript are correctly installed in the host computer as described in section 2 above. Black and white shadings represent the complete moment tensor solution (including the CLVD remainder) while red lines the best double couple nodal planes. The window summarizes some of the numerical information reported in the

Mechanism display and Additional parameters display windows with the same meanings and conventions described above.

As in the case of the Additional parameters window, three buttons permits to: print the layout of the window, close the window and return to the Mechanism display window, display a window giving a brief explanation of the function of all of the buttons.

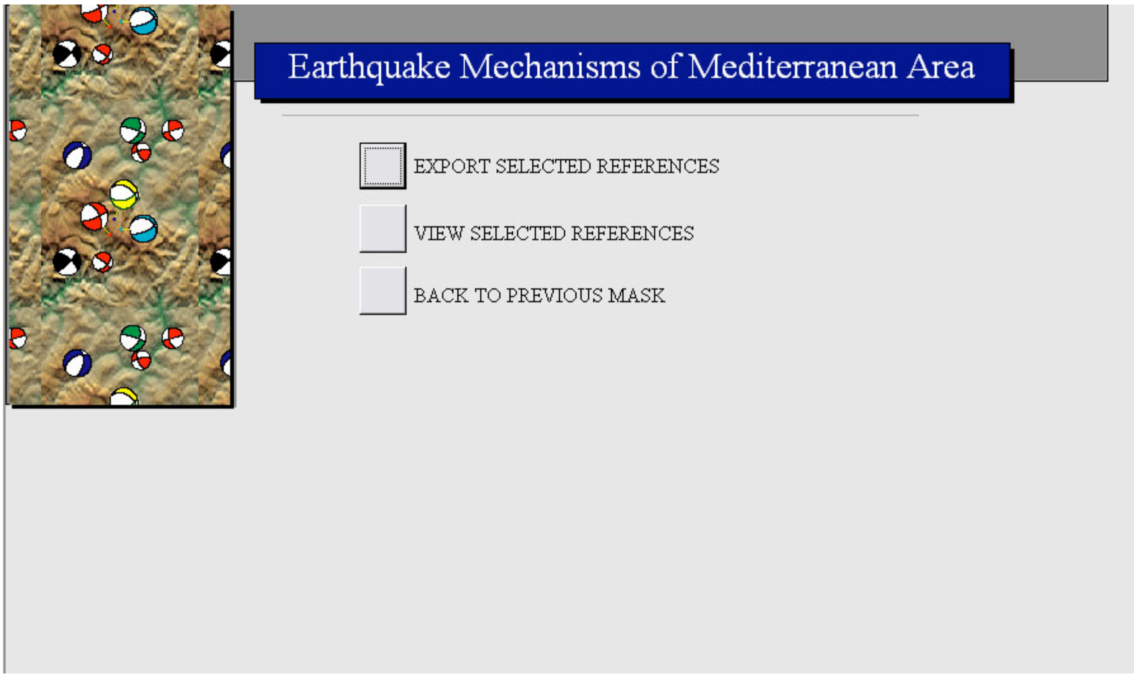

Figure 11 – References menu.

5.6 References export and Mechanism data export menus

The References export menu (Fig. 11) can be accessed both from the Complete EMMA database menu (see section 5.1) and from the button of the **Event selection mask** (section 5.3). The first two buttons launch two procedures that respectively export onto an ASCII file and display on the screen, the list of papers from which the selected focal mechanisms data have been taken (in alphabetical author order). These reference lists can include either the directly examined sources (direct references), the ones not directly examined (indirect references) but cited by others as well as the sum of both direct and indirect ones. The file names are in the first case REFERENCE_D.txt and REFERENCE_SEL_D.txt, for whole EMMA database and for selected data respectively, in the second case REFERENCE_I.txt and REFERENCE_SEL_I.txt and in the third case REFERENCE_C.txt and REFERENCE_SEL_C.txt.

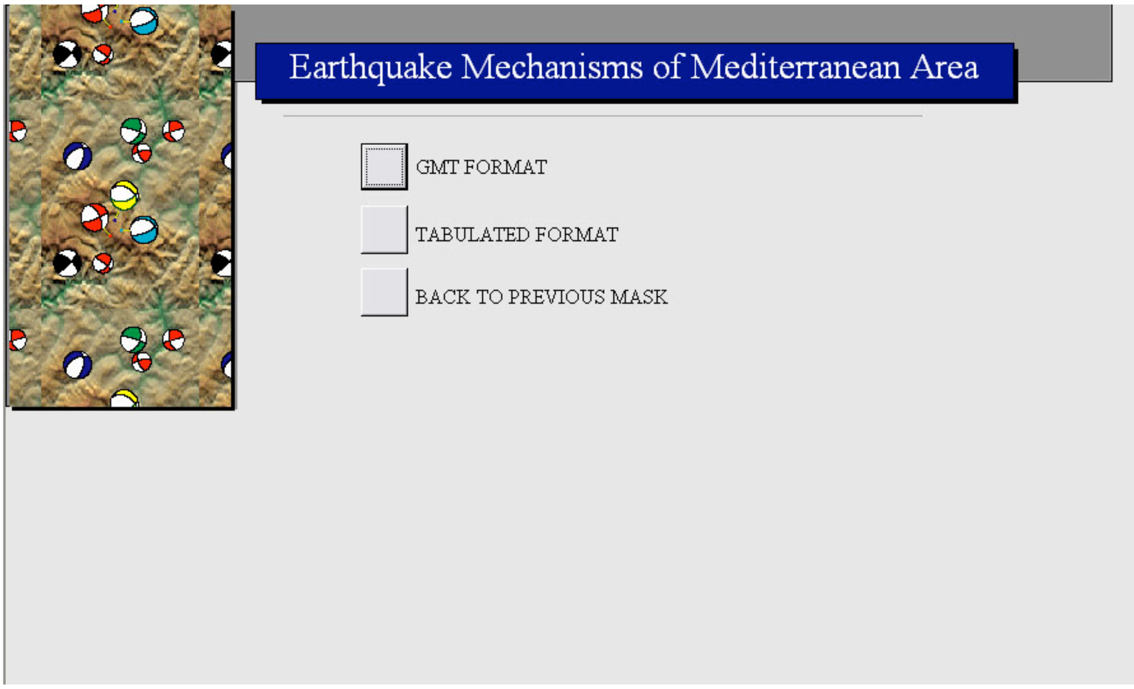

Figure 12 – Export menu.

Similarly, both the Complete EMMA database menu (section 5.1) and the  button of the **Event selection mask** (section 5.3) access the Mechanism data export menu (Fig. 12) allowing to display or to export onto an ASCII file, the focal solutions parameters. Two different output formats are available: a GMT format, only including the parameters required to plot the mechanisms using the GMT package, and a tabulated format including all the parameters stored in the database (about 140) separated by “tabs”. For both formats the user has the chance to directly export the data to predefined file names (see below) or to view the data within a worksheet and, in case, to save the data by choosing the file name and the format (MS-Excel, Lotus, RTF etc.) through the MS-Access standard export window.

In the GMT format, only the solutions that can be considered as “identifiable” and “correct” (both the ident. completeness flag and output correctness flag must be T) are exported to the output files (EMMA_DATABASE_CF_GMT_M.txt and TOT_DATABASE_SEL_CF_GMT_M.txt for the Complete database and for selected data respectively). These files can be directly used as “tabulated” input files for the GMT command “psmeca -Sm” (beach-ball plot using moment tensor components). The sample batch file named Italy.bat, included in the EMMA distribution folder, contains the simple GMT commands that use the data exported to the file “TOT_DATABASE_SEL_CF_GMT_M.txt” to create a mechanism map on the Postscript file Italy.ps.

The “tabulated” format files (EMMA_DATABASE_CF.txt, TOT_DATABASE_SEL_CF.txt for the Complete database and for selected data respectively) include instead all the mechanisms regardless their “identificability” and/or “correctness”.

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Appendix A – Definitions, conventions and formulas used to check and re-compute mechanism parameters

The focal mechanism of an earthquake can be completely represented by the seismic moment (symmetric) tensor M_{ij}. For a pure double couple it can be defined, in the Aki and Richards System (AR System), as a function of the outward normal and slip vectors of one of the nodal planes as

$$M_{ij}^{AR} = M_0 \begin{Vmatrix} 2n_x d_x & n_x d_y + n_y d_x & n_x d_z + n_z d_x \\ n_y d_x + n_x d_y & 2n_y d_y & n_y d_z + n_z d_y \\ n_z d_x + n_x d_z & n_z d_y + n_y d_z & 2n_z d_z \end{Vmatrix} \tag{A.1}$$

In this case only 4 components are independent, while for a general composite mechanism the independent components of the moment tensor are 6.

Most of CMT solutions available in the on-line catalogs are given in the Harvard CMT coordinate system. The tensor can be expressed as a function of the 6 independent components reported on the CMT catalog (M_{SS}, M_{EE}, M_{RR}, M_{SE}, M_{RS}, M_{RE}) as

$$M_{ij}^{Harvard} = M_0 \begin{Vmatrix} M_{SS} & M_{SE} & M_{RS} \\ M_{SE} & M_{EE} & M_{RE} \\ M_{RS} & M_{RE} & M_{RR} \end{Vmatrix} \tag{A.2}$$

As the direction of two coordinate axis (1 and 3) are reversed with respect to the AR System, the signs of the components 1-2 and 2-3 must be exchanged when passing from one to the other of the two systems

$$\begin{aligned} M_{12}^{AR} &= M_{21}^{AR} = -M_{12}^{Harvard} = -M_{21}^{Harvard} \\ M_{23}^{AR} &= M_{32}^{AR} = -M_{23}^{Harvard} = -M_{32}^{Harvard} \end{aligned} \tag{A.3}$$

The eigenvectors of the moment tensor corresponding to the most negative, most positive and intermediate eigenvalues coincide with the directions of the P, T and B axes. Hence these can be used to compute the nodal planes of the double couple best representing the mechanism. The latter however well represents the entire mechanism only when the most compressive and most tensional eigenvalues are close in modulus and the intermediate one is negligible with respect to them. Otherwise the mechanism is complex and can be decomposed making some assumptions on the causative mechanics (see *i.e.* Lay and Wallace, 1995 and Julian et al., 1998, for a comprehensive discussion of different cases).

All decomposition methods require the removal of the isotropic tensor component. The result of this operation (preliminary done in most CMT catalogs) is the deviatoric moment tensor that in the major axis coordinate system is given by

$$\begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_2' & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} = \begin{Vmatrix} \lambda_1 & 0 & 0 \\ 0 & \lambda_2 & 0 \\ 0 & 0 & \lambda_3 \end{Vmatrix} - \begin{Vmatrix} E & 0 & 0 \\ 0 & E & 0 \\ 0 & 0 & E \end{Vmatrix} \tag{A.4}$$

where $E = (\lambda_1 + \lambda_2 + \lambda_3)/3$. The most popular decomposition method subdivides the deviatoric moment tensor into the sum of two double couples. Assuming a decreasing ordering in modulus of deviatoric eigenvalues ($|\lambda_1'| > |\lambda_2'| > |\lambda_3'|$) we can write

$$\begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_2' & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} = \begin{Vmatrix} \mathrm{M}_0 & 0 & 0 \\ 0 & \text{-}\mathrm{M}_0 & 0 \\ 0 & 0 & 0 \end{Vmatrix} + \begin{Vmatrix} 0 & 0 & 0 \\ 0 & \mathrm{M}_1 & 0 \\ 0 & 0 & \text{-}\mathrm{M}_1 \end{Vmatrix} \tag{A.5}$$

where $|M_0|$ and $|M_1|$ are the scalar seismic moment of major and minor double couples respectively.

An alternative method, originally proposed by Knopoff and Randall (1970), decomposes the deviatoric moment tensor into the sum of a double couple and a Compensated Linear Vector Dipole (CLVD), with same P and T axes. Assuming again a decreasing ordering in modulus for the deviatoric moment tensor eigenvalues, this is given by

$$\begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_2' & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} = (1-\eta) \begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \text{-}\lambda_1' & 0 \\ 0 & 0 & 0 \end{Vmatrix} + \eta \begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \text{-}\lambda_1'/2 & 0 \\ 0 & 0 & \text{-}\lambda_1'/2 \end{Vmatrix} \tag{A.6}$$

where η=-2λ'_3/λ'_1 is a measure of the size of the CLVD component with respect to the total deviatoric moment tensor. It may range from 0 for a pure double couple to 1 for a pure CLVD. The scalar seismic moment of the double couple is given by $M_0=(1-\eta)|\lambda'_1|=|\lambda'_2-\lambda'_3|=|\lambda'_1-2\lambda'_3|$.

A slightly different procedure is followed by the Harvard CMT and other routine catalogs. They compute the scalar moment M_{0b} of largest possible (best) double couple that has a CLVD remainder (Dzievonski et al., 1987) as the average of the two largest eigenvalues in modulus

$$\mathrm{M}_{0b} = \frac{|\lambda_1'| + |\lambda_2'|}{2} = \frac{|\lambda_1' - \lambda_2'|}{2} \tag{A.7}$$

where the last passage is correct because the largest eigenvalue has opposed sign with respect to the other two due to the zero tensor trace and the assumed eigenvalues ordering. In this representation the isotropic moment tensor decomposes as

$$\begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_2' & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} = \begin{Vmatrix} (\lambda_1' - \lambda_2')/2 & 0 & 0 \\ 0 & (\lambda_2' - \lambda_1')/2 & 0 \\ 0 & 0 & 0 \end{Vmatrix} + \begin{Vmatrix} -\lambda_3'/2 & 0 & 0 \\ 0 & \text{-}\lambda_3'/2 & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} \tag{A.8}$$

The ratio between the sizes of CLVD remainder and total deviatoric moment tensor is now given by $\eta'=-\lambda'_3/(2\lambda'_1)$ that is exactly one fourth of previous definition. Thus equation (A.8) can be written as

$$\begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_2' & 0 \\ 0 & 0 & \lambda_3' \end{Vmatrix} = (1-\eta') \begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & -\lambda_1' & 0 \\ 0 & 0 & 0 \end{Vmatrix} + \eta' \begin{Vmatrix} \lambda_1' & 0 & 0 \\ 0 & \lambda_1' & 0 \\ 0 & 0 & -2\lambda_1' \end{Vmatrix} \qquad \text{(A.9)}$$

The lower limit of the ratio η'=0 still corresponds to a pure double couple, while the upper one η'=0.25 corresponds to a moment tensor apparently showing a pure CLVD mechanism. However, this decomposition scheme assumes that the double couple component is dominating (75% of the size of total deviatoric moment tensor).

The latter scheme could be preferable if the CLVD remainder is the result of inversion errors while the previous one (A.6) could be more appropriate if the CLVD component has a physical origin.

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Appendix C – List of original papers referred by others (indirect references). As they were not directly examined, some of the mechanisms reported by them maybe not included in the database.

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