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# SISPYR

## Sistema de Información Sísmica del Pirineo

## Système d’Information Sismique des Pyrénées

## Sistema d'Informació Sísmica dels Pirineus

# Shake map: GMPE, IPE and GMICE selection (Action 4.1)

| Main contributor: IGC. | 2012-04-30 |
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1. IGC, Institut Geològic de Catalunya

2. OMP, Université Paul Sabatier, Observatoire Midi-Pyrénées

3. UPC, Universitat Politècnica de Catalunya

4. IGN, Instituto Geografico Nacional

5. BRGM, Bureau de Recherches Géologiques et Minières

# SUMMARY

One of the main tasks to prepare the computation of shake maps in the Pyrenees is the selection of proper prediction equations for our region. The aim of this study is to define proper ground motion prediction equations (GMPE), intensity prediction equations (IPE) and ground motion intensity conversion equations (GMICE).

For GMPE selection available accelerometric and some velcimetric (BB) waveforms for $M_{IGN} \geq 3$ were collected. Some parameters were computed for this waveforms and different kind of residuals and statistical parameters were computed for a set of GMPEs.

Results show that Akkar and Boomer (2007) and Tapia (2006) are the best prediction equations for PGA and Akkar and Boomer (2007) for PGV, with good acceptance of adjustment. For PSA Tapia (2006) is the best GMPE for the three tested periods.

For bigger earthquakes $M_{IGN} \geq 4.5$ Akkar and Boomer (2007) is proposed as a first approach.

For the IPE selection the available macroseismic data from the Pyrenees from IGC, SISfrance and some from IGN were collected.

A statistical analysis to a selected list of IPEs was applied in order to select proper prediction equations for our region.

Results show that Isard-2008 (Goula et al. 2008) is the best prediction equations for macroseismic intensity for range of magnitude 3.0-6.0 and range of intensities 3-9.

For the GMICE selection the available macroseismic data from Pyrenean and Iberian earthquakes were collected from IGC, SISFrance and IGN data bases.

The GMICE selection has been performed comparing them to both data set and searching the coherency with the selected GMPE and IPE. Retained GMICE's are shown in the joint table

**<u>GMPE:</u>**

| GMPE | 3.0 ≤ Ml ≤ 4.5 | Ml >4.5 |
|---|---|---|
| PGA | Tapia 2006 (g)<br>h=10 km | Akkar and Boomer 2010 (cm/s2)<br>h=7.9 km |
| PGV | Akkar and Boomer 2007 (cm/s)<br>h=5.5 km | Akkar and Boomer 2010 (cm/s)<br>h=6.4 km |
| PSA (0.3 s) | Tapia 2006 (g)<br>h=10 km | Akkar and Boomer 2010 (cm/s2)<br>h=6.5 km |
| PSA (1s) | Tapia 2006 (g)<br>h=10 km | Akkar and Boomer 2010 (cm/s2)<br>h=5.0 km |
| PSA (3s) | Tapia 2006 (g)<br>h=10 km | Akkar and Boomer 2010 (cm/s2)<br>h=7.2 km |

## IPE:

| Isard 2008 | | |
|---|---|---|
| Equation | *$I = (-2.9297 + 1.921 M) – 3 \log_{10}(R / h) - 0.003 \log_{10}(e) (R-h) \pm 0.5$* | |
| NO Depth ranges | h=7.5 km | *$R=\sqrt{(D^2+7.5^2)}$*<br>*D=distance range* |

## GMICE:

| PGM | GMICE | | Units PGM |
|---|---|---|---|
| PGA | Souriau 2006 adapted to SISPyr dataset (R = 22,8km) from Monte-Carlo search | $I_{PGA} = 4.8108 + 2.70257 \log_{10} (PGA) + 1.2162 \log_{10}(22.8) \pm 0.484$ | $m/s^2$ |
| PGV | Faccioli et Cauzzi 2006 | $I_{PGV} = 8.69 + 1.8 \log_{10} (PGV) \pm 0.71$ | m/s |
| PSA (0.3s) | Kaka and Atkinson 2004 (0.2s) | $I = 2.45+2.10 \log_{10} (PSA) \pm 0.283$ | cm/s2 |
| PSA (1s) | Kaka and Atkinson 2004 (1s) | $I = 4.14+1.81 \log_{10} (PSA) \pm 0.332$ | cm/s2 |
| PSA (3s) | Linear fit to SISPyr dataset (3s) | $I = 9.978+1.7494 \log_{10} (PSA) \pm 0.551$ | g |

Notes:

- Reports concerning GMPE and IPE were finished in July 2011. This is the date of the reports. Some conclusions were updated later as it is indicated in the following notes.

- All the analysis performed on GMPE are made for PSA 0.2s, 1.0s and 2.0s. But there are too many modifications to do in the shakemap code for change the spectral periods. Finally we decide to keep the defaults PSA: 0.3s, 1.0s and 3.0s. Analyses made with 0.2s and 2.0s are considered to be valid for 0.3s and 3.0s.

- GMPE report concludes with the necessity to define a combined procedure to compute the predicted values in the intermediate range $4.5 < Ml_{IGN} < 5.0$ according to the magnitude bias. This is not applied in the final shakemap routines. We use Tapia (2006) for M [3 - 4.5] and Akkar & Bommer (2010) for M > 4.5.

# Shake map: GMPE selection

# Contents

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## List of Figures

## List of Tables

# 1. Introduction

The aim of action 4.1. of the SISPyr project is to implement a near real time shake map. After action A4.1. bibliographic revision and state of the art (see previous A4.1 SISPyr report) the selected method to determine the proper prediction equations for ground motion and for intensity shake maps was a residuals study.

The applicability of the ground motion prediction equations (GMPE) and Intensity prediction equations (IPE) derived in one region to others, hinges on the question of whether the models derived for one region could be applied to other.

Due to the big quantity of GMPE derived during the recent years we will focus in evaluate some of the existing GMPE to our region data in order to determine if any ”good” equation exist, and select the best one for our purposes. In order to define proper prediction equations (GMPE and IPE) to compute shake maps, existing Pyrenean data was collected (waveforms and macroseismic data). A statistical study to different residuals was done in order to select one of the existing equations to be applied to the Pyrenees.

The aim of this study is determine a GMPE for the Pyrenees, selecting one of the existing equations, to be used for the computation of shake maps. The equations are no tested properly using their definition of magnitude and component and within their magnitude and distance validity ranges. We tests all the prediction equations with IGN magnitude and maximum horizontal components (the ones that will be used for shake map). This simplification is done to avoid magnitude correlations (sometimes spurious correlations). If no acceptable results are find with this approach we will improve this treatment. The results of this study will be used for the computations of shake maps in the range of magnitudes in which we have enough data. For the bigger events, other methods have to be studied.

# 2. Data

## 2.1. Waveforms

We will focus on the A4.1. study region for our study (green box in figure 1), for collecting the data and for implementing the future shake maps. The available accelerometric three com- ponent recordings of local Pyrennean earthquakes from 1996 to 2008 were collected (IGC[1]-all the records; IGN[2]-$M_{IGN} \geq 2.0$ and RAP[3] $M_{RAP} \geq 3.0$ (BRGM[4] and OMP[5] stations)). Some Broad

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[1] Institut Geològic de Catalunya - www.igc.cat

[2] Instituto Geográfico Nacional - www.ign.es

[3] Réseau Accélérométrique Permanent – www.rap.obs.ujf-grenoble.fr/

[4] Bureau de recherches gologiques et minières - http://www.brgm.fr/

[5] Observatoire Midi-Pyrénées - http://www.omp.obs-mip.fr/omp/

Band velocimetric (BB) Pyrenean waveforms for the bigger earthquakes were also collected in order to add more records for bigger earthquakes and have more records for the Spanish side.

The BB records have been corrected of instrumental response and converted to acceleration derivating (two points difference) with the SAC Linux program. The collected accelerometric records were already corrected to ground movement.

After the collection and conversion to the same format, a selection was performed using the following rejection criteria:

• Very poor visual quality (a lot of noise) records were rejected. When the earthquake could be distinguished inside the noise, the records were used.

• Very short records (< 10s) were deleted.

• The $M_{IGN}$ < 3 earthquakes were rejected.

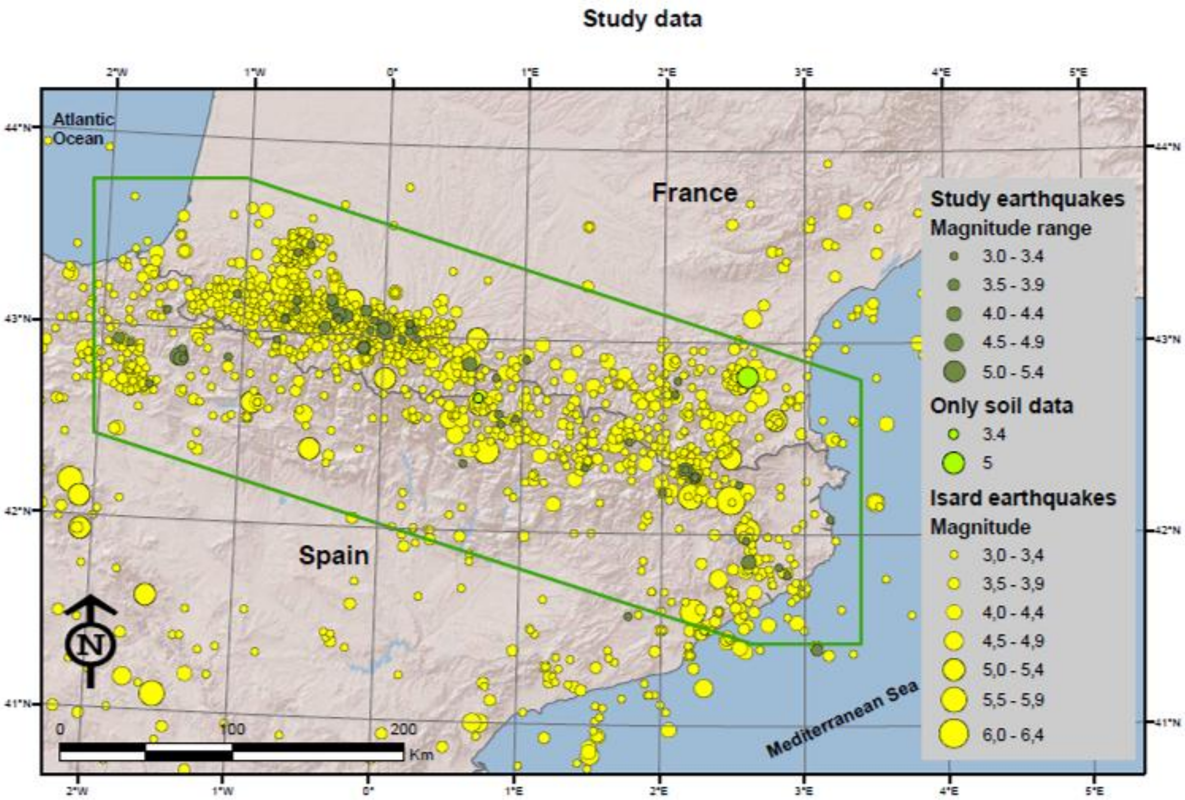


**Figure 1**: Study earthquakes (in green) versus Isard earthquakes (in yellow). The size of the circles indicates the magnitude. The ISARD earthquakes represents the historical and instrumental seismicity of the Pyrenees since 2002 (this magnitude is, in average,quite higher than the IGN magnitude. The bright green shows the earthquakes that only have soil stations waveforms.

The final data set after this rejection, consists of 72 events in the magnitude ($Ml_{ign}$) range from 3.0 to 5.0, with a total of **2220** waveforms (three components) recorded from Pyrennean events. Epicentral distance ranges from 2 to 375 km and they were obtained in soil and rock stations (54). Figure 1 shows the 72 earthquakes and the historical seismicity of the region.

For shake map computation the maximum PGM horizontal rock values will be used, for this we will focus on rock data subset for our study. Table 1 shows the number of records and earthquakes by magnitude range for all the data set and the rock site subset. The rock subset is composed by 596 records (one component) coming from 70 earthquakes. Table 2 presents the main characteristics of these 70 earthquakes.

| Acc+BB data | 3-3.4 | 3.5-3.9 | 4-4.4 | 4.5-4.9 | 5.0-5.4 | Total |
|---|---|---|---|---|---|---|
| **Records (all)** | 434 | 128 | 109 | 60 | 1 | 745 |
| **Earthquakes** | 53 | 9 | 7 | 2 | 1 | 72 |
| **Records (rock)** | 344 | 114 | 91 | 47 | 0 | 596 |
| **Earthquakes** | 52 | 9 | 7 | 2 | 0 | 70 |

**Table 1**: Nº of records (max horizontal) and nº of earthquakes with all the data (up) and with rock records data (down) by magnitude ranges.

## 2.2. Parameters

From this set of waveforms several parameters were computed and collected in a parameters database. It was done adapting some NERIES[6] MATLAB scripts (see appendix A). This database was computed using the IGN catalogue (for the magnitude, depth and epicentral distance values). The distribution of the data versus epicentral distance is presented in figure 2. Figure 3 shows the histogram of rock records by depth and by epicentral distance. Figure 4 shows the number of records from each station and the earthquakes used in the study.

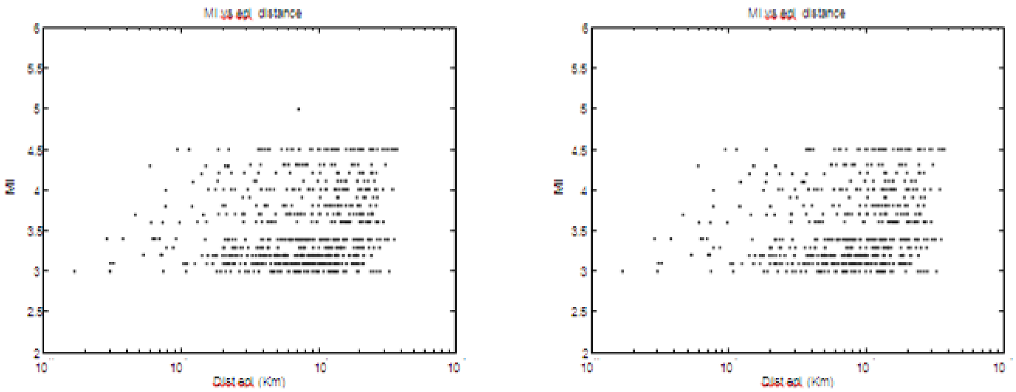


**Figure 2**: Maximum horizontal records distribution for all data (left) and for rock data (right).

## 2.3. Stations Metadata

Station metadata was extracted from the SISPyr total network database, elaborated within the SISPyr project and validated by the project partners.

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[6] For more information on this project: http://www.neries-eu.org. The computation of the parameters is explained in appendix A.

| Earthquake | Latitude (°) | Longitude (°) | Depth (Km) | $Ml_{ICN}$ | N° of records |
|---|---|---|---|---|---|
| 19991004.181426 | 42.87 | 0.62 | 3 | 4.2 | 1 |
| 20000103.182834 | 42.26 | 2.54 | 7 | 3.0 | 1 |
| 20010602.230249 | 42.22 | 2.00 | 99 | 3.2 | 2 |
| 20010604.191757 | 43.06 | 0.19 | 4 | 3.2 | 2 |
| 20010801.120749 | 43.07 | -0.03 | 11 | 3.1 | 2 |
| 20011007.182457 | 43.05 | 0.02 | 3 | 3.0 | 3 |
| 20011214.182854 | 42.96 | -0.76 | 3 | 3.1 | 1 |
| 20020221.102147 | 42.93 | -1.88 | 99 | 3.8 | 1 |
| 20020318.151854 | 42.91 | -1.80 | 99 | 3.3 | 3 |
| 20020516.145633 | 42.94 | -0.14 | 6 | 4.2 | 15 |
| 20020516.151444 | 42.94 | -0.14 | 4 | 3.7 | 14 |
| 20020519.044413 | 42.98 | 0.13 | 6 | 3.2 | 5 |
| 20020621.022630 | 41.79 | 2.88 | 4 | 3.0 | 8 |
| 20020905.204215 | 43.04 | -0.42 | 3 | 3.6 | 10 |
| 20021110.032712 | 42.70 | -1.65 | 99 | 3.3 | 1 |
| 20021209.134454 | 43.04 | 0.21 | 9 | 3.1 | 4 |
| 20021211.200951 | 43.15 | -0.37 | 99 | 3.6 | 11 |
| 20021212.175949 | 43.10 | -0.28 | 99 | 4.1 | 14 |
| 20030121.180100 | 43.11 | -0.33 | 2 | 4.0 | 15 |
| 20030226.033257 | 42.30 | 2.23 | 5 | 3.7 | 19 |
| 20030418.025435 | 41.83 | 2.82 | 99 | 3.0 | 3 |
| 20031003.234018 | 42.73 | 2.08 | 8 | 3.0 | 8 |
| 20031013.032818 | 43.46 | -0.55 | 99 | 3.3 | 2 |
| 20040113.113934 | 43.42 | -0.64 | 11 | 3.1 | 2 |
| 20040203.211614 | 42.56 | 0.85 | 11 | 3.2 | 10 |
| 20040601.165018 | 42.29 | 2.22 | 6 | 3.4 | 17 |
| 20040604.045650 | 42.30 | 2.23 | 6 | 3.1 | 8 |
| 20040718.021602 | 42.90 | 1.02 | 7 | 3.2 | 10 |
| 20040916.191709 | 42.86 | -1.45 | 6 | 3.2 | 5 |
| 20040917.025853 | 42.87 | -1.42 | 10 | 3.0 | 2 |
| 20040918.125215 | 42.85 | -1.45 | 7 | 4.5 | 17 |
| 20040918.195829 | 42.89 | -1.43 | 10 | 3.1 | 1 |
| 20040921.154804 | 42.34 | 2.16 | 3 | 4.3 | 21 |
| 20040923.095806 | 42.34 | 2.16 | 1 | 3.4 | 10 |
| 20040923.095947 | 42.34 | 2.16 | 5 | 2.6 | 7 |
| 20040930.130905 | 42.84 | -1.44 | 6 | 4.0 | 12 |
| 20041007.061629 | 42.84 | -1.42 | 3 | 3.4 | 13 |
| 20041127.222202 | 43.08 | -0.07 | 5 | 3.1 | 7 |
| 20050115.071306 | 42.80 | 0.81 | 11 | 3.1 | 15 |
| 20050209.152045 | 41.97 | 2.59 | 6 | 3.0 | 5 |
| 20050226.203649 | 42.61 | 0.83 | 6 | 3.2 | 14 |
| 20050615.212750 | 43.12 | -0.63 | 10 | 3.2 | 7 |
| 20051105.003008 | 43.03 | 0.18 | 11 | 3.3 | 8 |
| 20051227.213322 | 42.34 | 1.45 | 4 | 3.4 | 10 |
| 20060207.145919 | 42.48 | 1.76 | 4 | 3.2 | 9 |
| 20060329.124457 | 43.17 | -0.63 | 8 | 3.0 | 6 |
| 20060504.091305 | 43.08 | -0.70 | 13 | 3.0 | 5 |
| 20060504.094206 | 43.07 | -0.71 | 11 | 3.4 | 6 |
| 20060508.214753 | 42.80 | 2.10 | 9 | 3.1 | 7 |
| 20060520.053606 | 43.01 | -0.00 | 99 | 3.1 | 6 |
| 20061104.164457 | 43.09 | -0.34 | 99 | 3.2 | 5 |
| 20061117.181950 | 43.03 | 0.01 | 99 | 4.5 | 30 |
| 20061216.081701 | 43.03 | -0.10 | 5 | 3.3 | 22 |
| 20070216.225611 | 43.07 | 0.18 | 10 | 3.0 | 3 |
| 20070328.233208 | 42.08 | 3.18 | 11 | 3.1 | 7 |
| 20070402.164605 | 43.09 | -1.55 | 6 | 3.0 | 5 |
| 20070713.150259 | 42.59 | 0.95 | 6 | 3.1 | 10 |
| 20070808.164534 | 41.57 | 1.77 | 11 | 3.4 | 9 |
| 20070829.075317 | 42.86 | -1.10 | 7 | 3.1 | 5 |
| 20071115.134735 | 43.04 | 0.00 | 99 | 3.8 | 25 |
| 20071124.052452 | 43.19 | -1.06 | 15 | 3.2 | 8 |
| 20080215.073403 | 42.35 | 0.59 | 10 | 3.2 | 8 |
| 20080503.121421 | 42.99 | 0.24 | 9 | 3.4 | 7 |
| 20080518.015721 | 43.13 | -0.13 | 99 | 3.9 | 10 |
| 20080622.184830 | 41.86 | 2.60 | 5 | 3.1 | 7 |
| 20080716.203333 | 43.18 | -0.38 | 99 | 3.6 | 23 |
| 20080721.185933 | 41.85 | 2.60 | 99 | 3.1 | 6 |
| 20080722.223632 | 41.86 | 2.61 | 6 | 4.0 | 13 |
| 20080816.102121 | 41.40 | 3.09 | 6 | 3.7 | 1 |
| 20080918.125549 | 43.08 | -0.33 | 11 | 3.3 | 7 |

**Table 2**: Earthquakes used in this study. The number of records refers to the maximum horizontal number of records (i.e. only one component, the maximum horizontal, the other two (vertical and minimum horizontal) are no used).

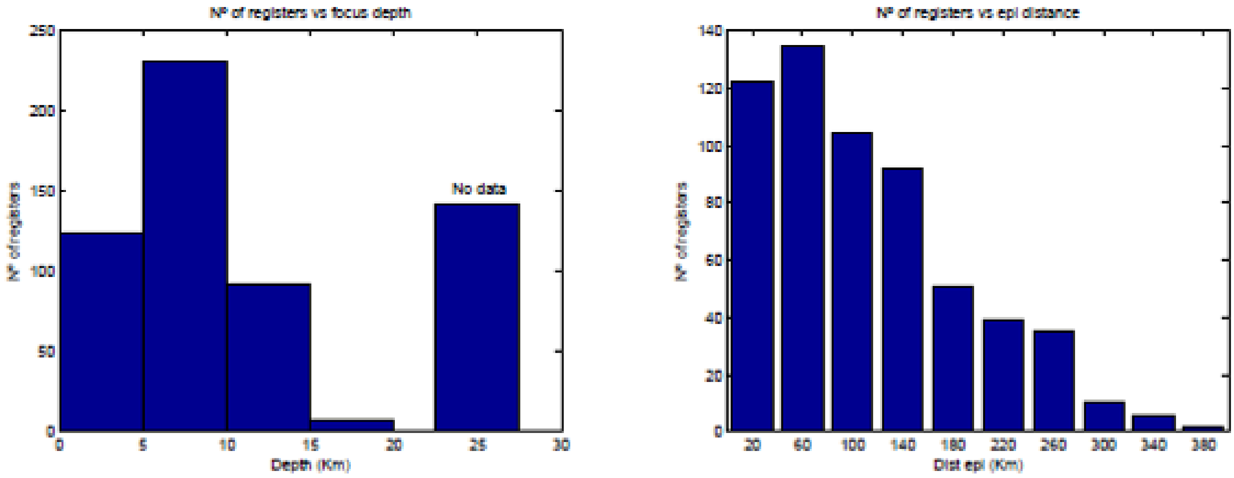


**Figure 3**: Number of maximum horizontal records for rock data by depth (left) and by epicentral distance (right).

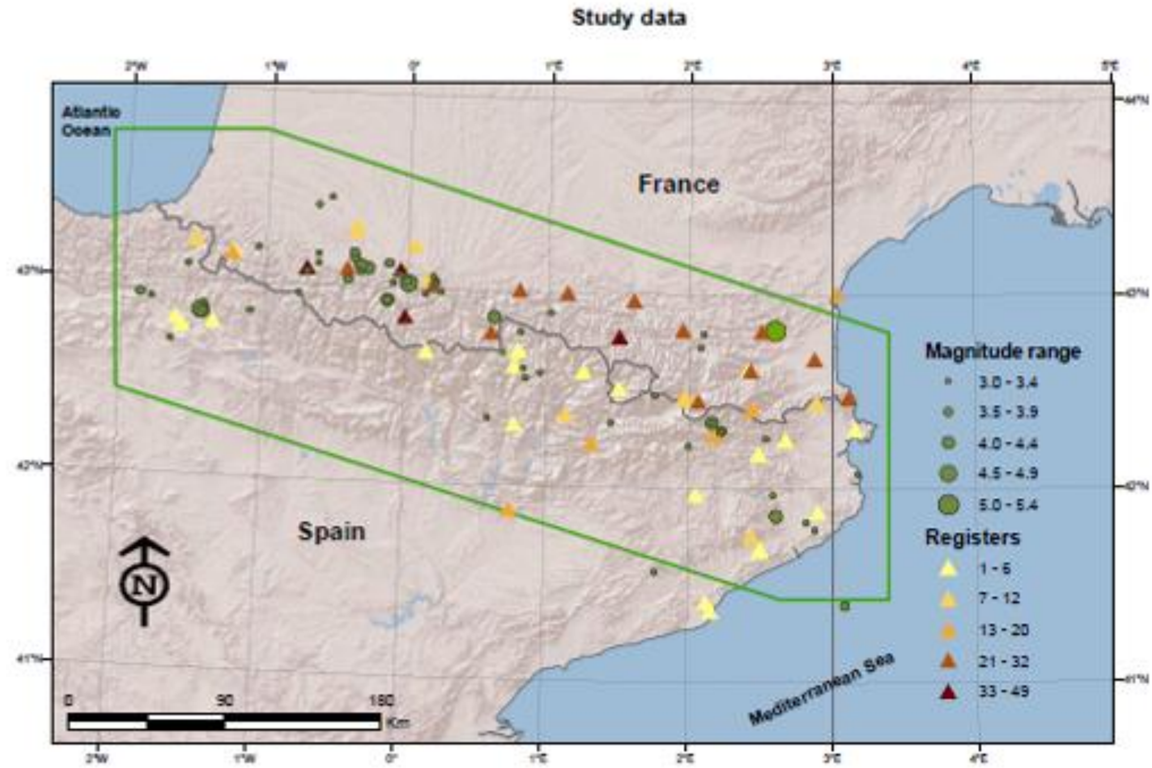


**Figure 4**: Earthquakes of all the data set (72), the size indicates the magnitude range. The triangles indicate the stations and the colour the number of records from each.

Each station is classified by rock or soil. We have data from 54 different stations 13 of them classified as soil stations and with 149 maximum horizontal records (around 20% of the database). Table 3 presents the coordinates, the site condition and the number of records from each station.

| Station | Type | Latitude (°) | Longitude (°) | Altitude (m) | Site condition | Number of records |
|---|---|---|---|---|---|---|
| AND1 | Acc | 42.5130 | 1.5040 | 1078 | Rock | 3 |
| CAVN | Vel | 41.8816 | 0.7506 | 634 | Rock | 18 |
| CBEU | Vel | 42.2556 | 2.6758 | 824 | Rock | 2 |
| CBRU | Vel | 42.2844 | 2.1790 | 1327 | Rock | 18 |
| CCAS | Vel | 41.8828 | 2.9042 | 197 | Rock | 5 |
| CELR | Acc | 41.6850 | 2.4990 | 140 | Rock | 5 |
| CELS | Acc | 41.6928 | 2.4992 | 150 | Soil | 6 |
| CEST | Vel | 42.5987 | 1.2541 | 1325 | Rock | 5 |
| CFON | Vel | 41.7612 | 2.4346 | 973 | Rock | 12 |
| CLLI | Vel | 42.4781 | 1.9730 | 1413 | Rock | 14 |
| CORG | Vel | 42.2291 | 1.3165 | 716 | Rock | 16 |
| CORI | Vel | 41.9724 | 2.0488 | 621 | Rock | 5 |
| CPAL | Vel | 42.3105 | 3.1624 | 223 | Rock | 3 |
| CSOR | Vel | 42.3744 | 1.1327 | 1227 | Rock | 12 |
| CTRE | Vel | 42.3223 | 0.7724 | 1318 | Rock | 4 |
| EALK | Vel | 43.2197 | -1.5071 | 965 | Rock | 9 |
| EARA | Vel | 42.7727 | -1.5797 | 476 | Rock | 2 |
| EBIE | Vel | 42.6862 | 0.1428 | 2130 | Rock | 6 |
| EJON | Vel | 42.4487 | 2.8886 | 570 | Rock | 11 |
| FBRR | Acc | 41.4164 | 2.1250 | 420 | Rock | 1 |
| ITOR | Acc | 42.7967 | -1.3597 | 520 | Rock | 1 |
| LLIR | Acc | 42.4792 | 1.9742 | 1413 | Rock | 9 |
| LLIS | Acc | 42.4647 | 1.9733 | 1190 | Soil | 9 |
| MTJR | Acc | 41.3711 | 2.1569 | 51 | Rock | 2 |
| OLOS | Acc | 42.1830 | 2.4900 | 436 | Soil | 3 |
| PAMR | Acc | 42.8140 | -1.6250 | 478 | Soil | 2 |
| PYAD | Acc | 43.0975 | -0.4258 | 450 | Rock | 30 |
| PYAS | Acc | 43.0119 | 0.7973 | 430 | Rock | 21 |
| PYAT | Acc | 43.0954 | -0.7114 | 340 | Rock | 37 |
| PYBA | Acc | 42.4740 | 3.1170 | 70 | Rock | 24 |
| PYBB | Acc | 43.0586 | 0.1489 | 567 | Rock | 11 |
| PYBE | Acc | 42.8200 | 1.9524 | 1080 | Rock | 23 |
| PYCA | Acc | 43.0239 | 0.1825 | 701 | Rock | 25 |
| PYFE | Acc | 42.8140 | 2.5070 | 270 | Soil | 24 |
| PYFO | Acc | 42.9680 | 1.6070 | 380 | Rock | 24 |
| PYLI | Acc | 43.0020 | 1.1360 | 424 | Rock | 30 |
| PYLL | Acc | 42.4530 | 2.0650 | 1430 | Rock | 23 |
| PYLO | Acc | 43.0982 | -0.0478 | 410 | Rock | 44 |
| PYLS | Acc | 42.8600 | -0.0090 | 770 | Rock | 45 |
| PYLU | Acc | 42.7906 | 0.6014 | 630 | Soil | 21 |
| PYOR | Acc | 42.7827 | 1.5067 | 1030 | Rock | 40 |
| PYP1 | Acc | 43.1632 | -1.2325 | 230 | Rock | 2 |
| PYPC | Acc | 43.2963 | -0.3740 | 200 | Soil | 9 |
| PYPD | Acc | 42.6142 | 2.4156 | 350 | Soil | 4 |
| PYPE | Acc | 42.6730 | 2.8780 | 100 | Soil | 21 |
| PYPM | Acc | 42.4160 | 2.4390 | 920 | Rock | 16 |
| PYPP | Acc | 43.1557 | -1.2407 | 270 | Rock | 13 |
| PYPR | Acc | 42.6137 | 2.4294 | 410 | Soil | 29 |
| PYPT | Acc | 43.0090 | 3.0330 | 60 | Rock | 18 |
| PYPU | Acc | 43.3149 | -0.3657 | 208 | Soil | 7 |
| PYTB | Acc | 43.2260 | 0.0489 | 305 | Soil | 11 |
| TUNR | Acc | 42.6228 | 0.7669 | 1582 | Rock | 4 |
| VIER | Acc | 42.7044 | 0.7922 | 994 | Rock | 3 |
| VIES | Acc | 42.7016 | 0.7969 | 986 | Soil | 3 |

**Table 3:** Stations used in this study.

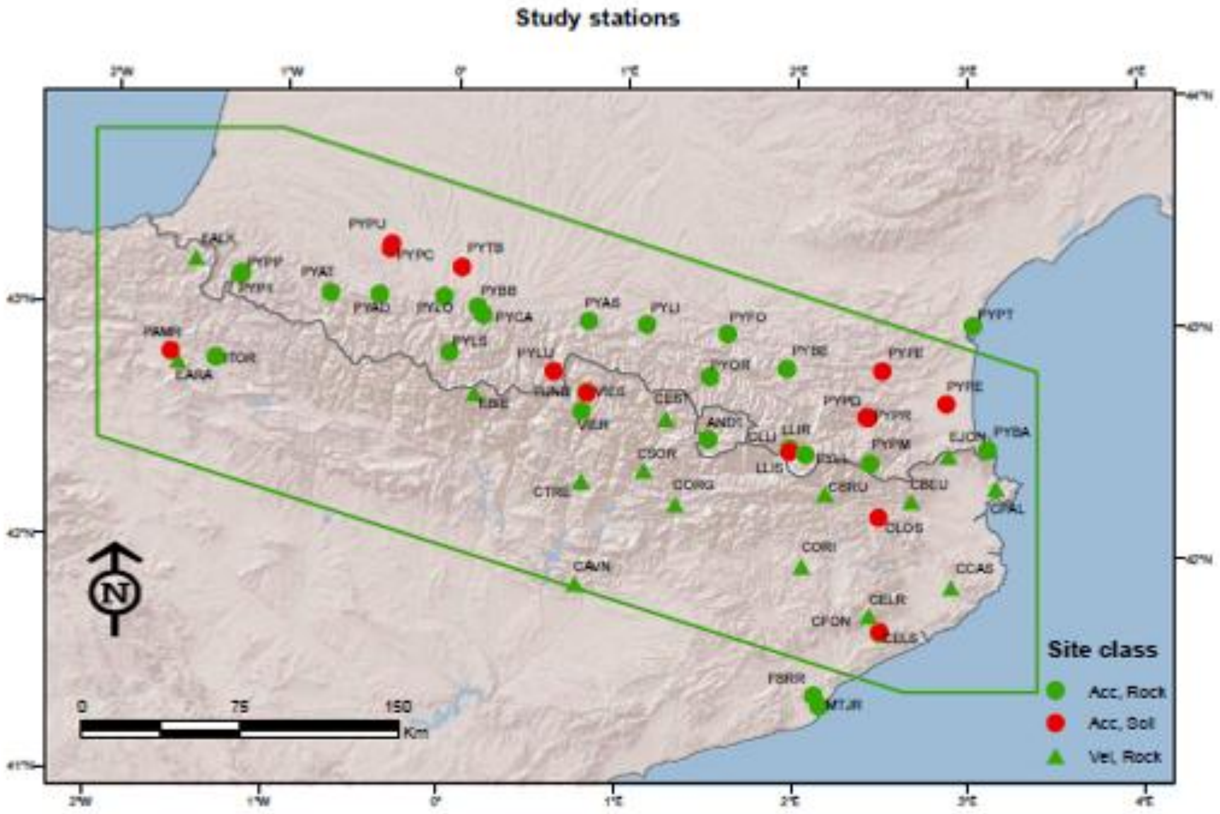


**Figure 5:** Rock site (in green) and soil site (in red) stations from which records were collected. The green line defines the A4.1.study zone.

# 3. Method

Exist several statistics tests that could be applied to determine the goodness-of-fit of a model to a sample of data (Scherbaum et al. [2004]). The methodology applied in this study consists in evaluate different statistical parameters of different kind of residuals to determine how the model adjust the data and how the model could be generated with this data.

For the maximum horizontal component of the different studied parameters (PGA, PGV, PSA ...) two kinds of residuals are studied:

1. Logarithmic measured minus logarithmic estimated value (we refer to it as Y).

2. Logarithmic measured minus logarithmic estimated value scaled with the standard deviation (σ) of the model (we refer to it as Z).

Next sections explain the computation and the interpretation of these residuals, which and how statistical parameters were computed and how were they studied.

| Rank | $\lvert med(Y)\rvert$ | $\lvert\overline{Y}\rvert$ | $\sigma_Y$ |
|---|---|---|---|
| 1 | $< 0.1$ | $< 0.1$ | $< 0.35$ |
| 2 | $< 0.25$ | $< 0.25$ | $< 0.5$ |
| 3 | $< 0.5$ | $< 0.5$ | $< 0.75$ |
| 4 | UNACCEPTABLE | | |

**Table 4:** Statistical values conditions for each rank. The rank is assigned when the three conditions are fulfilled.

## 3.1 Logarithmic residuals

These residuals were computed to determine how the data is adjusted by each prediction equation. They were computed for each observed value with the expression,

$$Y = \log(\mathrm{PGM}_{\mathrm{observed}}) - \log(\mathrm{PGM}_{\mathrm{predicted}}) \tag{1}$$

where $\mathrm{PGM}_{\mathrm{predicted}}$ is computed with the prediction equation for the magnitude, distance and soil type of the observed value.

From these residuals, the median, the average and the standard deviation were computed. They were also plotted versus magnitude range and versus epicentral distances to detect existing trends with these parameters.

Similar of what is done in Scherbaum et al. [2004] a ranking was proposed. This is based on the three statistical values computed for this residual. This ranking is no tested with other data and it is no based in 'objective' criteria. They are subjective values to assign a single number to the three parameters. The applied criteria are presented in table 4. It is only a complement to the assigned rank with the logarithmic normalized residuals based on existing bibliography.

## 3.2 Normalized logarithmic residuals

These residuals are studied in order to see the probability of a model to be generated by a defined set of data. Normalized logarithmic residuals were computed for each observed value by the expression

$$\mathrm{Z} = \frac{\log(\mathrm{PGM}_{\mathrm{observed}}) - \log(\mathrm{PGM}_{\mathrm{predicted}})}{\sigma_{\mathrm{model}}} \tag{2}$$

These residuals were studied applying the methodology proposed in Scherbaum et al. [2004]. Four statistical parameters were computed: normalized residuals mean ($\overline{\mathrm{Z}}$), median (med(Z)), standard deviation ($\sigma_Z$) and the median of likelihood parameter ($LH_0$). A ranking of the different prediction equations is done applying the proposed criteria. Table 5 shows the values of the statistical values to assign a rank to each GMPE.

Because of the convenient scaling of the residual Z, a good measure for the goodness-of-fit of the prediction equations is the probability for the absolute value of a random sample from the normalized distribution to fall into the interval between the modulus of a particular observation[7] ($|z_0|$) and ∞. Supposing a Gaussian probability distribution function ($f(z)$) this probability for a value $z_0$ is

$$u(|z_0|) = \int_{|z_0|}^{\infty} f(z)\,dz = \frac{1}{\sqrt{2\pi}} \int_{|z_0|}^{\infty} exp\left(\frac{-z^2}{2}\right) dz = \frac{1}{2} Erf\left(\frac{|Z_0|}{\sqrt{2}}, \infty\right) \tag{3}$$

where $Er\,f(x_0, x_1)) = Er\,f(x_1) - Er\,f(x_0)$ is the generalized form of the error function and $u(|z_0|)$ is the likelihood of the residual to be equal to or larger than $|z_0|$. Considering both tails of the distribution, for each normalized residual $z_0$ the LH parameter is defined as

$$LH(|Z_0|) = 2u(|Z_0|) = Erf\left(\frac{|Z_0|}{\sqrt{2}}, \infty\right) \tag{4}$$

replacing $Er\,f(\infty) = 1$, the LH parameter for each residual ($Z_0$) could be computed with the expression

$$LH(|Z_0|) = 1 - Erf\left(\frac{|Z_0|}{\sqrt{2}}\right) \tag{5}$$

As Erf(x) spans only from 0 to 1, the defined LH parameter spans from 1 to 0. To quantify goodness-of-fit, LH values have some interesting properties (Scherbaum et al. [2004]):

• LH reaches it maximum value of 1 for Z=0, for an observation that coincides with the predicted value of the GMPE.

• LH value decreases with increasing distance from the predicted value. For $|Z| = \infty$ we obtain LH=0.

• If the models assumption are matched exactly (Z having $\mu = 0$ and $\sigma = 1$) the samples of the random variable LH are distributed between 0 and 1.

In order to quantify this distribution of the LH parameter in a single number the median of LH is used, mainly because of its stability regarding outliers. To better understand the behaviour of the LH statistics, figure 6 presents some examples.

## 3.3 Sensitivity test

To have a first approximation of the sensitivity of our results to used data, the tests are repeated in five different conditions:

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[7] In this case the observations are the normalized residual

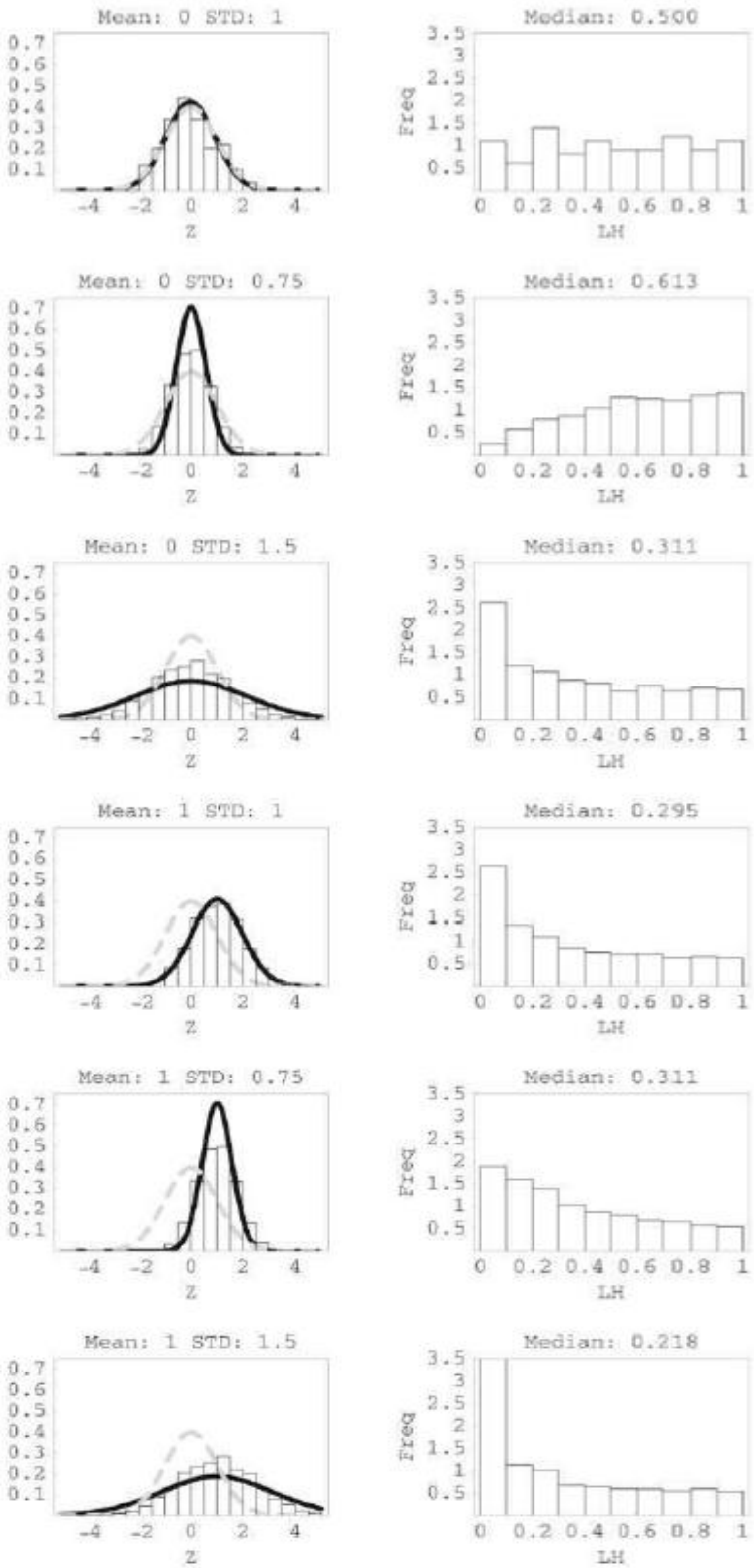


**Figure 6**: Distribution of residuals (left panels) and corresponding LH values (right panels) for different simulated distributions (the possible combinations of mean=O or 1 and sigma=O.75, 1 or 1.5). Mean values and standard deviations for the residual distributions are indicated on tops of the left panels. The two distribution functions in the left panel indicate the unit variance normal distribution and the actual residual distribution, respectively. On top of the right panels the median values of the resulting LH-value distributions are displayed. Adapted from Scherbaum et al. [2004].

| Rank | $med(LH)$ | $\|med(Z)\|$ | $\|\overline{Z}\|$ | $\sigma_Z$ |
|---|---|---|---|---|
| 1 | $> 0.4$ | $< 0.25$ | $< 0.25$ | $< 1.125$ |
| 2 | $> 0.3$ | $< 0.50$ | $< 0.50$ | $< 1.25$ |
| 3 | $> 0.2$ | $< 0.75$ | $< 0.75$ | $< 1.50$ |
| 4 | UNACCEPTABLE | | | |

**Table 5**: Statistical values conditions for each rank. The rank is assigned when the four conditions are fulfilled.

• Without three representative earthquakes from different magnitude ranges. This is the earthquakes with more records from the magnitudes ranges: near 3, near 4 and near 4.5:

– 20061117- M=4.5 - 30 waveforms

– 20071115 - 3.8 - 20 waveforms

– 20050226 - 3.2 - 14 waveforms

• Without a couple of important stations:

– PYAT - 37 earthquakes

– PYOR - 40 earthquakes

This separated analysis will give a first idea of the possible biases produced by these subsets of data to the results and test the sensitivity of the results from the input data.

In an upcoming report the sensitivity to the input parameters (magnitude, depth, epicentral distance ...) will be determined, in order to see how sensible are the selected relations to each of the input parameters.

## 3.4 Approximations and criteria

The criteria applied in this study are:

• IGN **magnitude** and localization were used. This magnitude is used supposing it has been constant during all the period (however the network has changed during the last years, and also the magnitude definition change in 2002).

• When the **depth** is no determined, by default, the medium depth of the records with a depth assignation (around 6-7 Km) is assigned to the records without depth assigned.

• No difference is done for the **type of rupture**

| Reference | Code | PGA | PGV | PSA | M | R (Km) | M type | Model PGA $\sigma$ | Region |
|---|---|---|---|---|---|---|---|---|---|
| Cabanas et al. [1999] | Cabanas99 | X | | | 3.5-6.5 | 1-200 | MbLg | – | Pyrennes |
| Lussou et al. [2001] | Lusetal01 | X | X | X | 3.7-6.3 | 10-200 | Mjma | 0.319 | Japan |
| Berge-Thierry et al. [2003] | Beretal03 | X | | X | 4-7.3 | $4-330$ | Ms | 0.2923 | Europe |
| Marin et al. [2004] | Maretal04 | X | | | 2.5-5.6 | 3.0-50 | ml | 0.55 | France |
| Ambraseys et al. [2005] | Ambetal05 | X | | X | $\geq 5$ | $\leq 100$ | Mw | 0.38-0.48 | Europe |
| Bragato and Slejko [2005] | BraaSle05 | X | X | X | 2.5-6.3 | $< 130$ | Ml | 0.399 | Alps |
| Tapia [2006] | Tapia06 | X | | X | 3.8-5.2 | 7.5-542 | Ml | 0.426 | West Med. |
| Souriau [2006] | Souria106 | X | | | 3-5.4 | ReNass | 2 | 0.37-0.41 | Pyrennes |
| | Souria206 | X | | | 3-5.4 | ReNass | 2 | 0.51-0.53 | Pyrennes |
| Akkar and Boomer [2007] | AkaaBom07 | X | X | X | 5-7.6 | $< 100$ | Mw | 0.34-0.42 | Europe & mid east |
| Mezcua et al. [2008] | Mezetal08 | X | | | 3-6.3 | $< 100$ | Mw | 0.69 | Spain |
| Massa et al. [2008] | Masetal08 | X | X | X | 3.5-6.3 | $< 100$ | Ml | 0.29 | Italy |
| Akkar and Boomer [2010] | AkaaBom10 | X | X | X | 5-7.6 | $< 100$ | Mw | 0.2793 | Europe & mid east |
| Quitoriano, small.pm | Quitori99 | X | X | X | 3-5.2 | 0-200 | Mw | 0.3667 | Active Tectonic (CA) |

**Table 6:** Summary of the main characteristics of the tested GMPE (Based on original references and/or derived studies).

• Aftershocks were also included. We don't make any special consideration, however in Perus and Fajfar [2009] is said that the aftershocks increase the scatter and therefore they are cleaned in some databases.

• The **component** used is the maximum horizontal, no the defined components of the prediction equations. This is not't the proper way of testing the GMPE, but is done in this way to select the proper prediction equations according to ShakeMap 3.5 procedure and avoiding intermediate correlations.

• The results are computed only with rock records. The objective is to select proper prediction equations on rock values. The available information on the station soil sites[8] is no enough to apply a proper correction and it represents a small part of the database (less than 20%).

• When magnitude dependent sigma is defined we use it to conserve the model properties as they were defined, although in Akkar and Boomer 2010 it is no recommended to use different magnitude ranges σ.

• The normalized logarithmic residuals are distributed in bins of 0.2 according to the quantity of data.

## 3.5 Tested GMPE

Due to the big amount of existing GMPE a selection was done. The selected equations are the regional ones, few from Europe and some of the already programmed in ShakeMap USGS scripts. Tested prediction equations with their main characteristics are presented in table 6. The general form of each model is presented in table 7.

[8] The classification used only differentiates between soil and rock stations.

| Code | General expression | Y | X | R |
|---|---|---|---|---|
| Cabanas99 | $Y = a_1 + a_2M + a_3X$ | $ln$PGM | $ln$R | Hypocentral+10 |
| Lusetal01 | $Y = a_2M + a_3X + a_4D + a_5Sr + a_6Ss$ | $log_{10}$PGM | $log_{10}$R | Hypocentral |
| Beretal03 | $Y = a_2M + a_3X + a_4D + a_5Sr + a_6Ss$ | $log_{10}$PGM | $log_{10}$R | Hypocentral |
| Maretal04 | $Y = a_1 + a_2M + a_3X$ | $log_{10}$PGM | $log_{10}$ R | Hypocentral |
| Ambetal05 | $Y = a_1 + a_2M + (a_3 + a_4M)X + a_6Ss + a_7Sa + a_8Fn + a_9Ft + a_{10}F_0$ | $log_{10}$PGM | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| BraaSle05 | $Y = a_1 + (a_2 + a_3M)M + (a_4 + a_5M^3)X$ | $log_{10}PGM$ | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| Tapia06 | $Y = a_1 + a_2M + a_3X + a_4D$ | $log_{10}PGM$ | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| Souria106 | $Y = a_1 + a_2M + a_3X$ | $log_{10}PGM$ | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| Souria206 | $Y = a_1 + a_2M + a_3X + a_4D$ | $log_{10}PGM$ | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| AkaaBom07 | $Y = a_1 + a_2M + a_3M^2 + (a_4 + a_5M)X + a_6Ss + a_7Sa + a_8FN + a_9FR$ | $log_{10}PGM$ | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| Mezetal08 | $Y = a_1 + a_2M + a_3X$ | $lnPGM$ | ln R | Hypocentral |
| Masetal08 | $Y = a_1 + a_2M + a_3X + a_4S_A + a_5S_{B,C}$ | $log_{10}$PGM | $log_{10}$R | $\sqrt{R_{epi}^2 + a_0^2}$ |
| AkaaBom10 | $Y = a_1 + a_2M + a_3M^2 + (a_4 + a_5M)X + a_6Ss + a_7Sa + a_8FN + a_9FR$ | $log_{10}$PGM | $log_{10}$R | $\sqrt{{R_{JB}^2}^9 + h^2}$ |
| Quitori99 | $Y = a_1 + a_2(M-6) + a_3X + a_4ln\left(\frac{vS}{vA}\right)$ | $log_{10}$PGM | $log_{10}$R | $\sqrt{R_{JB}^2 + h^2}$ |

**Table 7:** General forms of the selected equations.

# 4. Results

## 4.1 GMPE

For each tested prediction equation and range of magnitude the statistical parameters presented in section 3 are computed for the rock stations and soil stations subset. We present some results obtained with soil data in order to see the differences. However, how it is explained before, the soil results won't be used for selecting the GMPE to compute Shakemaps. The outstanding results for the statistical parameters computed for these residuals and rock data are presented in appendices (B and C). Appendix B presents the summary of the results obtained by each model. For each parameter and model four plots are presented (see figure 7):

• The LH statistical with a header presenting the computed mean, median and standard deviation of the normalized logarithmic residuals, the LH median and the rank assigned by the Scherbaum method.

• The normalized logarithmic residuals distribution, a Gaussian with the median and standard deviation of the data in green and a standard Gaussian (σ = 1) in black.

• Logarithmic residuals versus epicentral distance

• Logarithmic residuals versus IGN magnitude

It is also presented all the computed statistical parameters and assigned ranks for each model and parameter (table 12 of appendix B).

Appendix C summarizes in a table the computed statistical parameters for the magnitude ranges with an acceptable rank assignation (rank≤3). In the same appendixes the normalized residuals distribution by magnitude range for the acceptable equations are presented. Figure 8 is an example of the figures presented in this appendix.

The best equations for each PGM and type of data are presented in table 8. Table 9 summarizes the results for each tested equation and parameter for rock data. This table is a summary of the discussion presented in the following subsections.

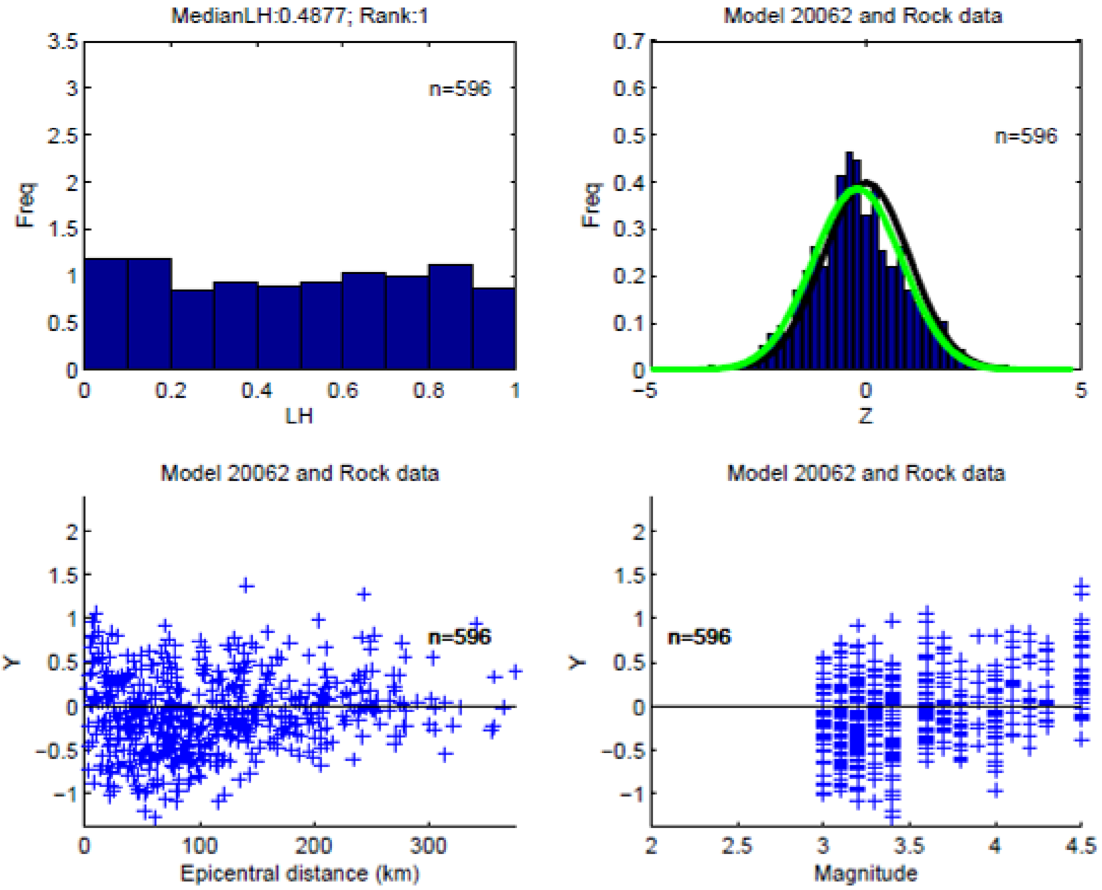


**Figure 7**: Summary of the results obtained for PGA and the study Rock data with the GMPE Tapia06. From up left to down right: LH statistical with assigned Z rank normalized logarithmic residuals distribution, logarithmic residuals versus epicentral distance and logarithmic residuals versus IGN magnitude.

These results were obtained with IGN magnitude, maximum horizontal records and rock site stations waveforms. They are useful for the range of distances (< 375 Km) and the range of magnitudes ($Ml_{IGN}$ = 3.0 − 4.5) of the tested data.

To take a first overview on the possible acceptable GMPE and the ones that are completely unacceptable, appendix D shows the plot of the studied parameters versus epicentral distance for rock data, with the predicted values by the GMPE by ranges of magnitude. The aim of this first overview is only to have a first idea of the acceptance of each GMPE.

### 4.1.1 PGA

This subsection describes and summarizes the interpretation of the tested GMPE. This interpretation is based on the results presented in tables and figures of appendixes B and C.

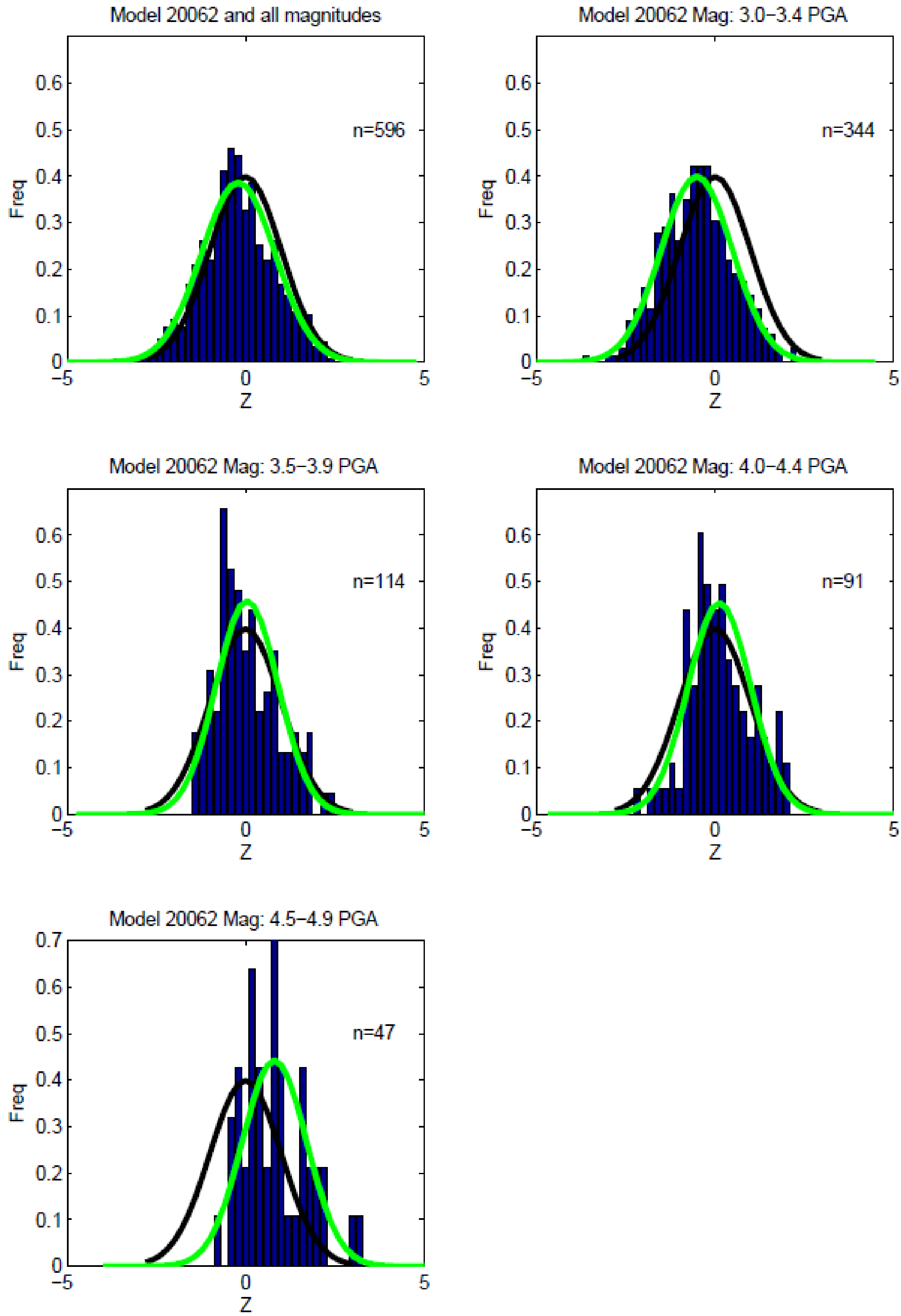


**Figure 8:** Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE Tapia06.

| Parameter | Data type | Nº of values | Catalogue[10] | Nº GMPE | Best equations | Z rank | Y rank |
|---|---|---|---|---|---|---|---|
| **PGA** | Rock | 596 | IGN | 13 | AkaaBom07; Tapia06 | 1 | 2 |
| **PGA** | Soil | 149 | IGN | 13 | AkaaBom07; Tapia06; Quitori99 | 2 | 2 |
| **PGV** | Rock | 596 | IGN | 5 | AkaaBom07 | 1 | 2 |
| **PGV** | Soil | 149 | IGN | 5 | AkaaBom07 | 1 | 2 |
| **PSA 0.2 s** | Rock | 596 | IGN | 8 | Tapia06 | 2 | 2 |
| **PSA 0.2 s** | Soil | 149 | IGN | 8 | Tapia06 | 1 | 2 |
| **PSA 1 s** | Rock | 596 | IGN | 9 | Tapia06, AkaaBom07 | 1 | 2 |
| **PSA 1 s** | Soil | 149 | IGN | 9 | Tapia06 | 2 | 2 |
| **PSA 2 s** | Rock | 596 | IGN | 8 | Tapia06 | 1 | 2 |
| **PSA 2 s** | Soil | 149 | IGN | 8 | Tapia06 | 2 | 2 |

**Table 8**: Best ranked equations for each parameter.

For each GMPE:

• **Cabanas et al. [1999]** - Four relations are tested from this study (the ones that no depends on Ms). Relation presented on this study is the one that obtains better results.

• **Ambraseys et al. [2005]** - Results are unacceptable taking into account Z and Y residuals. How is seen in appendix B the σ and the data distribution are quite good but it is displaced (average and mean < -1). Comparing by magnitudes, we observe that it improves for the higher magnitudes (this GMPE is defined for M > 5). However, the results on the magnitude range 4.5-4.9 don't have to be used.

• **Marin et al. [2004]** - Results are unacceptable taking into account Z and Y residuals. However how is seen in appendix B $\sigma_Z$ is lower than 1 and $\sigma_Y$ is one of the lower ones. The data distribution seems to be quite good. The problem is for the median and the average. Taking into account the general form of this GMPE (see table 7) by a higher magnitude assignation it will obtain a good rank. Taking into account the bias computation of ShakeMap v3.5 this GMPE could also be a good one for our purposes, moreover it don't obtains good results for the applied tests. Due to the good shape of the Gaussian and the good distribution of the data, it will be interesting to make a correlation with the magnitude definition and see how this GMPE improve their results with this redefinition (see appendix E.0.5).

• **Akkar and Boomer [2007]** - This GMPE obtains very good results, it is one of the best. How is seen in appendix B the data is well distributed around zero in both types of residuals obtaining one of the best average, median and deviation from the two types of residuals. It is as conservative as Tapia [2006] or Akkar and Boomer [2010]. About the shape of the distribution for all the data it fits correctly with a Gaussian except for the middle part in the plateau with a skewed peak. Looking for magnitude ranges, the distribution of the data is skewed for all the ranges.

| Code | PGA | | PGV | | PSA 0.2 s | | PSA 1.0s | | PSA 2.0s | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Z rank | Y rank | Z rank | Y rank | Z rank | Y rank | Z rank | Y rank | Z rank | Y rank |
| Cabanas99 | 4 | 4 | - | - | - | - | - | - | - | - |
| Lusetal01 | 4 | 4 | - | - | 4 | 4 | 4 | 4 | 4 | 3 |
| Beretal03 | 4 | 4 | - | - | 4 | 4 | 4 | 4 | 4 | 4 |
| Maretal04 | 4 | 4 | - | - | - | - | - | - | - | - |
| Ambetal05 | 4 | 4 | - | - | 4 | 4 | 4 | 4 | 4 | 4 |
| BraaSle05 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 3 |
| Tapia06 | 1 | 2 | - | - | 2 | 2 | 1 | 2 | 1 | 2 |
| Souria106 | 4 | 3 | - | - | - | - | - | - | - | - |
| Souria206 | 4 | 3 | - | - | - | - | - | - | - | - |
| AkaaBom07 | 1 | 2 | 1 | 2 | 4 | 3 | 1 | 2 | 2 | 2 |
| Mezcetal08 | 4 | 4 | - | - | - | - | - | - | - | - |
| Masetal08 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| AkaaBom10 | 3 | 2 | 3 | 2 | 4 | 3 | 3 | 2 | 2 | 2 |
| Quitori99 | 3 | 2 | 2 | 2 | - | - | 2 | 2 | - | - |

**Table 9**: Summary of the assigned ranks for parameter and GMPE.

• **Souriau [2006]**[9] - This reference presents two quite different GMPE that are identified by codes 20066 and 20067. Results are quite acceptable taking into account Z and Y residuals. According to the Y residual, data shows good values of σ with both GMPEs. The main differences between the two GMPE are on Z residuals due to the difference in the assigned σ. The data distribution is no as Gaussian as it is desired, it has two peaks and a minimum in the average value.

• **Tapia [2006]** - This GMPE obtains very good results, it is also one of the best ones. How is seen in appendix B the data is well distributed around zero in both types of residuals obtaining one of the best average, median and deviation from the two types of residuals. About the shape of the distribution it is quite skewed but fits correctly with the Gaussian.

• **Mezcua et al. [2008]** - Results are completely unacceptable taking into account Z and Y residuals. The data presents very big dispersion and big shift of the median and the average from zero. The data distribution is skewed.

• **Bragato and Slejko [2005]** - Results are unacceptable taking into account Z and Y residuals. The data presents big dispersion and big shift of the median and the average from zero. A tendency is seen with epicentral distances (bigger distances, bigger values for Y). For distances < 50 km the Y residuals are more centered around zero. After around 100km these residuals are shifted to higher Y values.

• **Akkar and Boomer [2010]** - This GMPE was derived with the same data and the same general expression as in Akkar and Boomer [2007]. This new

[9] The two prediction equations presented in this study don't have a model standard deviation. The value used is an estimation done with the uncertainties to each coefficient and a distance of 60 Km (is less than the median distance (around 100) but in this case it's better to underpredict the σ than to overestimate it)

GMPE reduces the σ changing the adjusting parameters. A unique σ is defined, different from Akkar and Boomer [2007] where a σ is defined for each magnitude. The results from this GMPE are quite different from one residual to the other. For the residual Z a rank 3 is assigned. This means that it is acceptable but no good enough. Observing the Z distribution (see appendix B) and the obtained parameters, it is clear that the difference is the σ of the model is smaller than the dispersion of the data. For the Y and X residuals statistics, this GMPE obtains nearly the same values as in Akkar and Boomer [2007]. From this we could conclude that this GMPE is as useful as Akkar and Boomer [2007], however the dispersion is better explained with the older GMPE.

• **Berge-Thierry et al. [2003]** - This GMPE is unacceptable for our purposes. It is shown by the rank assigned with Z and Y residuals, for all the magnitudes ranges.

• **Lussou et al. [2001]** - This GMPE is unacceptable for our purposes. It is shown by the rank assigned with Z and Y residuals, for all the magnitude ranges, and the skewed data distribution.

• **Quitoriano** - This GMPE presents good results for Y residual and regular for Z due to the median and average value, no to the σ of the distribution. The shape is also quite fitted to the Gaussian but no as much as the best ones. It is one of the acceptable models but no from the best ones.

• **Massa et al. [2008]** - This GMPE is completely unacceptable taking into account Z residual and the residuals distribution. The data presents very big dispersion and big shift of the median and the average from the zero.

### 4.1.2 PGV

The number of existing and tested PGV prediction equations is less than PGA prediction equations. The results obtained for the tested equations are:

• **Bragato and Slejko [2005]** - Unacceptable due to big values of all the statistical parameters.

• **Akkar and Boomer [2007]** - This is the best GMPE for PGV. It obtains ranks 1 and2 for Z and Y residuals, respectively.

• **Massa et al. [2008]** - Better results than in PGA but also unacceptable due to big dispersion.

• **Akkar and Boomer [2010]** - Similar results to PGA, acceptable for both residuals, but better for Y residuals. It’s due to the low variance associated to this model. The variance for the Y residuals is lower than the Akkar and Boomer [2007] GMPE variance.

**• Quitoriano -** This GMPE presents better results in PGV than in PGA for both residuals (Y and Z). It presents the best rank for Y residual and the second best rank for Z residuals.

### 4.1.3 PSA (0.2s, 1s and 2s)

The number of existing and tested PSA prediction equations is less than PGA prediction equations. The results obtained for the tested equations are:

• **Lussou et al. [2001]** - The results are unacceptable for the three periods. The predicted value is higher than the observed value. For higher periods the fitting improves but remains unacceptable. It also improves for higher magnitudes.

• **Berge-Thierry et al. [2003] -** Unacceptable for the three periods. It improves for higher magnitudes.

• **Ambraseys et al. [2005]** - Unacceptable for the three periods. It improves for higher magnitudes.

• **Bragato and Slejko [2005]** - For 0.2 s unacceptable for Z residuals rank due to the big dispersion PSA for 1s and 2s are acceptable for the Z and Y residuals ranks. A clear tendency is observed for Y residual with epicentral distances.

• **Tapia [2006]** - It is the best GMPE for 0.2s and 1s, and one of the best for PSA 2.0s. It obtains ranks for Z residuals from 1 to 3 and for Y residual 2 or 3.

• **Akkar and Boomer [2007]** - Results for PSA with this GMPE are very different from PGA and PGV. For PSA the results are unacceptable for the three studied periods and both residuals. This is due to a big displacement of the median and the average. The variance values are good. It seems that there is some error with the scaling factor but after revising it, the current one is the most coherent (however in 2.0 s results improve changing the factor from 100 to 10).

• **Massa et al. [2008] -** Completely unacceptable for the three periods due to the very big variance.

• **Akkar and Boomer [2010] -** Unacceptable for 0.2 s and Z rank, regular for 1s and one of the best for 2s (Z and Y ranks equal to 2).

• **Quitoriano** - It is a non published GMPE and we only have the parameters for the 1s period. For this period the results are acceptable and the second best ones of the tested GMPEs.

## 4.2 Best ranked GMPE sensitivity test

The two sensitivity tests described in section 3.3 have been done. A summary of the tests for the best GMPEs is presented in this section. Table 10 summarizes the main changes observed.

In general terms we could say:

• Each earthquake seems to have a clear tendency, as it could change the rank assigned to a magnitude range.

• According to this interevent variability and the low number of earthquakes (2) and registers (47) in the 4.5-4.9 magnitude range, the possible selections in this rangeare no enough robust. This means that the results obtained in this magnitude range are less significative than within the other magnitude ranges. Also the data distribution within this magnitude range is completely unequal, both earthquakes are M=4.5. With the tested subsets several changes on the ranks assigned in this range of magnitude are observed. However we could have a general idea of the acceptable and no acceptable equations.

• As it's expected the best rankings are the most sensitive (they are also the most restrictive), however this means that we don't have to only base our ranking in one residual, it is useful to use both (more robust) and to use all the statistical parameters values and the separated magnitudes study, to compare the acceptable equations with similar ranks.

| Subset | PGA | PGV |
|---|---|---|
| **20061117** | AkkaaBom07 and Tapia06 →Zrank 1 to 2 | Quitori99 → Zrank from 2 to 1 |
| **20071115** | No rank variations | M range 3.5-3.9 from Z rank 2 to 3?? |
| **20050226** | AkkaaBom07 → Zrank 2 to 1 | No rank variations |
| **PYAT** | Tapia06 and AkaaBoo07→ Zrank 1 to 2 | AkkaaBom10 (M=4-4.4)→Y rank 3 to 2 |
| **PYOR** | Tapia06 (3.0-3.4)→ Zrank 3 to 2 | Quitori99 (M=4-4.4)→Y rank 2 to 1 |

**Table 10:** Main variations to the study results for each subset and parameter.

## 5. Discussion and conclusions

According to the obtained results:

• Collected data is useful and of enough quality to select the best GMPEs in the range of magnitude 3 - 4.5 and epicentral distances < 375K m for the Pyrennes. For bigger earthquakes $Ml_{IGN}$ > 4.5 the data and methodology used in this study are useless.

• Few quantity of data on the magnitude range 4.5-4.9 invalidates the separated results in this magnitude range.

• Lower magnitude ranges have bigger influence because there are more registers within these ranges.

• Proposed method, combining the two types of residuals, is useful to select the best prediction equation and discard the worst, for PGM prediction in the Pyrenees from the tested equations.

• Some of the existing GMPEs predict with enough quality the observed PGM values, although we don't take into account the proper magnitude definition or component definition. By now, it's no necessary to test more GMPEs, because the tested ones are representative and obtain acceptable results for the shake map implementation.

• For PGA, Akkar and Boomer [2007] and Tapia [2006] are the best of the tested equations and can predict properly PGA values in rock sites for maximum horizontal component. However Tapia [2006] has a more simple general form than Akkar and Boomer [2007].

• For PGV, Akkar and Boomer [2007] obtain the best results and can predict properly the values of this parameter.

• For the three studied periods of the PSA the best GMPE is the one proposed in Tapia [2006]. It obtains good quality results for 1 second and 2 seconds and acceptable for 0.2s.

• To select the GMPEs to be used, and looking for coherence and robustness, the results obtained for different statistical parameters and different ranges of magnitudes should be taken into account (when it is possible).

• With this study we determine the best GMPEs without taking into account ShakeMap v3.5 bias calculation [10]According to this bias calculation some GMPEs that obtains bad ranks according to bad values for average and median could be used successfully for predicting the values within ShakeMap v3.5. This are expected to be the GMPEs that obtain low values of σ in both residuals, especially in Y residuals. This GMPEs are: Marin et al. [2004] and Souriau [2006] (for PGA) and Akkar and Boomer [2010] (for all the parameters). In order to see this effect (qualitativelly) a simple test adding 0.5 to all the magnitudes is done and Souriau and Marin obtains very good results (ranks 1 or 2 for both residuals)[11]. This means that for the ShakeMap v3.5 computation other GMPEs could be used, however the selected ones, not only obtain the best results, they usually obtains ranks of 1 or 2 for both residuals, what implies having low values of σ (near the lower ones), so they are also expected to be within the best GMPEs to be used (also with the bias calculation).

According to these we **conclude** for the **implementation** of **ShakeMap v3.5** (summarized in Table 11):

• To use Tapia [2006] as the default GMPE for the prediction of the PGA and PSA values in the magnitude range [3 - 4.5] and in the computation of SISPyr shake maps. This GMPE is selected for the obtained good results and for its simple general expression and the magnitude range of validity.

[10] Shakemap v3.5. bias computation procedure consist in change the defined magnitude to obtain better adjustment between the predicted value and the observed value. The magnitude that obtains lower misfit is selected. This magnitude bias is applied to estimate all the values.

[11] Results and brief description in appendix E.0.5

• To use Akkar and Boomer [2007] as the default GMPE for the PGV Pyrennean ShakeMap computation, as it obtains the best results and they are good ones.

• As a first approach for the bigger earthquakes $Ml_{IGN} > 5.0$ (without data on this magnitude range) to use the Akkar and Boomer [2010] GMPE because:

– It is an improvement of the Akkar and Boomer [2007] used and recommended for Europe in previous projects (NERIES).

– It is derived with European and middle east data for magnitudes between 5 and 7.6

– It is defined with Mw which is good correlated with our study magnitude IGN Ml.

• To define a combined procedure to compute the predicted values in the intermediate range $4.5 < Ml_{IGN} \leq 5.0$ according to the magnitude bias.

| Parameter | Magnitude range | Default GMPE | Other good ranked GMPEs | Possible GMPEs according to M bias calculation | Comments |
|---|---|---|---|---|---|
| PGA | [3.0-4.5] | Tapia06 | AkaaBom07 | AkkaBom10, Quitori99, Maretal04, Souria106, Souria206 | - |
| PGA | > 5 | AkaaBom10 | - | - | - |
| PGV | [3.0-4.5] | AkaaBom07 | Quitori99, AkaaBom10 | - | - |
| PGV | > 5 | AkaaBom10 | - | - | - |
| PSA 0.2s | [3.0-4.5] | Tapia06 | - | AkaaBom10, AkaaBom07 | - |
| PSA 0.2s | > 5 | AkaaBom10 | - | - | - |
| PSA 1.0s | [3.0-4.5] | Tapia06 | AkaaBom07, Quitori99 | AkaaBom10, BraaSle05 | - |
| PSA 1.0s | > 5 | AkaaBom10 | - | - | - |
| PSA 2.0s | [3.0-4.5] | Tapia06 | AkkaaBom10, AkaaBom07 | | - |
| PSA 2.0s | > 5 | AkaaBom10 | - | - | - |

**Table 11**: Conclusions on the GMPE usage for the SISPyr ShakeMap v3.5. implementation. For the $Ml_{IGN} > 5$ it is as a first approach.

# 6. Proposed improvements

Possible improvements to this study (depending on availability of time) are:

• Revise these results with a common study of the Ground Motion Prediction Equations, Intensity Prediction Equations and equations relating both parameters (GMICE and IGMCE)[12].

• Study the feasibility of the Hybrid empirical method (Campbell [2004]) to the study region to determine a proper GMPE for bigger earthquakes.

• To do a sensitivity study to the input GMPEs parameters (epicentral distance, depth, magnitude ...). In order to see the effect of the errors in the determination of the input parameters of GMPEs a sensitivity study to these parameters is required. The selected GMPEs can also be tested with the bigger recent earthquakes. This sensitivity study could change the defaults GMPEs done in these recommendations, but we take them as a first approach.

[12] GMICE: Ground Motion to Intensity Conversion Equation; IGMCE: Intensity to Ground Motion conversion equation

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# Appendix

# A. Parameters computation

The script paramacc.m and its functions programmed within the NERIES project by Mar Tapia and Albert Marsal, were adapted to compute our desired parameters. This appendix is an extraction of the D4 report from module NA5. It is presented to show how this parameters are computed and how could be computed within the Shakemap procedure.

From all the set of parameters in this study we only use the PGA, PGV and PSV in few periods. Here all the information is presents all the parameters computed for the parameters database for future uses in A4.1. SISPyr action.

It is considered that parameters computation modules are a set of specific functions that focus on the computation of each parameter Consequently, there is one function for each parameter to calculate. Here is a brief explanation of the important issues on the parameters computations and the parameters computed (indicated by*):

• **Raw acceleration**: acceleration time-history in cm/s2, base line corrected. It is supposed that the user should remove the offset of the record before processing it. In spite of this, the software allows (optional) an automatic base line correction for raw acceleration records by one degree polynomial approximation fitted in a least squares sense.

• **Record duration***: duration of raw acceleration record (in seconds).

• **Raw PGA (cm/s$^2$)***: PGA (peak ground acceleration) from raw acceleration record.

• **Highpass filter**: Butterworth IIR highpass filter of two poles is implemented. To maintain the homogeneity and to avoid being too restrictive, the cut-off frequency is 0,1Hz for all records, taking into account their variety and instruments resolution. Filtering is applied again in the opposite time direction in order to avoid phase distortion. Data padding has been introduced to avoid low frequency distortion. A number of zeros equivalent to 5% of the time duration has been added, both at the beginning and at the end of signal.

• **Filtered acceleration**: raw acceleration after the application of the previously defined filter.

• **PGA (cm/s$^2$)*:** PGA from filtered record. It is directly obtained from the maximum value of the filtered acceleration time-history.

• **AI (cm/s)*:** Arias intensity. A specific function according the next expression:

$$IA = \frac{\pi}{2g} \int_0^{\infty} a^2\,(t)\;dt \tag{6}$$

• **Trifunac duration (s)*:** Trifunac duration is the time interval between the 5 and 95% of a Husid plot:

$$H_{usid}\ (t) = \frac{\int_0^t\ a^2(t)\,dt}{\int_0^\infty\ a^2\ (t)\,dt} \tag{7}$$

• **CAV (cm/s)*:** Cumulative Absolute Velocity. Computed with the next expression:

$$CAV = \int_0^\infty |a|(t)dt \tag{8}$$

• **PSV (5%)*** (pseudovelocity) (cm/s) for 28 frequencies logarithmically equally spaced (from 0.15Hz to 39Hz) (frequencies: 0.15, 0.19, 0.23, 0.28, 0.34, 0.42, 0.52, 0.64, 0.78, 0.96, 1.18, 1.45, 1.78, 2.19, 2.69, 3.31, 4.06, 4.99, 6.13, 7.53, 9.25, 11.37, 13.96, 17.15, 21.07, 25.89, 31.80, 39.07 Hz). The first 5 frequencies PSV values are not offered in case of PGA<0.01g or PGV<1cm/s.

For this study this was adapted in order to obtain the PSV values at 28 periods: 2.4, 2.3, 2.2, 2.1, 2, 1.9, 1.8, 1.7, 1.6, 1.5, 1.4, 1.3, 1.2, 1.1, 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.35, 0.3, 0.25, 0.2, 0.15, 0.1 and 0.05 seconds.

• **Housner intensity*** or response spectrum intensity (cm). A specific function according to the next expression (with ξ = 5%):

$$I_{Housner}\ (\xi) = \int_{0.1}^{2.5} PSV(\xi, T)\ \ dT \tag{9}$$

• **Integration**: via the trapezoidal method (time domain) to obtain both velocity and displacement time-histories. After filtering the first time to remove noise from filtered acceleration record, any other filter is applied.

• **Velocity time history (cm/s):** integrated filtered acceleration time history.

• **PGV (cm/s)*:** It is directly obtained from the maximum value of the calculated velocity time-history.

• **Displacement time history (cm):** integrated velocity time history.

# B. Results summary by models for each PGM

This appendix presents a summary of the results obtained for the parameters with rock data and for the tested equations. Table 12 shows the results obtained for the studied statistical parameter for each residuals type.

For each parameter and model four plots are presented:

• The LH statistical with a header presenting the computed mean, median and standard deviation of the normalized logarithmic residuals, the LH median and the rank assigned by the Scherbaum method.

• The normalized logarithmic residuals distribution, a Gaussian with the median and sigma of the data in green and a standard Gaussian (σ = 1) in black.

• Logarithmic residuals versus epicentral distance

• Logarithmic residuals versus IGN magnitude

Each GMPE has a defined code that identifies the study in which it is based. This assignation and the qualities of the GMPE are presented in table 6 of section 3.5

| PGM | Type | GMPE | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PGA | Rock | Cabanas99-3 | 4 | -0.087 | -0.403 | 2.020 | 0.164 | 4 | -0.044 | -0.201 | 1.010 |
| PGA | Rock | Lusetal01 | 4 | -2.272 | -2.435 | 1.481 | 0.015 | 4 | -0.725 | -0.777 | 0.472 |
| PGA | Rock | Beretal03 | 4 | -3.922 | -4.130 | 1.700 | 0.000 | 4 | -1.147 | -1.207 | 0.497 |
| PGA | Rock | Maretal04 | 4 | 0.953 | 0.862 | 0.760 | 0.382 | 4 | 0.524 | 0.474 | 0.418 |
| PGA | Rock | Ambetal05 | 4 | -1.255 | -1.255 | 0.952 | 0.207 | 4 | -0.583 | -0.571 | 0.447 |
| PGA | Rock | BraaSle05 | 4 | 1.785 | 1.730 | 1.315 | 0.080 | 4 | 0.712 | 0.690 | 0.525 |
| PGA | Rock | Tapia06 | 1 | -0.202 | -0.239 | 1.032 | 0.488 | 2 | -0.086 | -0.102 | 0.440 |
| PGA | Rock | Souria106 | 4 | 0.978 | 0.945 | 0.872 | 0.326 | 3 | 0.493 | 0.482 | 0.436 |
| PGA | Rock | Souria206 | 3 | 0.690 | 0.677 | 0.665 | 0.484 | 3 | 0.451 | 0.444 | 0.433 |
| PGA | Rock | Mezetal08 | 4 | -1.291 | -1.572 | 1.582 | 0.089 | 4 | -0.891 | -1.084 | 1.091 |
| PGA | Rock | AkkaBom07 | 1 | -0.181 | -0.232 | 1.019 | 0.453 | 2 | -0.073 | -0.097 | 0.412 |
| PGA | Rock | Masetal08 | 4 | 0.820 | 0.999 | 3.852 | 0.010 | 4 | 0.238 | 0.290 | 1.117 |
| PGA | Rock | AkkaBom10 | 3 | -0.246 | -0.347 | 1.459 | 0.290 | 2 | -0.069 | -0.097 | 0.407 |
| PGA | Rock | Quitori99 | 3 | 0.559 | 0.506 | 1.123 | 0.442 | 2 | 0.205 | 0.185 | 0.412 |
| PGV | Rock | BraaSle05 | 4 | 1.462 | 1.457 | 1.440 | 0.125 | 4 | 0.539 | 0.538 | 0.531 |
| PGV | Rock | AkkaBom07 | 1 | -0.067 | -0.098 | 0.745 | 0.618 | 2 | -0.035 | -0.055 | 0.412 |
| PGV | Rock | Masetal08 | 4 | 0.320 | 0.566 | 3.415 | 0.025 | 4 | 0.090 | 0.158 | 0.956 |
| PGV | Rock | AkkaBom10 | 3 | -0.398 | -0.456 | 1.332 | 0.314 | 2 | -0.111 | -0.127 | 0.370 |
| PGV | Rock | Quitori99 | 2 | 0.210 | 0.145 | 1.131 | 0.475 | 2 | 0.069 | 0.048 | 0.370 |
| PSA 0.2s | Rock | Lusetal01 | 4 | -1.459 | -1.561 | 1.286 | 0.103 | 4 | -0.509 | -0.545 | 0.449 |
| PSA 0.2s | Rock | Beretal03 | 4 | -4.109 | -4.265 | 1.413 | 0.000 | 4 | -1.336 | -1.386 | 0.459 |
| PSA 0.2s | Rock | Ambetal05 | 4 | -1.588 | -1.601 | 0.939 | 0.109 | 4 | -0.847 | -0.840 | 0.512 |
| PSA 0.2s | Rock | BraaSle05 | 4 | 1.224 | 1.201 | 1.611 | 0.157 | 3 | 0.442 | 0.434 | 0.582 |
| PSA 0.2s | Rock | Tapia06 | 2 | -0.426 | -0.492 | 0.995 | 0.447 | 2 | -0.185 | -0.214 | 0.433 |
| PSA 0.2s | Rock | AkkaBom07 | 4 | -1.152 | -1.187 | 1.126 | 0.220 | 3 | -0.432 | -0.442 | 0.422 |
| PSA 0.2s | Rock | Masetal08 | 4 | 0.131 | 0.491 | 3.497 | 0.023 | 4 | 0.037 | 0.138 | 0.979 |
| PSA 0.2s | Rock | AkkaBom10 | 4 | -1.359 | -1.384 | 1.355 | 0.140 | 3 | -0.411 | -0.418 | 0.409 |
| PSA 1.0s | Rock | Lusetal01 | 4 | -1.334 | -1.404 | 1.096 | 0.154 | 4 | -0.500 | -0.526 | 0.411 |
| PSA 1.0s | Rock | Beretal03 | 4 | -3.938 | -4.054 | 1.216 | 0.000 | 4 | -1.472 | -1.515 | 0.454 |
| PSA 1.0s | Rock | Ambetal05 | 4 | -3.086 | -3.161 | 1.416 | 0.002 | 4 | -1.011 | -1.036 | 0.464 |
| PSA 1.0s | Rock | BraaSle05 | 4 | 0.777 | 0.791 | 1.369 | 0.285 | 3 | 0.270 | 0.275 | 0.475 |
| PSA 1.0s | Rock | Tapia06 | 1 | -0.070 | -0.108 | 0.620 | 0.667 | 2 | -0.040 | -0.062 | 0.357 |
| PSA 1.0s | Rock | AkkaBom07 | 1 | 0.159 | 0.168 | 0.503 | 0.721 | 2 | 0.128 | 0.133 | 0.404 |
| PSA 1.0s | Rock | Masetal08 | 4 | 0.092 | 0.289 | 2.649 | 0.088 | 4 | 0.028 | 0.087 | 0.795 |
| PSA 1.0s | Rock | AkkaBom10 | 3 | 0.599 | 0.557 | 1.109 | 0.390 | 2 | 0.195 | 0.181 | 0.361 |
| PSA 1.0s | Rock | Quitori99 | 2 | -0.392 | -0.406 | 0.898 | 0.488 | 2 | -0.157 | -0.162 | 0.359 |
| PSA 2.0s | Rock | Lusetal01 | 4 | -1.140 | -1.255 | 1.057 | 0.199 | 3 | -0.405 | -0.445 | 0.375 |
| PSA 2.0s | Rock | Beretal03 | 4 | -4.217 | -4.391 | 1.040 | 0.000 | 4 | -1.699 | -1.770 | 0.419 |
| PSA 2.0s | Rock | Ambetal05 | 4 | -3.637 | -3.704 | 1.263 | 0.000 | 4 | -1.136 | -1.156 | 0.394 |
| PSA 2.0s | Rock | BraaSle05 | 4 | 0.764 | 0.768 | 1.137 | 0.352 | 3 | 0.336 | 0.338 | 0.500 |
| PSA 2.0s | Rock | Tapia06 | 1 | -0.201 | -0.242 | 0.580 | 0.659 | 2 | -0.116 | -0.140 | 0.335 |
| PSA 2.0s | Rock | AkkaBom07 | 2 | 0.346 | 0.374 | 0.691 | 0.601 | 2 | 0.192 | 0.199 | 0.367 |
| PSA 2.0s | Rock | Masetal08 | 4 | 0.072 | 0.251 | 2.990 | 0.045 | 4 | 0.020 | 0.070 | 0.837 |
| PSA 2.0s | Rock | AkkaBom10 | 2 | 0.430 | 0.422 | 1.099 | 0.428 | 2 | 0.141 | 0.138 | 0.361 |

**Table 12:** Statistical parameters for each PGM, data set (all the magnitudes) and prediction equation. The presented statistical parameters are: for logarithmic residuals (Y) and normalized logarithmic residuals (Z = Y /σ) the average ( E()),the median (o), the σ of the prediction equation (std) and the median of the likelihood parameter ($LH_0$). Also the Scherbaum, 2004 assigned rank for the Z residual and a similar residual assigned to Y residual is presented (Rank). The computation and meaning of these parameters was explained in section 3.

## B.1 PGA

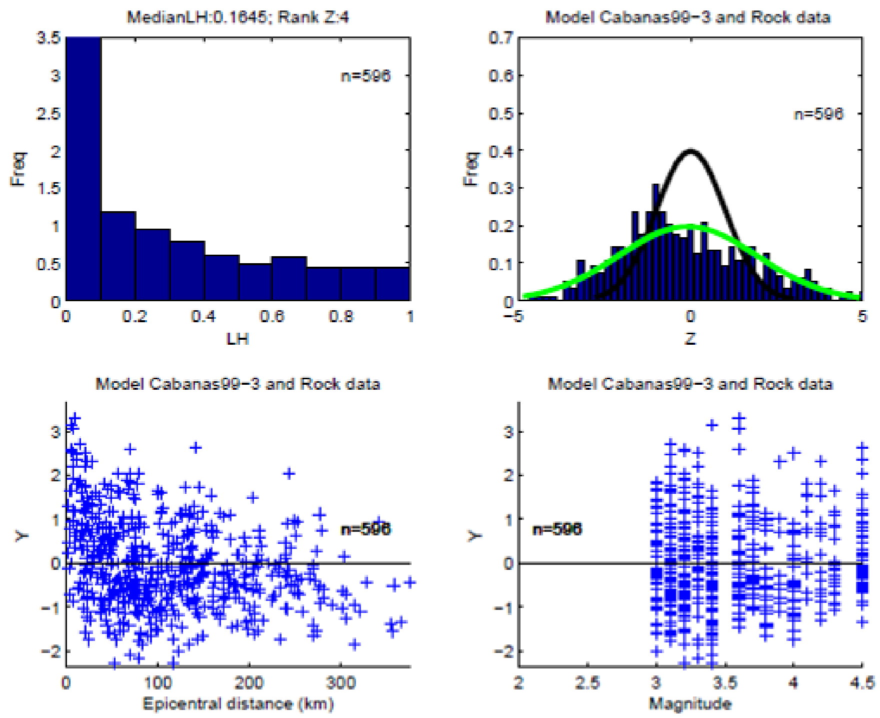



**Figure 9**: Summary of the results obtained for PGA and the study Rock data with the GMPE Cabanas99-3.

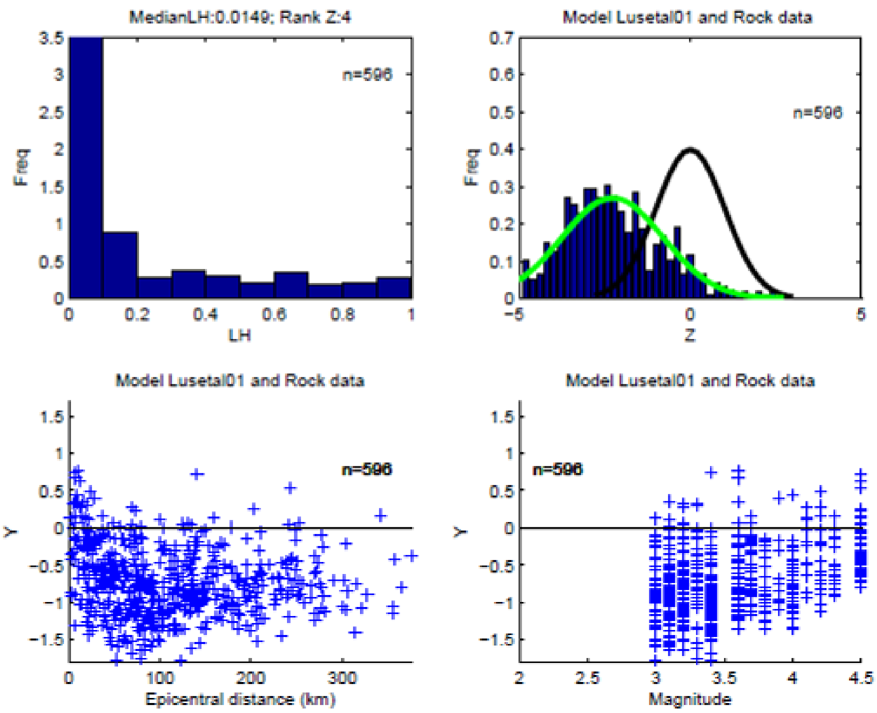



**Figure 10**: Summary of the results obtained for PGA and the study Rock data with the GMPE Lusetal01.

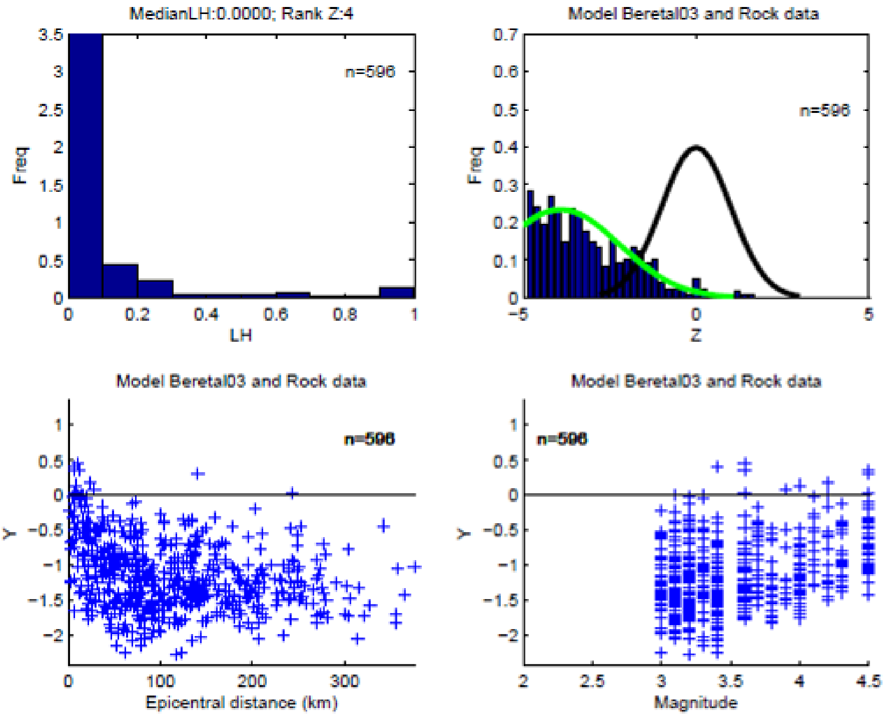



**Figure 11**: Summary of the results obtained for PGA and the study Rock data with the GMPE Beretal03.

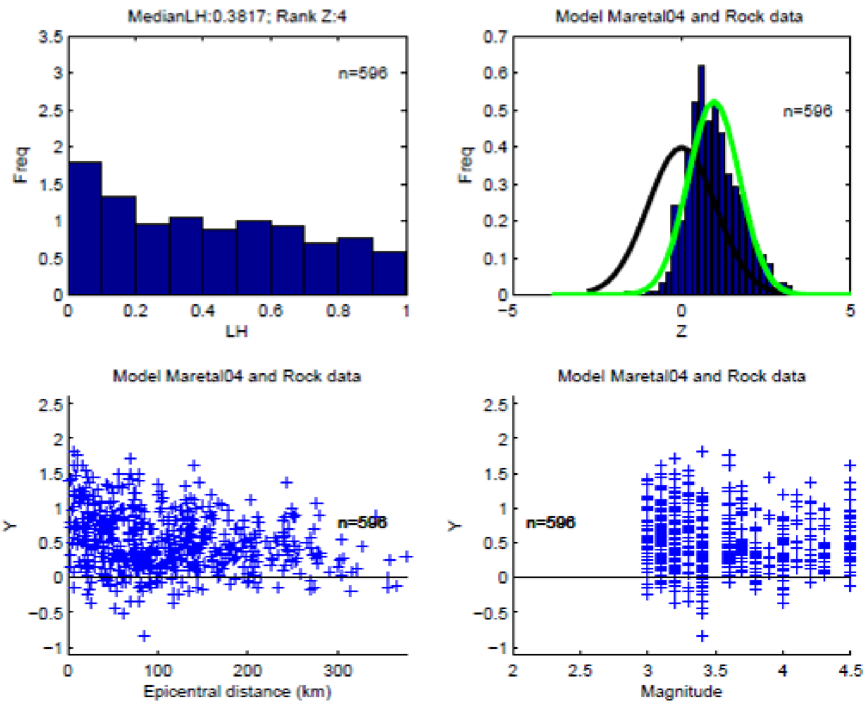



**Figure 12:** Summary of the results obtained for PGA and the study Rock data with the GMPE Maretal04

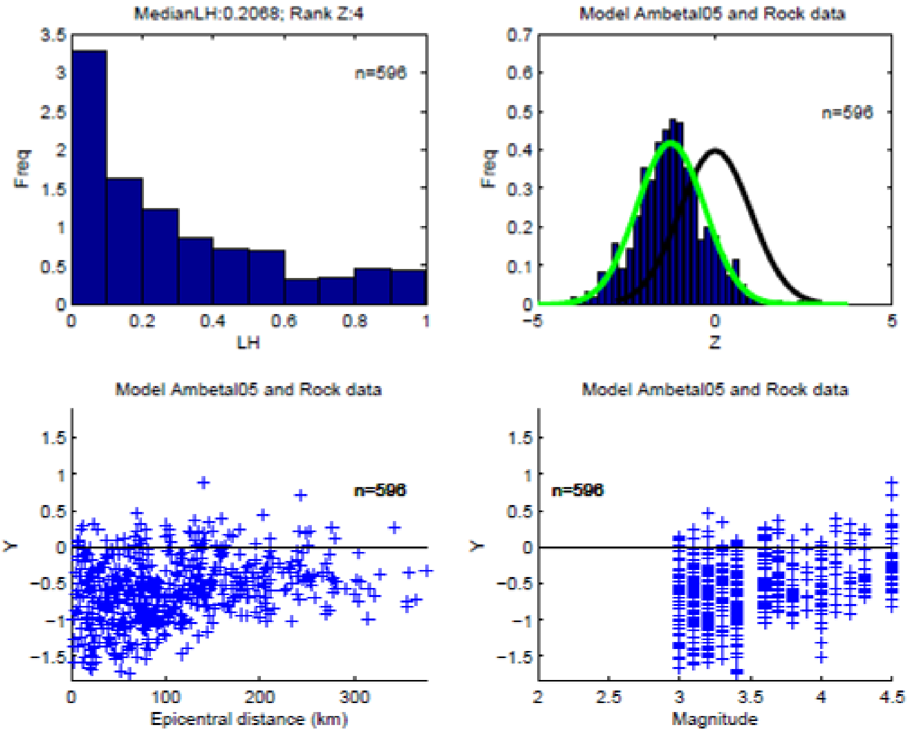



**Figure 13**: Summary of the results obtained for PGA and the study Rock data with the GMPE Ambetal05.

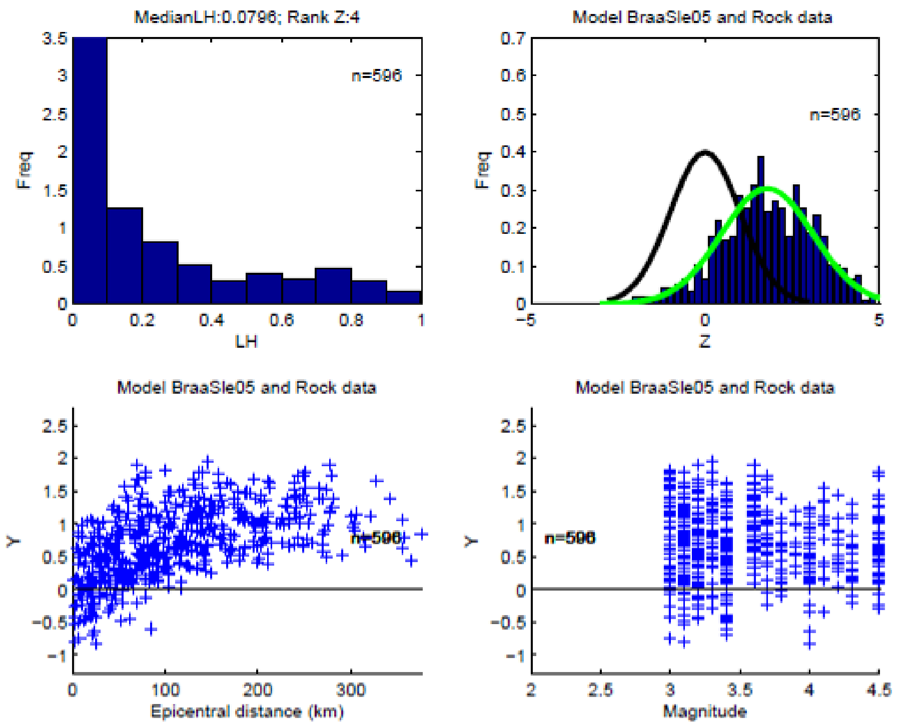



**Figure 14:** Summary of the results obtained for PGA and the study Rock data with the GMPE BraaSle05

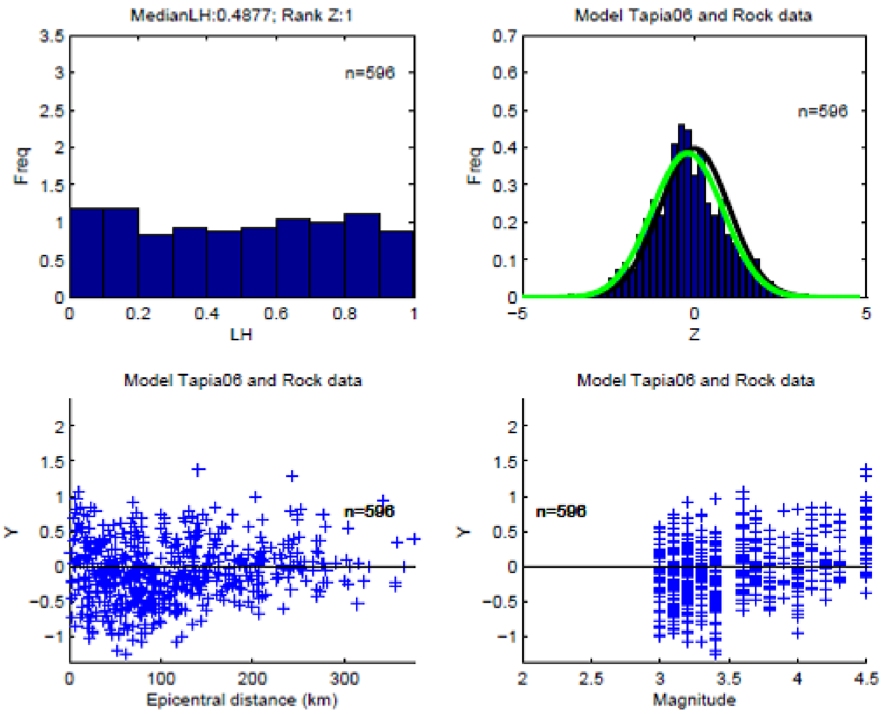



**Figure 15**: Summary of the results obtained for PGA and the study Rock data with the GMPE Tapia06.

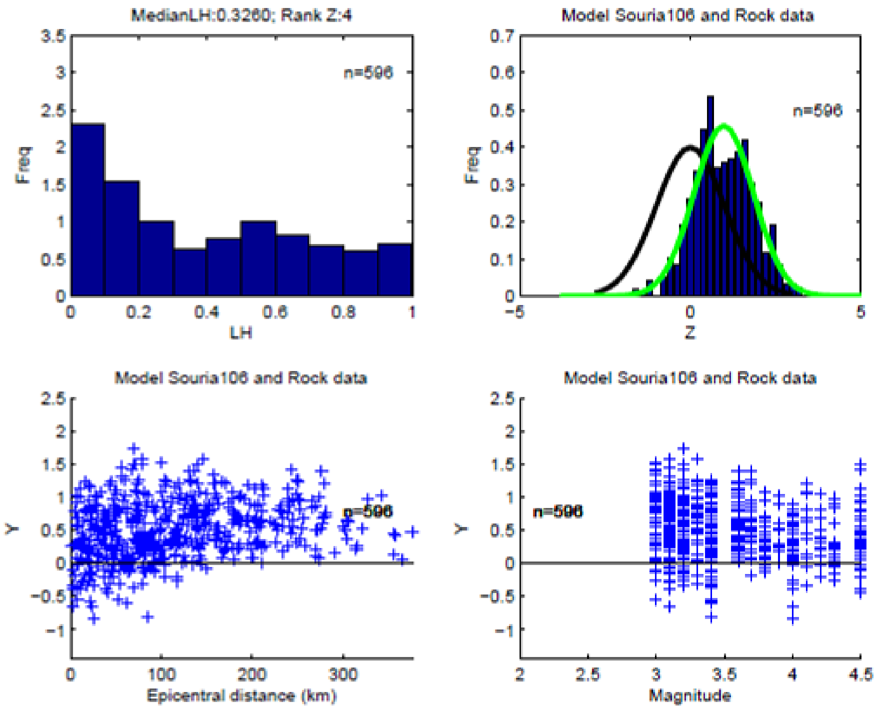



**Figure 16**: Summary of the results obtained for PGA and the study Rock data with the GMPE Souria106.

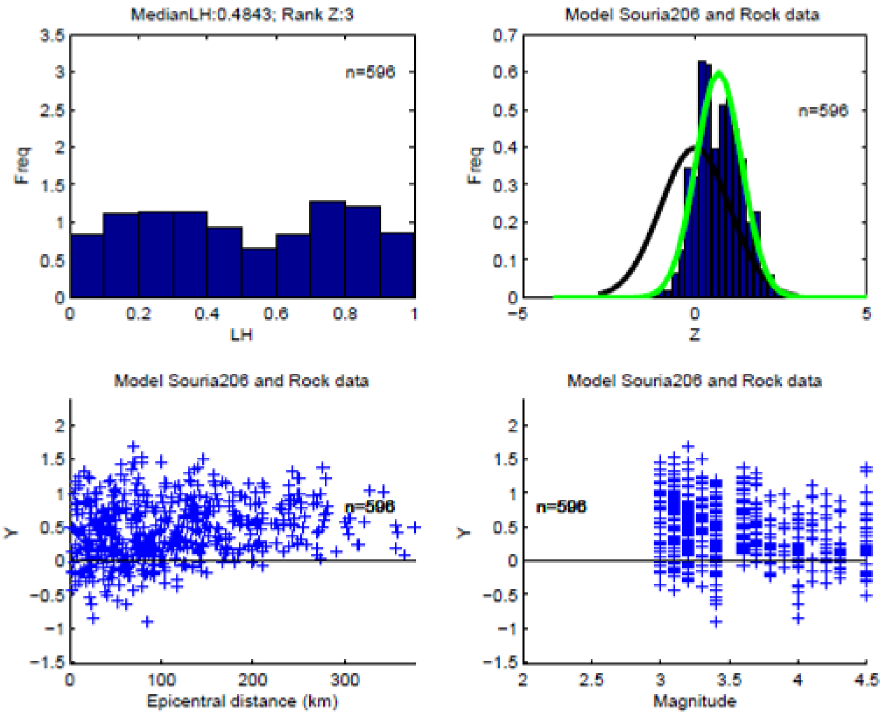



**Figure 17**: Summary of the results obtained for PGA and the study Rock data with the GMPE Souria206.

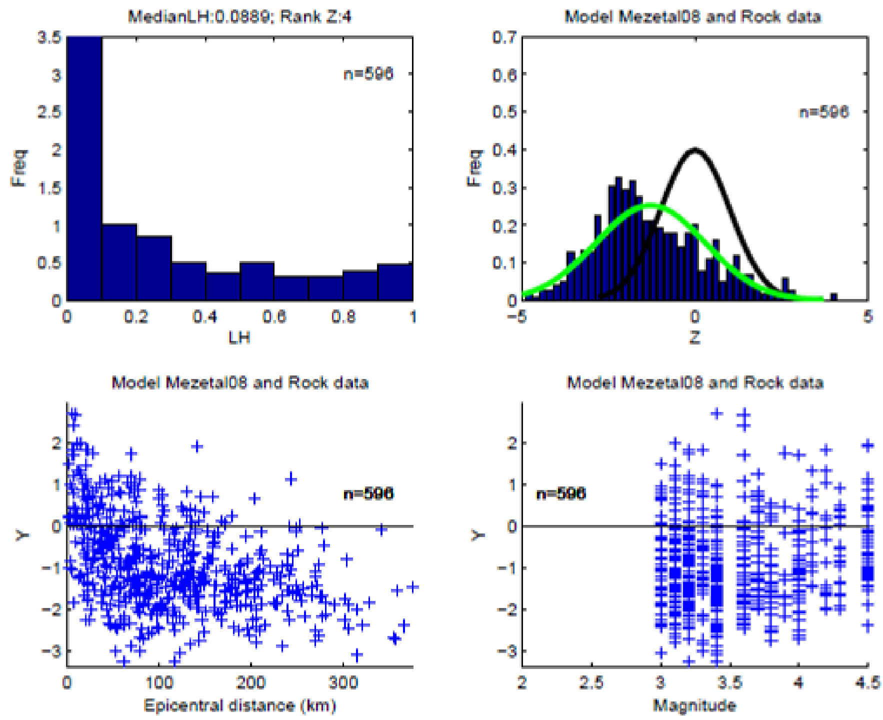



**Figure 18**: Summary of the results obtained for PGA and the study Rock data with the GMPE Mezetal08.

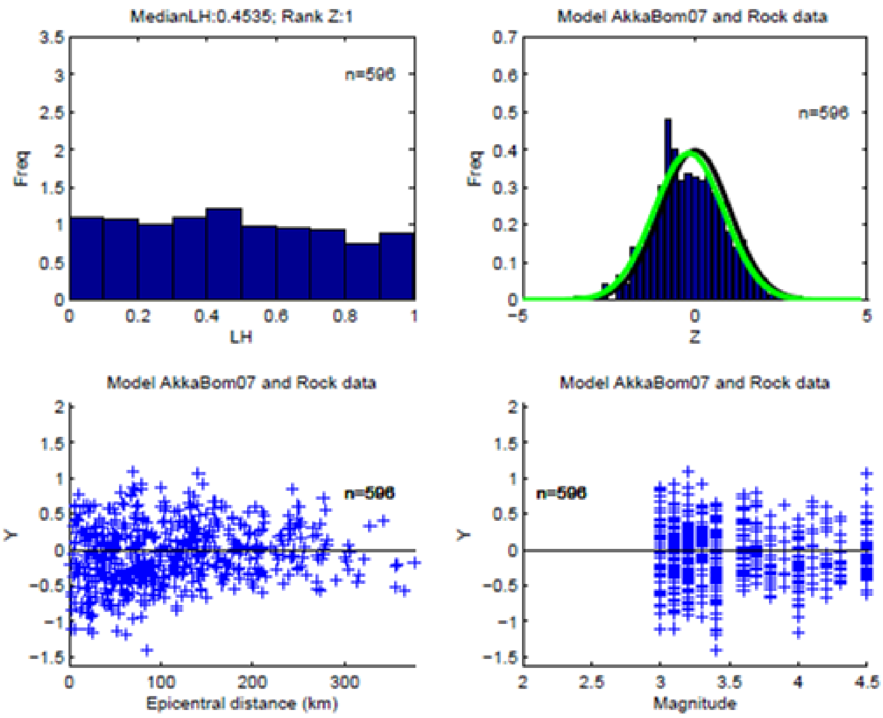



**Figure 19**: Summary of the results obtained for PGA and the study Rock data with the GMPE AkkaBom07.

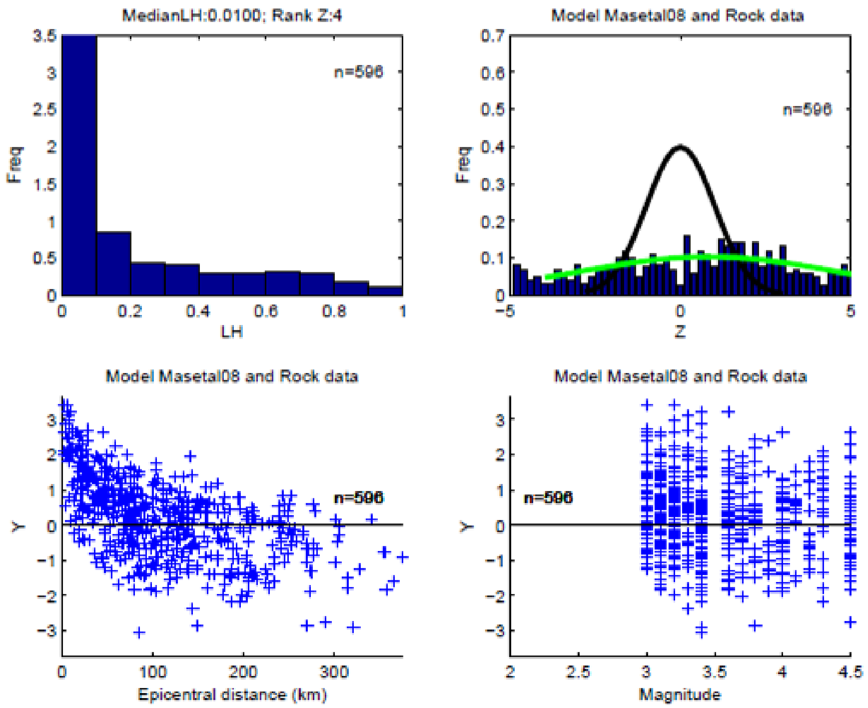



**Figure 20:** Summary of the results obtained for PGA and the study Rock data with the GMPE Masetal08.

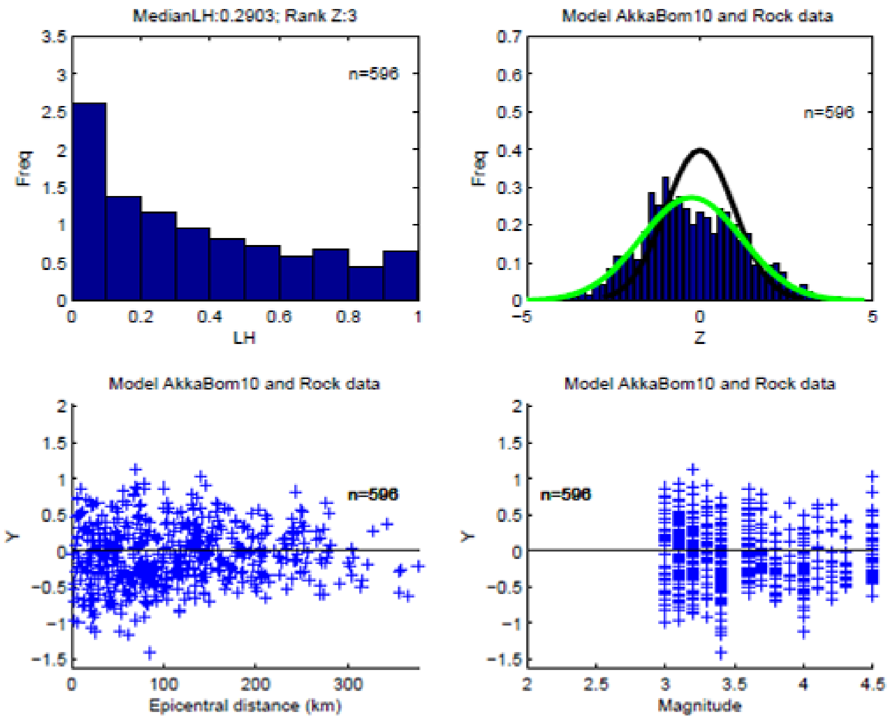



**Figure 21**: Summary of the results obtained for PGA and the study Rock data with the GMPE AkkaBom10.

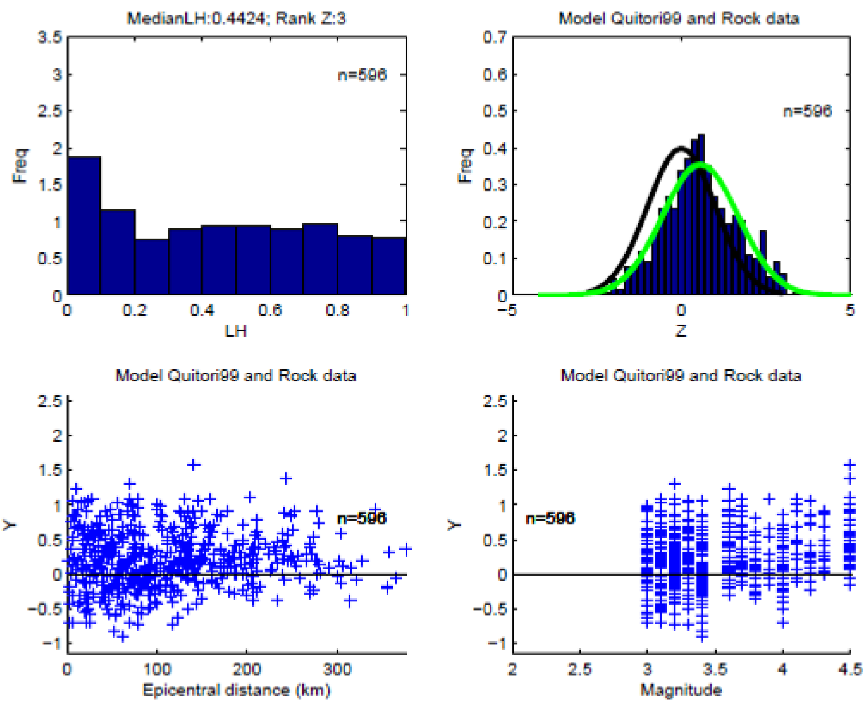



**Figure 22**: Summary of the results obtained for PGA and the study Rock data with the GMPE Quitori99.

## B.2 PGV

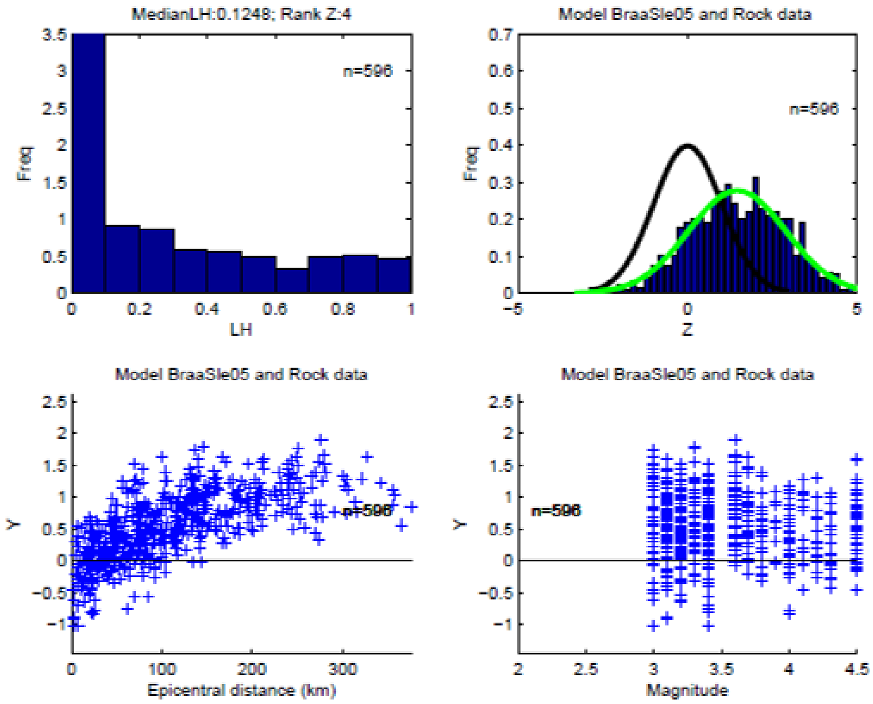



**Figure 23**: Summary of the results obtained for PGV and the study Rock data with the GMPE BraaSle05.

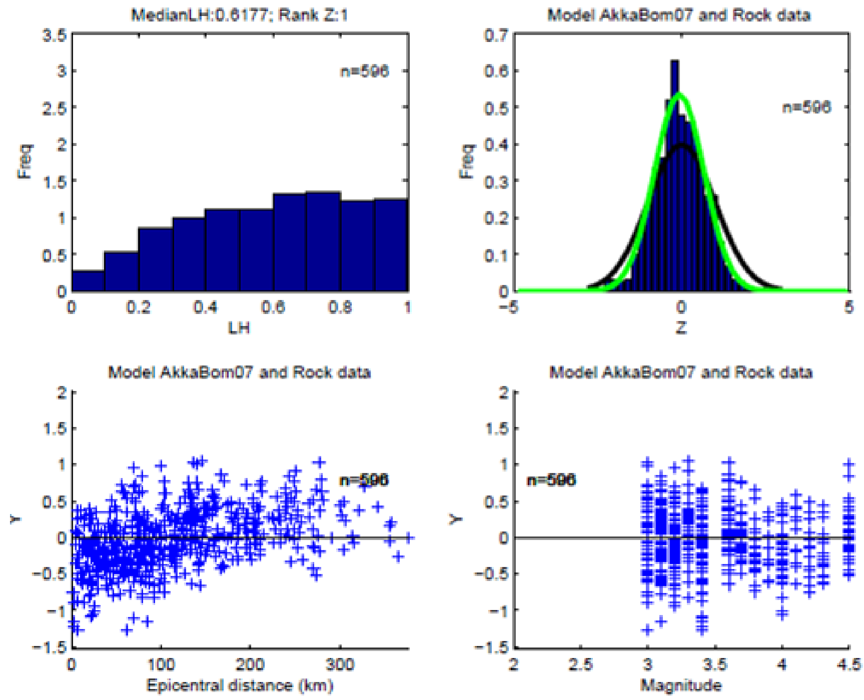



**Figure 24**: Summary of the results obtained for PGV and the study Rock data with the GMPE AkkaBom07.

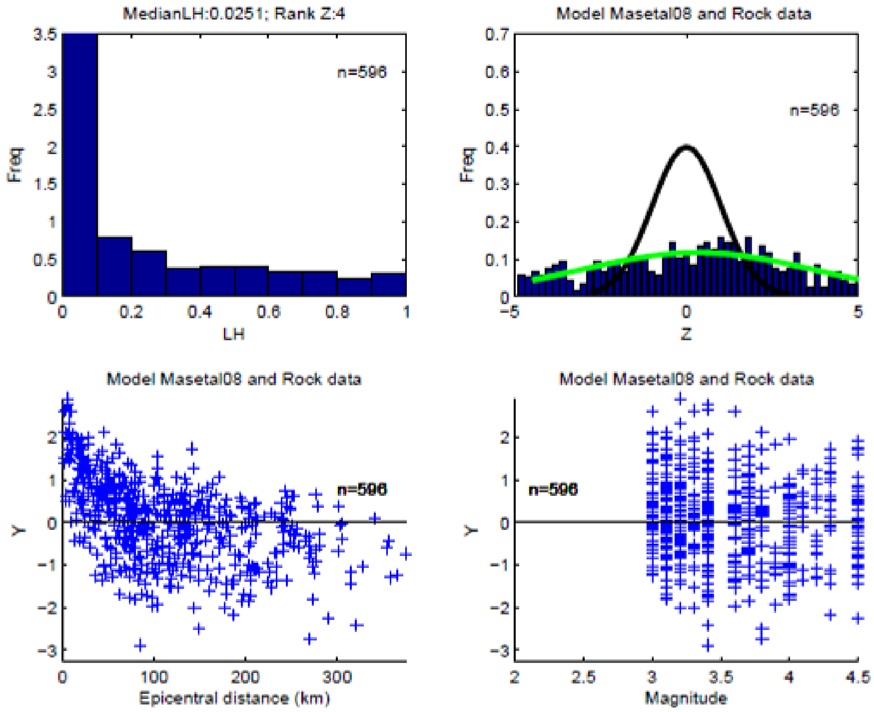



**Figure 25:** Summary of the results obtained for PGV and the study Rock data with the GMPE Masetal08.

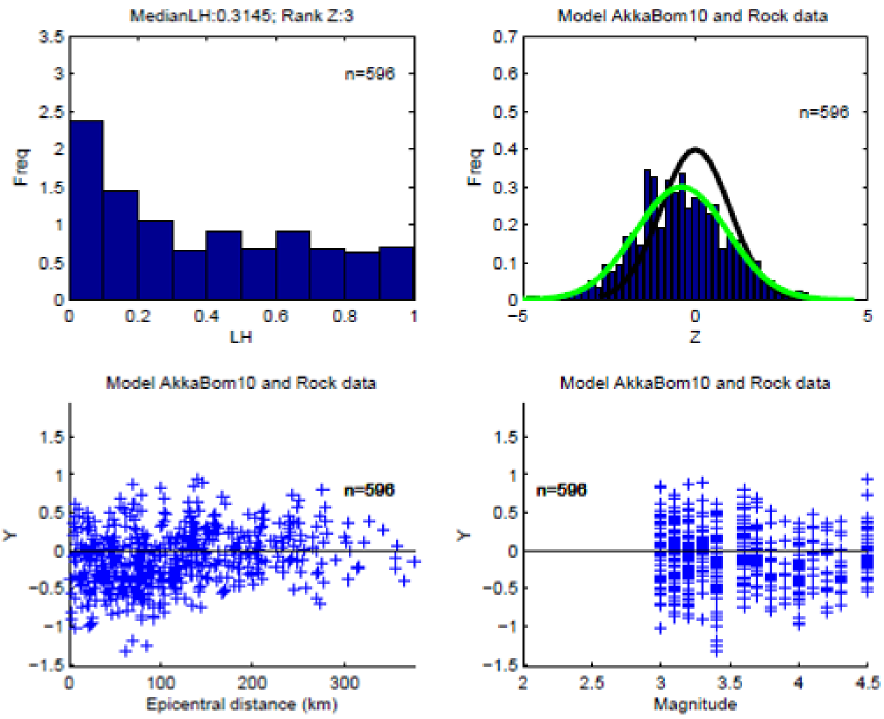



**Figure 26**: Summary of the results obtained for PGV and the study Rock data with the GMPE AkkaBom10.

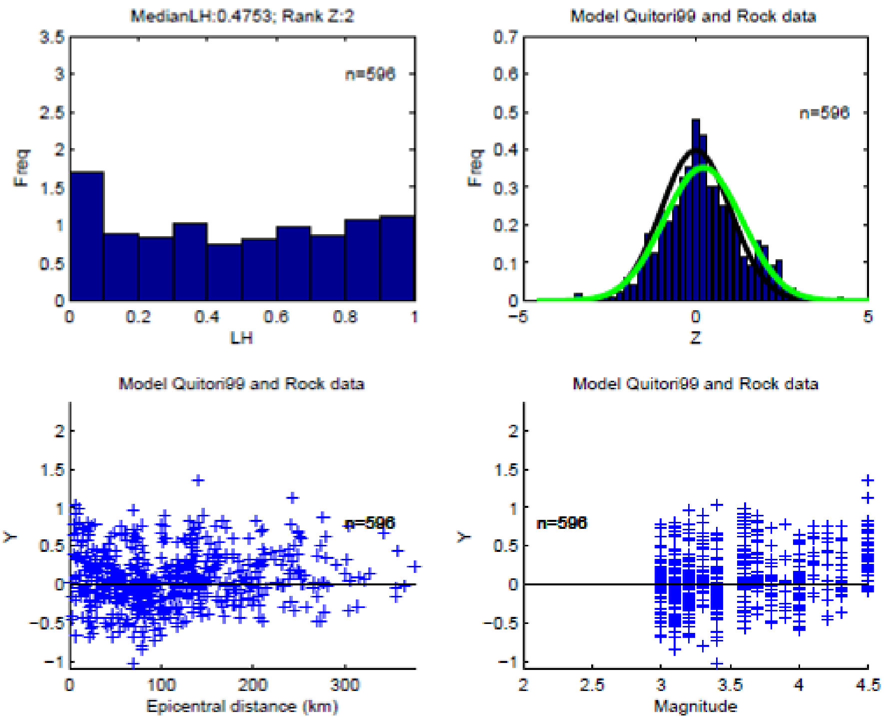



**Figure 27**: Summary of the results obtained for PGV and the study Rock data with the GMPE Quitori99.

## B.3 PSA 0.2s

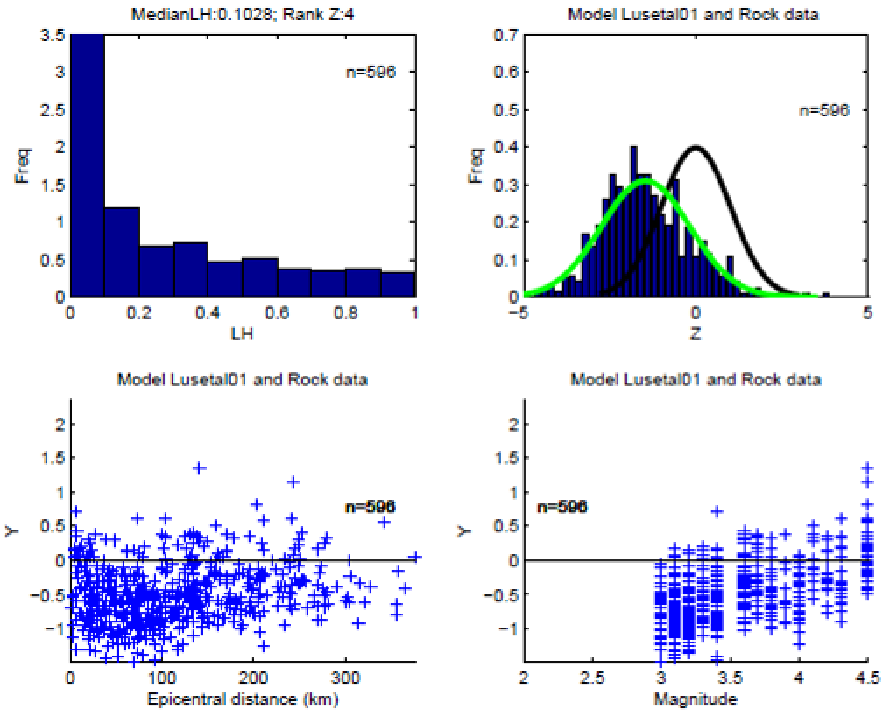



**Figure 28:** Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE Lusetal01.

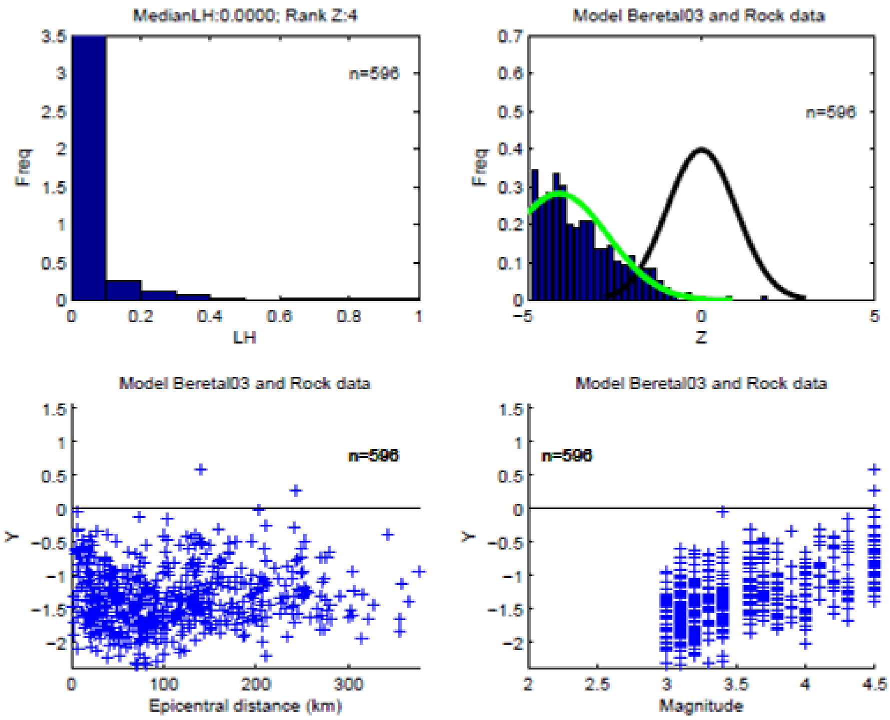



**Figure 29:** Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE Beretal03

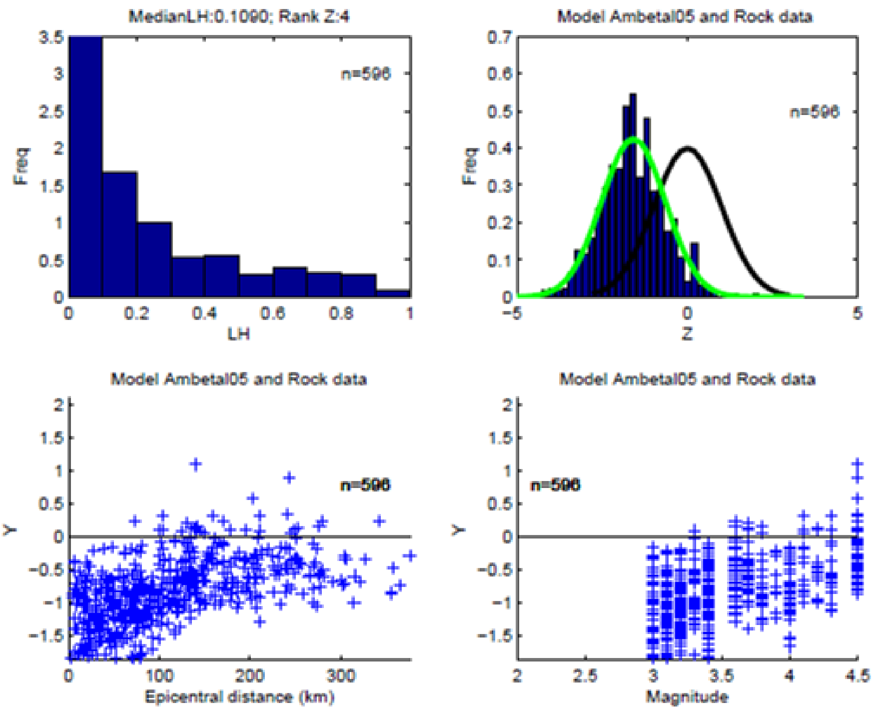



**Figure 30:** Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE Ambetal05.

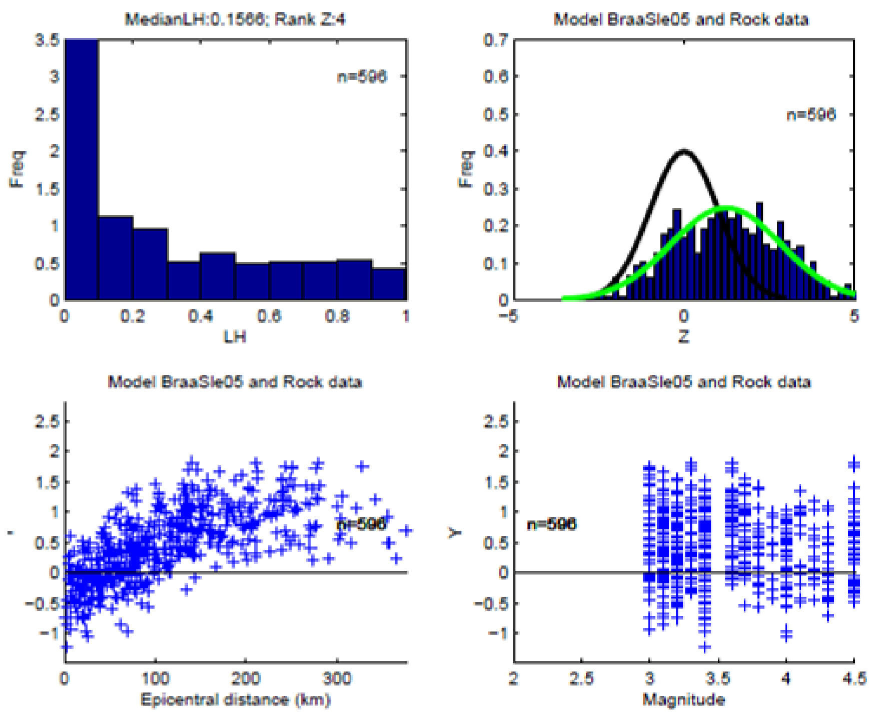



**Figure 31**: Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE BraaSle05.

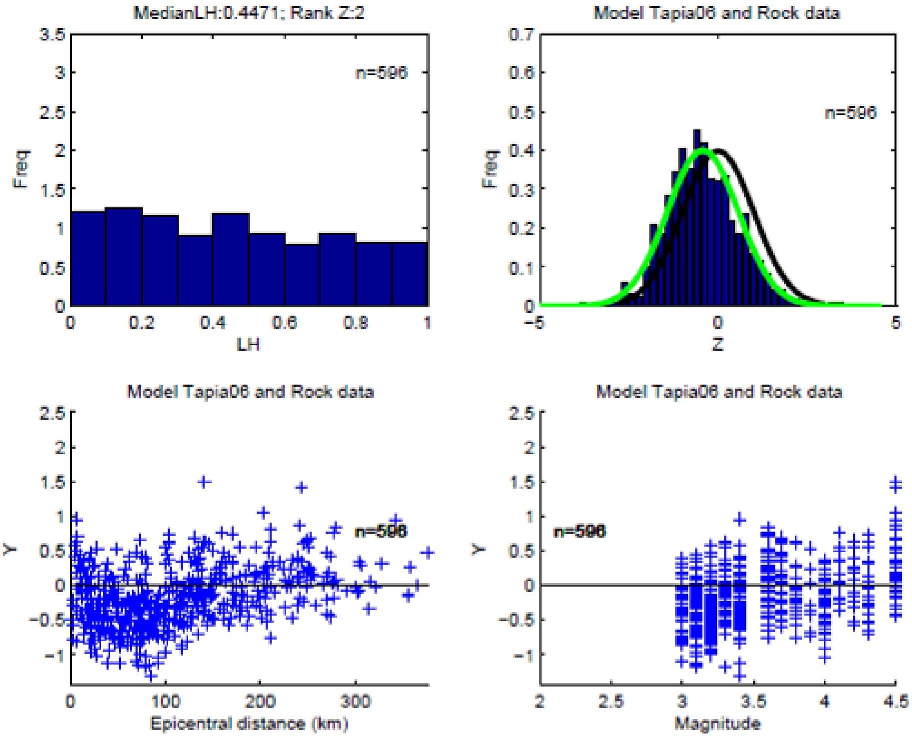



**Figure 32**: Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE Tapia06.

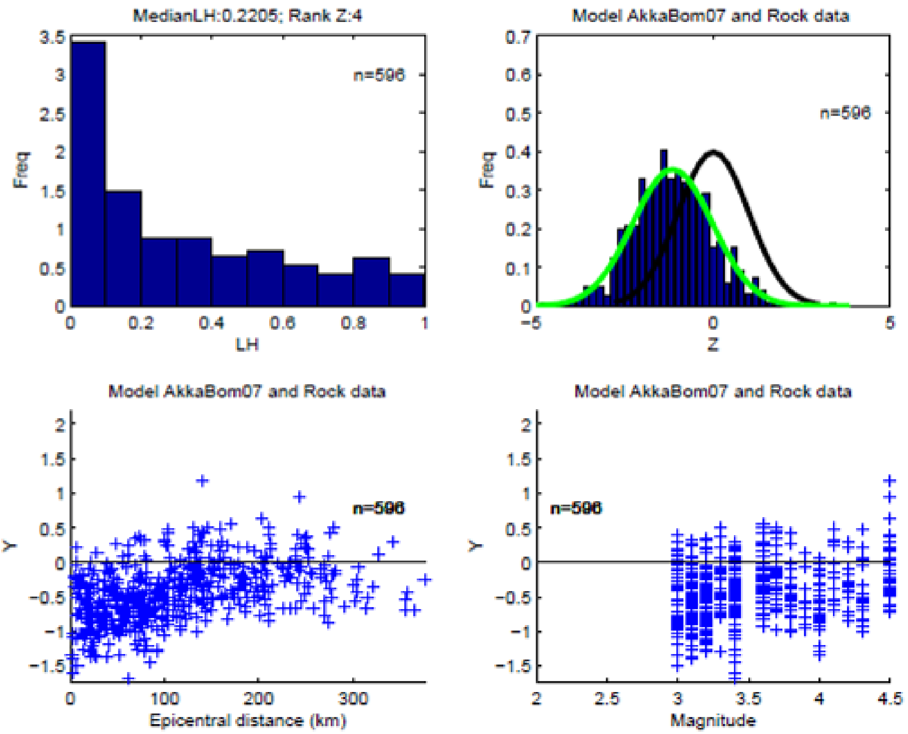



**Figure 33**: Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE AkkaBom07.

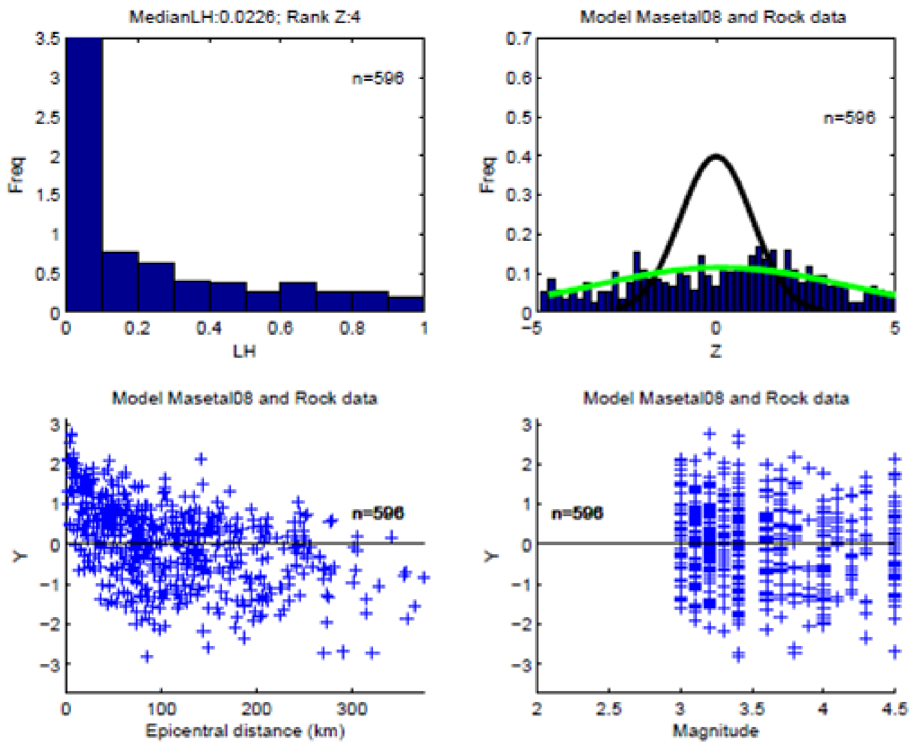



**Figure 34**: Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE Masetal08.

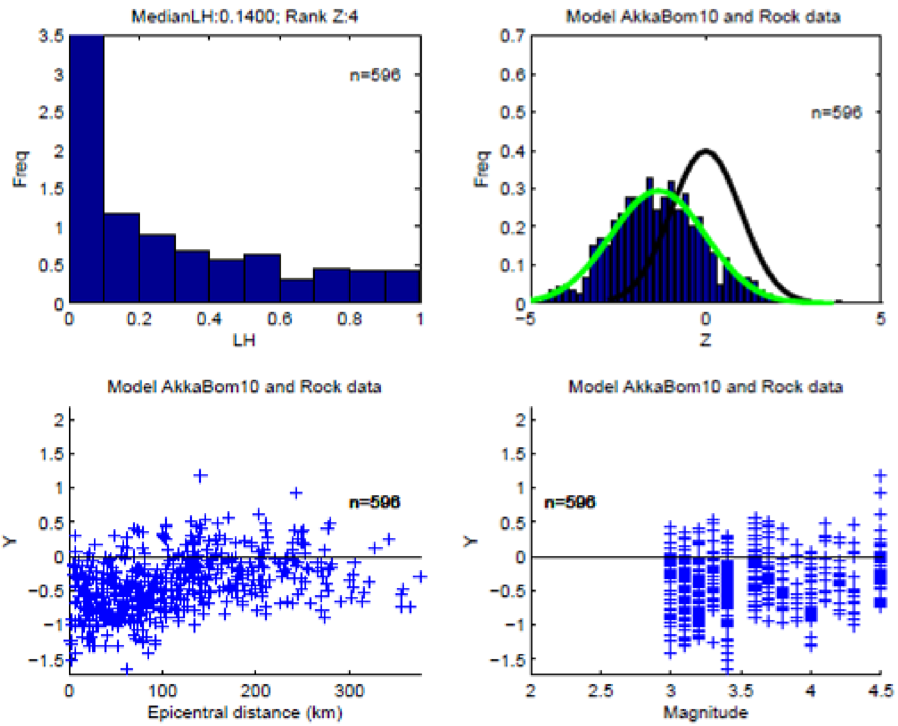



**Figure 35:** Summary of the results obtained for PSA 0.2s and the study Rock data with the GMPE AkkaBom10.

## B.4 PSA 1.0s

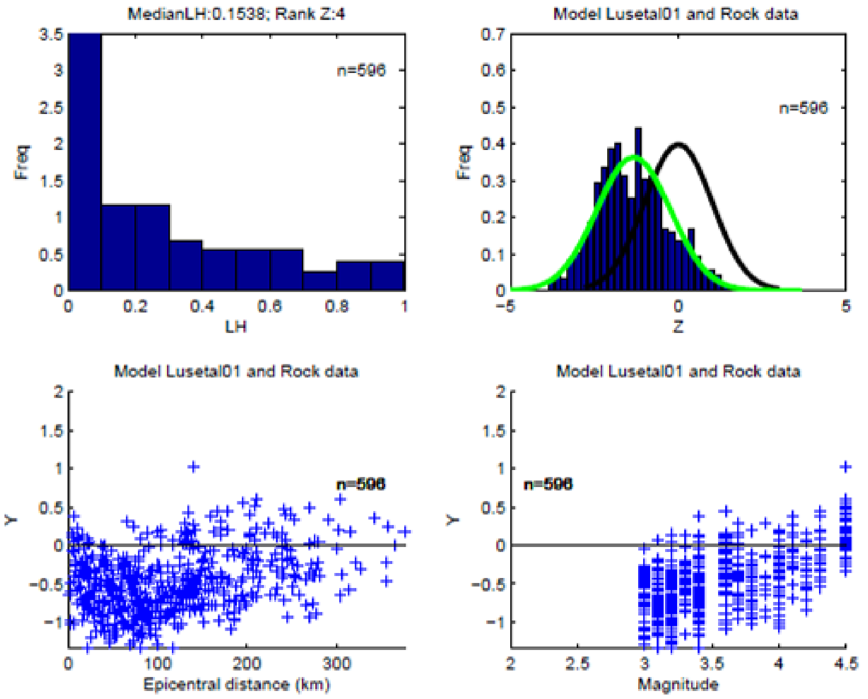



**Figure 36**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Lusetal01.

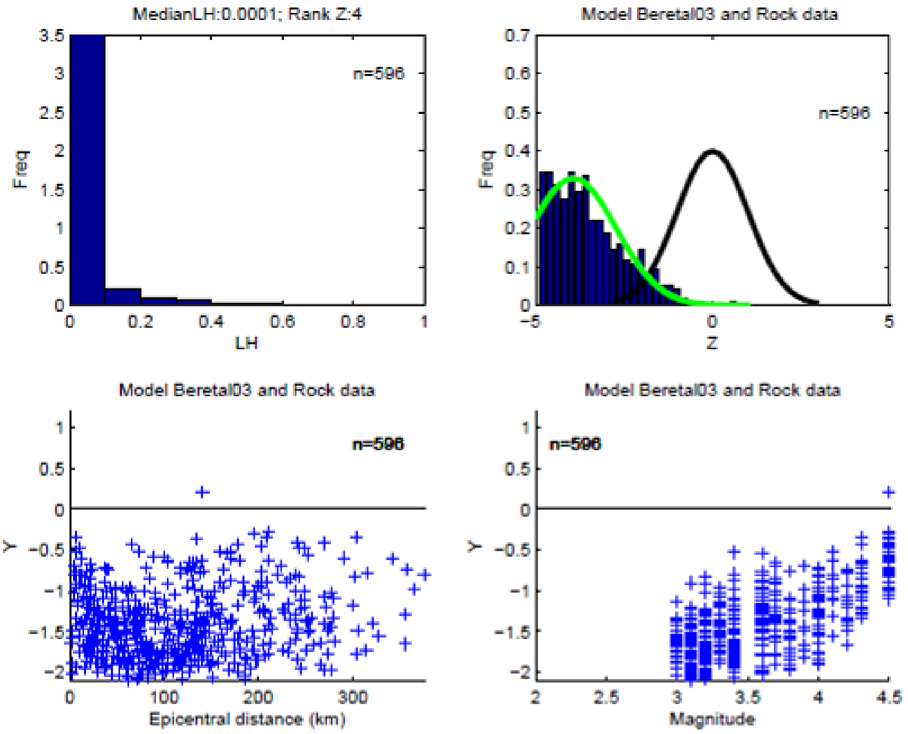



**Figure 37**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Beretal03.

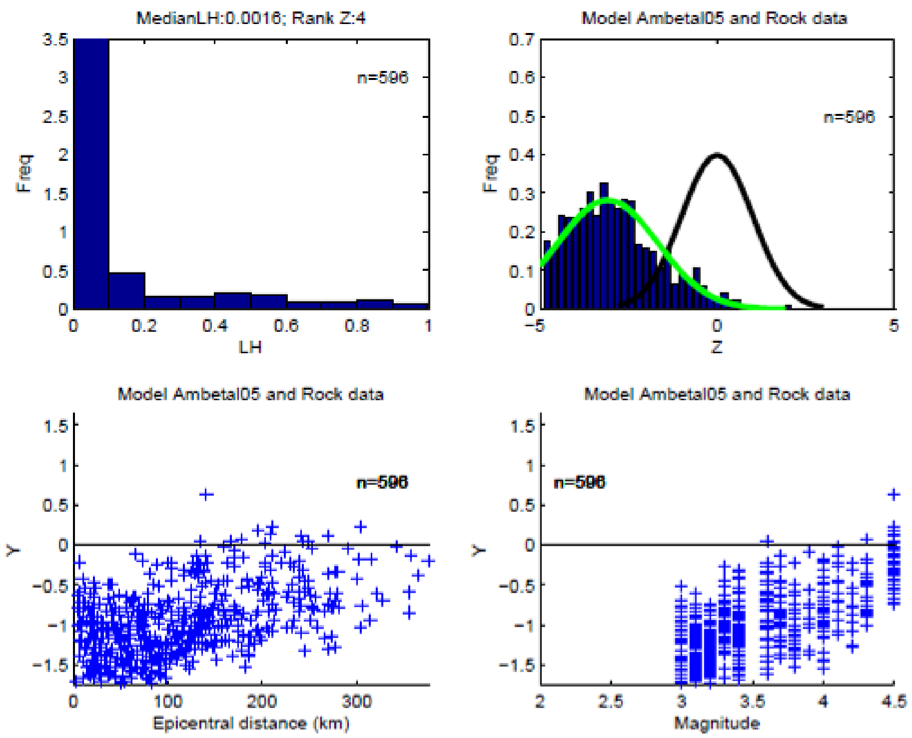



**Figure 38**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Ambetal05

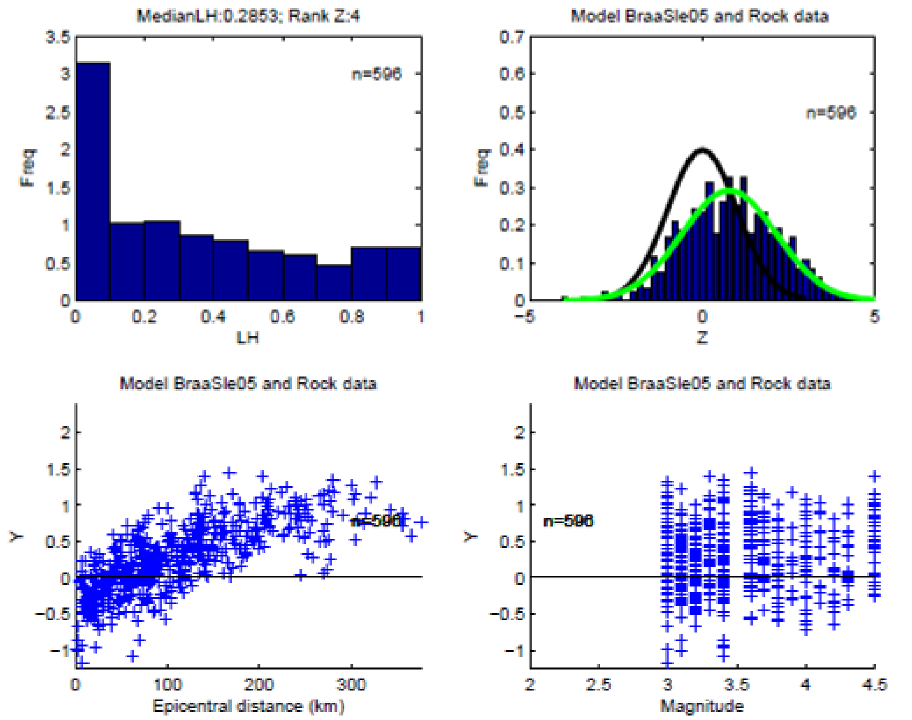



**Figure 39**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE BraaSle05.

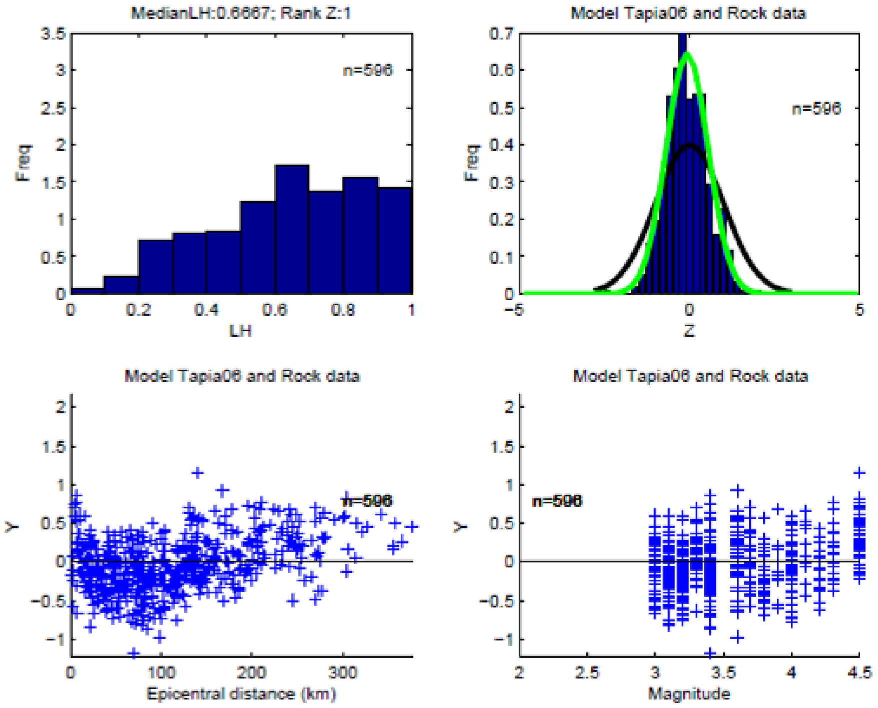



**Figure 40**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Tapia06.

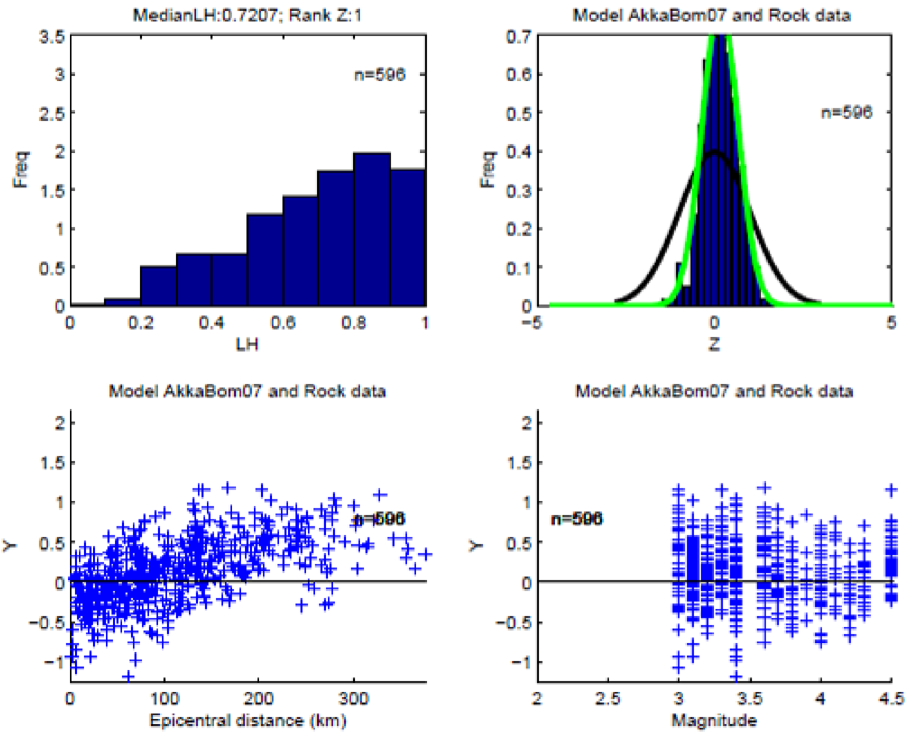



**Figure 41**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE AkkaBom07.

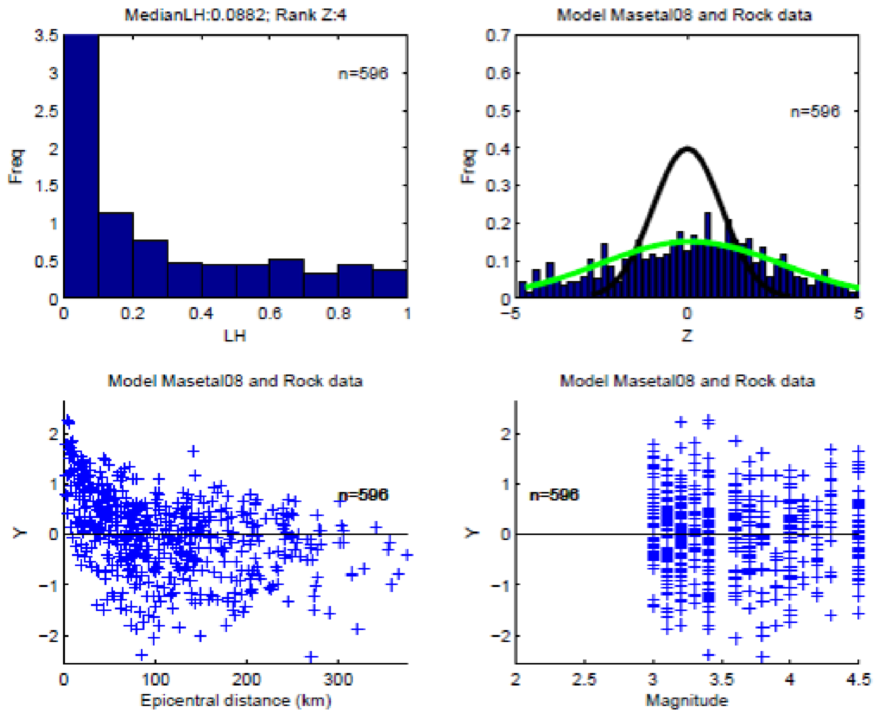



**Figure 42**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Masetal08.

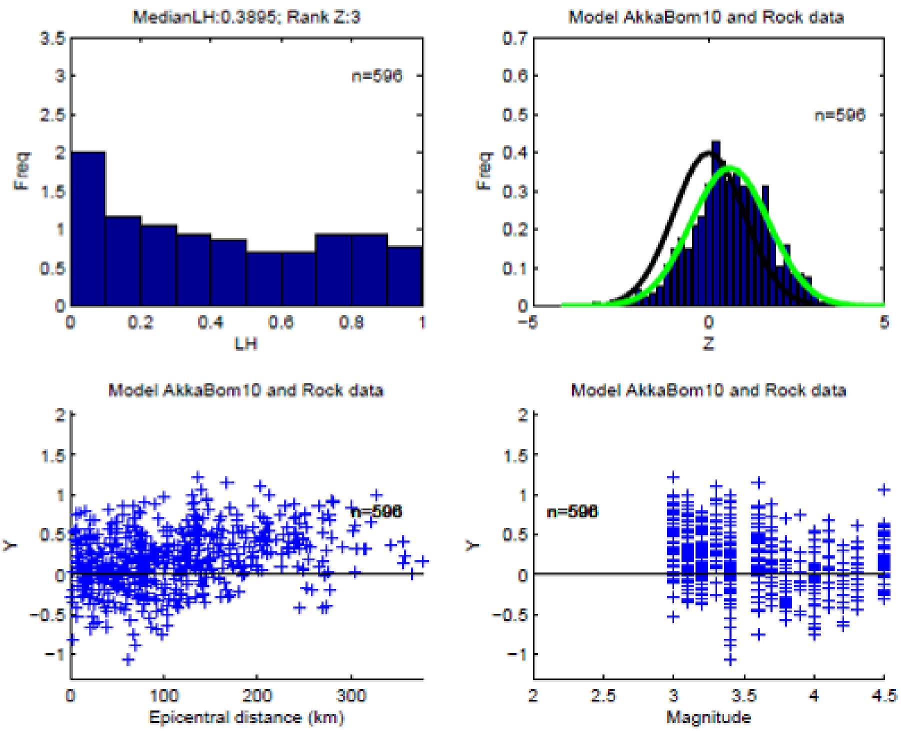



**Figure 43**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE AkkaBom10.

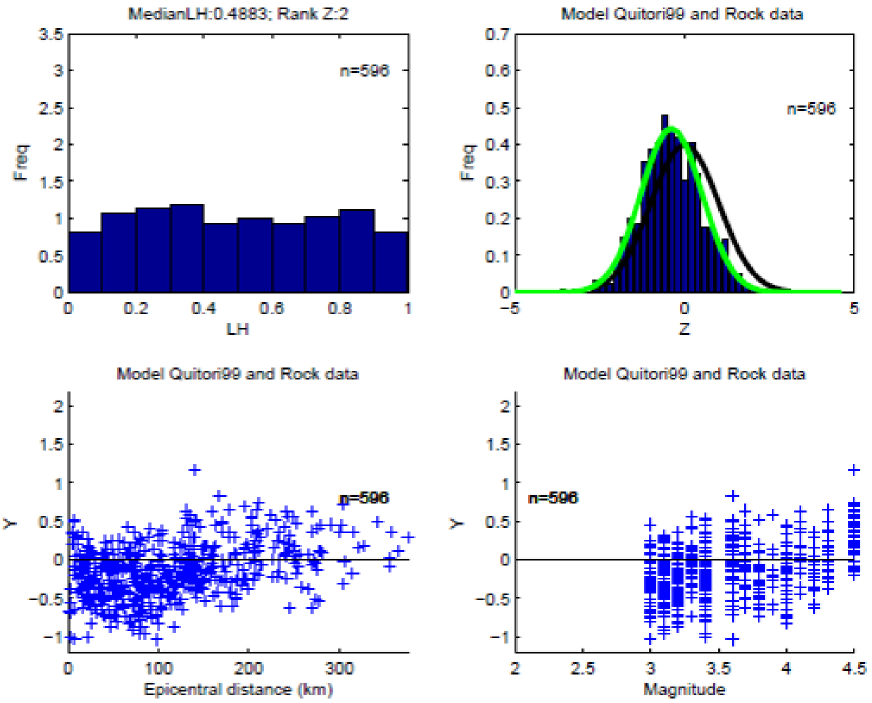



**Figure 44**: Summary of the results obtained for PSA 1.0s and the study Rock data with the GMPE Quitori99.

## B.5 PSA 2.0s

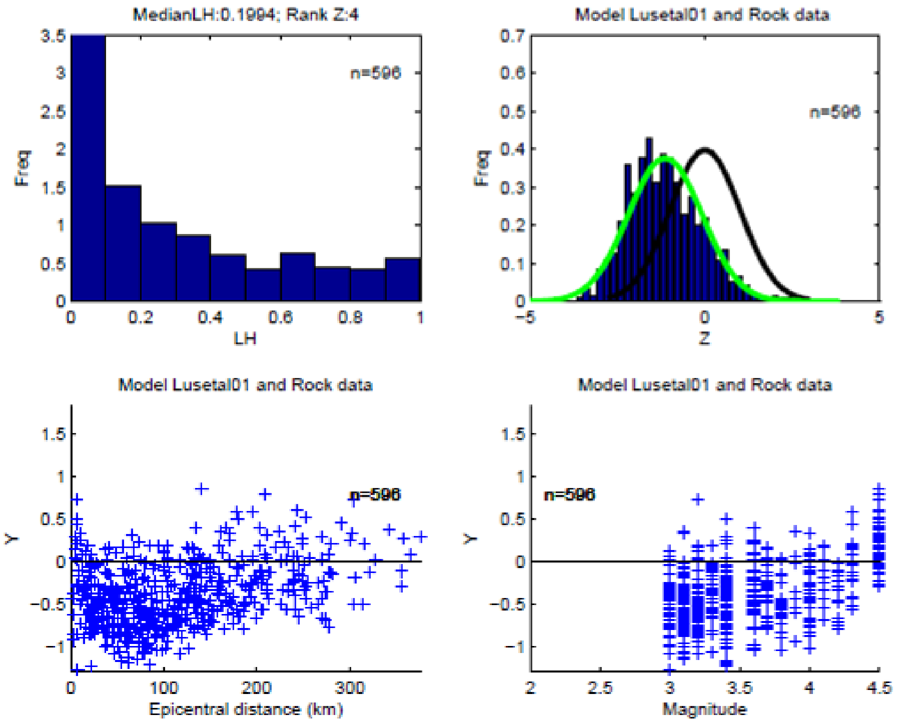



**Figure 45:** Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE Lusetal01.

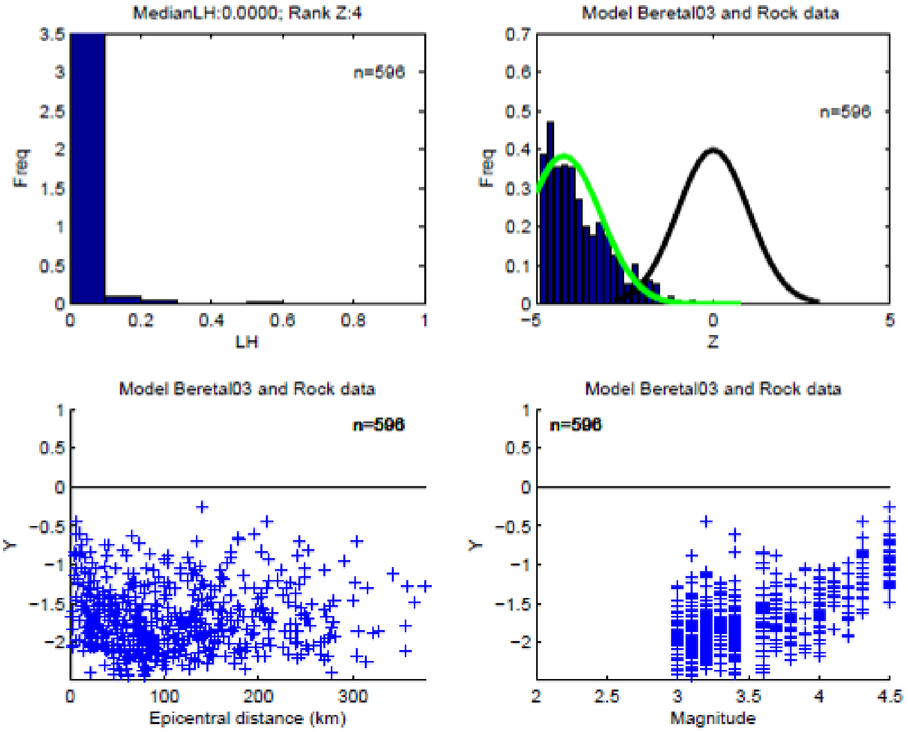



**Figure 46:** Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE Beretal03**.**

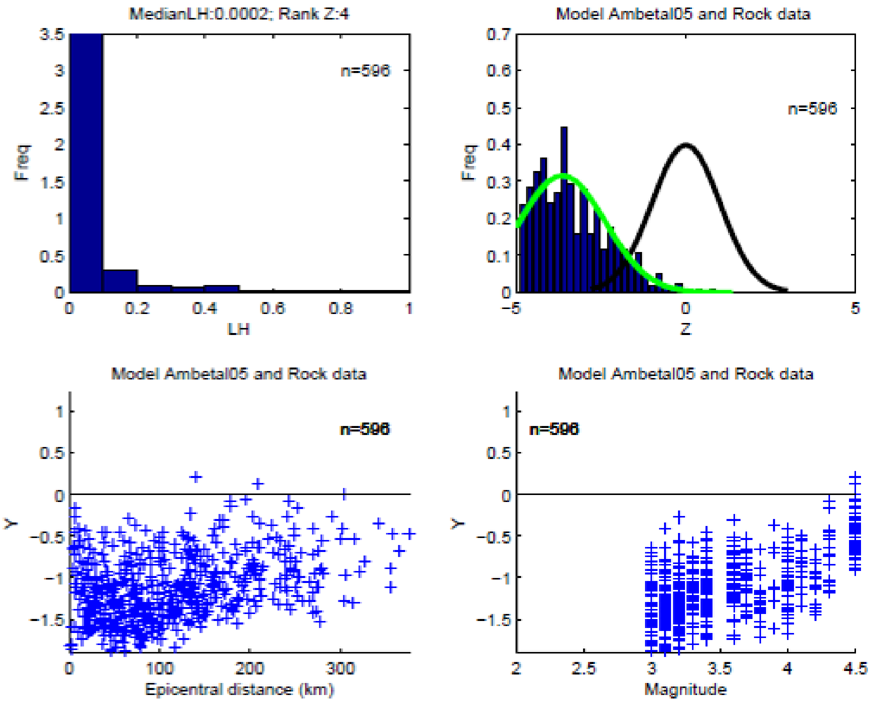



**Figure 47**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE Ambetal05.

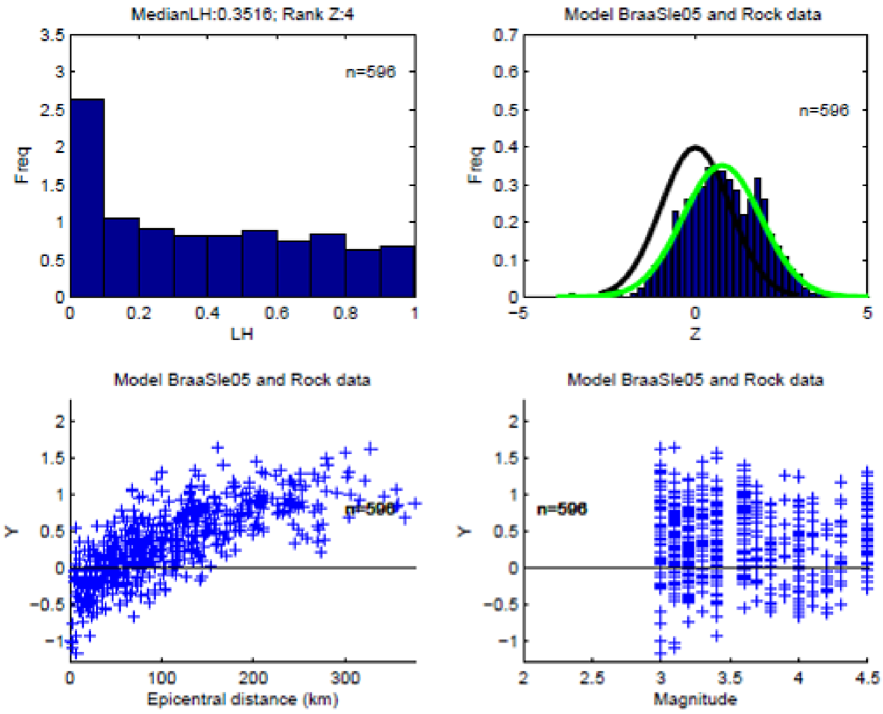



**Figure 48**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE BraaSle05.

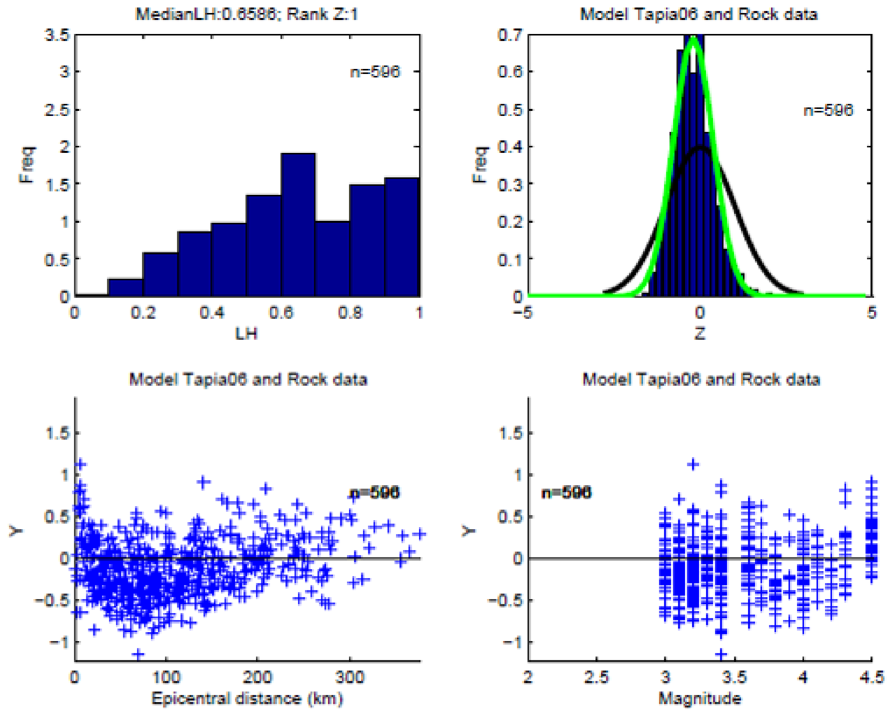



**Figure 49**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE Tapia06.

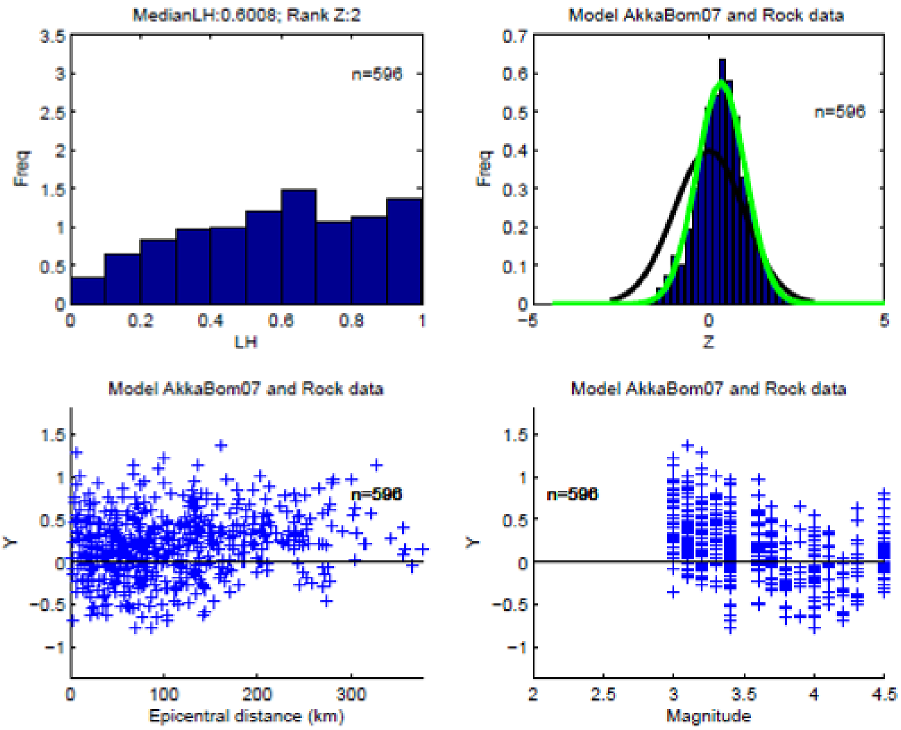



**Figure 50**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE AkkaBom07.

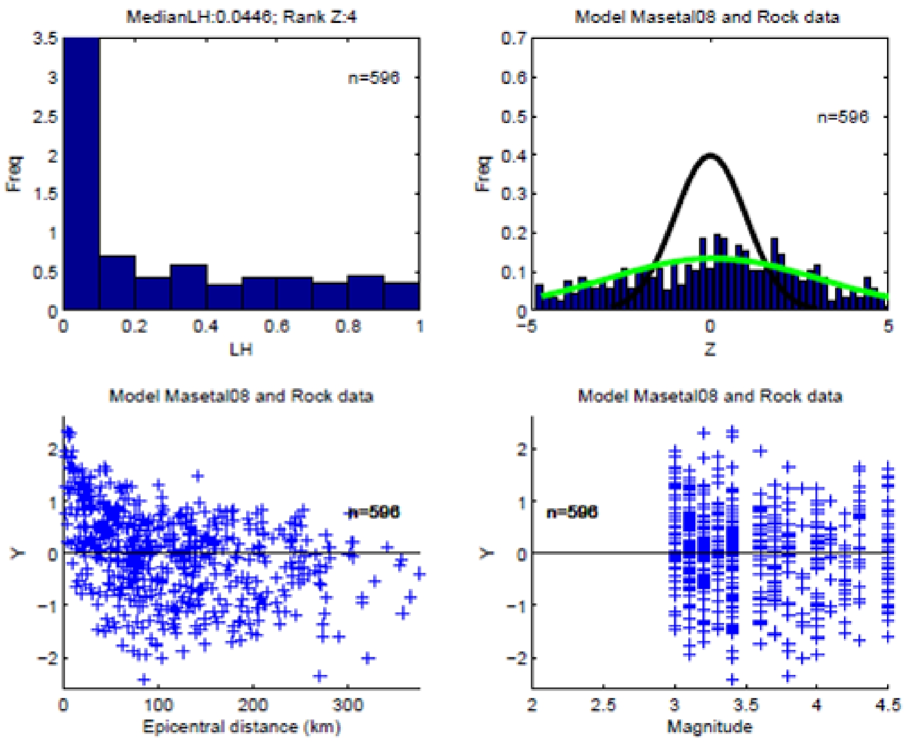



**Figure 51**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE Masetal08.

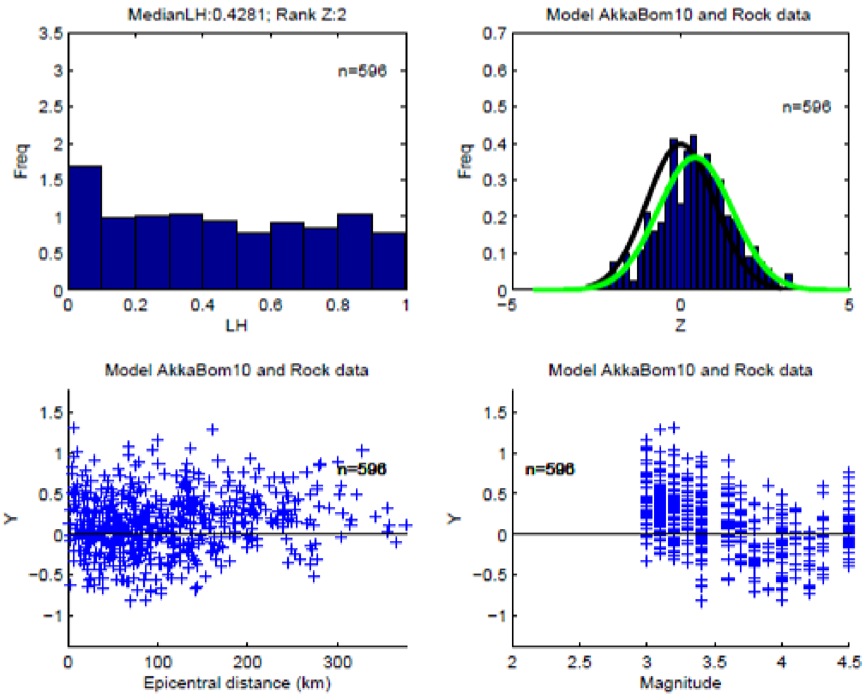



**Figure 52**: Summary of the results obtained for PSA 2.0s and the study Rock data with the GMPE AkkaBom10.

# C. Normalized logarithmic residuals by magnitude ranges for the acceptable models.

This appendix presents the normalized residuals for each rank of magnitude for the acceptable prediction equations (rank ≤ 3) and for all the magnitude ranges.

Tables present the assigned ranks and the statistical values computed for each prediction equation, and magnitude range. Figures present the normalized logarithmic residuals (Z) distribution in each magnitude range. They are organized in subsections relating each studied parameter.

## C.1 PGA

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Ambetal05 | 4.5-4.9 | 47 | 3 | -0.468 | -0.615 | 0.981 | 0.403 | 2 | -0.177 | -0.233 | 0.371 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 3 | -0.510 | -0.507 | 0.999 | 0.435 | 2 | -0.217 | -0.216 | 0.425 |
| Rock | Tapia06 | 3.5-3.9 | 114 | 1 | 0.047 | -0.117 | 0.870 | 0.548 | 2 | 0.020 | -0.050 | 0.370 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | 0.126 | 0.087 | 0.877 | 0.603 | 2 | 0.054 | 0.037 | 0.374 |
| Rock | Souria106 | 4.0-4.4 | 91 | 3 | 0.559 | 0.476 | 0.713 | 0.587 | 3 | 0.302 | 0.257 | 0.385 |
| Rock | Souria106 | 4.5-4.9 | 47 | 3 | 0.721 | 0.666 | 0.741 | 0.498 | 3 | 0.407 | 0.376 | 0.419 |
| Rock | Souria206 | 3.5-3.9 | 114 | 3 | 0.723 | 0.702 | 0.557 | 0.483 | 3 | 0.481 | 0.467 | 0.370 |
| Rock | Souria206 | 4.0-4.4 | 91 | 2 | 0.334 | 0.258 | 0.544 | 0.725 | 2 | 0.230 | 0.178 | 0.375 |
| Rock | Souria206 | 4.5-4.9 | 47 | 2 | 0.447 | 0.336 | 0.582 | 0.681 | 3 | 0.319 | 0.240 | 0.416 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.183 | -0.125 | 1.051 | 0.455 | 2 | -0.077 | -0.053 | 0.444 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | -0.070 | -0.213 | 0.899 | 0.478 | 2 | -0.028 | -0.084 | 0.356 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 3 | -0.398 | -0.548 | 0.976 | 0.444 | 2 | -0.148 | -0.203 | 0.361 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | -0.018 | -0.231 | 1.072 | 0.420 | 2 | -0.006 | -0.080 | 0.369 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 3 | -0.138 | -0.378 | 1.293 | 0.308 | 2 | -0.038 | -0.106 | 0.361 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 3 | -0.560 | -0.718 | 1.295 | 0.303 | 2 | -0.156 | -0.200 | 0.362 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 3 | -0.091 | -0.423 | 1.318 | 0.281 | 2 | -0.025 | -0.118 | 0.368 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 2 | 0.339 | 0.361 | 1.145 | 0.435 | 2 | 0.124 | 0.132 | 0.420 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 3 | 0.743 | 0.628 | 0.988 | 0.454 | 3 | 0.273 | 0.230 | 0.362 |

**Table 13**: Rank, likelihood parameter median (LHo), and residual average (E(Z)), median (Zo) and standard deviation (stdres) for PGA, rock data, prediction equation and magnitude range.

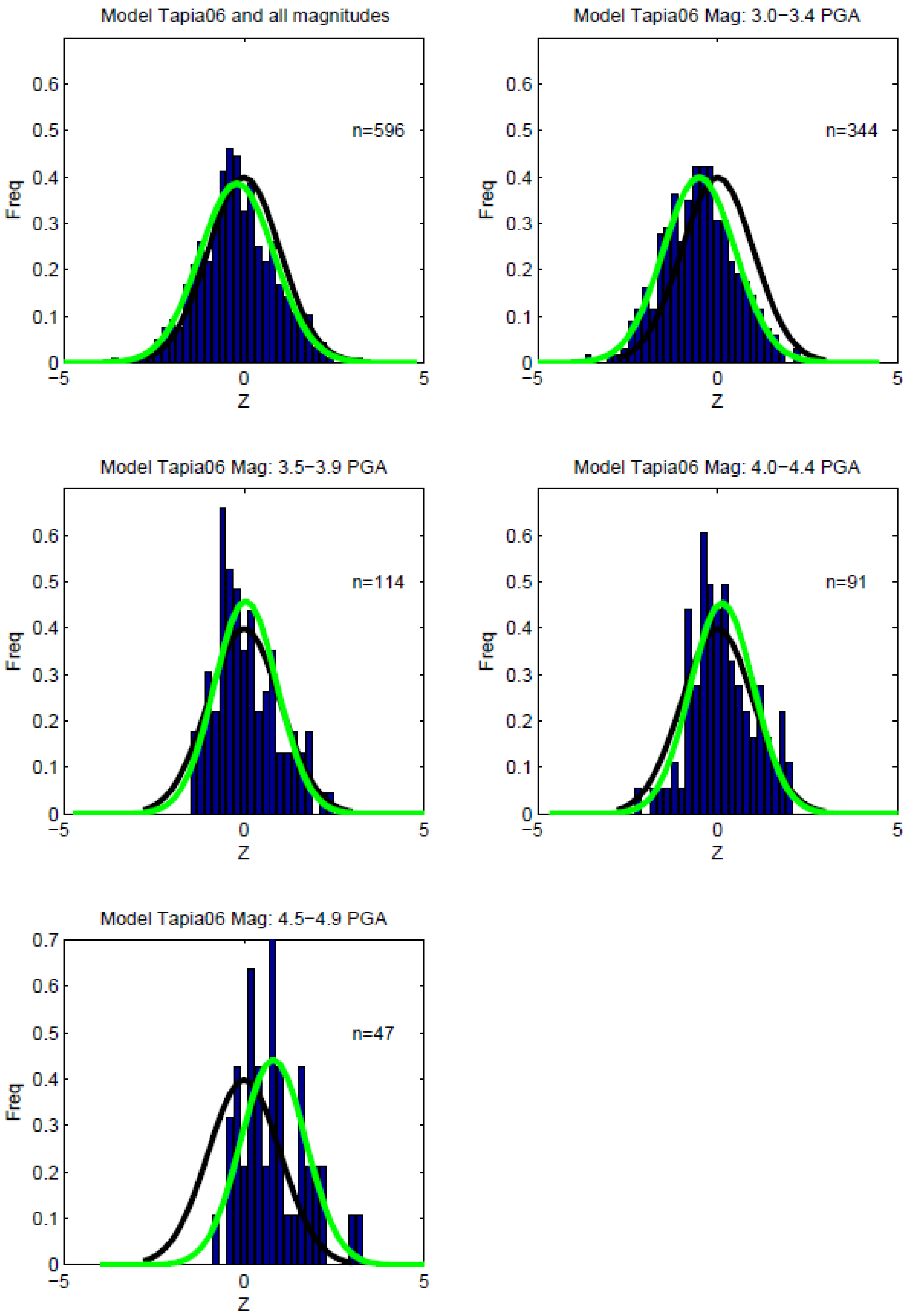



**Figure 53**: Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE Tapia06.

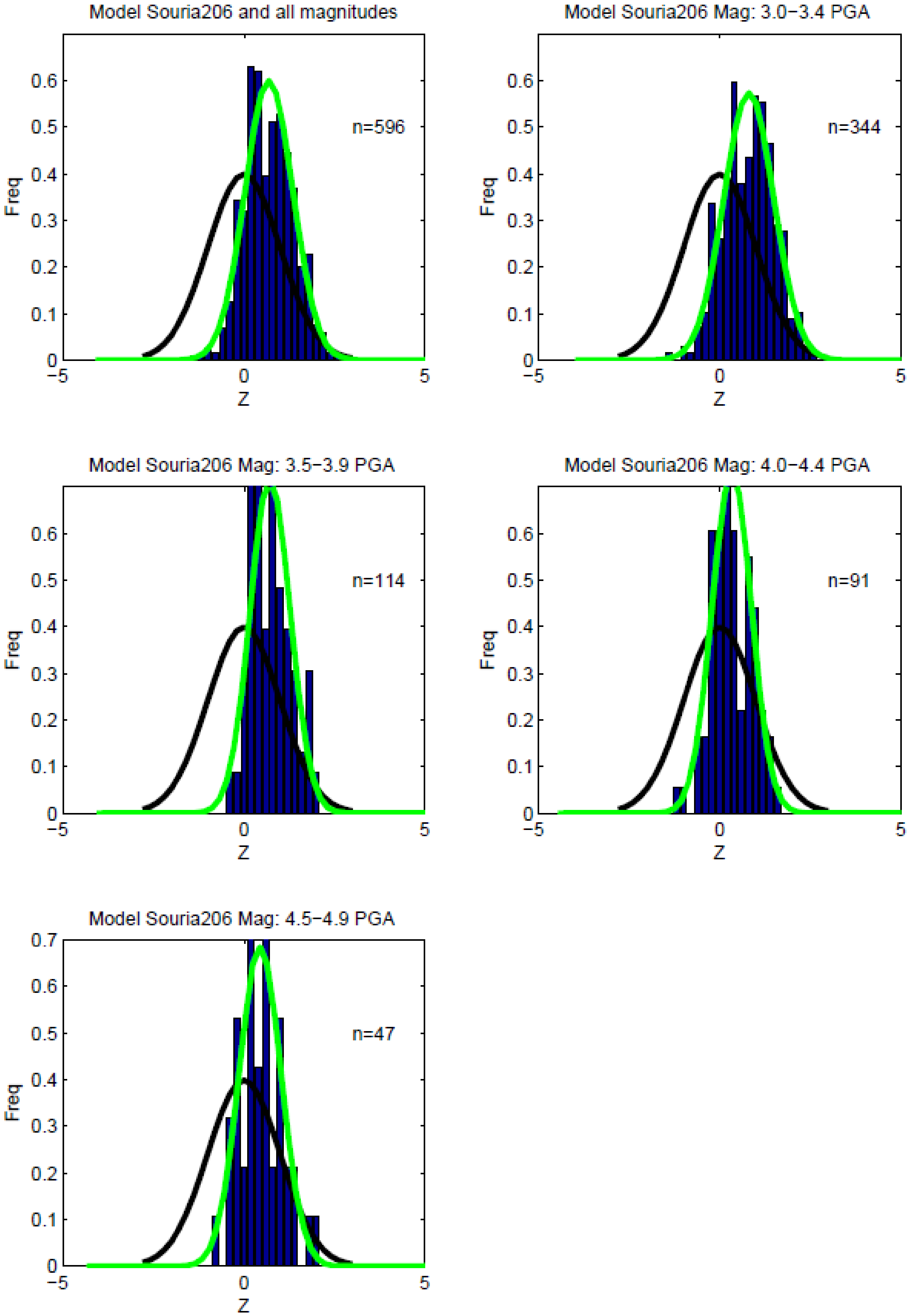



**Figure 54**: Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE Souria206.

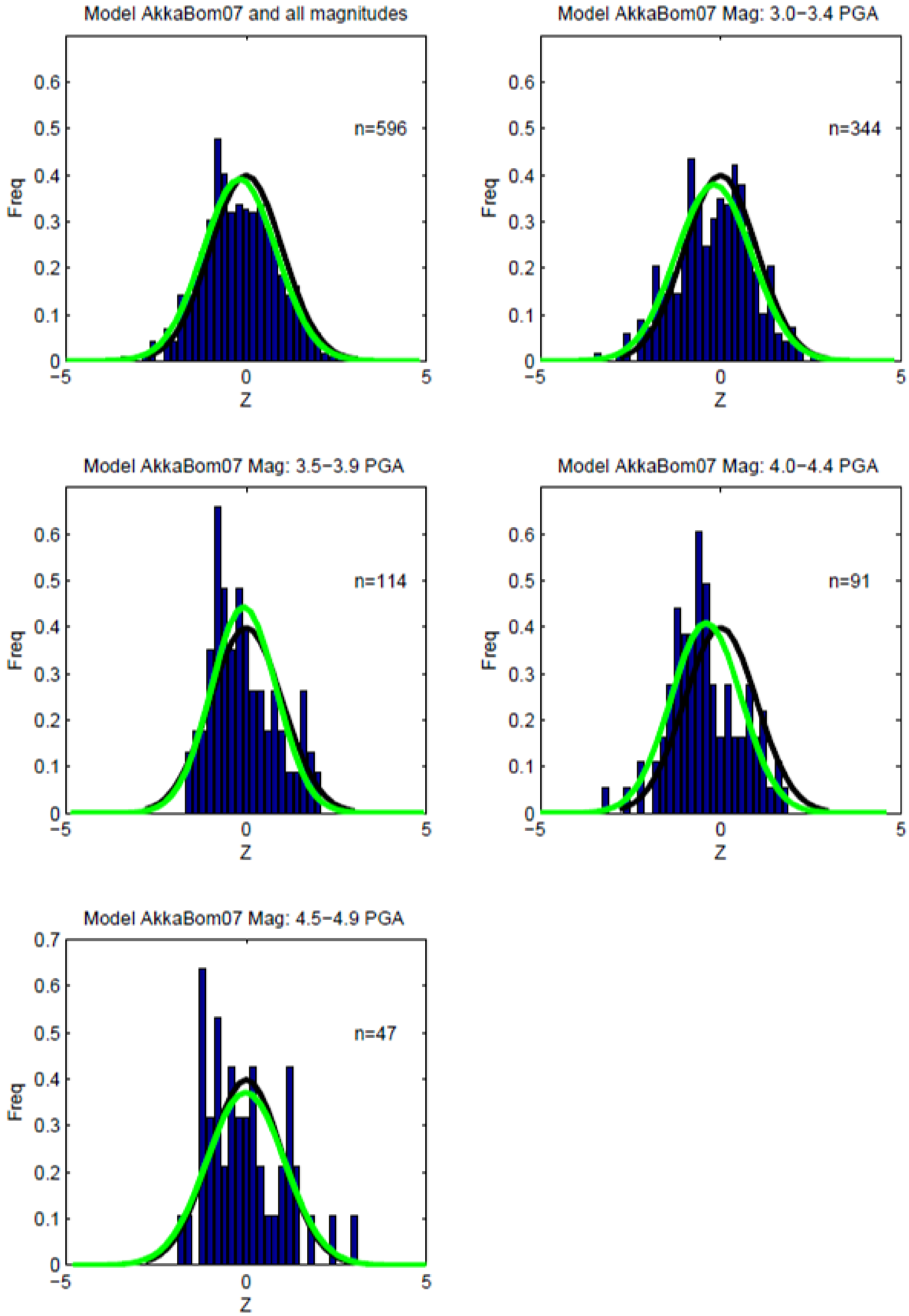



**Figure 55**: Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE AkkaBom07.

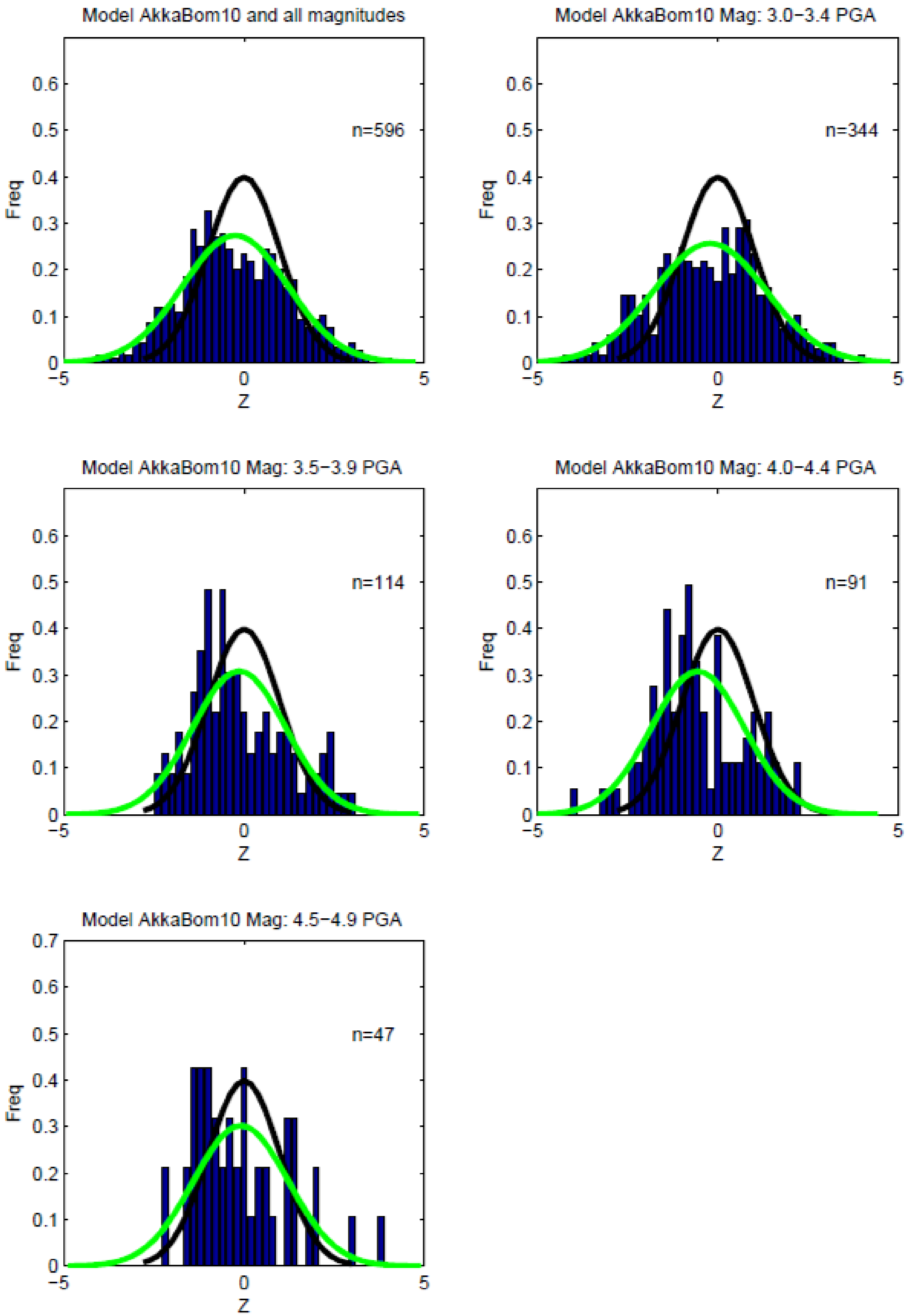



**Figure 56**: Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE AkkaBom10.

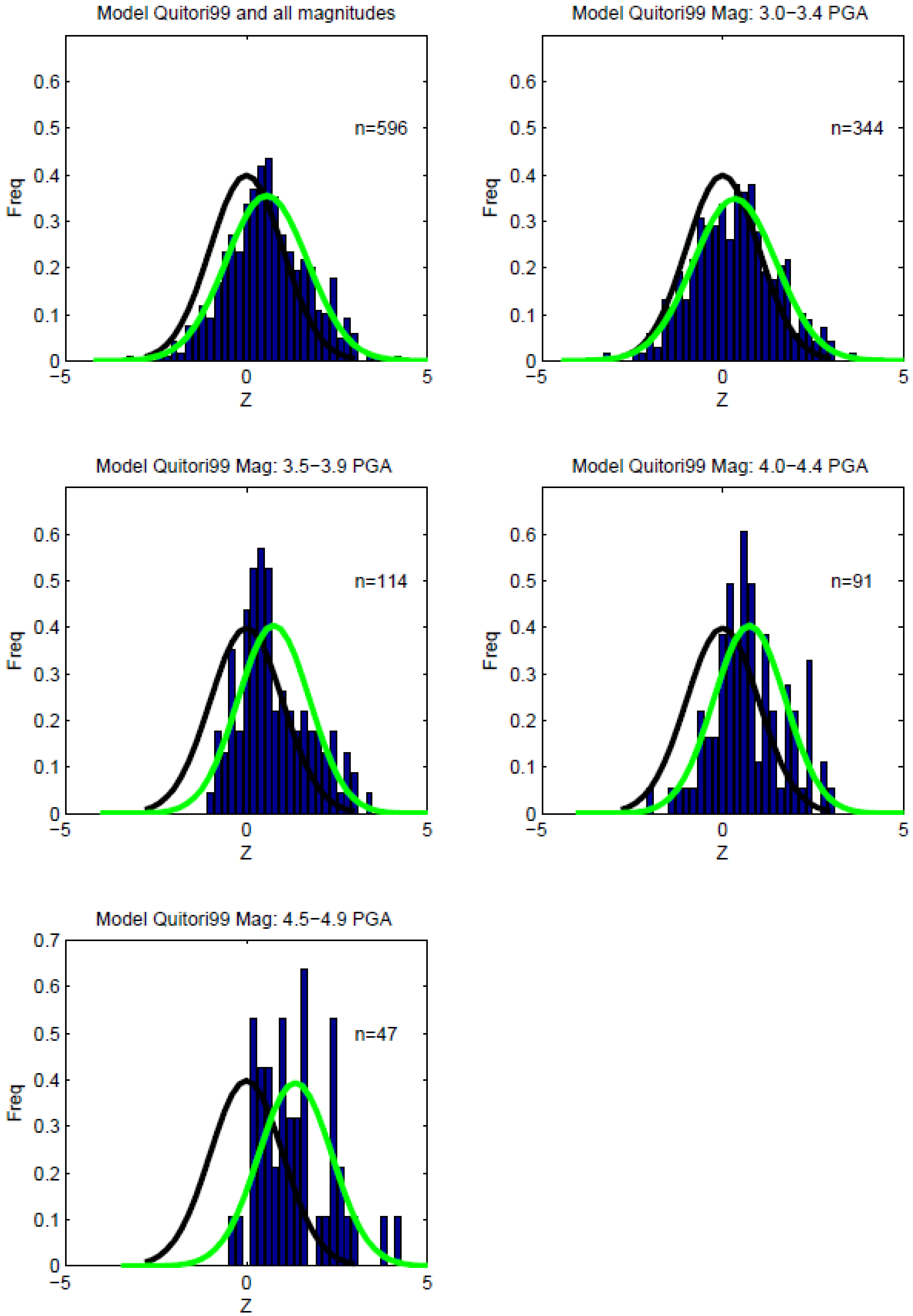



**Figure 57:** Normalized logarithmic residuals by magnitude ranges for PGA and the study Rock data with the GMPE Quitori99.

## C.2 PGV

| | | | | Z (Norm log) | | | | Y(Log) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Type** | **GMPE** | **Magnitude range** | **Nº** | **Z Rank** | **E(Z)** | **Zo** | **stdZ** | **LHo** | **Y Rank** | **E(Y)** | **Yo** | **stdY** |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.046 | -0.057 | 0.731 | 0.641 | 2 | -0.027 | -0.034 | 0.435 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | 0.052 | 0.004 | 0.708 | 0.618 | 2 | 0.028 | 0.002 | 0.382 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 2 | -0.386 | -0.467 | 0.733 | 0.473 | 2 | -0.187 | -0.226 | 0.355 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | 0.111 | -0.005 | 0.770 | 0.656 | 1 | 0.048 | -0.002 | 0.331 |
| Rock | AkkaBom10 | 3.0-3.4 | 344 | 3 | -0.376 | -0.363 | 1.369 | 0.334 | 2 | -0.105 | -0.101 | 0.381 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 3 | -0.243 | -0.461 | 1.319 | 0.277 | 2 | -0.068 | -0.128 | 0.367 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 1 | -0.031 | -0.210 | 1.090 | 0.479 | 1 | -0.009 | -0.058 | 0.303 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 1 | -0.035 | -0.045 | 1.090 | 0.510 | 2 | -0.011 | -0.015 | 0.356 |
| Rock | Quitori99 | 3.5-3.9 | 114 | 2 | 0.438 | 0.237 | 1.135 | 0.400 | 2 | 0.143 | 0.077 | 0.371 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 2 | 0.316 | 0.153 | 1.004 | 0.520 | 2 | 0.103 | 0.050 | 0.328 |

**Table 14**: Rank, likelihood parameter median (LHo), and residual average (E(Z)), median (Zo) and standard deviation (stdres) for PGV, rock data, prediction equation and magnitude range.

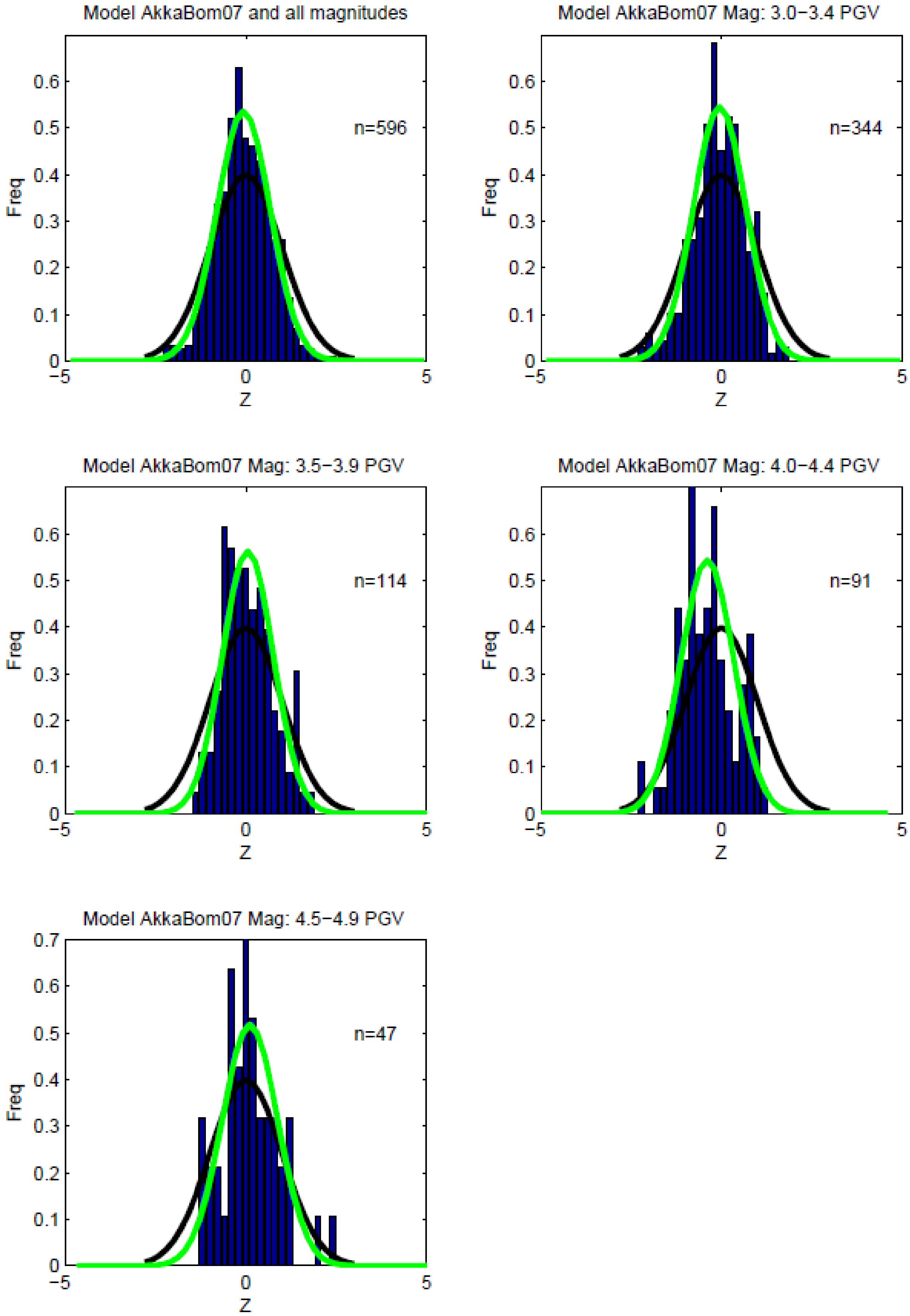



**Figure 58**: Normalized logarithmic residuals by magnitude ranges for PGV and the study Rock data with the GMPE AkkaBom07.

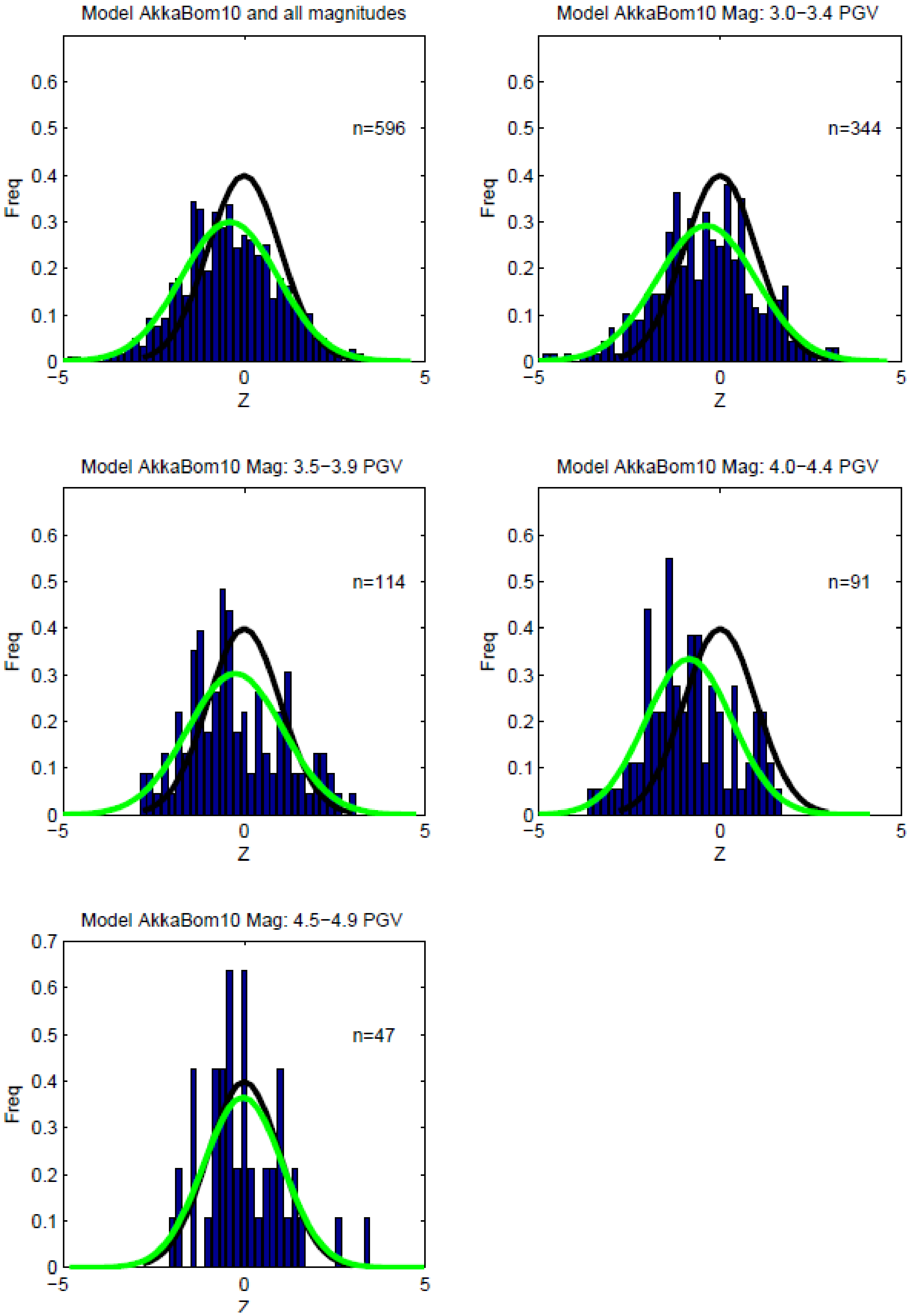



**Figure 59**: Normalized logarithmic residuals by magnitude ranges for PGV and the study Rock data with the GMPE AkkaBom10.

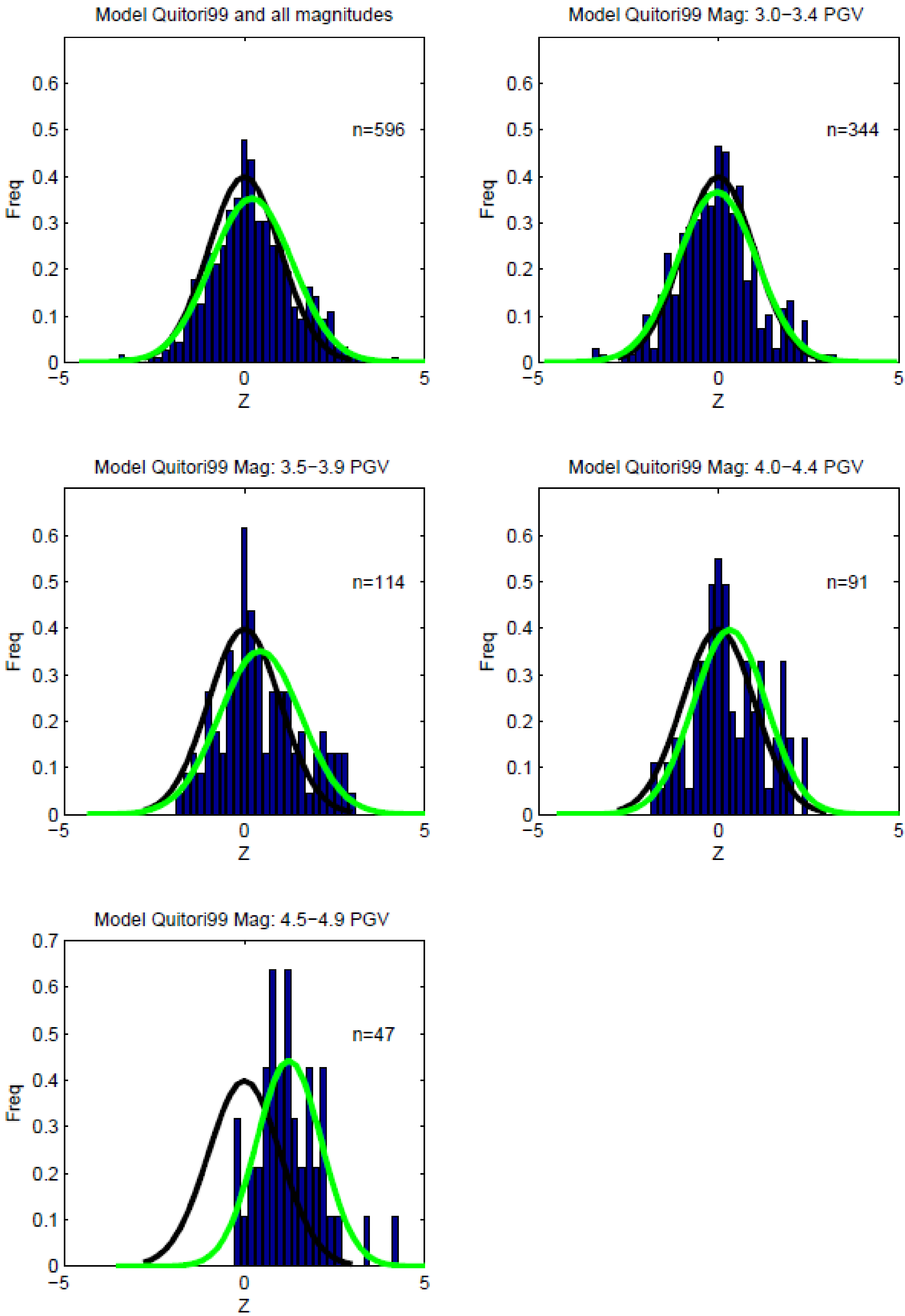



**Figure 60**: Normalized logarithmic residuals by magnitude ranges for PGV and the study Rock data with the GMPEQuitori99.

## C.3 PSA 0.2s

| | | | | Z (Norm log) | | | | Y(Log) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | GMPE | Magnitude range | N° | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
| Rock | Lusetal01 | 4.5-4.9 | 47 | 2 | 0.283 | 0.110 | 1.118 | 0.540 | 2 | 0.099 | 0.038 | 0.390 |
| Rock | Ambetal05 | 4.5-4.9 | 47 | 3 | -0.543 | -0.724 | 0.997 | 0.413 | 3 | -0.233 | -0.310 | 0.426 |
| Rock | BraaSle05 | 4.0-4.4 | 91 | 3 | 0.580 | 0.230 | 1.460 | 0.260 | 3 | 0.209 | 0.083 | 0.527 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 3 | -0.750 | -0.750 | 0.890 | 0.388 | 3 | -0.326 | -0.326 | 0.387 |
| Rock | Tapia06 | 3.5-3.9 | 114 | 1 | -0.030 | -0.096 | 0.879 | 0.530 | 2 | -0.013 | -0.042 | 0.382 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 2 | -0.240 | -0.259 | 0.917 | 0.479 | 2 | -0.104 | -0.113 | 0.399 |
| Rock | Tapia06 | 4.5-4.9 | 47 | 3 | 0.627 | 0.598 | 0.970 | 0.455 | 3 | 0.273 | 0.260 | 0.422 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 3 | -0.373 | -0.698 | 1.204 | 0.376 | 2 | -0.127 | -0.237 | 0.409 |

**Table 15:** Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for PSA 0.2s, rock data, prediction equation and magnitude range.

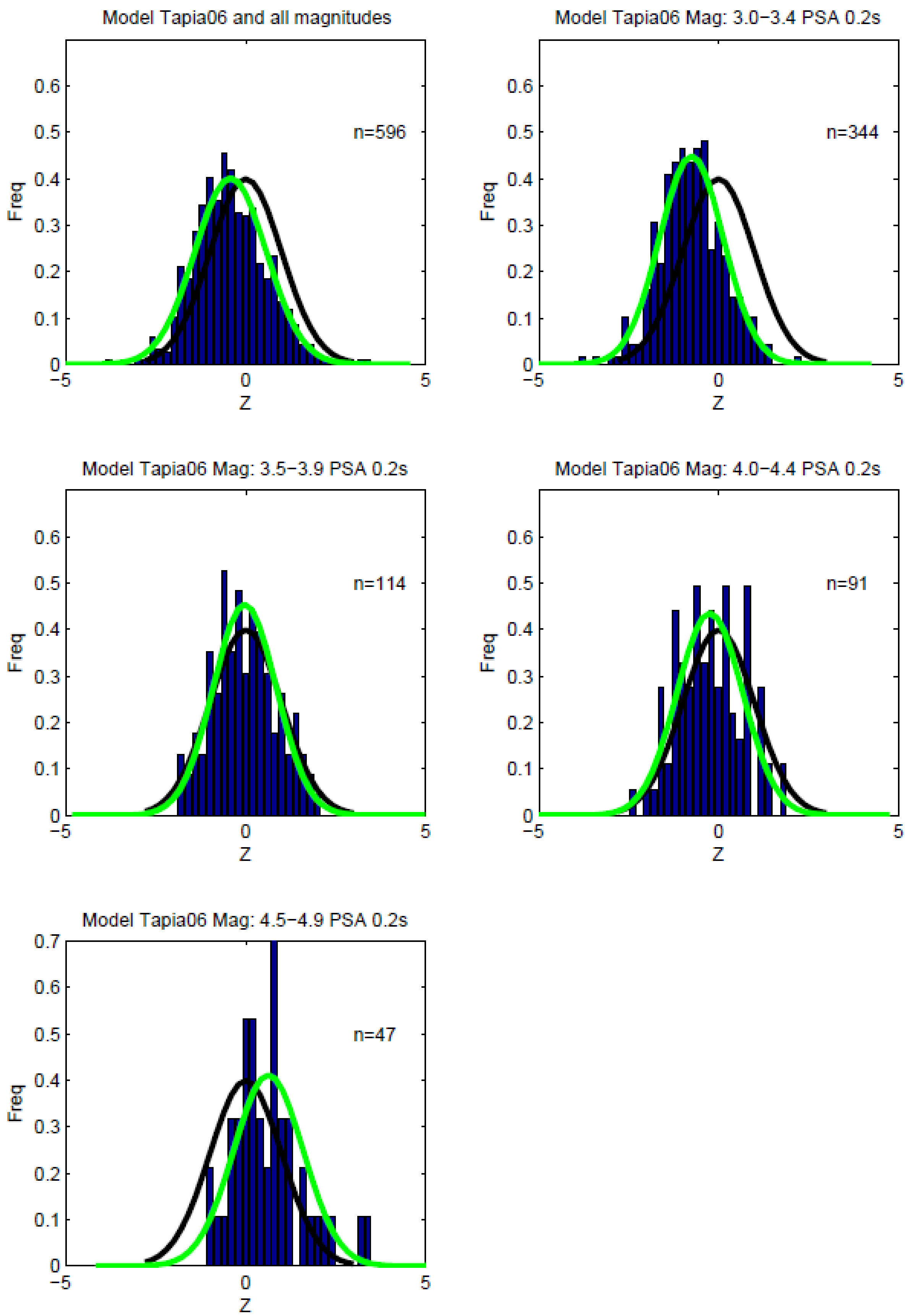



**Figure 61**: Normalized logarithmic residuals by magnitude ranges for PSA 0.2s and the study Rock data with the GMPE Tapia06

## C.4 PSA 1.0s

| | | | | Z (Norm log) | | | | Y(Log) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
| Rock | Lusetal01 | 4.0-4.4 | 91 | 3 | -0.745 | -0.714 | 0.891 | 0.411 | 3 | -0.279 | -0.268 | 0.334 |
| Rock | Lusetal01 | 4.5-4.9 | 47 | 2 | 0.474 | 0.469 | 0.709 | 0.563 | 2 | 0.178 | 0.176 | 0.266 |
| Rock | Ambetal05 | 4.5-4.9 | 47 | 3 | -0.695 | -0.713 | 0.893 | 0.458 | 2 | -0.228 | -0.234 | 0.293 |
| Rock | BraaSle05 | 4.0-4.4 | 91 | 3 | 0.517 | 0.296 | 1.341 | 0.309 | 2 | 0.179 | 0.103 | 0.465 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 1 | -0.195 | -0.228 | 0.572 | 0.671 | 2 | -0.112 | -0.131 | 0.330 |
| Rock | Tapia06 | 3.5-3.9 | 114 | 1 | -0.002 | -0.021 | 0.636 | 0.661 | 2 | -0.001 | -0.012 | 0.366 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | -0.017 | -0.021 | 0.600 | 0.688 | 1 | -0.010 | -0.012 | 0.346 |
| Rock | Tapia06 | 4.5-4.9 | 47 | 3 | 0.578 | 0.526 | 0.506 | 0.599 | 3 | 0.333 | 0.303 | 0.292 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | 0.165 | 0.179 | 0.467 | 0.740 | 2 | 0.145 | 0.158 | 0.411 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | 0.163 | 0.136 | 0.511 | 0.712 | 2 | 0.129 | 0.107 | 0.404 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 1 | -0.022 | -0.055 | 0.538 | 0.707 | 2 | -0.015 | -0.039 | 0.377 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 2 | 0.457 | 0.457 | 0.517 | 0.648 | 3 | 0.280 | 0.280 | 0.317 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 2 | 0.399 | 0.390 | 1.125 | 0.373 | 2 | 0.130 | 0.127 | 0.366 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 1 | -0.123 | -0.133 | 1.022 | 0.457 | 1 | -0.040 | -0.043 | 0.333 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 3 | 0.600 | 0.575 | 0.846 | 0.480 | 2 | 0.195 | 0.187 | 0.275 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 3 | -0.648 | -0.677 | 0.798 | 0.458 | 3 | -0.259 | -0.271 | 0.319 |
| Rock | Quitori99 | 3.5-3.9 | 114 | 2 | -0.267 | -0.258 | 0.862 | 0.525 | 2 | -0.107 | -0.103 | 0.345 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 1 | -0.169 | -0.229 | 0.832 | 0.561 | 1 | -0.068 | -0.092 | 0.333 |

**Table 16**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for PSA 1.0 s, rock data, prediction equation and magnitude range.

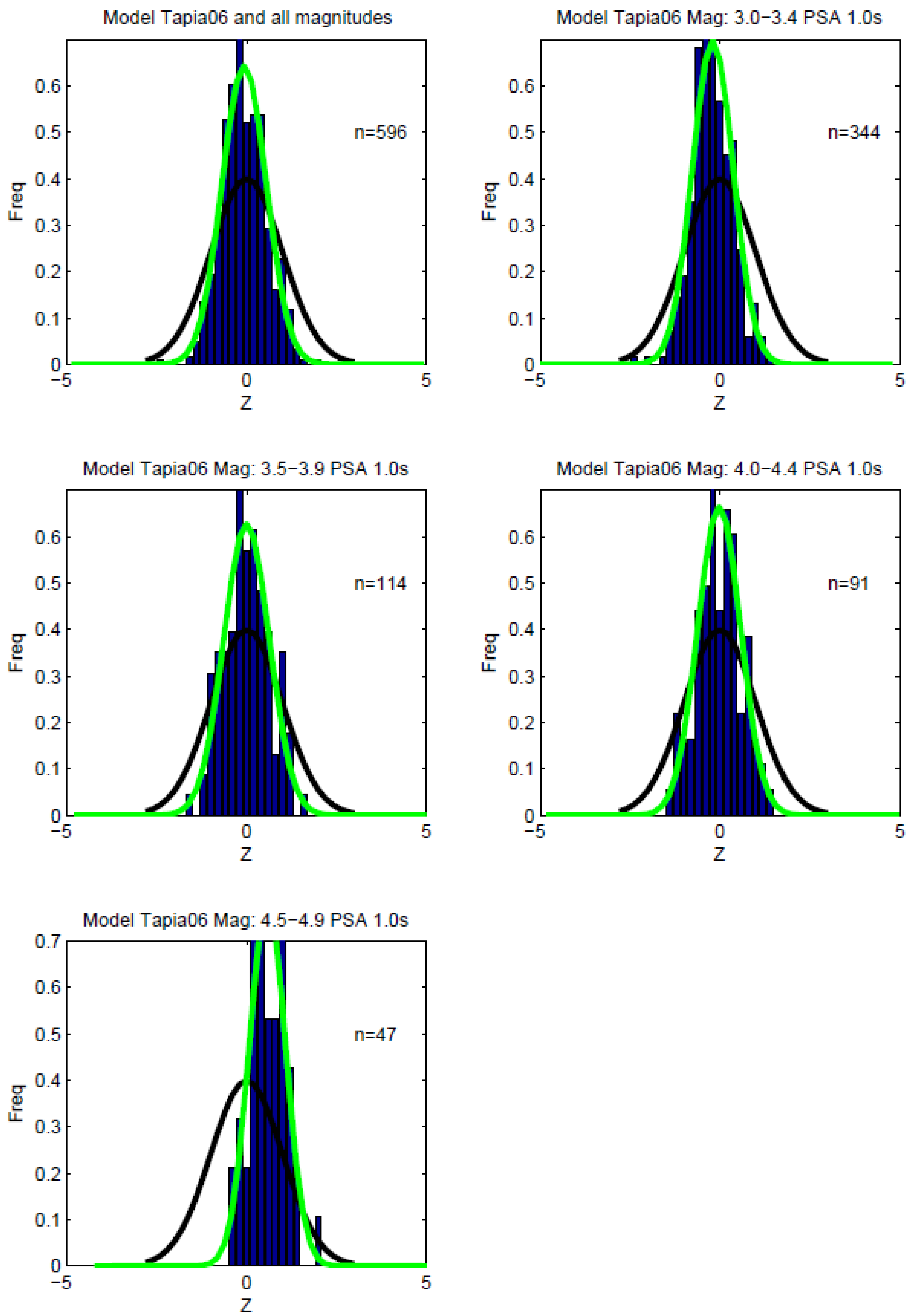



**Figure 62**: Normalized logarithmic residuals by magnitude ranges for PSA 1.0s and the study Rock data with the GMPE Tapia06.

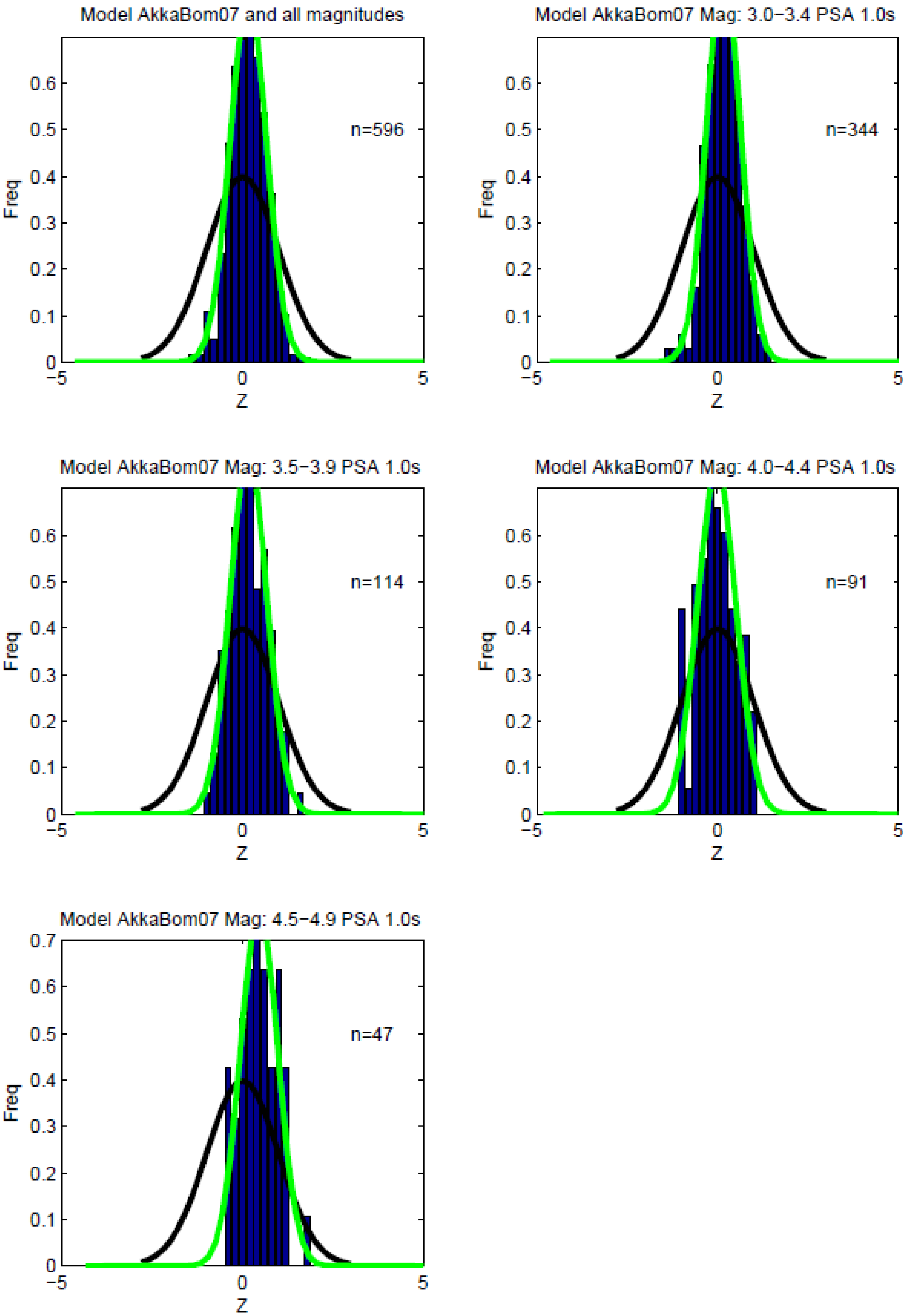



**Figure 63**: Normalized logarithmic residuals by magnitude ranges for PSA 1.0s and the study Rock data with the GMPE AkkaBom07.

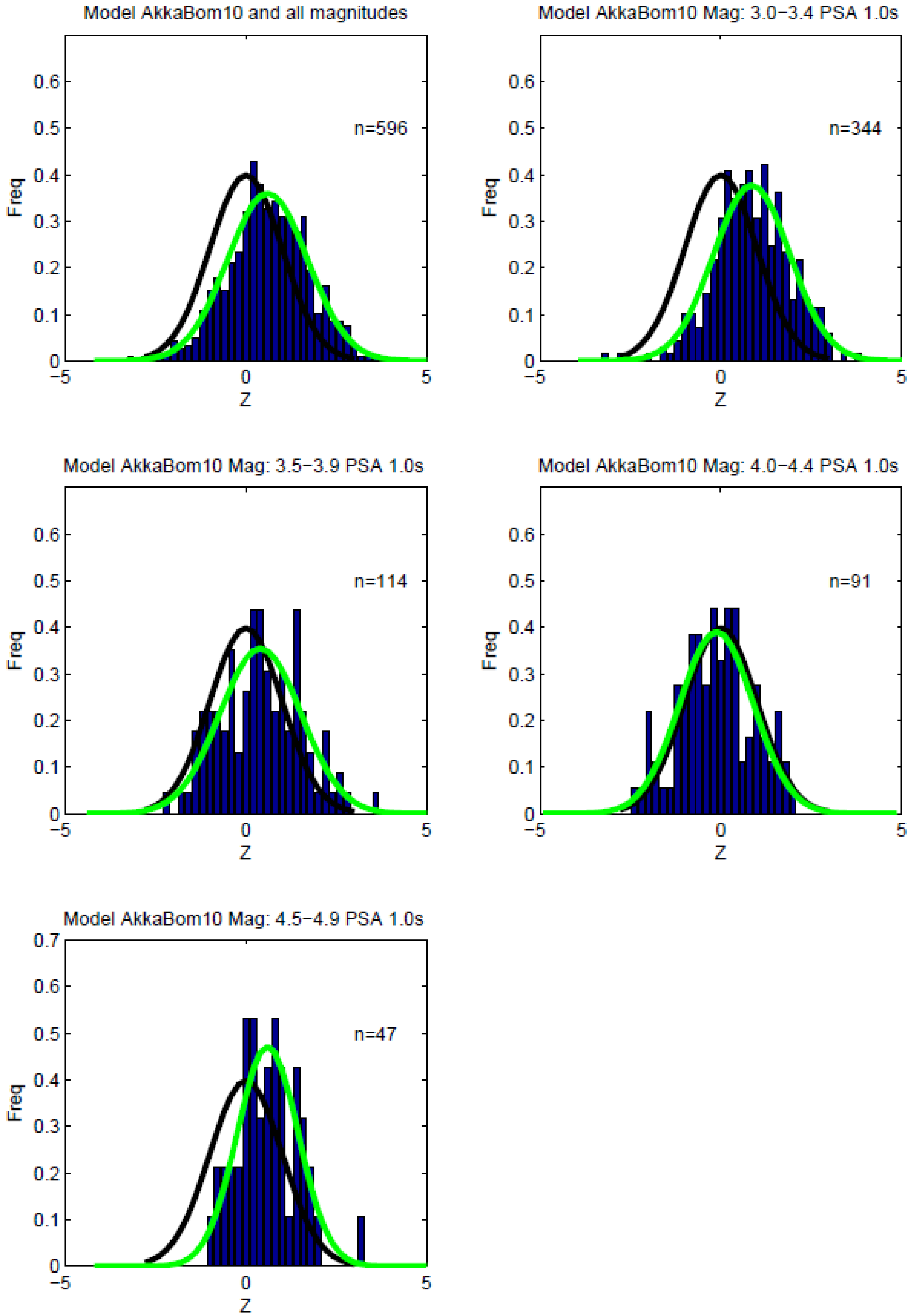



**Figure 64**: Normalized logarithmic residuals by magnitude ranges for PSA 1.0s and the study Rock data with the GMPE AkkaBom10.

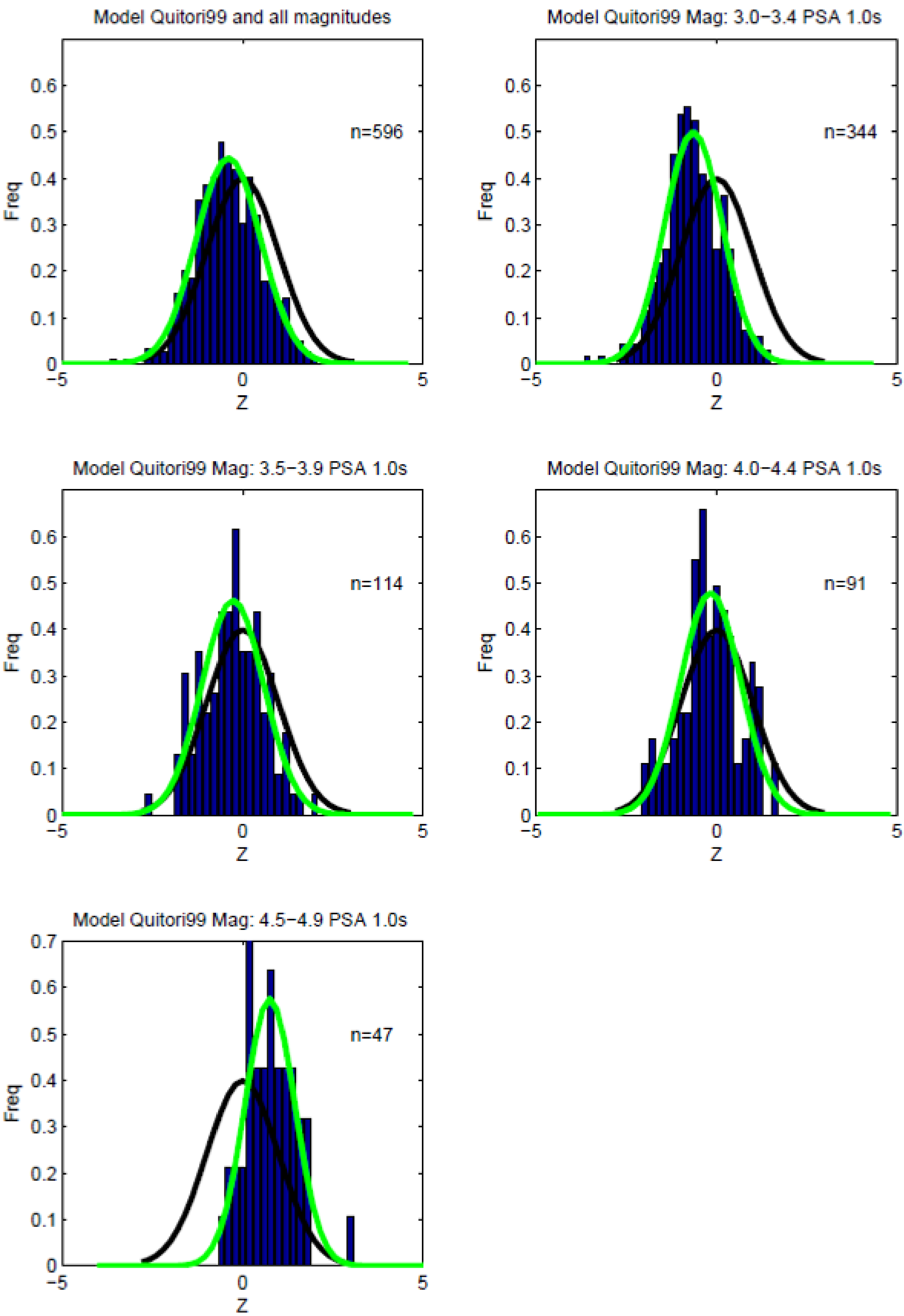



**Figure 65**: Normalized logarithmic residuals by magnitude ranges for PSA 1.0s and the study Rock data with the GMPE Quitori99.

## C.5 PSA 2.0s

| | | | | Z (Norm log) | | | | Y(Log) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
| Rock | Lusetal01 | 4.5-4.9 | 47 | 3 | 0.549 | 0.470 | 0.753 | 0.515 | 2 | 0.195 | 0.167 | 0.267 |
| Rock | BraaSle05 | 4.0-4.4 | 91 | 2 | 0.429 | 0.342 | 1.073 | 0.349 | 2 | 0.189 | 0.150 | 0.472 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 2 | -0.286 | -0.346 | 0.550 | 0.657 | 2 | -0.165 | -0.200 | 0.317 |
| Rock | Tapia06 | 3.5-3.9 | 114 | 2 | -0.214 | -0.254 | 0.577 | 0.660 | 2 | -0.123 | -0.147 | 0.333 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | -0.191 | -0.207 | 0.549 | 0.662 | 2 | -0.110 | -0.120 | 0.317 |
| Rock | Tapia06 | 4.5-4.9 | 47 | 2 | 0.438 | 0.420 | 0.447 | 0.675 | 3 | 0.253 | 0.242 | 0.258 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 3 | 0.571 | 0.549 | 0.607 | 0.571 | 3 | 0.319 | 0.307 | 0.339 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | 0.152 | 0.113 | 0.654 | 0.625 | 1 | 0.079 | 0.058 | 0.339 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 2 | -0.240 | -0.257 | 0.653 | 0.628 | 2 | -0.114 | -0.122 | 0.311 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 2 | 0.302 | 0.205 | 0.605 | 0.668 | 2 | 0.131 | 0.089 | 0.263 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 1 | 0.079 | 0.116 | 1.028 | 0.418 | 1 | 0.026 | 0.038 | 0.337 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 2 | -0.472 | -0.486 | 0.938 | 0.459 | 2 | -0.155 | -0.160 | 0.308 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 2 | 0.288 | 0.193 | 0.792 | 0.636 | 1 | 0.095 | 0.064 | 0.260 |

**Table 17**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for PSA 2.0 s, rock data, prediction equation and magnitude range.

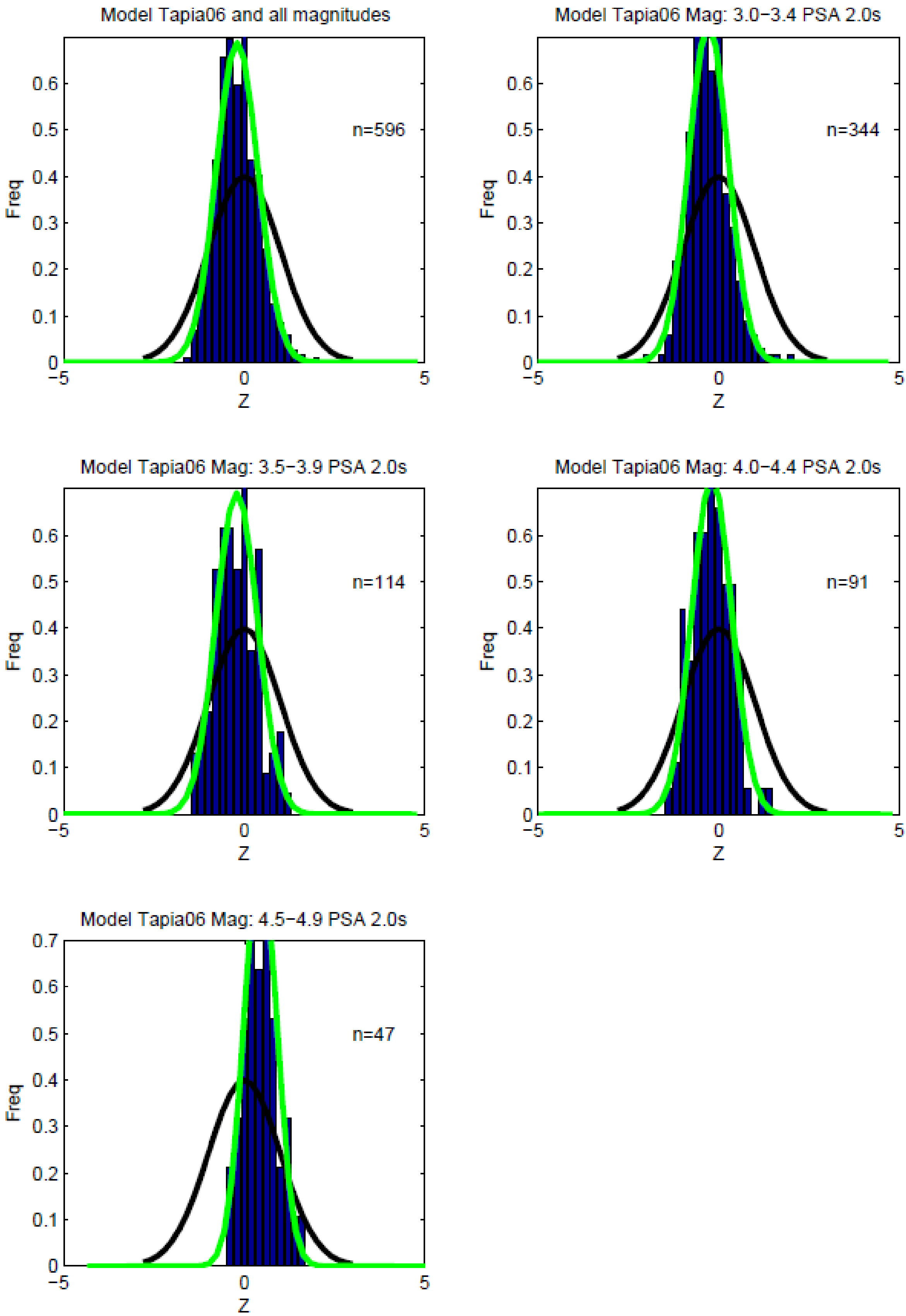



**Figure 66:** Normalized logarithmic residuals by magnitude ranges for PSA 2.0s and the study Rock data with the GMPE Tapia06.

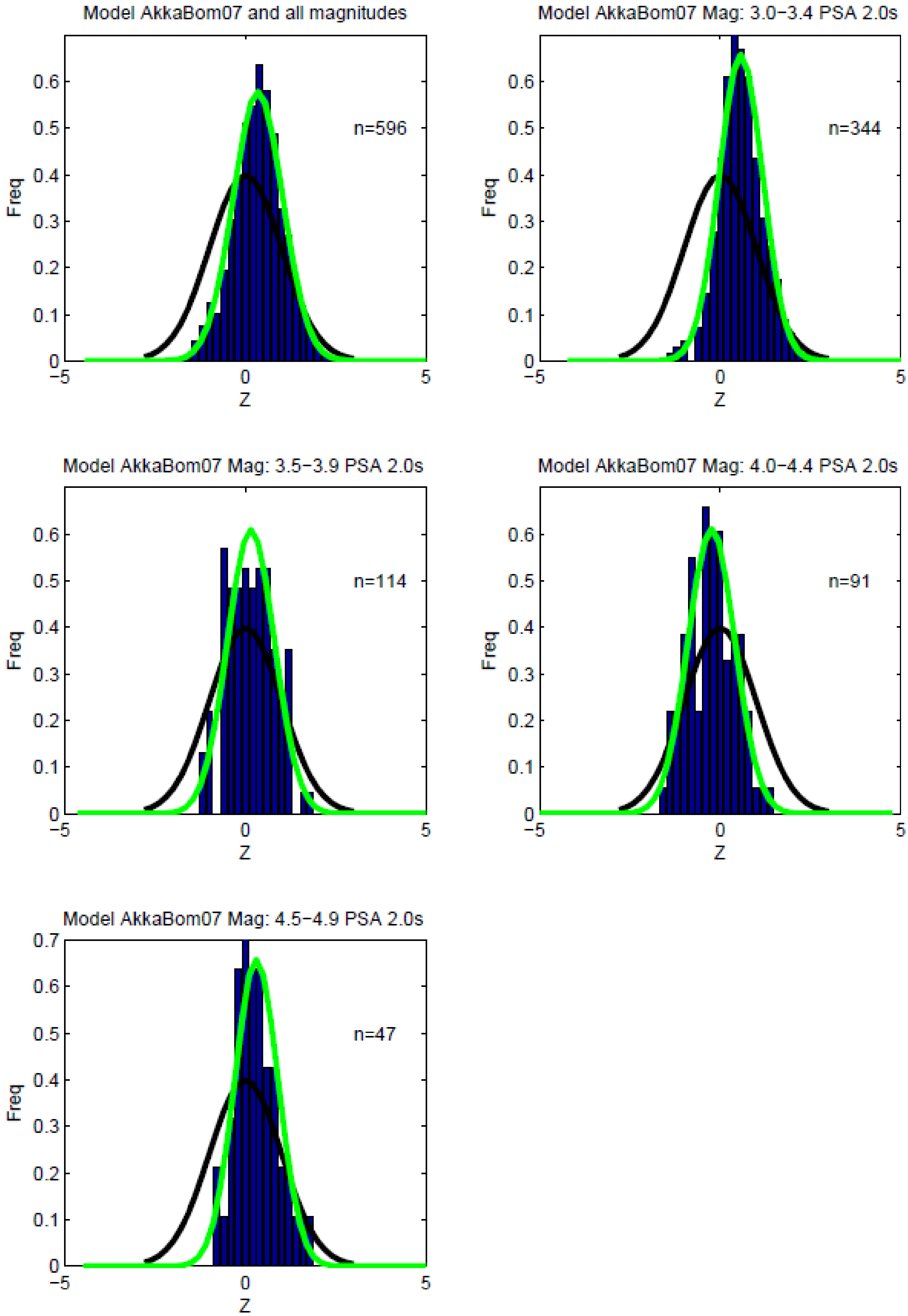



**Figure 67**: Normalized logarithmic residuals by magnitude ranges for PSA 2.0s and the study Rock data with the GMPE AkkaBom07.

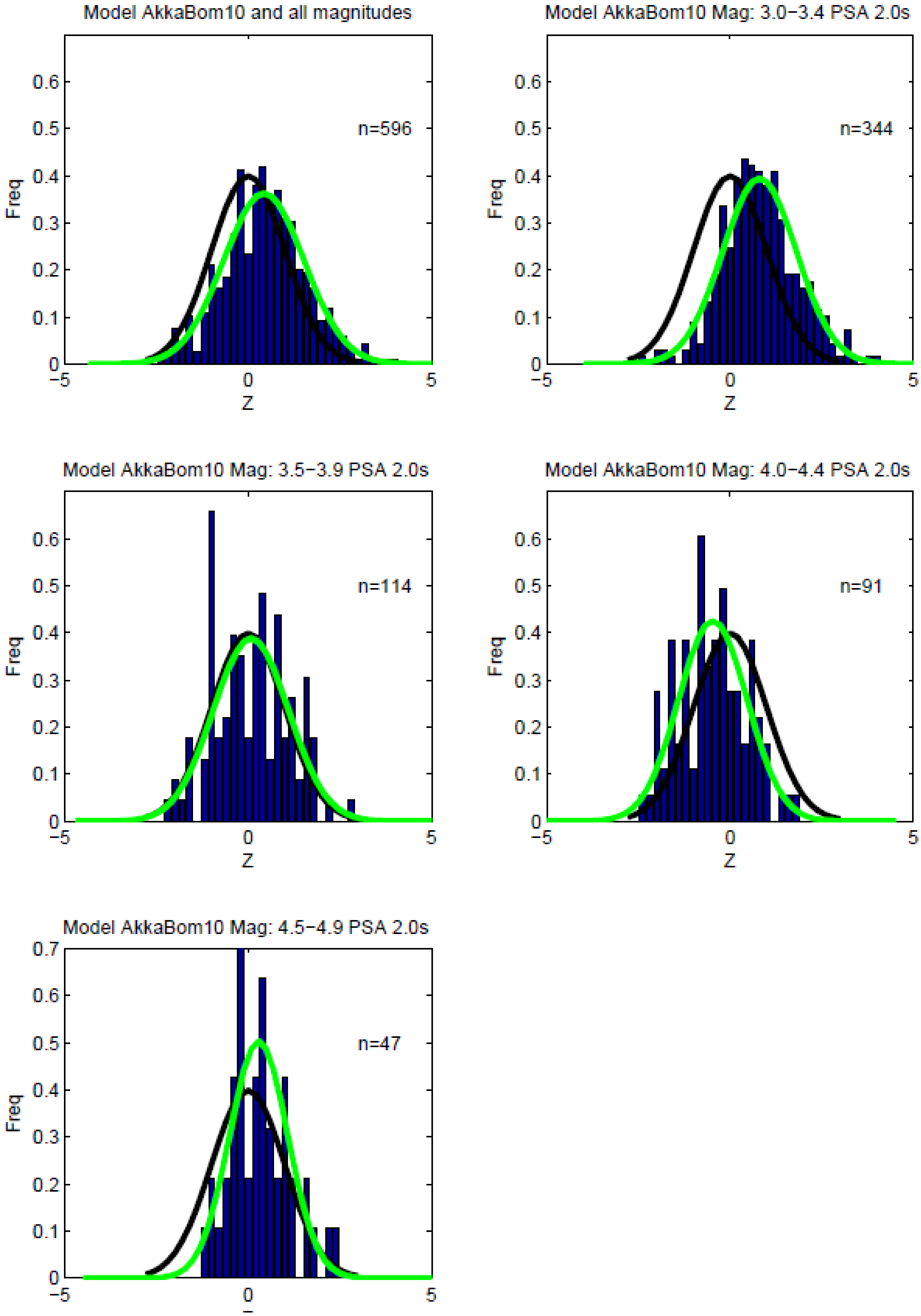
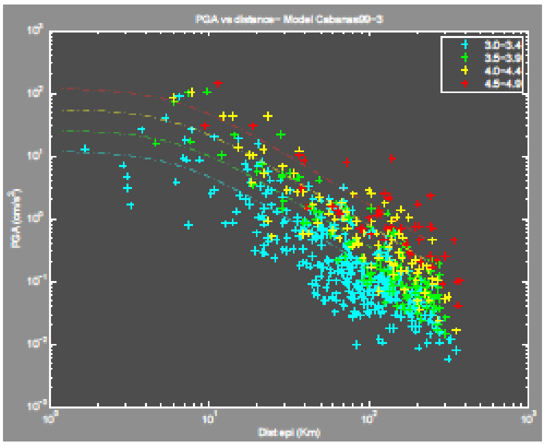
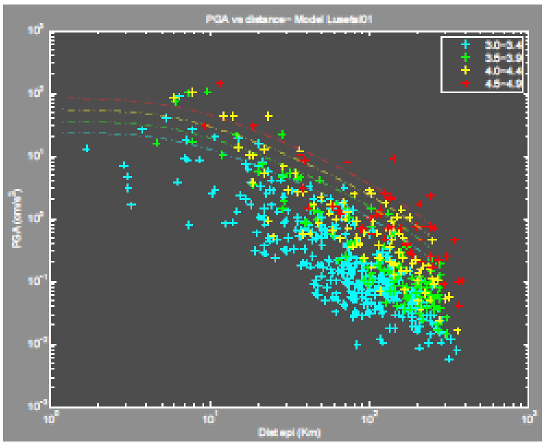


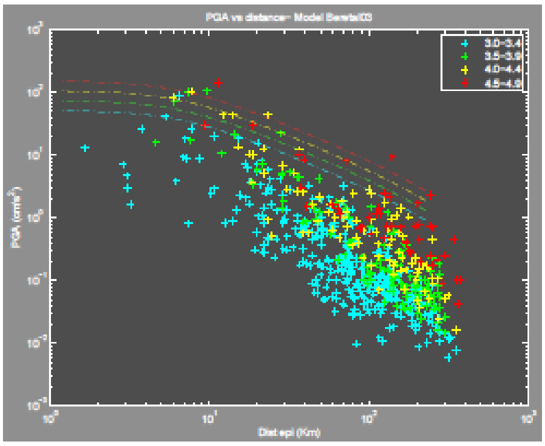

**Figure 68**: Normalized logarithmic residuals by magnitude ranges for PSA 2.0s and the study Rock data with the GMPE AkkaBom10.

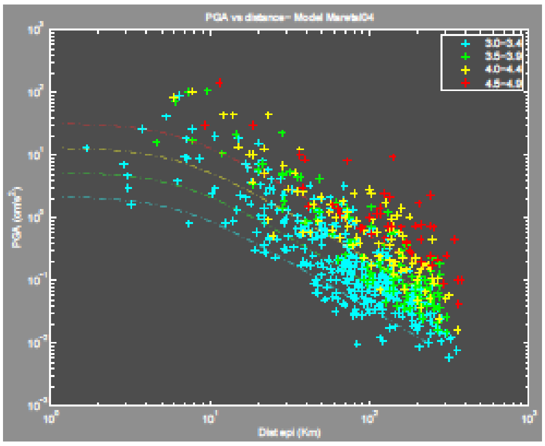
# D. First overview of the equations with all the data

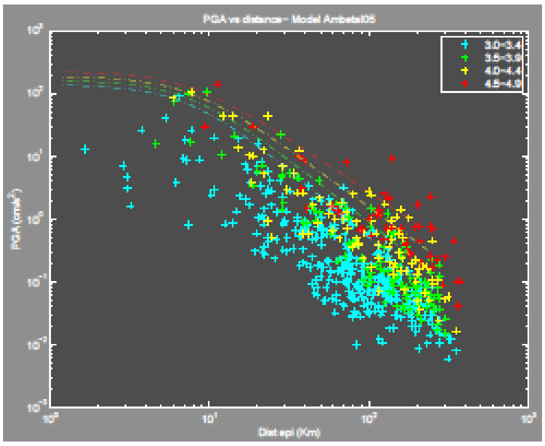
## D.1 PGA

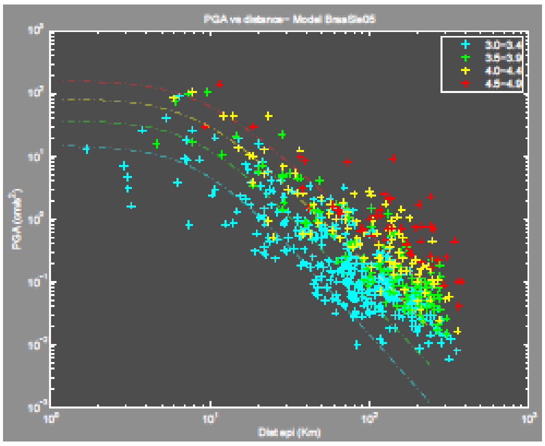


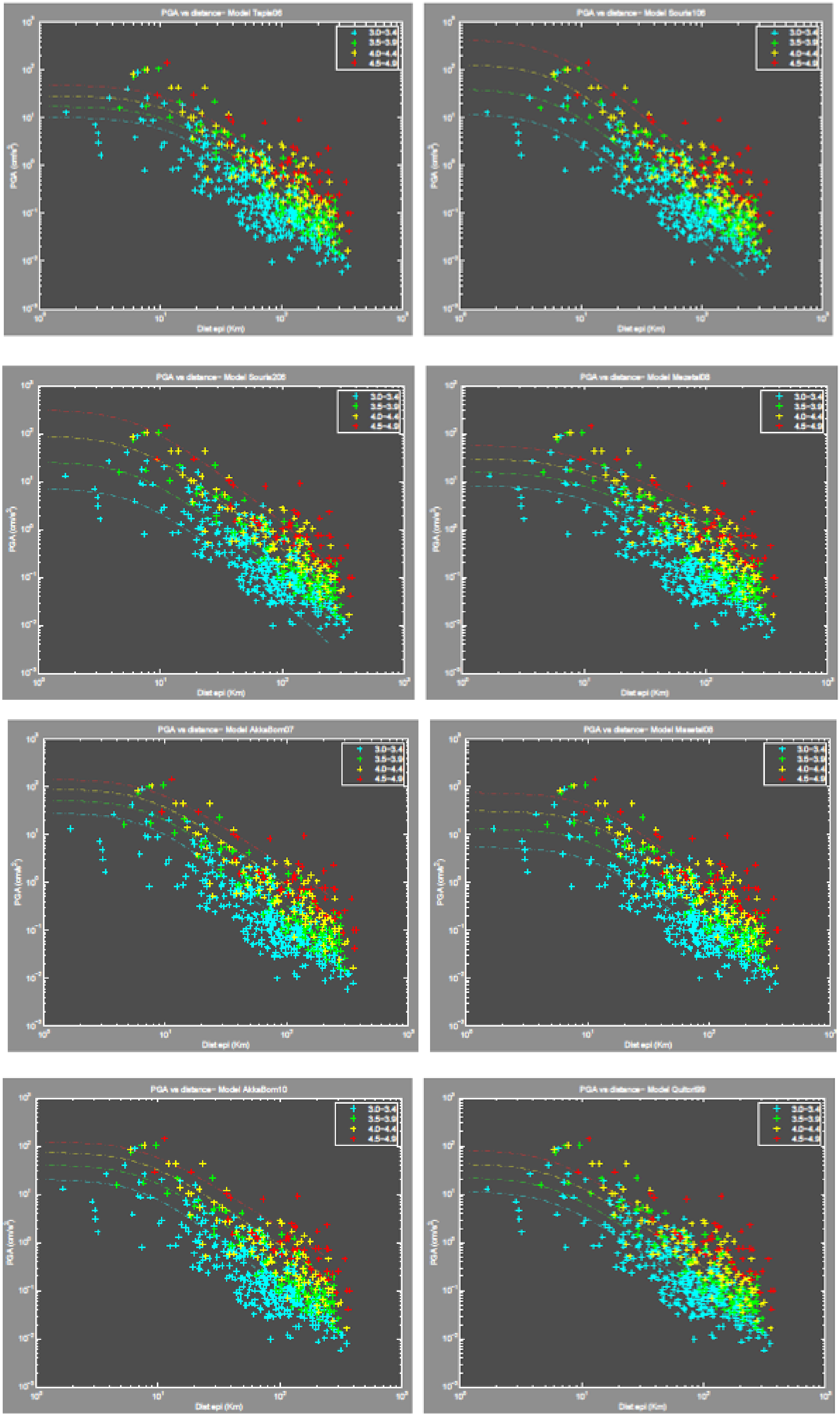



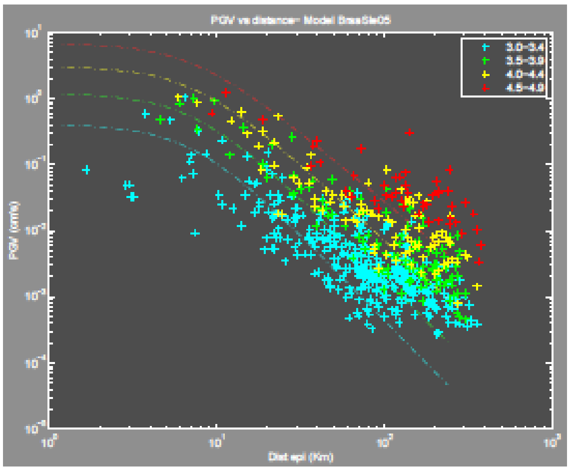



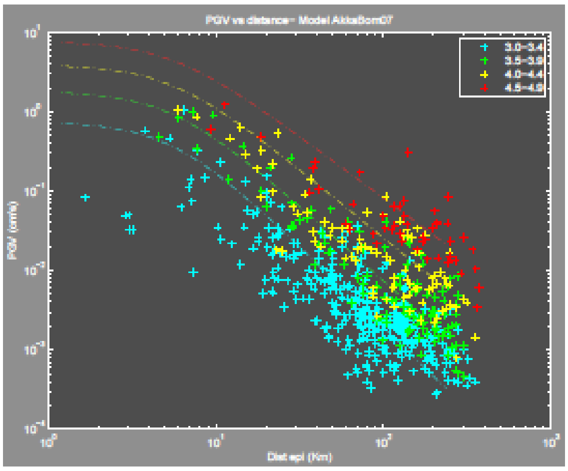



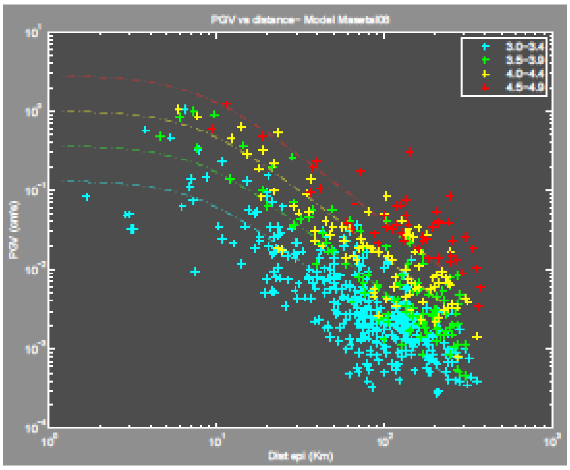



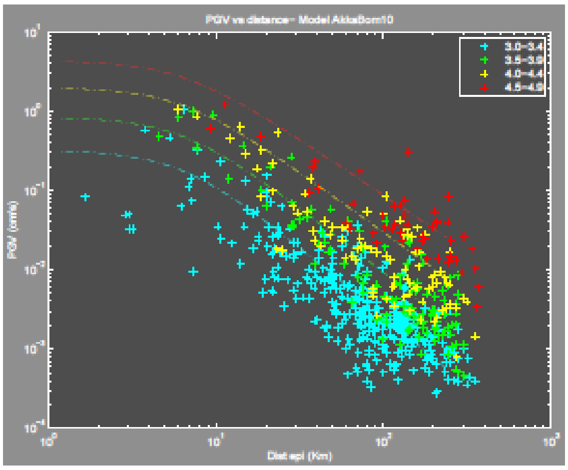

3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
Dist epi (Km)

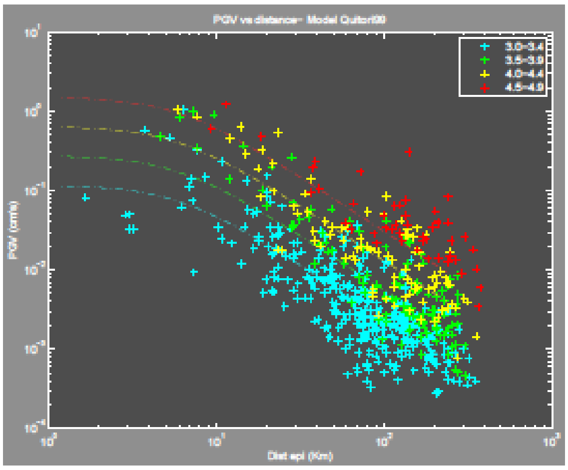
## D.2 PGV


PGV vs distance- Model AkkaBom07
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
PGV (cm/s)
Dist epi (Km)

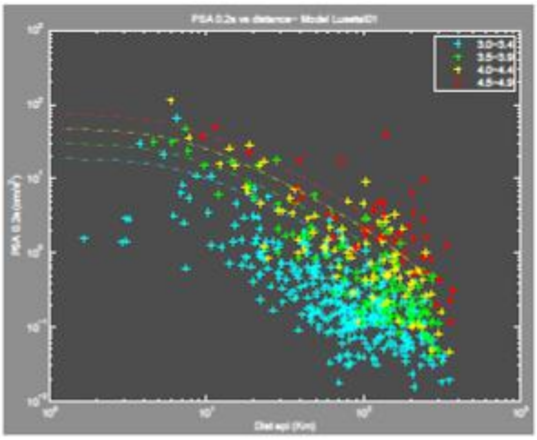
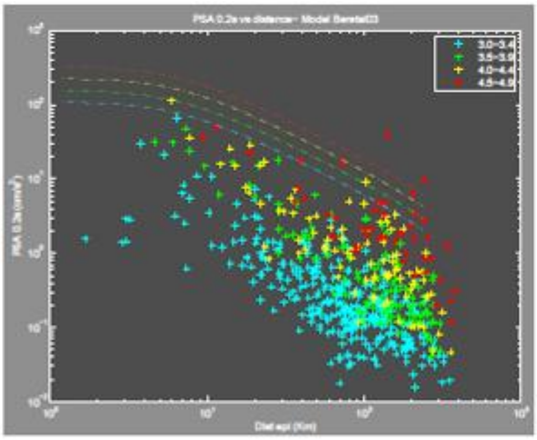
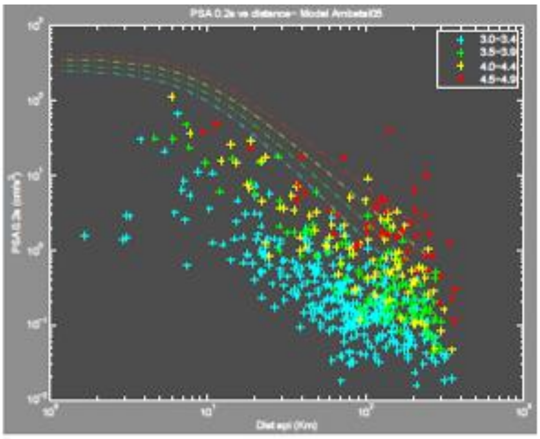
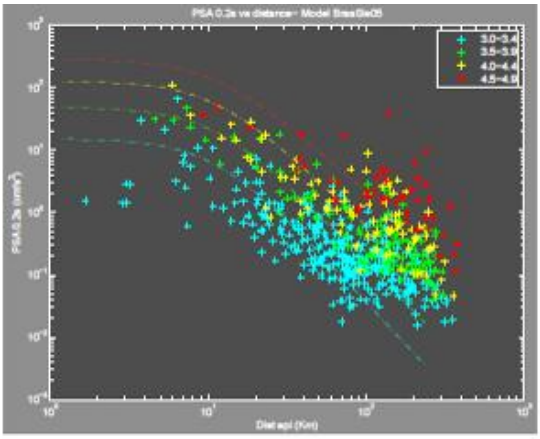
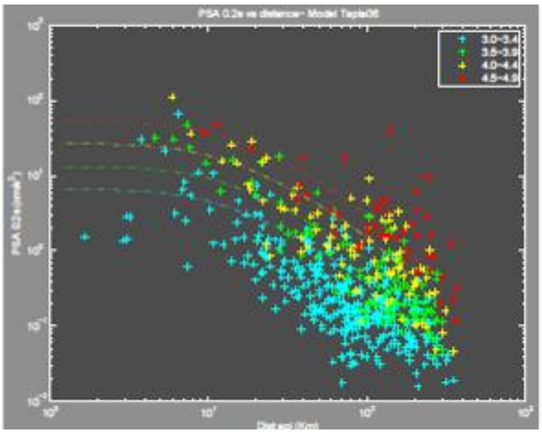
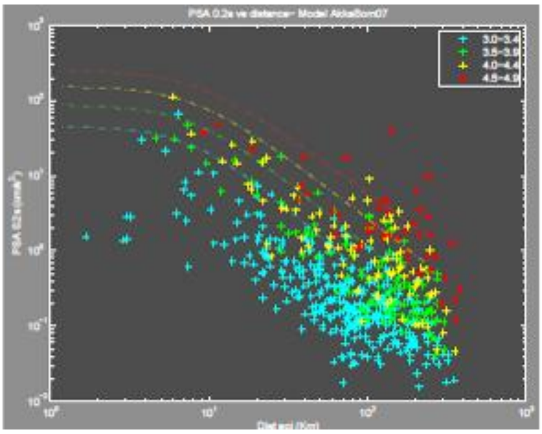
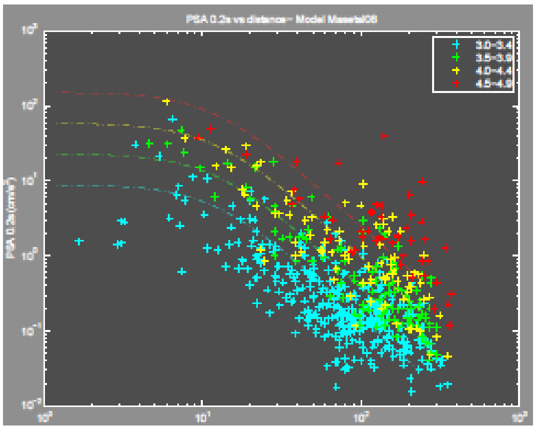
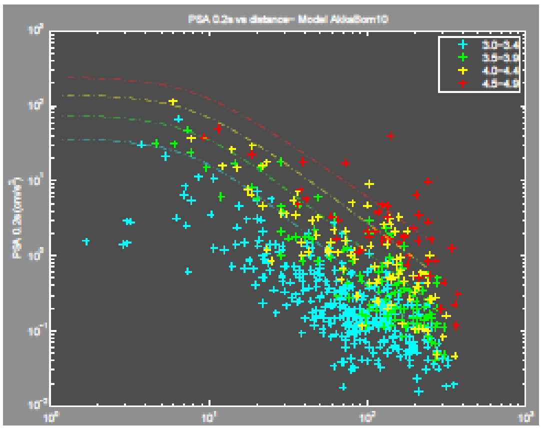

PGV vs distance- Model AkkaBom07
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
PGV (cm/s)
Dist epi (Km)


3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
PGV (cm/s)
Dist epi (Km)

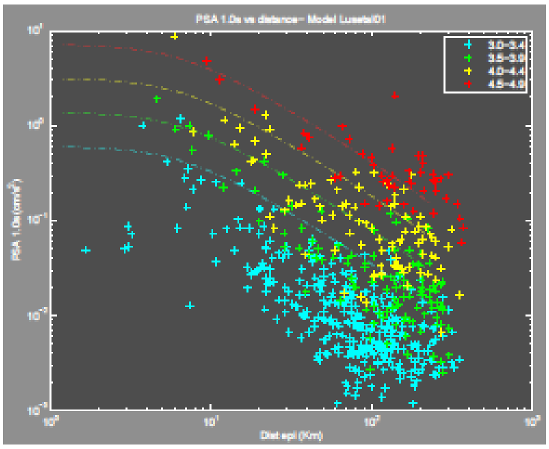
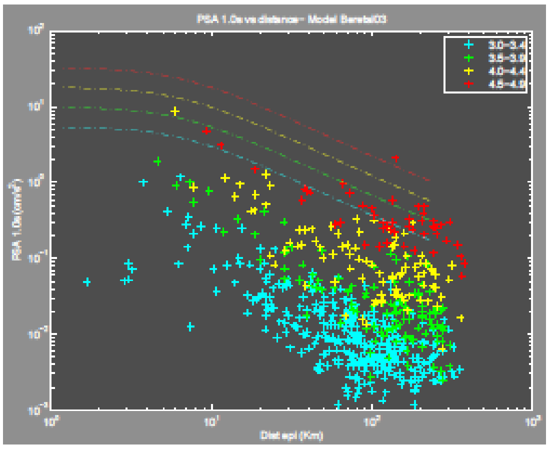

PGV vs distance- Model AkkaBom10
3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
PGV (cm/s)
Dist epi (Km)

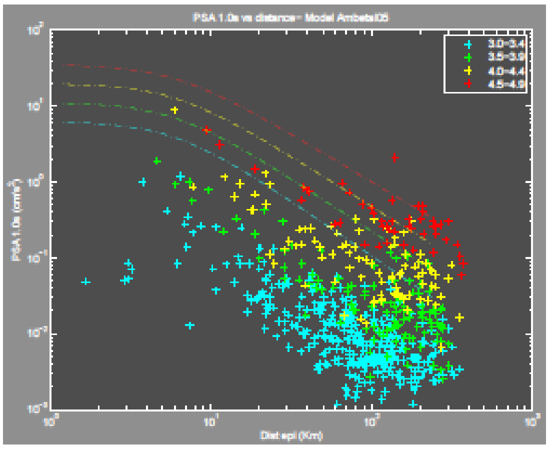
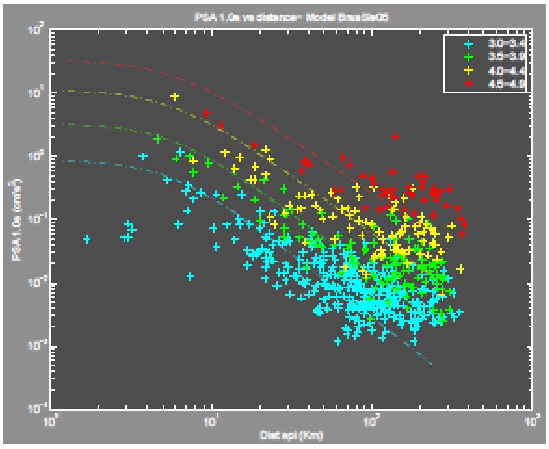

3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
PGV (cm/s)
Dist epi (Km)

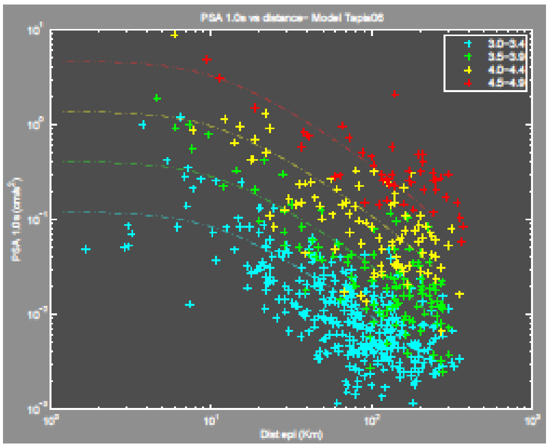
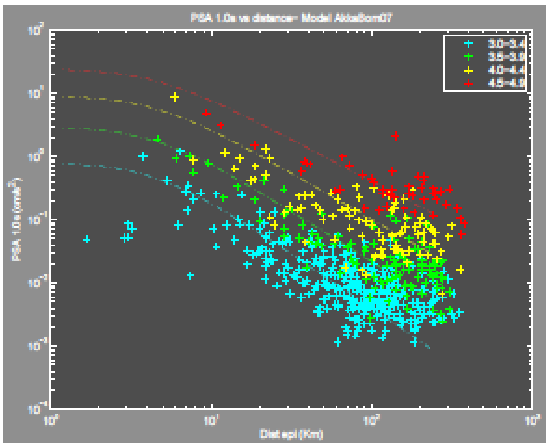
## D.3 PSA 0.2s

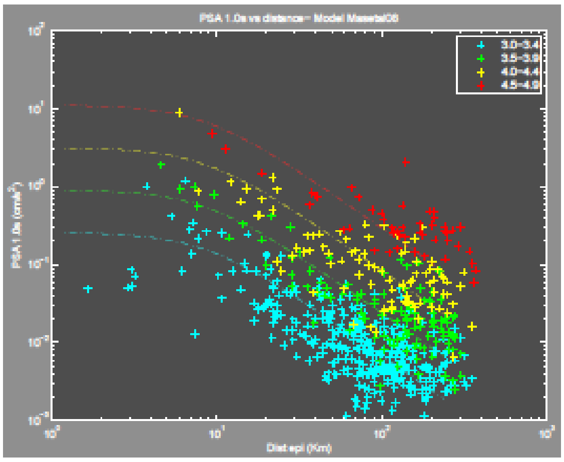









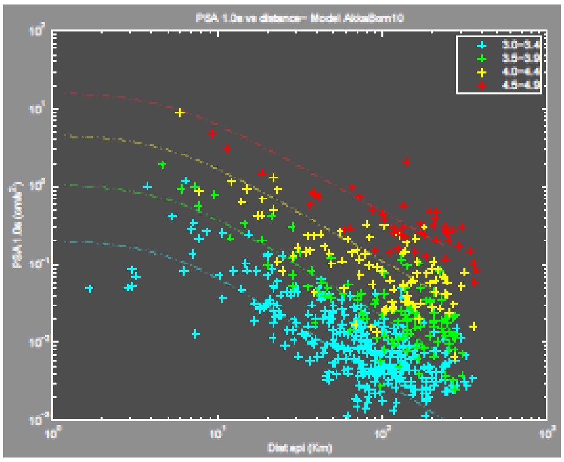
## D.4 PSA 1.0s

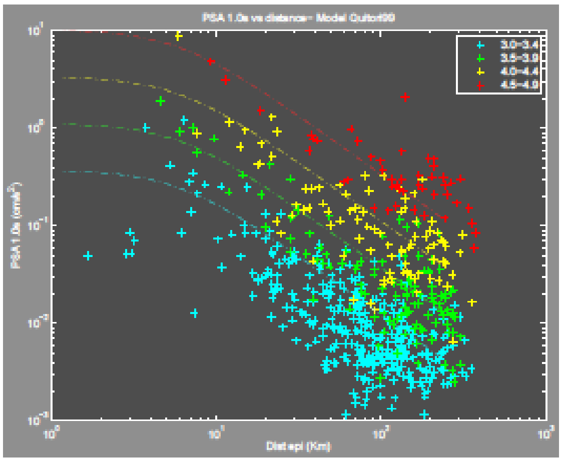



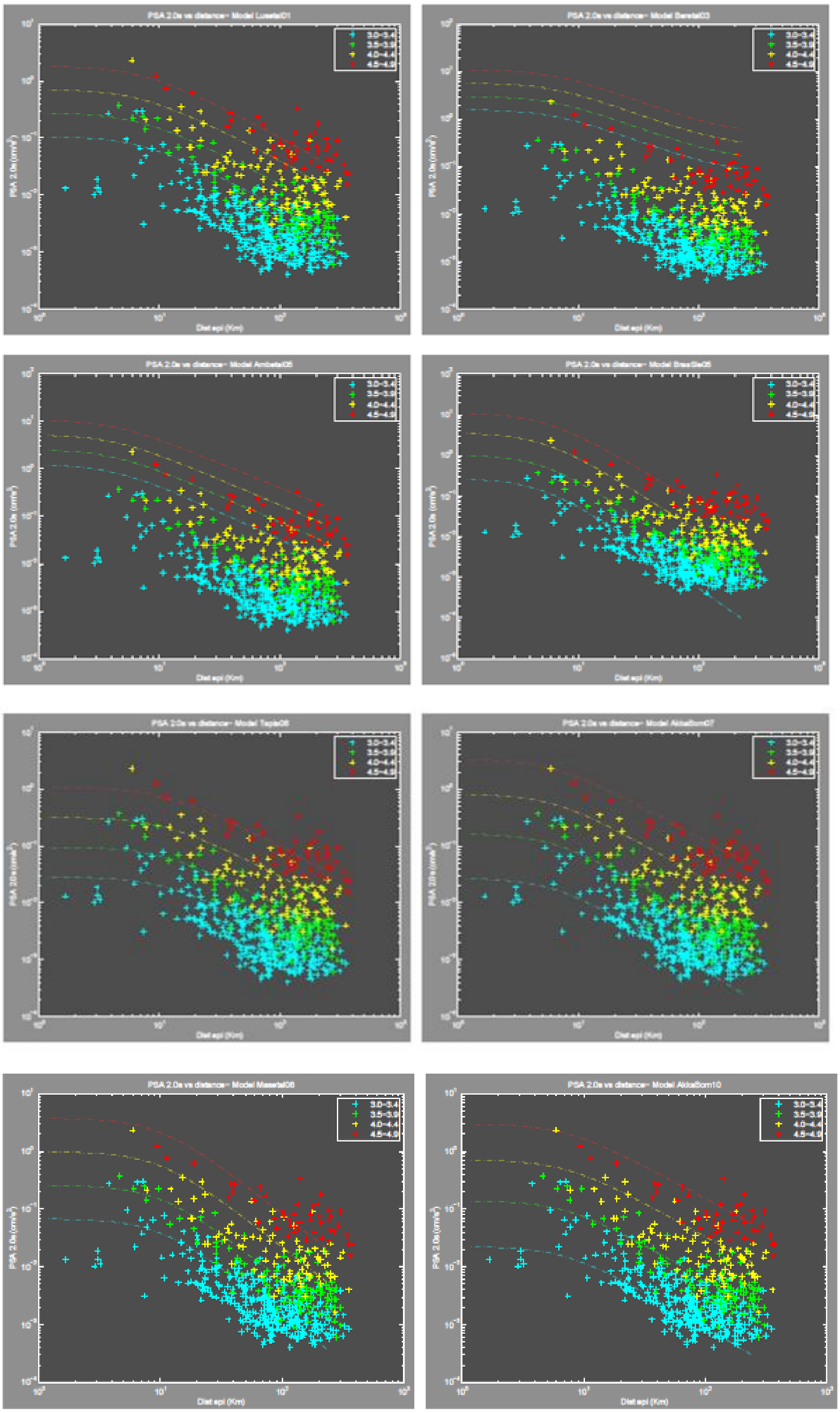




3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
Dist epi (Km)


3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
Dist epi (Km)


3.0-3.4
3.5-3.9
4.0-4.4
4.5-4.9
Dist epi (Km)

## D.5 PSA 2.0s



# E. Sensitivity study results

### E.0.1 20050226

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Maretal04 | 4.5-4.9 | 17 | 3 | 0.714 | 0.480 | 0.568 | 0.631 | 3 | 0.393 | 0.264 | 0.312 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 3 | -0.510 | -0.507 | 0.999 | 0.435 | 2 | -0.217 | -0.216 | 0.425 |
| Rock | Tapia06 | 3.5-3.9 | 114 | 1 | 0.047 | -0.117 | 0.870 | 0.548 | 2 | 0.020 | -0.050 | 0.370 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | 0.126 | 0.087 | 0.877 | 0.603 | 2 | 0.054 | 0.037 | 0.374 |
| Rock | Tapia06 | 4.5-4.9 | 17 | 3 | 0.588 | 0.427 | 0.858 | 0.455 | 3 | 0.250 | 0.182 | 0.365 |
| Rock | Souria106 | 4.0-4.4 | 91 | 3 | 0.559 | 0.476 | 0.713 | 0.587 | 3 | 0.302 | 0.257 | 0.385 |
| Rock | Souria106 | 4.5-4.9 | 17 | 3 | 0.589 | 0.549 | 0.715 | 0.461 | 3 | 0.333 | 0.310 | 0.404 |
| Rock | Souria206 | 3.5-3.9 | 114 | 3 | 0.723 | 0.702 | 0.557 | 0.483 | 3 | 0.481 | 0.467 | 0.370 |
| Rock | Souria206 | 4.0-4.4 | 91 | 2 | 0.334 | 0.258 | 0.544 | 0.725 | 2 | 0.230 | 0.178 | 0.375 |
| Rock | Souria206 | 4.5-4.9 | 17 | 2 | 0.369 | 0.328 | 0.582 | 0.681 | 3 | 0.264 | 0.234 | 0.416 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.183 | -0.125 | 1.051 | 0.455 | 2 | -0.077 | -0.053 | 0.444 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | -0.070 | -0.213 | 0.899 | 0.478 | 2 | -0.028 | -0.084 | 0.356 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 3 | -0.398 | -0.548 | 0.976 | 0.444 | 2 | -0.148 | -0.203 | 0.361 |
| Rock | AkkaBom07 | 4.5-4.9 | 17 | 3 | -0.431 | -0.709 | 0.958 | 0.288 | 2 | -0.148 | -0.244 | 0.330 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 3 | -0.138 | -0.378 | 1.293 | 0.308 | 2 | -0.038 | -0.106 | 0.361 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 3 | -0.560 | -0.718 | 1.295 | 0.303 | 2 | -0.156 | -0.200 | 0.362 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 2 | 0.339 | 0.361 | 1.145 | 0.435 | 2 | 0.124 | 0.132 | 0.420 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 3 | 0.743 | 0.628 | 0.988 | 0.454 | 3 | 0.273 | 0.230 | 0.362 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.046 | -0.057 | 0.731 | 0.641 | 2 | -0.027 | -0.034 | 0.435 |
| Rock | AkkaBom07 | 3.5-3.9 | 114 | 1 | 0.052 | 0.004 | 0.708 | 0.618 | 2 | 0.028 | 0.002 | 0.382 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 2 | -0.386 | -0.467 | 0.733 | 0.473 | 2 | -0.187 | -0.226 | 0.355 |
| Rock | AkkaBom07 | 4.5-4.9 | 17 | 1 | 0.140 | -0.010 | 0.647 | 0.645 | 1 | 0.060 | -0.004 | 0.278 |
| Rock | AkkaBom10 | 3.0-3.4 | 344 | 3 | -0.376 | -0.363 | 1.369 | 0.334 | 2 | -0.105 | -0.101 | 0.381 |
| Rock | AkkaBom10 | 3.5-3.9 | 114 | 3 | -0.243 | -0.461 | 1.319 | 0.277 | 2 | -0.068 | -0.128 | 0.367 |
| Rock | AkkaBom10 | 4.5-4.9 | 17 | 2 | -0.077 | -0.329 | 0.921 | 0.395 | 1 | -0.021 | -0.091 | 0.256 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 1 | -0.035 | -0.045 | 1.090 | 0.510 | 2 | -0.011 | -0.015 | 0.356 |
| Rock | Quitori99 | 3.5-3.9 | 114 | 2 | 0.438 | 0.237 | 1.135 | 0.400 | 2 | 0.143 | 0.077 | 0.371 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 2 | 0.316 | 0.153 | 1.004 | 0.520 | 2 | 0.103 | 0.050 | 0.328 |

**Table 18**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for the best ranked GMPEs by parameter and magnitude range, tested with rock data without 20050226 waveforms.

### E.0.2 20061117

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Ambetal05 | 4.5-4.9 | 47 | 3 | -0.468 | -0.615 | 0.981 | 0.403 | 2 | -0.177 | -0.233 | 0.371 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 3 | -0.510 | -0.507 | 0.999 | 0.435 | 2 | -0.217 | -0.216 | 0.425 |
| Rock | Tapia06 | 3.5-3.9 | 89 | 1 | 0.146 | 0.020 | 0.889 | 0.544 | 2 | 0.062 | 0.009 | 0.379 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | 0.126 | 0.087 | 0.877 | 0.603 | 2 | 0.054 | 0.037 | 0.374 |
| Rock | Souria106 | 4.0-4.4 | 91 | 3 | 0.559 | 0.476 | 0.713 | 0.587 | 3 | 0.302 | 0.257 | 0.385 |
| Rock | Souria106 | 4.5-4.9 | 47 | 3 | 0.721 | 0.666 | 0.741 | 0.498 | 3 | 0.407 | 0.376 | 0.419 |
| Rock | Souria206 | 4.0-4.4 | 91 | 2 | 0.334 | 0.258 | 0.544 | 0.725 | 2 | 0.230 | 0.178 | 0.375 |
| Rock | Souria206 | 4.5-4.9 | 47 | 2 | 0.447 | 0.336 | 0.582 | 0.681 | 3 | 0.319 | 0.240 | 0.416 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.183 | -0.125 | 1.051 | 0.455 | 2 | -0.077 | -0.053 | 0.444 |
| Rock | AkkaBom07 | 3.5-3.9 | 89 | 1 | 0.065 | -0.060 | 0.900 | 0.476 | 2 | 0.026 | -0.024 | 0.357 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 3 | -0.398 | -0.548 | 0.976 | 0.444 | 2 | -0.148 | -0.203 | 0.361 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | -0.018 | -0.231 | 1.072 | 0.420 | 2 | -0.006 | -0.080 | 0.369 |
| Rock | AkkaBom10 | 3.5-3.9 | 89 | 3 | 0.054 | -0.207 | 1.299 | 0.298 | 2 | 0.015 | -0.058 | 0.363 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 3 | -0.560 | -0.718 | 1.295 | 0.303 | 2 | -0.156 | -0.200 | 0.362 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 3 | -0.091 | -0.423 | 1.318 | 0.281 | 2 | -0.025 | -0.118 | 0.368 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 2 | 0.339 | 0.361 | 1.145 | 0.435 | 2 | 0.124 | 0.132 | 0.420 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 3 | 0.743 | 0.628 | 0.988 | 0.454 | 3 | 0.273 | 0.230 | 0.362 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.046 | -0.057 | 0.731 | 0.641 | 2 | -0.027 | -0.034 | 0.435 |
| Rock | AkkaBom07 | 3.5-3.9 | 89 | 1 | 0.164 | 0.103 | 0.698 | 0.632 | 2 | 0.088 | 0.056 | 0.377 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 2 | -0.386 | -0.467 | 0.733 | 0.473 | 2 | -0.187 | -0.226 | 0.355 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | 0.111 | -0.005 | 0.770 | 0.656 | 1 | 0.048 | -0.002 | 0.331 |
| Rock | AkkaBom10 | 3.0-3.4 | 344 | 3 | -0.376 | -0.363 | 1.369 | 0.334 | 2 | -0.105 | -0.101 | 0.381 |
| Rock | AkkaBom10 | 3.5-3.9 | 89 | 3 | -0.040 | -0.295 | 1.314 | 0.336 | 2 | -0.011 | -0.082 | 0.365 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 1 | -0.031 | -0.210 | 1.090 | 0.479 | 1 | -0.009 | -0.058 | 0.303 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 1 | -0.035 | -0.045 | 1.090 | 0.510 | 2 | -0.011 | -0.015 | 0.356 |
| Rock | Quitori99 | 3.5-3.9 | 89 | 3 | 0.579 | 0.304 | 1.153 | 0.375 | 2 | 0.189 | 0.099 | 0.377 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 2 | 0.316 | 0.153 | 1.004 | 0.520 | 2 | 0.103 | 0.050 | 0.328 |

**Table 19:** Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for the best ranked GMPEs by parameter and magnitude range, tested with rock data without 20061117 waveforms.

## E.0.3 20071115

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Ambetal05 | 4.5-4.9 | 47 | 3 | -0.468 | -0.615 | 0.981 | 0.403 | 2 | -0.177 | -0.233 | 0.371 |
| Rock | Tapia06 | 3.0-3.4 | 344 | 3 | -0.510 | -0.507 | 0.999 | 0.435 | 2 | -0.217 | -0.216 | 0.425 |
| Rock | Tapia06 | 3.5-3.9 | 89 | 1 | 0.146 | 0.020 | 0.889 | 0.544 | 2 | 0.062 | 0.009 | 0.379 |
| Rock | Tapia06 | 4.0-4.4 | 91 | 1 | 0.126 | 0.087 | 0.877 | 0.603 | 2 | 0.054 | 0.037 | 0.374 |
| Rock | Souria106 | 4.0-4.4 | 91 | 3 | 0.559 | 0.476 | 0.713 | 0.587 | 3 | 0.302 | 0.257 | 0.385 |
| Rock | Souria106 | 4.5-4.9 | 47 | 3 | 0.721 | 0.666 | 0.741 | 0.498 | 3 | 0.407 | 0.376 | 0.419 |
| Rock | Souria206 | 4.0-4.4 | 91 | 2 | 0.334 | 0.258 | 0.544 | 0.725 | 2 | 0.230 | 0.178 | 0.375 |
| Rock | Souria206 | 4.5-4.9 | 47 | 2 | 0.447 | 0.336 | 0.582 | 0.681 | 3 | 0.319 | 0.240 | 0.416 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.183 | -0.125 | 1.051 | 0.455 | 2 | -0.077 | -0.053 | 0.444 |
| Rock | AkkaBom07 | 3.5-3.9 | 89 | 1 | 0.065 | -0.060 | 0.900 | 0.476 | 2 | 0.026 | -0.024 | 0.357 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 3 | -0.398 | -0.548 | 0.976 | 0.444 | 2 | -0.148 | -0.203 | 0.361 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | -0.018 | -0.231 | 1.072 | 0.420 | 2 | -0.006 | -0.080 | 0.369 |
| Rock | AkkaBom10 | 3.5-3.9 | 89 | 3 | 0.054 | -0.207 | 1.299 | 0.298 | 2 | 0.015 | -0.058 | 0.363 |
| Rock | AkkaBom10 | 4.0-4.4 | 91 | 3 | -0.560 | -0.718 | 1.295 | 0.303 | 2 | -0.156 | -0.200 | 0.362 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 3 | -0.091 | -0.423 | 1.318 | 0.281 | 2 | -0.025 | -0.118 | 0.368 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 2 | 0.339 | 0.361 | 1.145 | 0.435 | 2 | 0.124 | 0.132 | 0.420 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 3 | 0.743 | 0.628 | 0.988 | 0.454 | 3 | 0.273 | 0.230 | 0.362 |
| Rock | AkkaBom07 | 3.0-3.4 | 344 | 1 | -0.046 | -0.057 | 0.731 | 0.641 | 2 | -0.027 | -0.034 | 0.435 |
| Rock | AkkaBom07 | 3.5-3.9 | 89 | 1 | 0.164 | 0.103 | 0.698 | 0.632 | 2 | 0.088 | 0.056 | 0.377 |
| Rock | AkkaBom07 | 4.0-4.4 | 91 | 2 | -0.386 | -0.467 | 0.733 | 0.473 | 2 | -0.187 | -0.226 | 0.355 |
| Rock | AkkaBom07 | 4.5-4.9 | 47 | 1 | 0.111 | -0.005 | 0.770 | 0.656 | 1 | 0.048 | -0.002 | 0.331 |
| Rock | AkkaBom10 | 3.0-3.4 | 344 | 3 | -0.376 | -0.363 | 1.369 | 0.334 | 2 | -0.105 | -0.101 | 0.381 |
| Rock | AkkaBom10 | 3.5-3.9 | 89 | 3 | -0.040 | -0.295 | 1.314 | 0.336 | 2 | -0.011 | -0.082 | 0.365 |
| Rock | AkkaBom10 | 4.5-4.9 | 47 | 1 | -0.031 | -0.210 | 1.090 | 0.479 | 1 | -0.009 | -0.058 | 0.303 |
| Rock | Quitori99 | 3.0-3.4 | 344 | 1 | -0.035 | -0.045 | 1.090 | 0.510 | 2 | -0.011 | -0.015 | 0.356 |
| Rock | Quitori99 | 3.5-3.9 | 89 | 3 | 0.579 | 0.304 | 1.153 | 0.375 | 2 | 0.189 | 0.099 | 0.377 |
| Rock | Quitori99 | 4.0-4.4 | 91 | 2 | 0.316 | 0.153 | 1.004 | 0.520 | 2 | 0.103 | 0.050 | 0.328 |

**Table 20**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for the best ranked GMPEs by parameter and magnitude range, tested with rock data without 20071115 waveforms.

## E.0.4 PYAT

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Ambetal05 | 4.5-4.9 | 45 | 3 | -0.423 | -0.603 | 0.978 | 0.416 | 2 | -0.160 | -0.228 | 0.370 |
| Rock | Tapia06 | 3.0-3.4 | 318 | 2 | -0.495 | -0.481 | 1.022 | 0.425 | 2 | -0.211 | -0.205 | 0.435 |
| Rock | Tapia06 | 3.5-3.9 | 110 | 1 | 0.045 | -0.130 | 0.881 | 0.541 | 2 | 0.019 | -0.055 | 0.375 |
| Rock | Tapia06 | 4.0-4.4 | 86 | 1 | 0.142 | 0.090 | 0.897 | 0.584 | 2 | 0.061 | 0.038 | 0.382 |
| Rock | Souria106 | 4.0-4.4 | 86 | 3 | 0.576 | 0.483 | 0.729 | 0.574 | 3 | 0.311 | 0.261 | 0.394 |
| Rock | Souria206 | 3.5-3.9 | 110 | 3 | 0.724 | 0.702 | 0.563 | 0.483 | 3 | 0.482 | 0.467 | 0.374 |
| Rock | Souria206 | 4.0-4.4 | 86 | 2 | 0.346 | 0.277 | 0.556 | 0.710 | 2 | 0.239 | 0.191 | 0.383 |
| Rock | Souria206 | 4.5-4.9 | 45 | 2 | 0.479 | 0.344 | 0.573 | 0.666 | 3 | 0.343 | 0.246 | 0.410 |
| Rock | AkkaBom07 | 3.0-3.4 | 318 | 1 | -0.160 | -0.076 | 1.075 | 0.448 | 2 | -0.068 | -0.032 | 0.454 |
| Rock | AkkaBom07 | 3.5-3.9 | 110 | 1 | -0.071 | -0.247 | 0.911 | 0.475 | 2 | -0.028 | -0.098 | 0.361 |
| Rock | AkkaBom07 | 4.0-4.4 | 86 | 3 | -0.379 | -0.502 | 0.999 | 0.438 | 2 | -0.141 | -0.186 | 0.370 |
| Rock | AkkaBom07 | 4.5-4.9 | 45 | 1 | 0.030 | -0.173 | 1.071 | 0.430 | 2 | 0.010 | -0.060 | 0.369 |
| Rock | AkkaBom10 | 3.5-3.9 | 110 | 3 | -0.140 | -0.413 | 1.309 | 0.297 | 2 | -0.039 | -0.115 | 0.366 |
| Rock | AkkaBom10 | 4.0-4.4 | 86 | 3 | -0.537 | -0.711 | 1.326 | 0.290 | 2 | -0.150 | -0.199 | 0.370 |
| Rock | AkkaBom10 | 4.5-4.9 | 45 | 3 | -0.035 | -0.294 | 1.319 | 0.309 | 2 | -0.010 | -0.082 | 0.369 |
| Rock | Quitori99 | 3.0-3.4 | 318 | 2 | 0.363 | 0.372 | 1.175 | 0.406 | 2 | 0.133 | 0.136 | 0.431 |
| Rock | Quitori99 | 3.5-3.9 | 110 | 3 | 0.748 | 0.521 | 0.998 | 0.554 | 3 | 0.274 | 0.191 | 0.366 |
| Rock | AkkaBom07 | 3.0-3.4 | 318 | 1 | -0.027 | -0.034 | 0.733 | 0.636 | 2 | -0.016 | -0.020 | 0.435 |
| Rock | AkkaBom07 | 3.5-3.9 | 110 | 1 | 0.059 | 0.004 | 0.716 | 0.611 | 2 | 0.032 | 0.002 | 0.386 |
| Rock | AkkaBom07 | 4.0-4.4 | 86 | 2 | -0.371 | -0.419 | 0.748 | 0.483 | 2 | -0.180 | -0.203 | 0.363 |
| Rock | AkkaBom07 | 4.5-4.9 | 45 | 1 | 0.150 | 0.029 | 0.760 | 0.656 | 1 | 0.064 | 0.012 | 0.327 |
| Rock | AkkaBom10 | 3.0-3.4 | 318 | 3 | -0.345 | -0.316 | 1.389 | 0.334 | 2 | -0.096 | -0.088 | 0.386 |
| Rock | AkkaBom10 | 3.5-3.9 | 110 | 3 | -0.236 | -0.461 | 1.336 | 0.270 | 2 | -0.066 | -0.128 | 0.371 |
| Rock | AkkaBom10 | 4.5-4.9 | 45 | 1 | 0.022 | -0.039 | 1.078 | 0.479 | 1 | 0.006 | -0.011 | 0.300 |
| Rock | Quitori99 | 3.0-3.4 | 318 | 1 | -0.013 | -0.045 | 1.114 | 0.501 | 2 | -0.004 | -0.015 | 0.364 |
| Rock | Quitori99 | 3.5-3.9 | 110 | 2 | 0.439 | 0.237 | 1.151 | 0.393 | 2 | 0.143 | 0.077 | 0.376 |
| Rock | Quitori99 | 4.0-4.4 | 86 | 2 | 0.326 | 0.160 | 1.030 | 0.462 | 2 | 0.107 | 0.052 | 0.337 |

**Table 21**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for the best ranked GMPEs by parameter and magnitude range, tested with rock data without PYAT waveforms.

## E.0.5 PYOR

| Type | GMPE | Magnitude range | Nº | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock | Ambetal05 | 4.5-4.9 | 45 | 3 | -0.514 | -0.669 | 0.977 | 0.392 | 3 | -0.195 | -0.253 | 0.370 |
| Rock | Tapia06 | 3.0-3.4 | 315 | 3 | -0.558 | -0.534 | 1.011 | 0.408 | 2 | -0.238 | -0.228 | 0.430 |
| Rock | Tapia06 | 3.5-3.9 | 109 | 1 | 0.026 | -0.167 | 0.880 | 0.544 | 2 | 0.011 | -0.071 | 0.375 |
| Rock | Tapia06 | 4.0-4.4 | 87 | 1 | 0.099 | 0.054 | 0.880 | 0.603 | 2 | 0.042 | 0.023 | 0.375 |
| Rock | Souria106 | 4.0-4.4 | 87 | 3 | 0.529 | 0.439 | 0.706 | 0.597 | 3 | 0.285 | 0.237 | 0.381 |
| Rock | Souria106 | 4.5-4.9 | 45 | 3 | 0.685 | 0.594 | 0.737 | 0.502 | 3 | 0.387 | 0.336 | 0.417 |
| Rock | Souria206 | 3.5-3.9 | 109 | 3 | 0.708 | 0.698 | 0.561 | 0.485 | 3 | 0.471 | 0.464 | 0.373 |
| Rock | Souria206 | 4.0-4.4 | 87 | 2 | 0.312 | 0.256 | 0.538 | 0.727 | 2 | 0.215 | 0.177 | 0.372 |
| Rock | Souria206 | 4.5-4.9 | 45 | 2 | 0.420 | 0.328 | 0.580 | 0.696 | 3 | 0.300 | 0.234 | 0.415 |
| Rock | AkkaBom07 | 3.0-3.4 | 315 | 2 | -0.250 | -0.230 | 1.052 | 0.454 | 2 | -0.106 | -0.097 | 0.444 |
| Rock | AkkaBom07 | 3.5-3.9 | 109 | 2 | -0.097 | -0.285 | 0.906 | 0.476 | 2 | -0.039 | -0.113 | 0.359 |
| Rock | AkkaBom07 | 4.0-4.4 | 87 | 3 | -0.433 | -0.574 | 0.975 | 0.444 | 2 | -0.160 | -0.213 | 0.361 |
| Rock | AkkaBom07 | 4.5-4.9 | 45 | 2 | -0.067 | -0.284 | 1.068 | 0.430 | 2 | -0.023 | -0.098 | 0.368 |
| Rock | AkkaBom10 | 3.5-3.9 | 109 | 3 | -0.175 | -0.432 | 1.304 | 0.298 | 2 | -0.049 | -0.121 | 0.364 |
| Rock | AkkaBom10 | 4.5-4.9 | 45 | 3 | -0.151 | -0.477 | 1.315 | 0.309 | 2 | -0.042 | -0.133 | 0.367 |
| Rock | Quitori99 | 3.0-3.4 | 315 | 2 | 0.281 | 0.276 | 1.158 | 0.441 | 2 | 0.103 | 0.101 | 0.425 |
| Rock | Quitori99 | 3.5-3.9 | 109 | 3 | 0.725 | 0.498 | 0.995 | 0.585 | 3 | 0.266 | 0.183 | 0.365 |
| Rock | Quitori99 | 4.0-4.4 | 87 | 3 | 0.711 | 0.556 | 0.990 | 0.489 | 3 | 0.261 | 0.204 | 0.363 |
| Rock | AkkaBom07 | 3.0-3.4 | 315 | 1 | -0.102 | -0.111 | 0.722 | 0.651 | 2 | -0.061 | -0.066 | 0.429 |
| Rock | AkkaBom07 | 3.5-3.9 | 109 | 1 | 0.036 | -0.011 | 0.716 | 0.618 | 2 | 0.020 | -0.006 | 0.386 |
| Rock | AkkaBom07 | 4.0-4.4 | 87 | 2 | -0.410 | -0.477 | 0.727 | 0.473 | 2 | -0.199 | -0.231 | 0.353 |
| Rock | AkkaBom07 | 4.5-4.9 | 45 | 1 | 0.077 | -0.010 | 0.767 | 0.685 | 1 | 0.033 | -0.004 | 0.330 |
| Rock | AkkaBom10 | 3.0-3.4 | 315 | 3 | -0.475 | -0.460 | 1.357 | 0.360 | 2 | -0.132 | -0.128 | 0.377 |
| Rock | AkkaBom10 | 3.5-3.9 | 109 | 3 | -0.270 | -0.490 | 1.336 | 0.268 | 2 | -0.075 | -0.136 | 0.371 |
| Rock | AkkaBom10 | 4.5-4.9 | 45 | 2 | -0.079 | -0.272 | 1.086 | 0.479 | 1 | -0.022 | -0.076 | 0.302 |
| Rock | Quitori99 | 3.0-3.4 | 315 | 1 | -0.095 | -0.095 | 1.095 | 0.516 | 2 | -0.031 | -0.031 | 0.358 |
| Rock | Quitori99 | 3.5-3.9 | 109 | 2 | 0.418 | 0.232 | 1.154 | 0.403 | 2 | 0.137 | 0.076 | 0.377 |
| Rock | Quitori99 | 4.0-4.4 | 87 | 2 | 0.293 | 0.149 | 1.007 | 0.520 | 1 | 0.096 | 0.049 | 0.329 |

**Table 22**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for the best ranked GMPEs by parameter and magnitude range, tested with rock data without PYOR waveforms.

# F. Magnitude shift study

As a first approach to see the magnitude scaling to the assigned rank, all the magnitudes are uprised 0.5. Doing this we obtain that the better GMPEs are: Maretal2004 and the both proposed in Souriau [2006]. The residuals and the ranks obtained for rock data with this magnitude shift are presented in table 23.

| PGM | Type | GMPE | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PGA | Rock | Lusetal01 | 4 | -2.960 | -3.070 | 1.517 | 0.002 | 4 | -0.944 | -0.979 | 0.484 |
| PGA | Rock | Beretal03 | 4 | -4.581 | -4.758 | 1.733 | 0.000 | 4 | -1.339 | -1.391 | 0.506 |
| PGA | Rock | Maretal04 | 2 | 0.301 | 0.231 | 0.785 | 0.595 | 2 | 0.166 | 0.127 | 0.432 |
| PGA | Rock | Ambetal05 | 4 | -1.986 | -2.009 | 0.985 | 0.045 | 4 | -0.875 | -0.854 | 0.452 |
| PGA | Rock | BraaSle05 | 3 | 0.488 | 0.434 | 1.261 | 0.354 | 3 | 0.195 | 0.173 | 0.503 |
| PGA | Rock | Tapia06 | 4 | -0.838 | -0.858 | 1.056 | 0.333 | 3 | -0.357 | -0.366 | 0.450 |
| PGA | Rock | Souria106 | 2 | 0.043 | 0.020 | 1.166 | 0.420 | 2 | 0.013 | 0.008 | 0.445 |
| PGA | Rock | Souria206 | 1 | -0.071 | -0.078 | 0.860 | 0.523 | 2 | -0.040 | -0.040 | 0.445 |
| PGA | Rock | Mezetal08 | 4 | -2.185 | -2.449 | 1.615 | 0.014 | 4 | -1.507 | -1.690 | 1.115 |
| PGA | Rock | AkkaBom07 | 4 | -1.234 | -1.281 | 1.070 | 0.195 | 3 | -0.476 | -0.492 | 0.414 |
| PGA | Rock | Masetal08 | 4 | -0.272 | -0.199 | 3.958 | 0.011 | 4 | -0.079 | -0.058 | 1.148 |
| PGA | Rock | AkkaBom10 | 4 | -1.684 | -1.769 | 1.479 | 0.075 | 3 | -0.470 | -0.494 | 0.413 |
| PGA | Rock | Quitori99 | 2 | -0.282 | -0.301 | 1.141 | 0.428 | 2 | -0.103 | -0.110 | 0.418 |

**Table 23**: Statistical parameters for PGA for each prediction equation. The presented statistical parameters are: for logarithmic residuals (Y) and normalized logarithmic residuals (Z = Y /σ) the average ( E()),the median (o), the σ of the prediction equation (std) and the median of the likelihood parameter ($LH_0$ ). Also the Scherbaum, 2004 assigned rank for the Z residual and a similar residual assigned to Y residual is presented (Rank). The computation and meaning of this parameters was explained in section 3.

# Shake map: IPE selection

## Contents



## List of figures

---

## List of Tables

# 1 Introduction

The aim of action 4.1 of SISPyr project is to implement a near real time shake map. After action A4.1 bibliographic revision and state of the art (see previous A4.1 SISPyr report) the selected method to determine the proper prediction equations for ground motion and for intensity shake maps was a residuals study.

The applicability of the Ground Motion Prediction Equations (GMPE) and Intensity Prediction Equations (IPE) derived in one region to others, hinges on the question of whether the models derived for one region could be applied to other.

The aim of this study is determine a IPE for the Pyrenees, selecting one of the existing equations, to be used for the computation of shake maps. The equations are no tested properly using their definition of magnitude and within their magnitude and distance validity ranges. If no acceptable results are find with this approach we will improve this treatment.

# 2 Data

We will focus on the A4.1 study region for our study (green box in figure 1), for collecting the data and for implementing the future shake maps. The available macroseimic data from IGC[1] (all the MDPs until 2008); IGN[2] (few, 170) and Sisfrance database[3] (all MDPs $I \geq 3$ until 2007) for the earthquakes with epicenter between latitudes 41.5 to 44 and longitudes - 2.2 to 3.5 were collected.

After this collection the data was homogenized to the same format using different MATLAB scripts. The different steps were:

• Build for each agency a mdp file with agency code of the earthquake and all the available mdp information.

• Build each agency catalogue with information of the earthquakes that have macroseismic data.

• Associate each earthquake after 1976 with macroseismic data with the IGN catalogue (magnitude and localization).

• Associate each earthquake before 1977 with macroseismic data with ISARD catalogue www.isard-project.eu.

After this homogenization procedure and unification in one catalogue, some mdps are loosed due to differences from IGN catalogue and each agency catalogue, we discard loosed mdps coming from earthquakes with $I_0 \leq 5.0$ (we

[1] Institut Geològic de Catalunya - www.igc.cat

[2] Instituto Geográfico Nacional - www.ign.es

[3] www.sisfrance.net

have enough data from this type). The rest of MDPs ($I \geq 5.0$) were inspected with more detail due to their relative importance. The reason of the problems in associating one earthquake from a catalogue to the other is mainly:

• No definition of time: In this case the assignation is done

• No defined in the IGN catalogue: These earthquakes were no used (few)

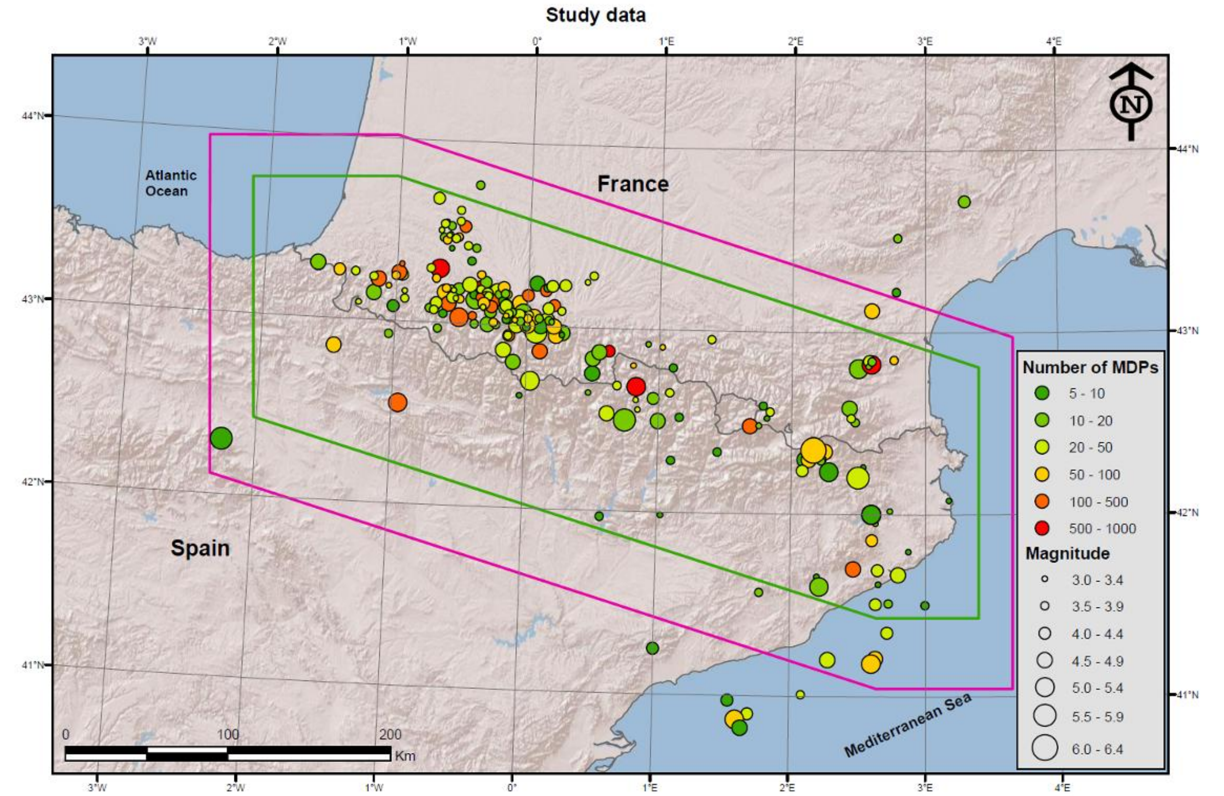



**Figure 1**: *Study earthquakes. The size of the circles indicates the magnitude. The colour scale indicates the number of mdps for each earthquake*

For the bigger earthquakes ($I_o \geq 5$) before 1977, a depth of 8 km is assigned and the expression from Secanell et al. (2008) is used to compute a correlated magnitude;

$$M = 0.503 I_o + 1.491$$

With this process we obtain the raw set of data. In order to study properly the prediction equations we apply the following rejection criteria to raw MDPs:

• Intensity values, $I < 3$.

• MDPs out of the study region (green box of figure 1).

• MDPs coming from earthquakes with magnitude $Ml_{IGN} < 3$.

• MDPs coming from an earthquake with less than 5 MDPs values.

The final data set after this rejection, consists of 233 events in the magnitude (*Mlign*) range from 3.0 to 6.0, with a total of 11 698 MDPs recorded from Pyrenean events. Epicentral distance ranges from 0 to 333 km. Table 1 summarizes the number of MDPs and earthquakes for magnitude range. Table 2 summarizes the number of mdps for each intensity range.

| | 3-3.4 | 3.5-3.9 | 4-4.4 | 4.5-4.9 | 5.0-5.4 | 5.5-5.9 | 6.0-6.4 | Total |
|---|---|---|---|---|---|---|---|---|
| MDPs | 1535 | 1973 | 3167 | 2557 | 1386 | 1024 | 56 | 11698 |
| Earthquakes | 57 | 73 | 38 | 20 | 33 | 11 | 1 | 233 |

**Table 1:** Number of MDPs and number of earthquakes by magnitude ranges

| | 3-3.5 | 4-4.5 | 5-5.5 | 6-6.5 | 7-7.5 | 8-8.5 | 9-9.5 | Total |
|---|---|---|---|---|---|---|---|---|
| MDPs | 4427 | 4667 | 1859 | 494 | 187 | 63 | 1 | 11698 |

**Table 2:** Number of MDPs and by intensity ranges

Figure 2 shows the number of MDPS for each epicentral density bin. How it is observed most of the data comes from epicentral distances between 10 - 100 km. Figures 3 shows the information about the epicentral depth by mdps. Only the half of the earthquakes has information on depth, however most of the MDPs have information on depth

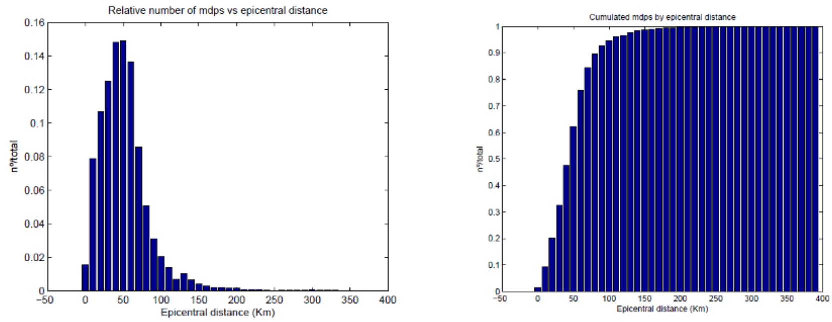



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**Figure 2:** Relative number of MDPs for each epicentral distance bin (left) and comulated number of MDPs by epicentral distance (right)

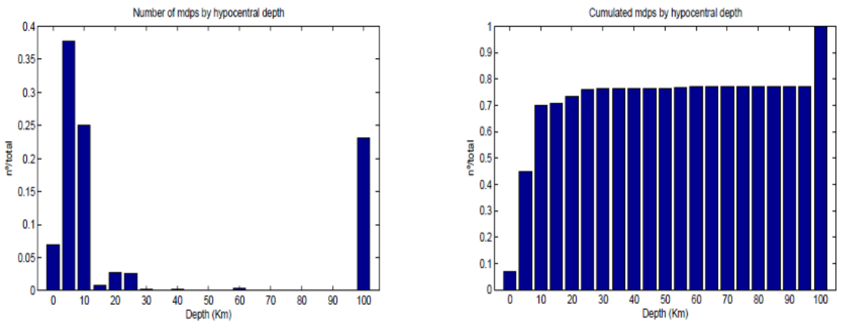


**Figure 3:** Relative number of MDPs for each depth bin (left) and cumulated number of MDPs by depth (right). When don’t exist information on depth 100 km is assigned.

Figures 4 and 5 shows studied earthquake density and ISARD[4] catalogue earthquakes density, respectively.

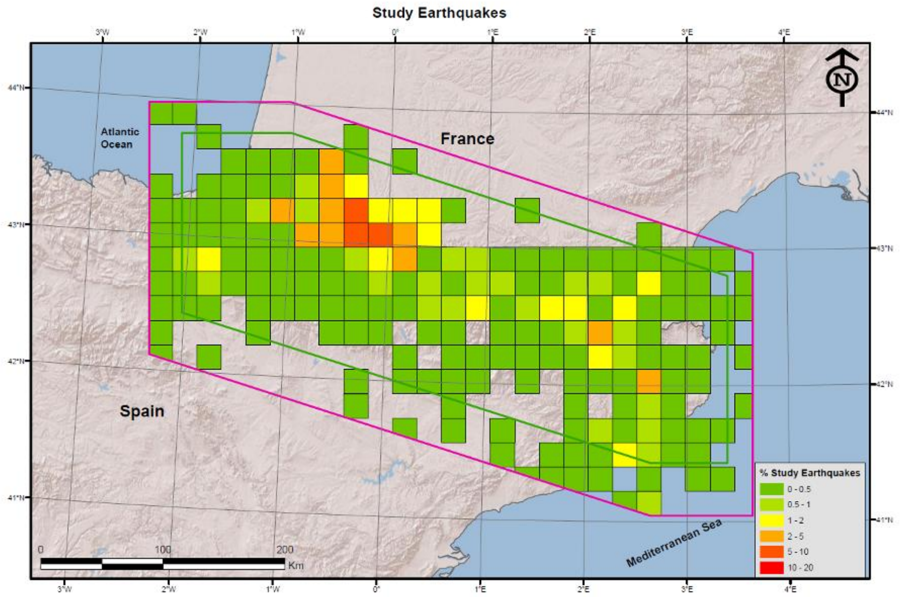


**Figure 4**: Study earthquakes density.

How is seen the relative density (% of the total number of earthquakes) have a similar distribution, so the studied earthquakes represent properly the seismicity of the region.

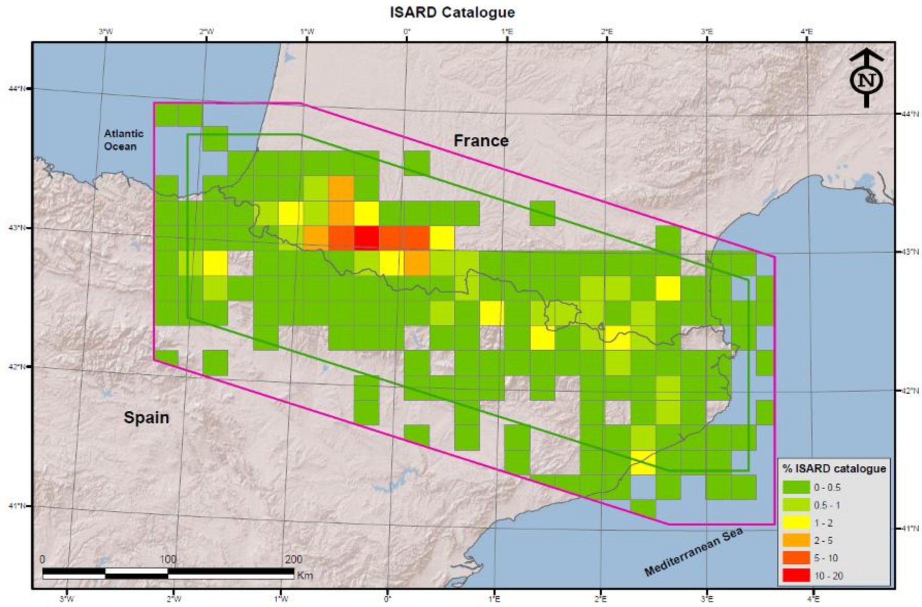


**Figure 5:** Isard Catalogue density earthquakes.

[4] ISARD Interreg Project: hhtp:isard-project.eu

Figures 6, 7 and 8 show, for each 20x20 km cell, the number of mdps, the average intensity value (for cells with more than 5 MDPs) and the maximum intensity value, respectively.

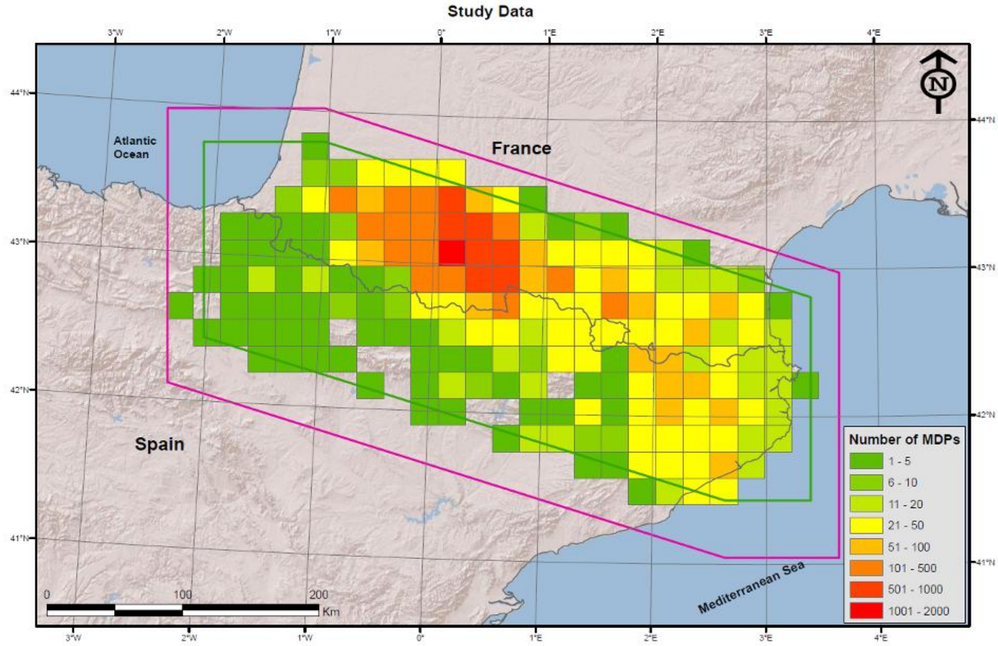


**Figure 6:** Number of MDPs for each 20 km per 20 km cells

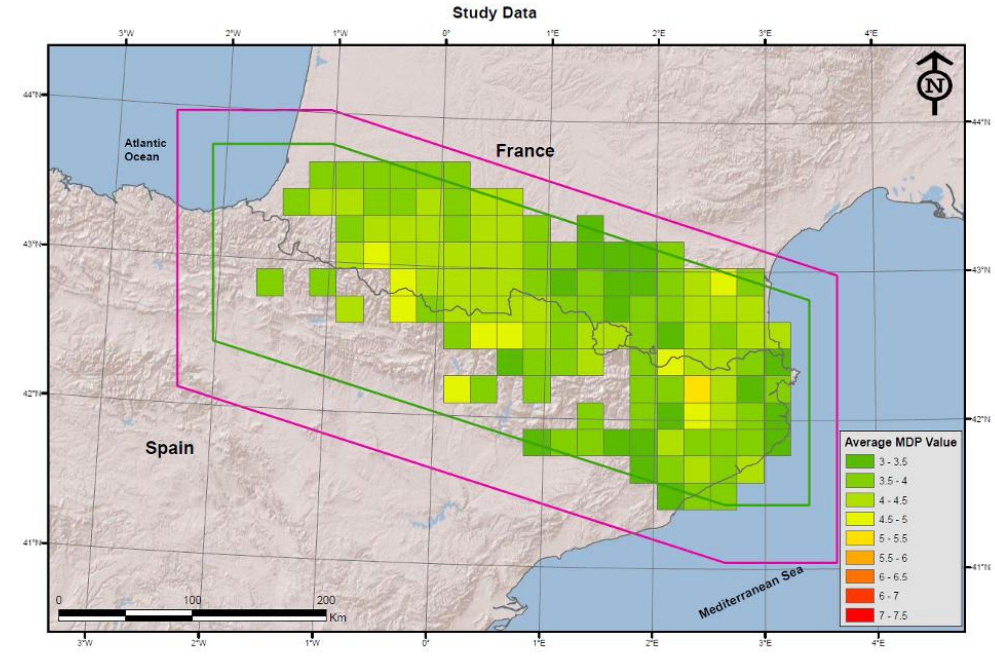


**Figure 7:** Intensity medium value for the cells with more than 5 values.

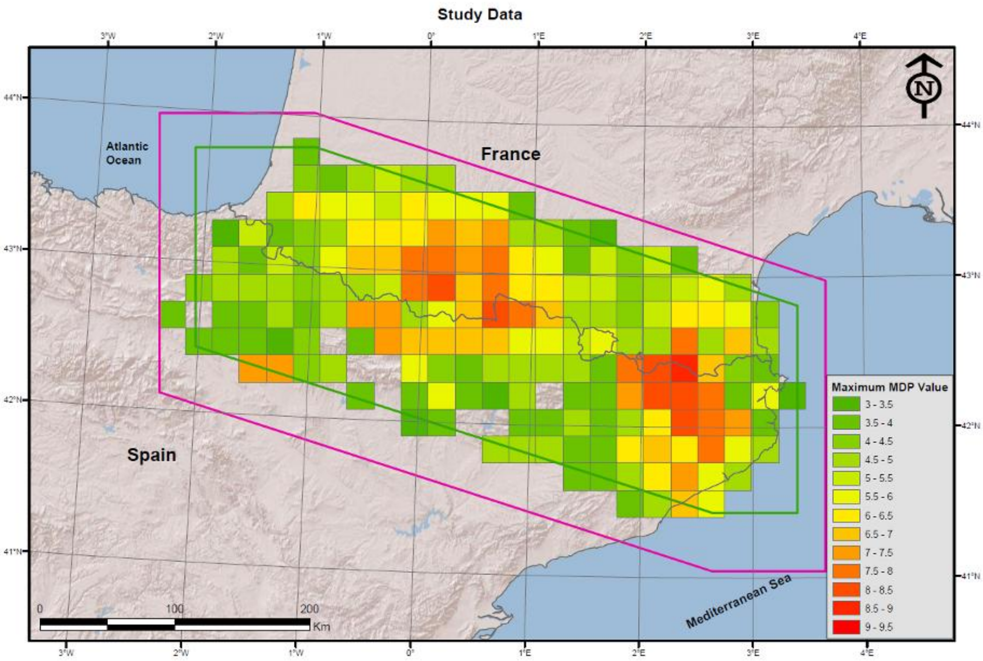


**Figure 8**: Maximum intensity value for each cell.

# 3 Method

Exist several statistics tests that could be applied to determine the goodness-of-fit of a model to a sample of data Scherbaum et al. (2004). The methodology applied in this study consists in evaluate different statistical parameters of different kind of residuals to determine how the model adjust the data and how the model could be generated with this data. It is very similar to the methodology applied in the GMPE selection.

For each intensity value two kinds of residuals are studied:

1. Observed value minus estimated value (we refer to it as *Y)*.

2. Observed value minus estimated value and scaled with the standard deviation (σ) of the model (we refer to it as *Z*).

Next sections explain the computation and the interpretation of these residuals, which and how statistical parameters were computed and how were they studied.

## 3.1 Residuals (Y)

These residuals were computed to determine how the data is adjusted by each prediction equation. They were computed for each observed value with the expression,

$$Y = I_{observed} - I_{predicted} \qquad (1)$$

where $I_{predicted}$ is computed with the prediction equation for the magnitude and distance of the observed value. From these residuals, the median, the average and the standard deviation were computed. They were also plotted versus magnitude range and versus epicentral distances to detect existing trends with these parameters. Similar of what is done in Scherbaum et al. (2004) a ranking was proposed. This is based on three statistical values computed for this residual. This ranking is no tested with other data and it is no based in 'objective' criteria. They are subjective values to assign a single number to the three parameters. The applied criteria are presented in table 3.

| Rank | $\|med(Y)\|$ | $\|\overline{Y}\|$ | $\sigma_Y$ |
|---|---|---|---|
| 1 | $< 0.25$ | $< 0.25$ | $< 1$ |
| 2 | $< 0.50$ | $< 0.50$ | $< 1.25$ |
| 3 | $< 0.75$ | $< 0.75$ | $< 1.5$ |
| 4 | UNACCEPTABLE | | |

**Table 3:** Statistical values conditions for each rank for residual Y. The rank assigned when the conditions are fulfilled.

## 3.2 Normalized residuals (Z)

These residuals are studied in order to estimate the probability of a model to be generated by a defined set of data. Normalized residuals were computed for each observed value by the expression:

$$Z = \frac{I_{observed} - I_{predicted}}{\sigma_{model}} \tag{2}$$

These residuals were studied applying the methodology proposed in Scherbaum et al. (2004). Four statistical parameters were computed: normalized residuals mean (Z), median (med(Z)), standard deviation ($\sigma_Z$) and the median of likelihood parameter ($LH_0$).

A ranking of the different prediction equations is done applying the proposed criteria.

Table 4 shows the values of the statistical values to assign a rank to each IPE. These values are defined in order to allow a ranking between the models. They are an adaptation of the values proposed in *Scherbaum* et al. (2004).

Because of the convenient scaling of the residual Z, a good measure for the goodness-of-fit of the prediction equations is the probability for the absolute value of a random sample from the normalized distribution to fall into the interval between the modulus of a particular observation[5] ($|z_0|$) and ∞. Supposing a Gaussian probability distribution function ($f(z)$) this probability for a value $z_0$ is

$$u(|z_0|) = \int_{|z_0|}^{\infty} f(z)\, dz = \frac{1}{\sqrt{2\pi}} \int_{|z_0|}^{\infty} \exp\left(\frac{-z^2}{2}\right) dz = \frac{1}{2} Erf\left(\frac{|z_0|}{\sqrt{2}} \cdot \infty\right) \tag{3}$$

where $Erf(x_0; x_1) = Erf(x_1) - Erf(x_0)$ is the generalized form of the error function and $u(|z_0|)$ is the likelihood of the residual to be equal to or larger than $|z_0|$. Considering both tails of the distribution for each normalized residual $z_0$ the LH parameter is defined as:

[5] In this case the observations aret he normalized residual

$$LH(|Z_0|) = 2u(|Z_0|) = Erf\left(\frac{|Z_0|}{\sqrt{2}} \cdot \infty\right) \tag{4}$$

replacing $Erf(\infty) = 1$, the LH parameter for each residual ($Z_0$) could be computed with the expression

$$LH(|Z_0|) = 1 - Erf\left(\frac{|Z_0|}{\sqrt{2}}\right) \tag{5}$$

As Erf(x) spans only from 0 to 1, the defined LH parameter spans from 1 to 0. To quantify goodness-of-fit, LH values have some interesting properties Scherbaum et al. (2004):

• LH reaches it maximum value of 1 for Z=0, for an observation that coincides with the predicted value of the IPE.

• LH value decreases with increasing distance from the predicted value. For $|Z|=\infty$ we obtain LH=0.

• If the models assumption are matched exactly (Z having $\mu = 0$ and $\sigma = 1$) the samples of the random variable LH are distributed between 0 and 1.

In order to quantify this distribution of the LH parameter in a single number the median of LH is used, mainly because of its stability regarding outliers. To better understand the behaviour of the LH statistics, figure 9 presents some examples.

This separated analysis will give a first idea of the sensitivity of our results for different variables.

## 3.3 Approximations and criteria.

Different approximations and criteria are applied to do this study (see Table 4):

| Rank | $med(LH)$ | $\|med(Z)\|$ | $\|\overline{Z}\|$ | $\sigma_Z$ |
|---|---|---|---|---|
| 1 | $> 0.4$ | $< 0.25$ | $< 0.25$ | $< 1.125$ |
| 2 | $> 0.3$ | $< 0.50$ | $< 0.50$ | $< 1.25$ |
| 3 | $> 0.2$ | $< 0.75$ | $< 0.75$ | $< 1.50$ |
| 4 | UNACCEPTABLE | | | |

**Table 4:** *Statistical values conditions for each rank. The rank is assigned when the four conditions are fulfilled*.

• Magnitude is preferred than *I*0 for source identification, due to the properties of each of the variables and available automatic data for the generation of Shake maps (Pasolini et al., 2008a; Pasolini et al., 2008b).

• Two kind of prediction equations are tested, the ones where source is described with *I*0 and the ones where it is described by magnitude. For shakemap purposes we need to have the prediction equations as a function of magnitude. For these reasons, equations that depend on *I*0 are redefined in function of magnitude using a magnitude vs $I_0$ correlation. For our study we use the relation used in ISARD project ("teleavís"'):

$I_0 = -2.9297 + 1.921M$ if $h < 12$ km

$I_0 = -3.4297 + 1.921M$ if $h > 12$ km

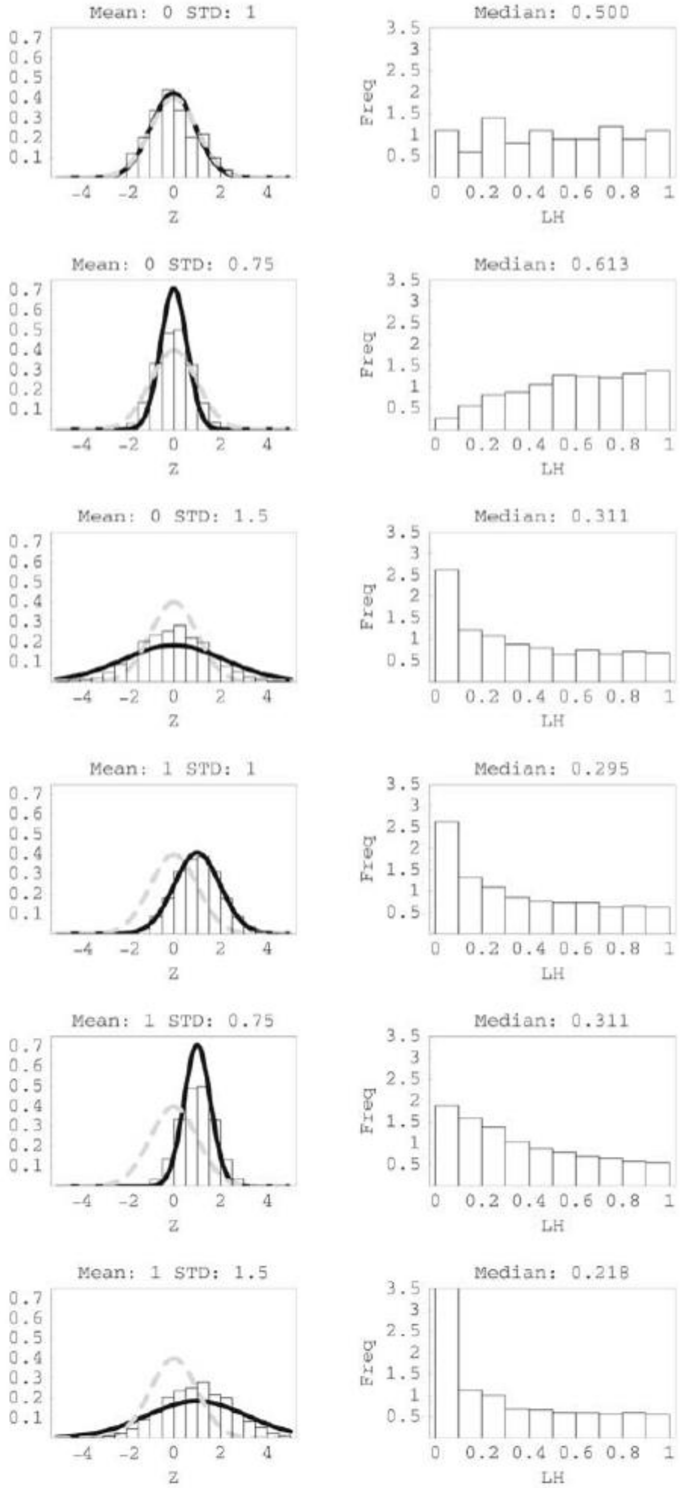


**Figure 9**: Distribution of residuals (left panels) and corresponding LH values (right panels) for different simulated distributions (the possible combinations of mean=0 or 1 and sigma= 0.75, 1 or 1.5). Mean values and standard deviations or the residual distributions are indicated on tops of the left panels. The two distribution functions in the left panel indicate the unit variance normal distribution and the actual residual distribution, respectively. On top of the right panels the median values of the resulting LH-value distributions are displayed. Adapted from Scherbaum et al. (2004).

• IGN magnitude and localization were used (We use IGN catalogue to unify all the data). This magnitude is used supposing it has been constant during all the period (however the network and the magnitude definition have changed). For the bigger earthquakes ($I_0 \geq 6$) with no associated magnitude in the IGN catalogue, a depth of 8 km is assigned and the expression derived from Secanell et al. (2008) is used to compute a correlated magnitude:

$$M = 0.503 I_o + 1.491$$

• $I_0$ value for each earthquake is the bigger of the different used catalogues.

• The different intensity scales are supposed to be the same Cabañas et al. (2009).

• The size of the source is not considered, neither for the bigger ones.

• When the depth is no determined, by default, the medium depth of the mdps with depth assignation (around 8 km) is assigned to the records without depth assigned.

• The site effects are no considered, so the data contains mixed amplifications patterns.

• When no available sigma exists it is fixed to 0.7. This is considered in the Z residuals interpretation.

• Only earthquakes with 5 or more mdps are used in order to include enough information of each.

• The normalized residuals are distributed in bins of 0.2 according to the quantity of data.

## 3.4 Tested IPE

Due to the big amount of existing IPE a selection was done. The selected equations are the exiting in the Pyrenees, most important from Iberia and France, few from Europe and some of the already programmed in ShakeMap USGS scripts. Tested prediction equations with their main characteristics are presented in table 5. The general form of each model is presented in table 6.

| Reference | Code | M | R (Km) | I | M type | I scale | Model $\sigma$ | Region |
|---|---|---|---|---|---|---|---|---|
| Levret (1994) | Levret1994-$I_0$ | 0 | 0 | 0 | Ml or Md | 0 | 0 | France |
| Jimenez and Garcia-Fernandez (1999) | Jimenez1999-M | 0 | 0 | 0 | - | 0 | - | Portugal |
| Jimenez and Garcia-Fernandez (1999) | Jimenez1999-$I_0$ | 0 | 0 | 0 | 0 | 0 | - | Spain |
| Mezcua et al. (2004) | Mezcua2004-M | 5.0-8.0 | 0 | 0 | Mw | 0 | - | Iberian peninsula |
| Secanell (2004) | Secanell2004-M | 0 | 0 | 0 | m | 0 | - | Catalonia |
| Marin et al. (2004) | Marin2004-M | 0 | 0 | 0 | Ml | MSK | 0.5 | 0 |
| Bakun and Scotti (2006) | BakunScotti2006-M | 4.9-6 | <150 | 3-7 | Mw | MSK | 0.65 | Pyrenees france |
| Atkinson and Wald (2007) | AtkinWald12007-M | 2.3-7.8 | 2-500 | 2-10 | Mw | MMI | 0.4 | Clifornia |
| Atkinson and Wald (2007) | AtkinWald22007-M | 2-7.8 | 6-1000 | 2-11 | Mw | MMI | 0.4 | ENA |
| Secanell et al. (2008) | Secanell12008-$I_0$ | 0 | 0 | 0 | 0 | 0 | 0.9 | Catalonia |
| Secanell et al. (2008) | Secanell22008-$I_0$ | 0 | 0 | 0 | 0 | 0 | 0.98 | Catalonia |
| Pasolini (2008) | Pasolini2008-$I_0$ | 0 | 0 | 0 | 0 | 0 | 0.69 | 0 |
| Pasolini (2008) | Pasolini2008-M | 4.4-7.4 | 1-200 | 4-11 | 0 | 0 | 0.69 | 0 |
| Secanell (2008) | Isard2008-M | 0 | 0 | 0 | 0 | 0 | 0.5 | Pyrenees |
| Trevor and Allen (2009) | Allen2009-M | 0 | 0 | 0 | 0 | 0 | 0.61746 | 0 |
| Stromeyer (2009) | Stromeyer2009-$I_0$ | 2.4-5.7 | <400 | 3-7.5 | Mw | 0 | 0.687 | Germany, France, Neth, and Czech Republic |
| Sorensen (2009) | Sorensen2009-M | 5.9-7.4 | 1-350 | 5-10 | Mw | EMS-98 | 0.7 | Turkey (Marmara sea) |
| Trevor and Allen (2010) | TrevorAllen2010-M | 4.9-7.9 | <300 | 3-10 | 0 | 0 | 0.73 | 0 |
| Gomez (2010) | Gomez2010-M | 0 | 0 | 0 | 0 | 0 | 0.72 | Iberia |

**Table 5:** Summary of the main Characteristics of the tested GMPE (Based on originals references and/or derived studies).

| Code | General expression | Source input variable | X | R |
|---|---|---|---|---|
| Levret (1994)-$I_0$ | $I = a1 + a2M + a3X$ | M | 0 | 0 |
| Jimenez and Garcia-Fernandez (1999)-M | $I = a1 + a2M + a3X$ | M | $\ln(R)$ | $R_{hypo} + 14$ |
| Jimenez and Garcia-Fernandez (1999)-$I_0$ | $I = a1 + aoIo + a3X$ | $I_0$ | $\ln(R)$ | $R_{hypo} + 25$ |
| Mezcua et al. (2004) | $I = a1 + a2M + a3X$ | M | $\log(R)$ | median epicentral |
| Secanell (2004)-M | $I = a1 + a2M + a3X + a5 \log h$ | M | $\log(R)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Marin et al. (2004)-M | $I = a1 + a2M + a3X$ | M | $\log_{10}(R)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Bakun and Scotti (2006)-M | $I = a1 + a2M + a3X$ | M | $\log(R)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Atkinson and Wald (2007)-M | $I = a1 + a2(M-6) + a4(M-6)^2 + a3X + a5R + a6B + a7M \log R$ | M | $\log R$ | $\sqrt{(D_{epi}^2 + 14^2)}$ |
| Atkinson and Wald (2007)-M | $I = a1 + a2(M-6) + a4(M-6)^2 + a3X + a5R + a6B + a7M \log R$ | M | $\log R$ | $\sqrt{(D_{epi}^2 + 17^2)}$ |
| Secanell et al. (2008)-$I_0$ | $I = I_0 + a1 + a6R + a3X$ | $I_0$ | $\log_{10}(R)$ | $D_{epi}$ |
| Secanell et al. (2008)-$I_0$ | $I = I_0 + a3X + a1 + a6R$ | $I_0$ | $\log_{10}(R/8.89)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Pasolini (2008)-$I_0$ | $I = aoI_0 + a1 + a3X + a6R$ | $I_0$ | $\ln(R)$ | $\sqrt{(D_{epi}^2 + 3.91^2)}$ |
| Pasolini (2008)-M | $I = a1 + a2M + a3X + a6R$ | M | $\ln(R)$ | $\sqrt{(D_{epi}^2 + 3.91^2)}$ |
| Isard (2008)-M | $I = I_0 + a3X + a6(R-h)$ | $I_0$ | $\log_{10}(R)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Allen and Wald (2010)-M | $I = a1I_0 + a2M + a3X + a6B$ | M | $\ln(\sqrt{(R^2 + (1 + a4\, e^{(M-5)})^2)})$ | $R_{JB}$ |
| Stromeyer (2009)-$I_0$ | $I = I_0 + a3X + a6(R-h)$ | $I_0$ | $\log_{10}(R/h)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Sorensen (2009)-M | $I = a1 + a2M + a3X + a6(R-h)$ | M | $\log_{10}(R/h)$ | $\sqrt{(D_{epi}^2 + h^2)}$ |
| Trevor and Allen (2010)-M | $I = a1 + a2M + a3X$ | M | $\ln(\sqrt{(R^2 + (1 + 0.72\, e^{(M-5)})^2)})$ | Hypocentral |
| Gomez (2010)-M | $I = a1 + a2M + a3X + a6R$ | M | $\ln(\sqrt{(R^2 + (1 + 0.72\, e^{(M-5)})^2)})$ | Hypocentral |

**Table 6:** General forms of the selected equations.

| IPE/Magnitude | 3.0-3.4 | | 3.5-3.9 | | 4.0-4.4 | | 4.5-4.9 | | 5.0-5.4 | | 5.5-5.9 | | 6.0-6.4 | | All data | | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Residual | Z | Y | Z | Y | Z | Y | Z | Y | Z | Y | Z | Y | Z | Y | Z | Y | |
| Jimenez1999-M | 4 | 1 | 4 | 2 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 1 | 4 | 4 | 54 |
| Jimenez1999-Io | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 3 | 2 | 4 | 4 | 59 |
| Mezcua2004-M | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 2 | 4 | 2 | 4 | 4 | 4 | 3 | 57 |
| Secanell2004-M | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 2 | 4 | 3 | 4 | 2 | 4 | 4 | 57 |
| Marin2004-M | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 4 | 57 |
| BakunScotti2006-M | 4 | 4 | 4 | 3 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 4 | 2 | 51 |
| AtkinWald12007-M | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 64 |
| AtkinWald22007-M | 4 | 4 | 4 | 3 | 4 | 1 | 4 | 1 | 4 | 2 | 4 | 1 | 4 | 3 | 4 | 1 | 48 |
| Secanell12008-Io | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 1 | 1 | 2 | 1 | 2 | 2 | 4 | 4 | 47 |
| Secanell22008-Io | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 4 | 4 | 42 |
| Pasolini2008-Io | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | 61 |
| Pasolini2008-M | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 2 | 1 | 4 | 4 | 58 |
| Isard2008-M | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 2 | 4 | 1 | 4 | 1 | 2 | 1 | 4 | 4 | 50 |
| Allen2009-M | 4 | 4 | 4 | 4 | 2 | 2 | 3 | 3 | 2 | 2 | 3 | 3 | 4 | 4 | 4 | 3 | 51 |
| Stromeyer2009-Io | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 1 | 4 | 3 | 48 |
| Sorensen2009-M | 4 | 2 | 4 | 3 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 59 |
| TrevorAllen2010-M | 4 | 4 | 4 | 4 | 3 | 2 | 4 | 3 | 3 | 2 | 4 | 3 | 4 | 4 | 4 | 3 | 55 |
| Gomez2010-M | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 1 | 3 | 2 | 2 | 1 | 4 | 4 | 48 |
| Total general | 72 | 67 | 72 | 67 | 68 | 58 | 66 | 52 | 61 | 43 | 65 | 44 | 55 | 41 | 72 | 63 | 966 |

**Table 7:** Summary of ranks for each prediction equation and magnitude ranks are filled with red colour.

# 4 Results

## 4.1 IPE

For each tested prediction equation and range of magnitude the statistical parameters presented in section 3 are computed for selected MDPs. The results for the statistical parameters computed for these residuals are presented in appendices A - E. Appendix A presents the summary of the results obtained by each model. For each parameter and model four plots are presented (see figure 10):

• The LH statistical with a header presenting the computed mean, median and standard deviation of the normalized residuals, the LH median and the rank assigned by the Scherbaum method.

• The normalized residuals distribution, a Gaussian with the median and standard deviation of the data in green and a standard Gaussian (mean=0, $\sigma$ = 1) in black.

• Residuals versus epicentral distance.

• Residuals versus IGN magnitude.

The computed statistical parameters and assigned ranks for each model are also presented in table 11 of appendix A. Appendix C summarizes the computed statistical parameters for Y and Z residuals and the magnitude ranges with an acceptable rank assignation (rank ≤ 3). Appendix D and E present the normalized residuals distribution and the residuals distribution by magnitude range, respectively.

Table 7 summarizes the results for each tested equation. This table is a summary of the forward discussion. To take a first overview on the possible acceptable IPEs and the ones that are completely unacceptable, appendix F shows the plot of studied parameters versus epicentral distance, with the predicted values with each IPE by ranges of magnitude. The aim of this first overview is only to have a first idea of acceptance of each prediction equation. This subsection describes and summarizes the interpretation of tested IPEs. This interpretation is based on the results presented in tables and figures of appendixes A, B, C, D and E. We can say that for most of IPEs:

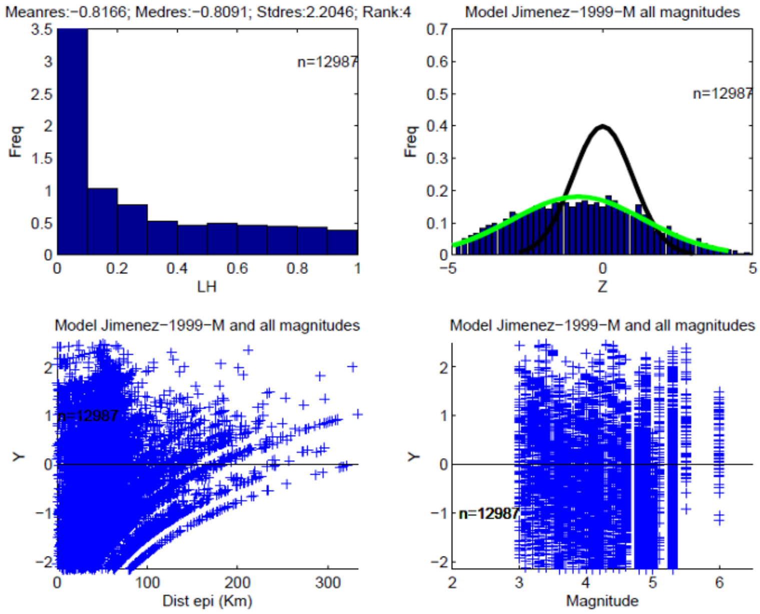


**Figure 10:** Summary of results obtained with all the data and IPE Jimenez and Garcia-Fernandez, 1999. From up left to down right: LH statistical with assigned Z rank, normalized residuals distribution, residuals versus epicentral distance and residuals versus IGN magnitude.

• Best ranks are obtained for bigger earthquakes (it is expected as most of equations are defined for this magnitude range). Lower magnitude range has bigger standard deviation (probably due the uncertainty of these ranges). Also bigger earthquakes have less variance.

• Y residuals have different pattern for different magnitude ranges.

• Studied data present bigger deviation than the expected by the prediction equations. This causes that Z residuals values are usually unacceptable.

Ranking is than analysed using only Y residuals criteria.

# 5 Discussion and conclusions

According to the obtained results:

• Collected data is useful and of enough quality to select the best IPEs in the range of magnitude 3.0 - 6.0 and epicentral distances < 300*km* for the Pyrenees.

• Different patterns observed with all IPEs, indicate the importance of using different prediction equations for smaller and for bigger earthquakes.

• Proposed method, combining two types of residuals, is useful to select the bests prediction equation and discard the worsts.

• The site effects are included on intensity values. In order to have them better into account we will suppose that all the data comes from B soil class (most of the villages, especially big ones, on valleys) in order to no overestimate the amplification value to apply to the estimated value generated with IPE for the generation of the maps.

• Some of tested IPEs predict with enough quality the observed Intensity values, although we don't take into account the proper magnitude and range of validity definition. By now, it's no necessary to test more IPEs, because the tested ones are representative and obtain acceptable results for shake map implementation.

• To select IPEs to be used, and looking for coherence and robustness, the results obtained for different statistical parameters and different ranges of magnitudes should be taken into account (when it is possible).

• With this study we determine the best IPEs without taking into account ShakeMap v3.5 bias calculation[6]. According to this bias calculation some IPEs that obtain bad ranks according to bad values for average and median could be used successfully for predicting the values within ShakeMap v3.5. This are expected to be IPEs that obtain low values of $\sigma$ in both residuals, especially in Y residuals. For our study these IPEs are: Jimenez and Garcia-Fernandez (1999), Pasolini (2008a)-M, Pasolini (2008b)-$I_0$ and Atkinson and Wald (2007)-M.

• For $M \geq 4.0$ some IPEs obtain acceptable results for Y residuals. The best ones are obtained by: Jimenez and Garcia-Fernandez (1999), Mezcua et al. (2004), Marin et al. (2004), Atkinson and Wald (2007), Trevor and Allen (2009) and Allen and Wald (2010) obtain the best results for Y residuals. However for Z residuals the most acceptable IPE in this range of magnitude (4.0 - 6.0) is Isard-2008 (Goula et al., 2008).

[6] Shakemap v3.5. bias computation procedure consist in change the defined magnitude to obtain better adjustment between the predicted value and the observed value. The magnitude that obtains lower misfit is selected. This magnitude bias is applied to estimate all the values.

According to these we conclude for the implementation of ShakeMap v3.5:

• To use Isard (2008) as default IPE for the prediction of intensity values in the magnitude range [3.5 - 6], as it obtains the best results and they are good ones.

For the final Shakemap we used only Isard (2008) for the all the ranges of magnitude

# 6 Proposed improvements

Possible improvement to this study (depending on availability of time) is:

• Verify and improve these results with a common study of Ground Motion Prediction Equations, Intensity Prediction Equations and conversion equations, relating both parameters (GMICE and IGMCE)[7].

• When the SISPyr simplification map is available, mdps could be associated to their estimated amplification, and test intensity prediction equations taking into account site effects.

# 7 References

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[7] GMICE: Ground Motion to Intensity Conversion Equation; IGMCE: Intensity to Ground Motion conversion equation.

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# Appendix

# A Results summary by models. Table

This appendix presents a summary of the results obtained for the parameters and for the tested equations. Table 11 shows the results obtained for the studied statistical parameter for each residuals type.

| IPE | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|
| Jimenez-1999-M | 4 | -1.312 | -1.390 | 1.403 | 0.139 | 4 | -0.919 | -0.973 | 0.982 |
| Jimenez1999-Io | 4 | 1.316 | 1.089 | 2.144 | 0.118 | 4 | 0.921 | 0.762 | 1.501 |
| Mezcua2004-M | 4 | 0.740 | 0.684 | 1.676 | 0.237 | 3 | 0.518 | 0.479 | 1.173 |
| Secanell2004-M | 4 | 0.955 | 0.631 | 2.255 | 0.154 | 4 | 0.668 | 0.442 | 1.578 |
| Marin2004-M | 4 | 1.150 | 1.005 | 1.816 | 0.180 | 4 | 0.805 | 0.704 | 1.271 |
| BakunScotti2006-M | 4 | -0.226 | -0.287 | 1.856 | 0.187 | 2 | -0.147 | -0.187 | 1.206 |
| AtkinWald12007-M | 4 | 2.470 | 2.405 | 2.149 | 0.013 | 4 | 0.988 | 0.962 | 0.860 |
| AtkinWald22007-M | 4 | 0.274 | 0.221 | 2.269 | 0.133 | 1 | 0.110 | 0.088 | 0.908 |
| Secanell12008-Io | 4 | 1.051 | 0.974 | 1.345 | 0.263 | 4 | 0.946 | 0.877 | 1.210 |
| Secanell22008-Io | 3 | 0.611 | 0.488 | 1.276 | 0.387 | 3 | 0.599 | 0.478 | 1.251 |
| Pasolini2008-Io | 4 | 2.331 | 2.135 | 2.026 | 0.029 | 4 | 1.608 | 1.473 | 1.398 |
| Pasolini2008-M | 4 | 2.835 | 2.625 | 2.233 | 0.008 | 4 | 1.956 | 1.811 | 1.541 |
| Isard2008-Io | 4 | 1.286 | 1.039 | 2.521 | 0.085 | 3 | 0.643 | 0.520 | 1.261 |
| Allen2009-M | 3 | 0.586 | 0.444 | 1.101 | 0.465 | 2 | 0.444 | 0.403 | 0.920 |
| Stromeyer2009-Io | 4 | 0.755 | 0.603 | 1.806 | 0.229 | 3 | 0.518 | 0.415 | 1.241 |
| Sorensen2009-M | 4 | -1.683 | -1.747 | 1.361 | 0.076 | 4 | -1.178 | -1.223 | 0.952 |
| TrevorAllen2010-M | 3 | 0.692 | 0.632 | 1.283 | 0.347 | 3 | 0.505 | 0.461 | 0.937 |
| Gomez2010-M | 4 | 0.919 | 0.761 | 1.771 | 0.221 | 3 | 0.662 | 0.548 | 1.275 |

**Table 8:** Statistical parameters for all the data and prediction equations. The presented statistical parameters are: for logarithmic residuals (Y ) and normalized logarithmic residuals (Z = Y/σ) the average (E(Z)), the median (o), the σ of the prediction equation (std) and the median of the likelihood parameter ($LH_0$). Also the Scherbaum, 2004 assigned rank for the Z residual and a similar residual assigned to Y residual is presented (Rank). The computation and meaning of this parameters was explained in section 3.

# B Results summary by models. Graphics

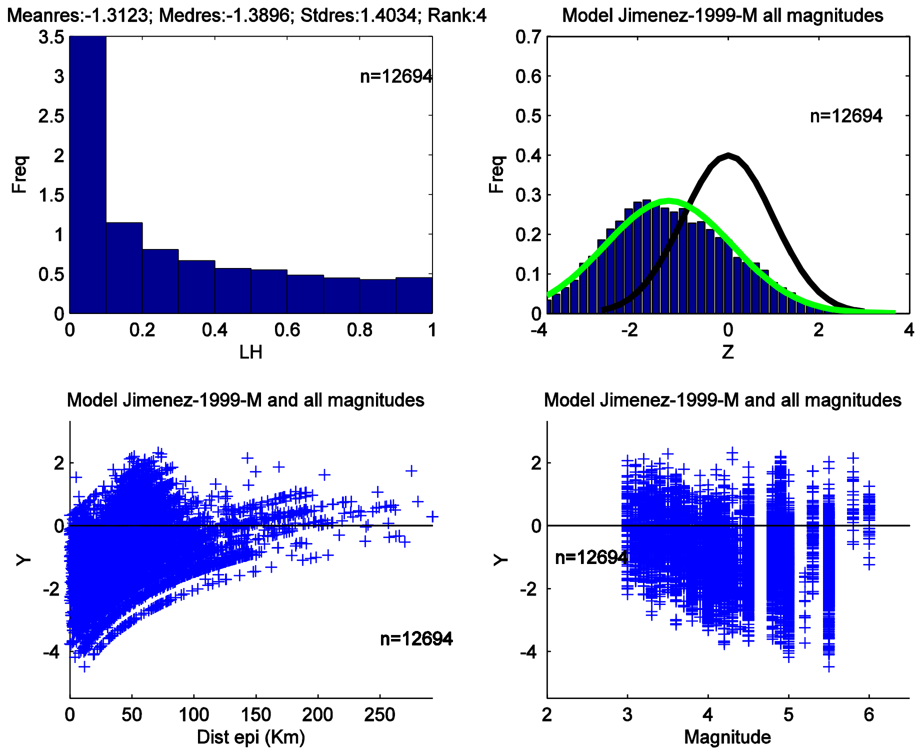



**Figure 11**: Summary of the results obtained with all data for Jimenez-1999-M.

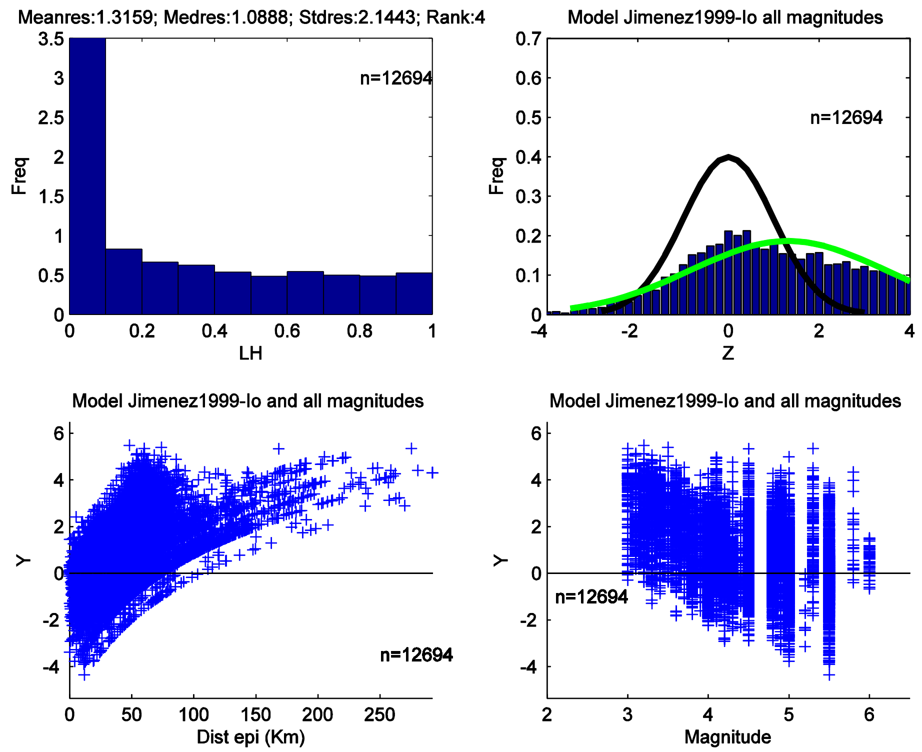



**Figure 12**: Summary of the results obtained with all data for Jimenez1999-Io.

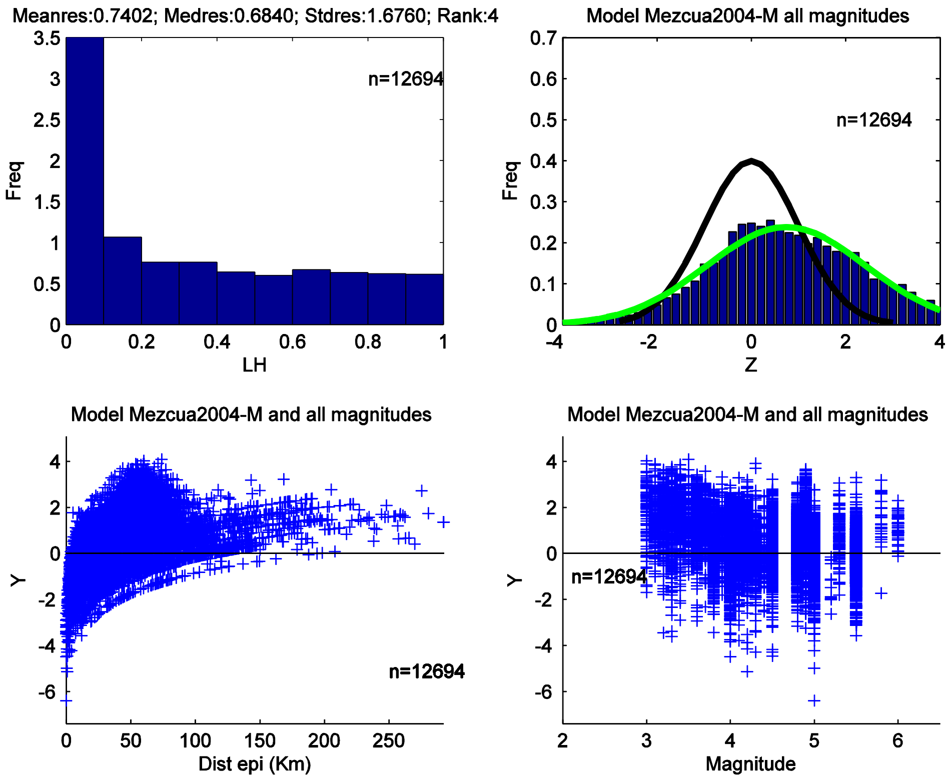



**Figure 13**: Summary of the results obtained with all data for Mezcua2004-M.

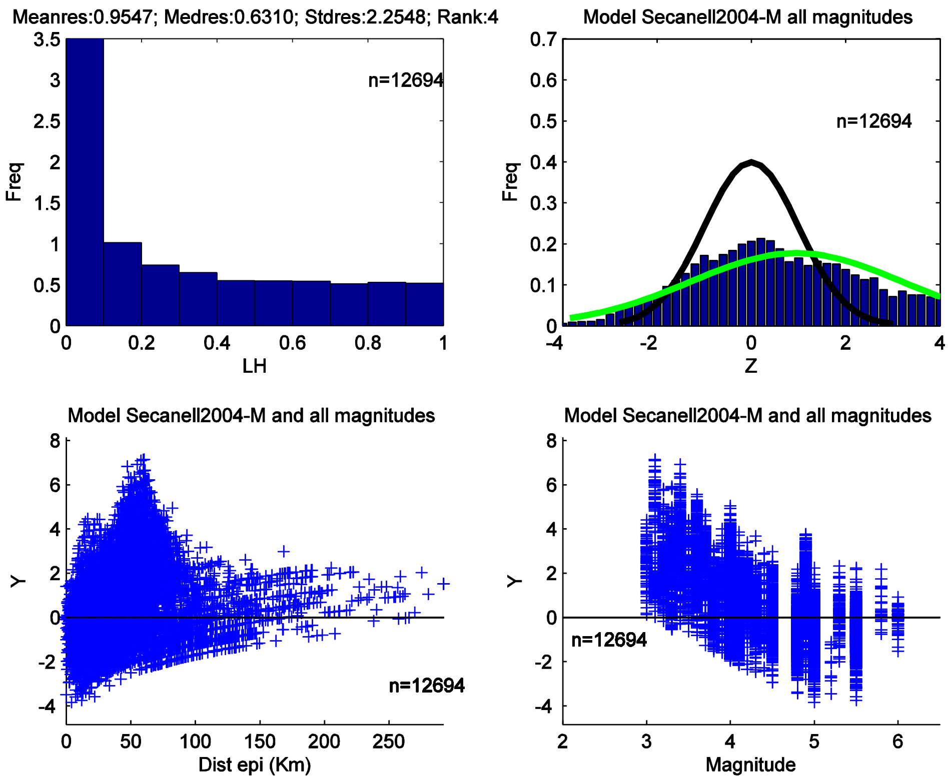



**Figure 14**: Summary of the results obtained with all data for Secanell2004-M.

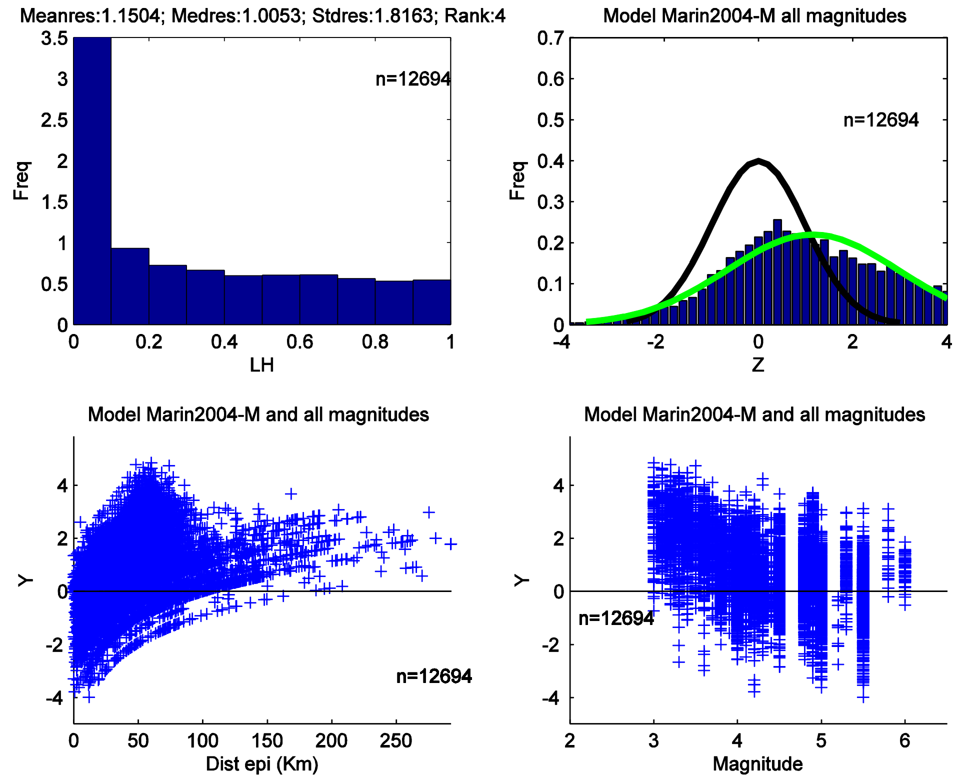



**Figure 15**: Summary of the results obtained with all data for Marin2004-M.

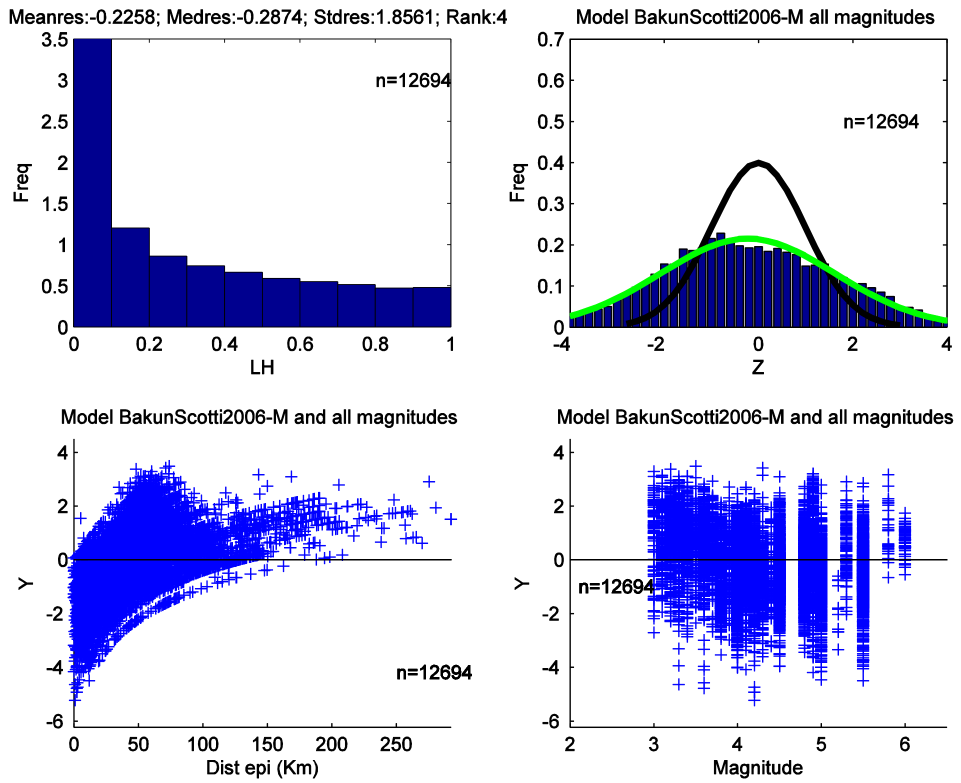



**Figure 16**: Summary of the results obtained with all data for BakunScotti2006-M

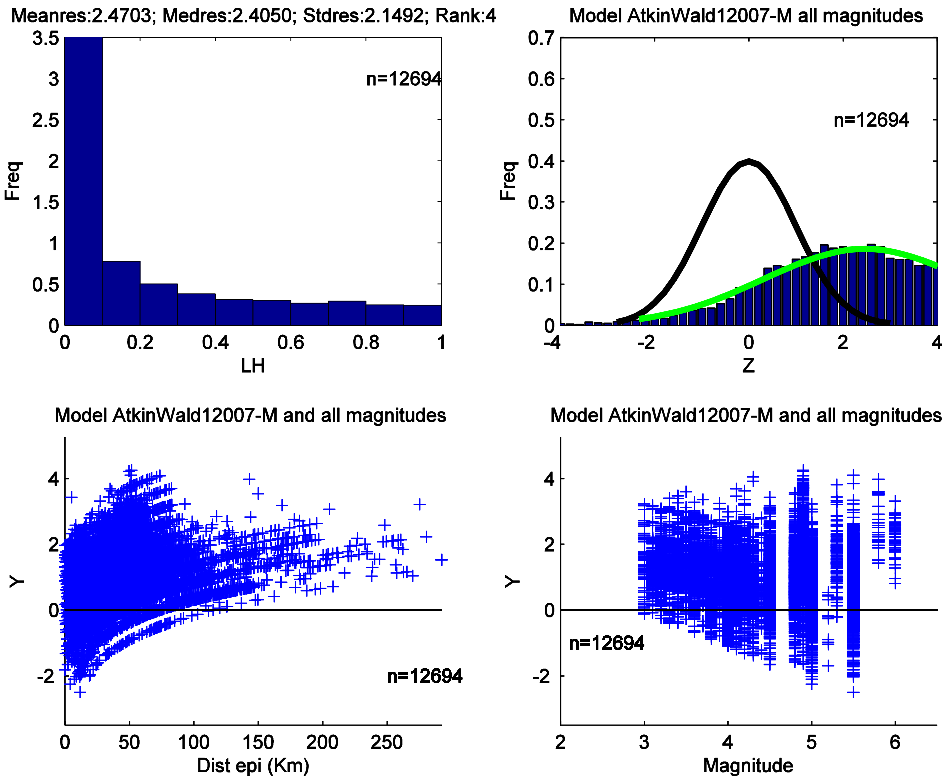



**Figure 17**: Summary of the results obtained with all data for AtkinWald12007-M.

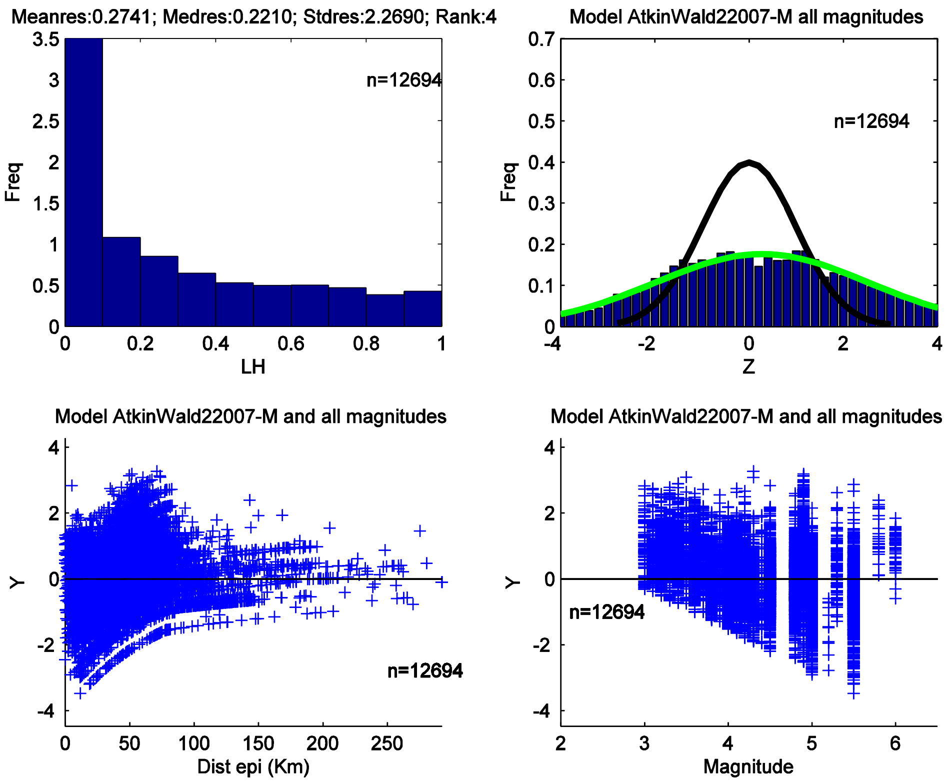



**Figure 18:** Summary of the results obtained with all data for AtkinWald22007-M.

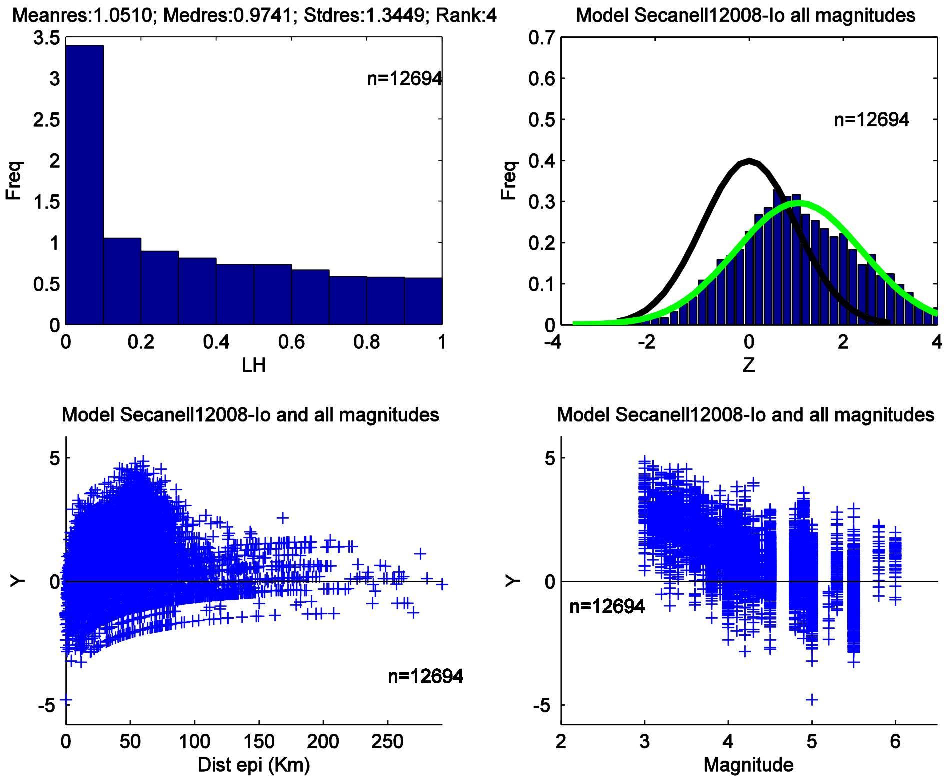



**Figure 19**: Summary of the results obtained with all data for Secanell12008-Io

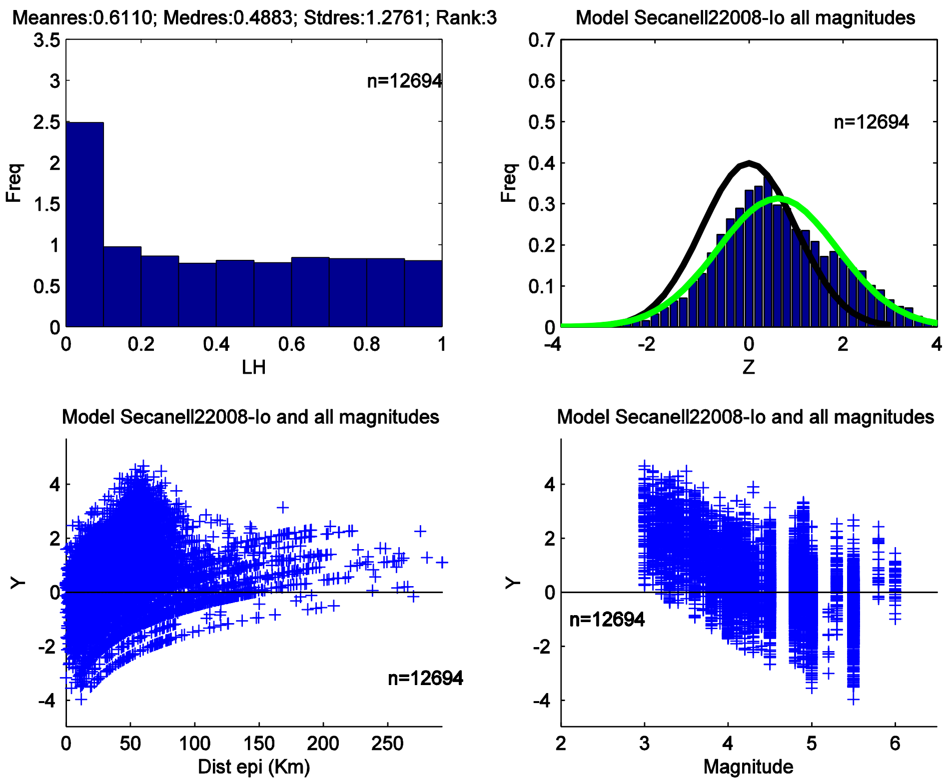



**Figure 20**: Summary of the results obtained with all data for Secanell22008-Io.

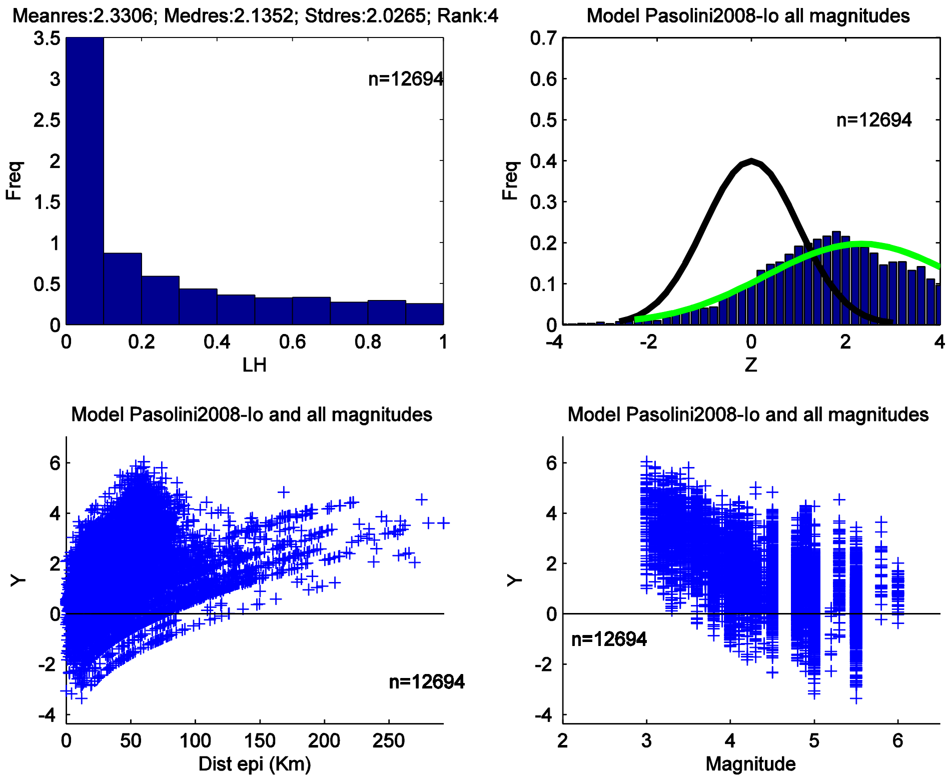



**Figure 21**: Summary of the results obtained with all data for Pasolini2008-Io.

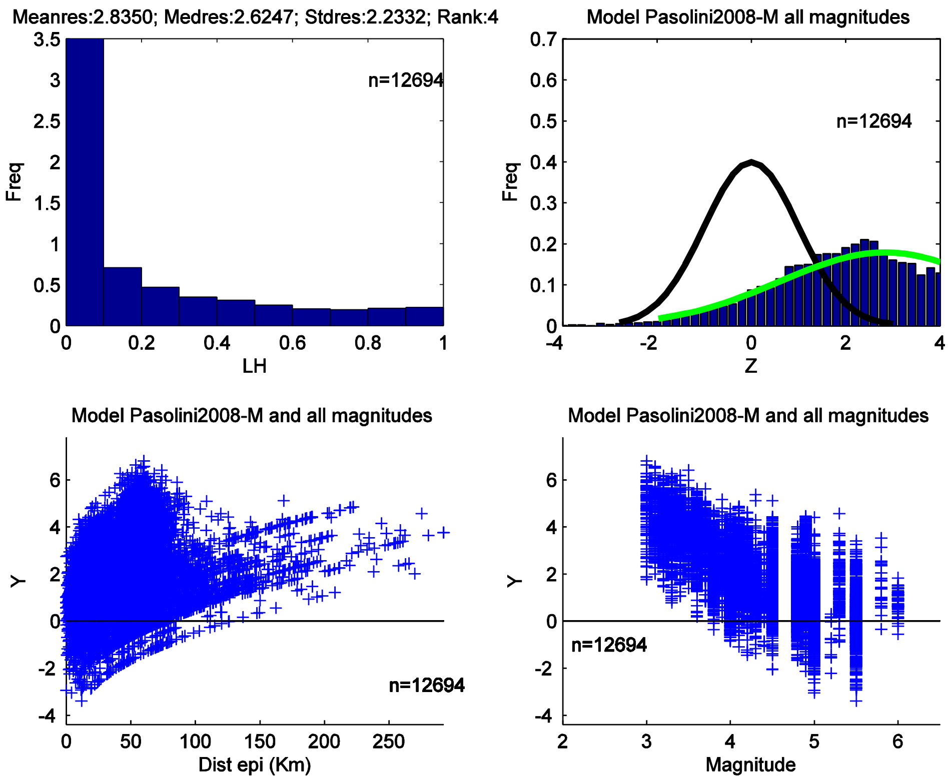



**Figure 22**: Summary of the results obtained with all data for Pasolini2008-M.

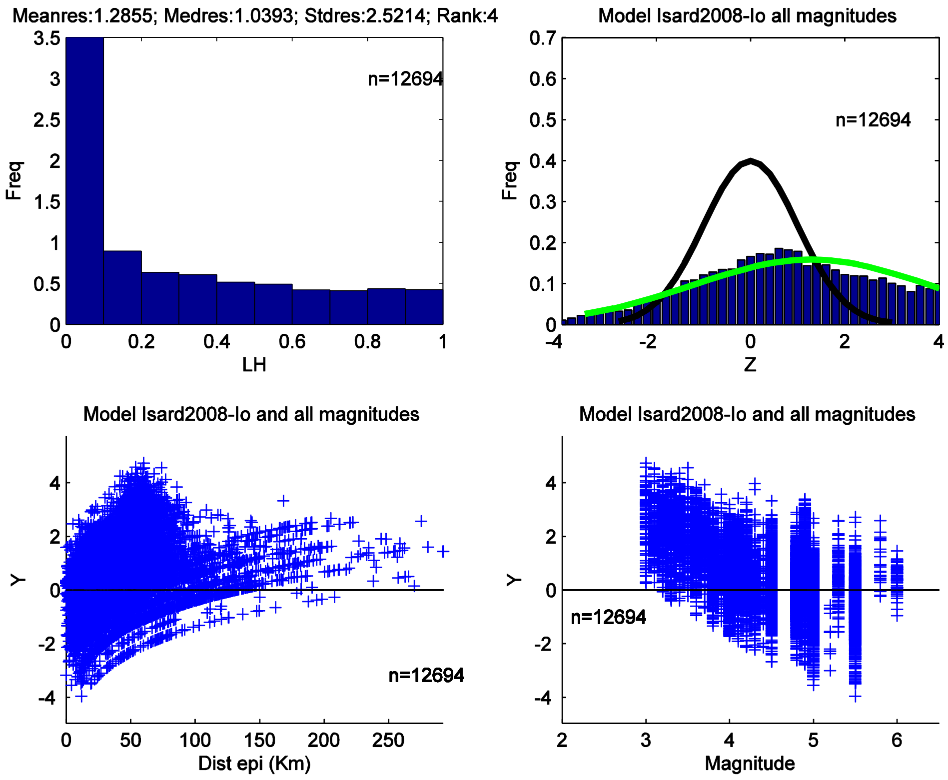



**Figure 23**: Summary of the results obtained with all data for Isard2008-Io.

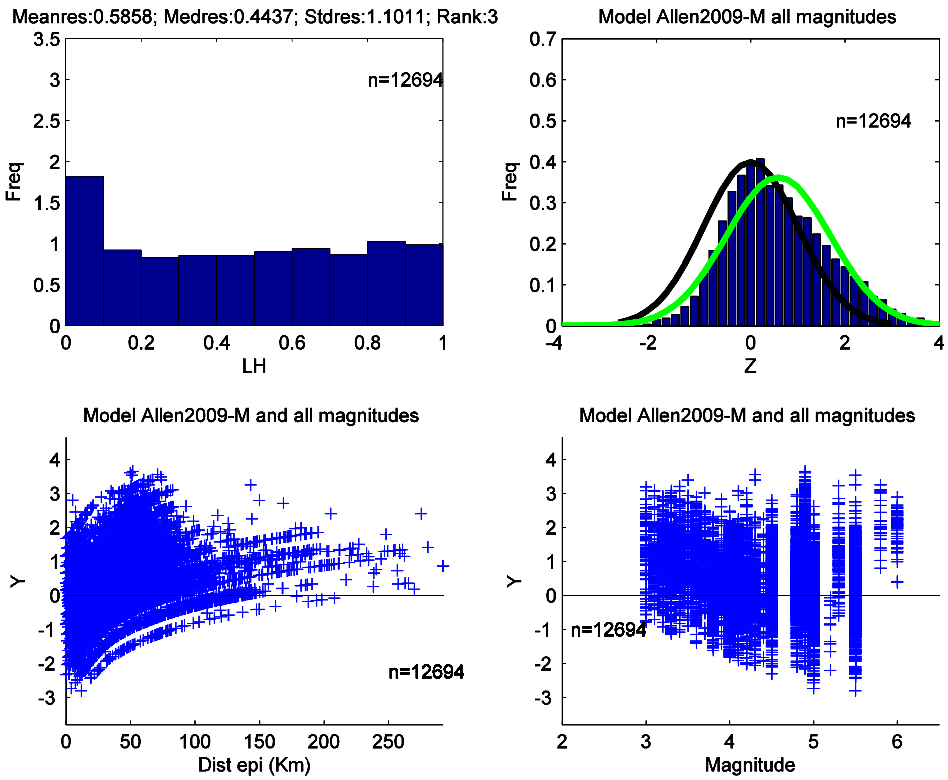



**Figure 24**: Summary of the results obtained with all data for Allen2009-M

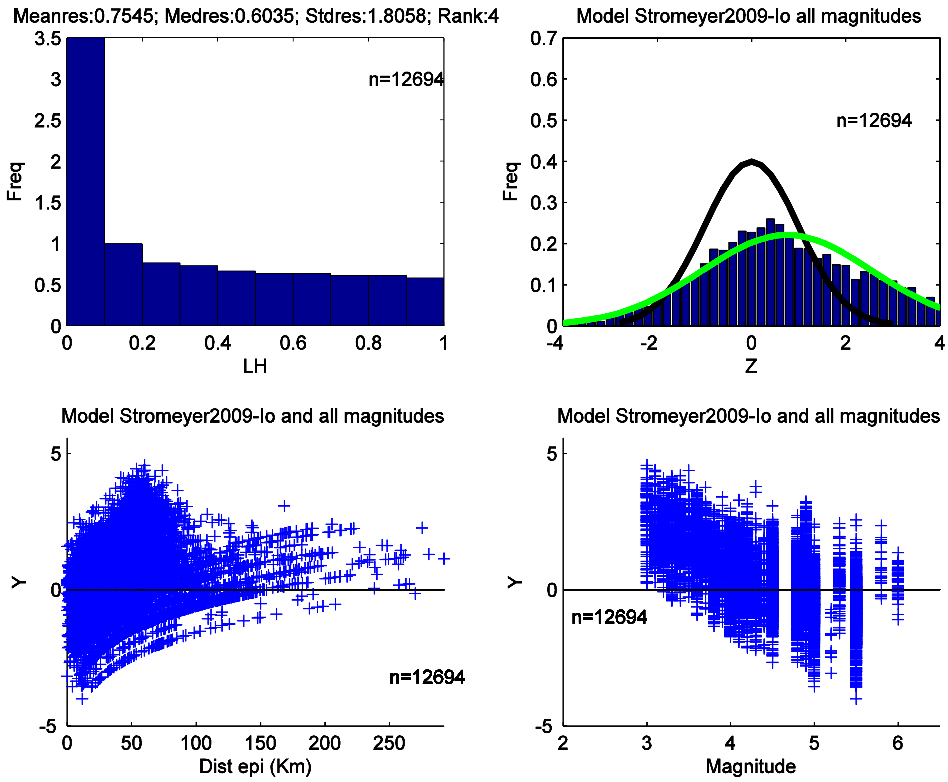



**Figure 25**: Summary of the results obtained with all data for Stromeyer2009-Io.

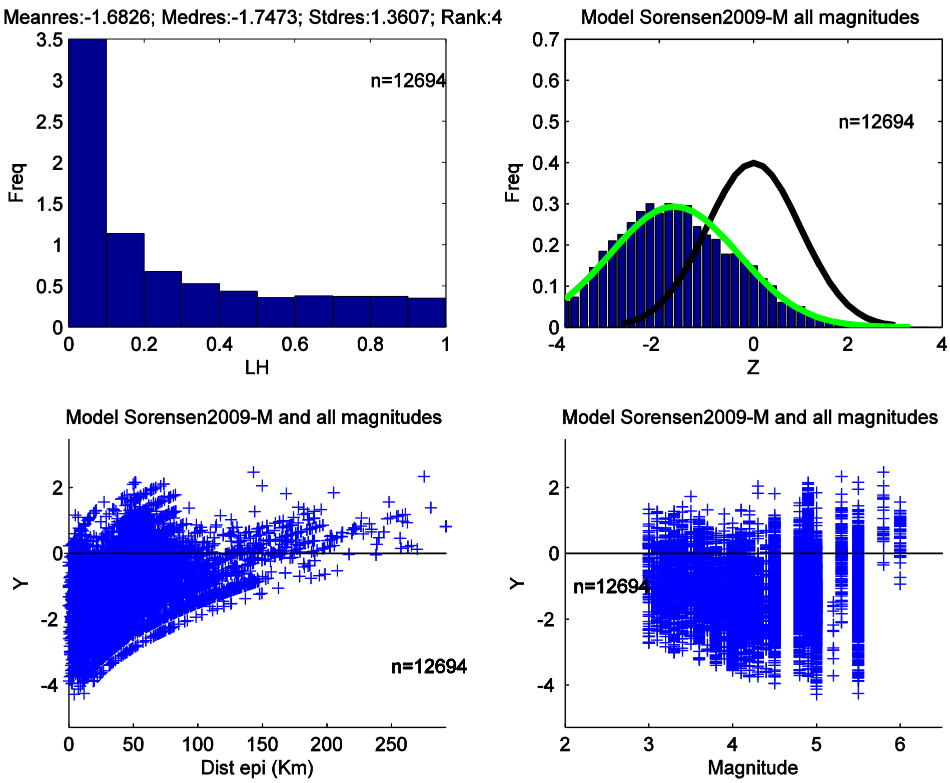



**Figure 26:** Summary of the results obtained with all data for Sorensen2009-M.

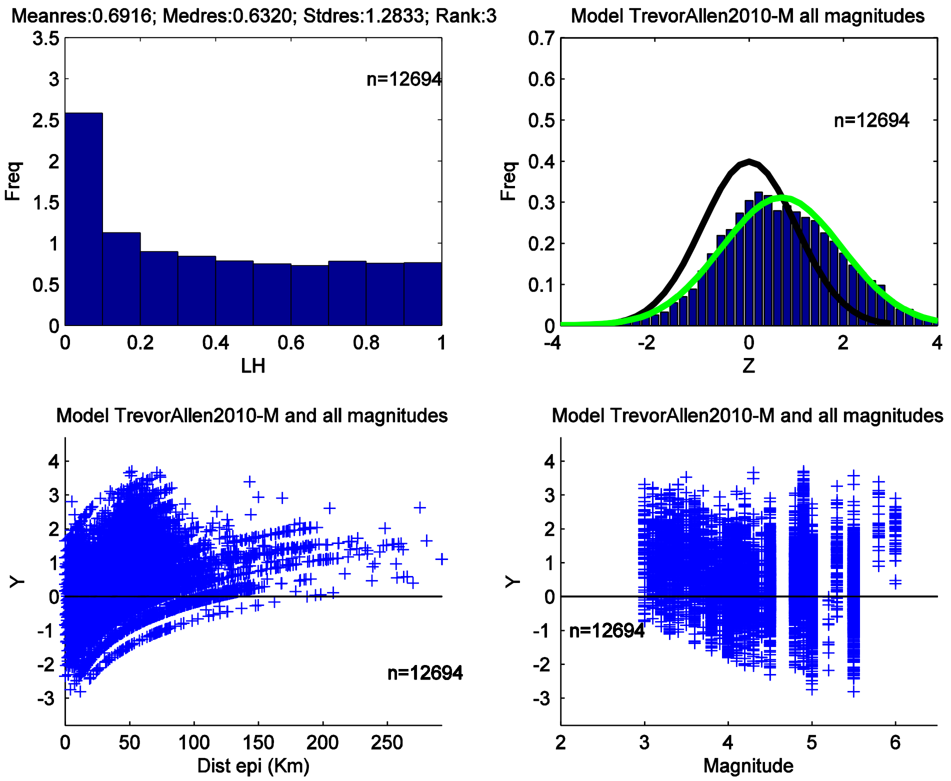



**Figure 27**: Summary of the results obtained with all data for TrevorAllen2010-M.

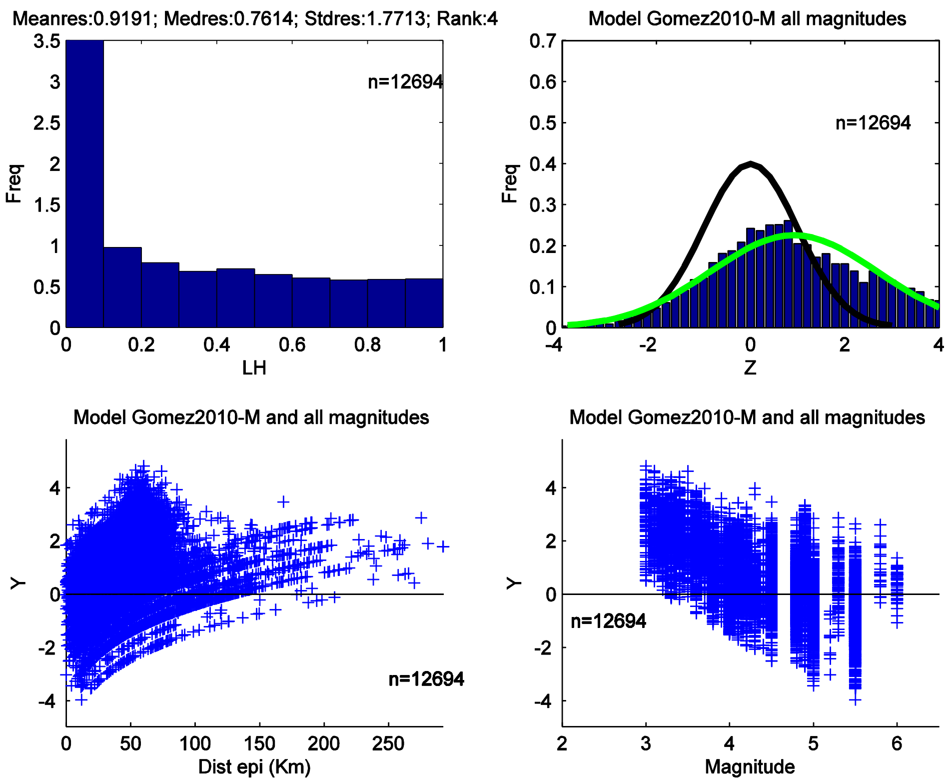



**Figure 28:** Summary of the results obtained with all data for Gomez2010-M.

# C Z and Y statistics

| IPE | Magnitude range | Number | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jimenez-1999-M | 3.0-3.4 | 1535 | 4 | -0.369 | -0.392 | 1.728 | 0.225 | 1 | -0.184 | -0.196 | 0.864 |
| Jimenez-1999-M | 3.5-3.9 | 1973 | 4 | -0.835 | -0.712 | 1.807 | 0.214 | 2 | -0.417 | -0.356 | 0.904 |
| Jimenez-1999-M | 6.0-6.4 | 56 | 2 | 0.220 | 0.008 | 1.173 | 0.403 | 1 | 0.110 | 0.004 | 0.586 |
| Jimenez1999-Io | 5.0-5.4 | 1386 | 4 | 1.105 | 1.189 | 2.651 | 0.042 | 3 | 0.553 | 0.595 | 1.326 |
| Jimenez1999-Io | 5.5-5.9 | 1024 | 4 | 1.218 | 0.803 | 2.733 | 0.101 | 3 | 0.609 | 0.402 | 1.366 |
| Jimenez1999-Io | 6.0-6.4 | 56 | 3 | 0.309 | 0.526 | 1.364 | 0.203 | 2 | 0.155 | 0.263 | 0.682 |
| Secanell12008-Io | 4.5-4.9 | 2557 | 3 | 0.739 | 0.689 | 1.009 | 0.408 | 3 | 0.665 | 0.620 | 0.908 |
| Secanell12008-Io | 5.0-5.4 | 1386 | 1 | -0.039 | -0.219 | 1.023 | 0.524 | 1 | -0.035 | -0.197 | 0.920 |
| Secanell12008-Io | 5.5-5.9 | 1024 | 2 | -0.208 | -0.254 | 1.049 | 0.466 | 1 | -0.188 | -0.229 | 0.944 |
| Secanell12008-Io | 6.0-6.4 | 56 | 2 | 0.469 | 0.398 | 0.850 | 0.563 | 2 | 0.422 | 0.358 | 0.765 |
| Secanell22008-Io | 4.0-4.4 | 3167 | 3 | 0.657 | 0.602 | 1.004 | 0.442 | 3 | 0.644 | 0.590 | 0.984 |
| Secanell22008-Io | 4.5-4.9 | 2557 | 2 | 0.378 | 0.354 | 1.002 | 0.489 | 2 | 0.371 | 0.347 | 0.982 |
| Secanell22008-Io | 5.0-5.4 | 1386 | 1 | -0.187 | -0.244 | 0.982 | 0.521 | 1 | -0.183 | -0.239 | 0.962 |
| Secanell22008-Io | 5.5-5.9 | 1024 | 2 | -0.267 | -0.286 | 0.993 | 0.497 | 2 | -0.261 | -0.280 | 0.973 |
| Secanell22008-Io | 6.0-6.4 | 56 | 1 | 0.030 | -0.114 | 0.634 | 0.607 | 1 | 0.029 | -0.112 | 0.621 |

**Table 9**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for each prediction equation and magnitude range.

| IPE | Magnitude range | Number | Z Rank | E(Z) | Zo | stdZ | LHo | Y Rank | E(Y) | Yo | stdY |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Pasolini2008-Io | 5.5-5.9 | 1024 | 4 | 0.946 | 0.803 | 1.598 | 0.245 | 3 | 0.653 | 0.554 | 1.103 |
| Pasolini2008-Io | 6.0-6.4 | 56 | 3 | 0.731 | 0.694 | 0.999 | 0.342 | 3 | 0.504 | 0.479 | 0.689 |
| Pasolini2008-M | 5.5-5.9 | 1024 | 4 | 0.904 | 0.763 | 1.596 | 0.248 | 3 | 0.624 | 0.526 | 1.101 |
| Pasolini2008-M | 6.0-6.4 | 56 | 2 | 0.334 | 0.297 | 0.999 | 0.422 | 1 | 0.230 | 0.205 | 0.689 |
| Isard2008-Io | 4.0-4.4 | 3167 | 4 | 1.371 | 1.270 | 2.003 | 0.116 | 3 | 0.685 | 0.635 | 1.001 |
| Isard2008-Io | 4.5-4.9 | 2557 | 4 | 0.845 | 0.824 | 1.991 | 0.160 | 2 | 0.423 | 0.412 | 0.996 |
| Isard2008-Io | 5.0-5.4 | 1386 | 4 | -0.224 | -0.304 | 1.956 | 0.203 | 1 | -0.112 | -0.152 | 0.978 |
| Isard2008-Io | 5.5-5.9 | 1024 | 4 | -0.355 | -0.395 | 1.984 | 0.186 | 1 | -0.178 | -0.197 | 0.992 |
| Isard2008-Io | 6.0-6.4 | 56 | 2 | 0.120 | -0.119 | 1.241 | 0.314 | 1 | 0.060 | -0.060 | 0.620 |
| Allen2009-M | 4.0-4.4 | 3167 | 3 | 0.504 | 0.342 | 1.049 | 0.515 | 2 | 0.365 | 0.299 | 0.888 |
| Allen2009-M | 4.5-4.9 | 2557 | 3 | 0.716 | 0.573 | 1.171 | 0.428 | 3 | 0.539 | 0.490 | 0.944 |
| Allen2009-M | 5.0-5.4 | 1386 | 2 | 0.417 | 0.245 | 1.172 | 0.463 | 2 | 0.302 | 0.183 | 0.940 |
| Allen2009-M | 5.5-5.9 | 1024 | 3 | 0.712 | 0.680 | 1.268 | 0.347 | 3 | 0.545 | 0.507 | 0.967 |
| Stromeyer2009-Io | 4.0-4.4 | 3167 | 4 | 0.816 | 0.730 | 1.413 | 0.297 | 3 | 0.561 | 0.502 | 0.971 |
| Stromeyer2009-Io | 4.5-4.9 | 2557 | 3 | 0.410 | 0.378 | 1.416 | 0.362 | 2 | 0.282 | 0.259 | 0.973 |
| Stromeyer2009-Io | 5.0-5.4 | 1386 | 3 | -0.395 | -0.491 | 1.392 | 0.337 | 2 | -0.271 | -0.337 | 0.956 |
| Stromeyer2009-Io | 5.5-5.9 | 1024 | 3 | -0.510 | -0.536 | 1.427 | 0.303 | 2 | -0.350 | -0.368 | 0.980 |
| Stromeyer2009-Io | 6.0-6.4 | 56 | 2 | -0.063 | -0.290 | 0.894 | 0.454 | 1 | -0.043 | -0.199 | 0.614 |
| Sorensen2009-M | 5.5-5.9 | 1024 | 4 | -0.956 | -1.031 | 1.499 | 0.177 | 3 | -0.669 | -0.722 | 1.050 |
| Sorensen2009-M | 6.0-6.4 | 56 | 3 | 0.740 | 0.540 | 0.854 | 0.541 | 3 | 0.518 | 0.378 | 0.598 |
| TrevorAllen2010-M | 4.0-4.4 | 3167 | 3 | 0.583 | 0.497 | 1.239 | 0.389 | 2 | 0.426 | 0.363 | 0.904 |
| TrevorAllen2010-M | 4.5-4.9 | 2557 | 4 | 0.817 | 0.752 | 1.307 | 0.335 | 3 | 0.596 | 0.549 | 0.954 |
| TrevorAllen2010-M | 5.0-5.4 | 1386 | 3 | 0.509 | 0.354 | 1.293 | 0.422 | 2 | 0.372 | 0.259 | 0.944 |
| TrevorAllen2010-M | 5.5-5.9 | 1024 | 4 | 0.835 | 0.789 | 1.333 | 0.286 | 3 | 0.610 | 0.576 | 0.973 |
| Gomez2010-M | 4.0-4.4 | 3167 | 4 | 0.980 | 0.891 | 1.377 | 0.274 | 3 | 0.705 | 0.641 | 0.992 |
| Gomez2010-M | 4.5-4.9 | 2557 | 3 | 0.567 | 0.554 | 1.375 | 0.334 | 2 | 0.408 | 0.399 | 0.990 |
| Gomez2010-M | 5.0-5.4 | 1386 | 3 | -0.185 | -0.237 | 1.359 | 0.367 | 1 | -0.133 | -0.171 | 0.978 |
| Gomez2010-M | 5.5-5.9 | 1024 | 3 | -0.300 | -0.361 | 1.417 | 0.326 | 2 | -0.216 | -0.260 | 1.020 |
| Gomez2010-M | 6.0-6.4 | 56 | 2 | -0.044 | -0.259 | 0.832 | 0.508 | 1 | -0.031 | -0.186 | 0.599 |

**Table 10**: Rank, likelihood parameter median ($LH_o$), and residual average (E(Z)), median ($Z_o$) and standard deviation (stdres) for each prediction equation and magnitude range.

# D Normalized Residuals (Z)

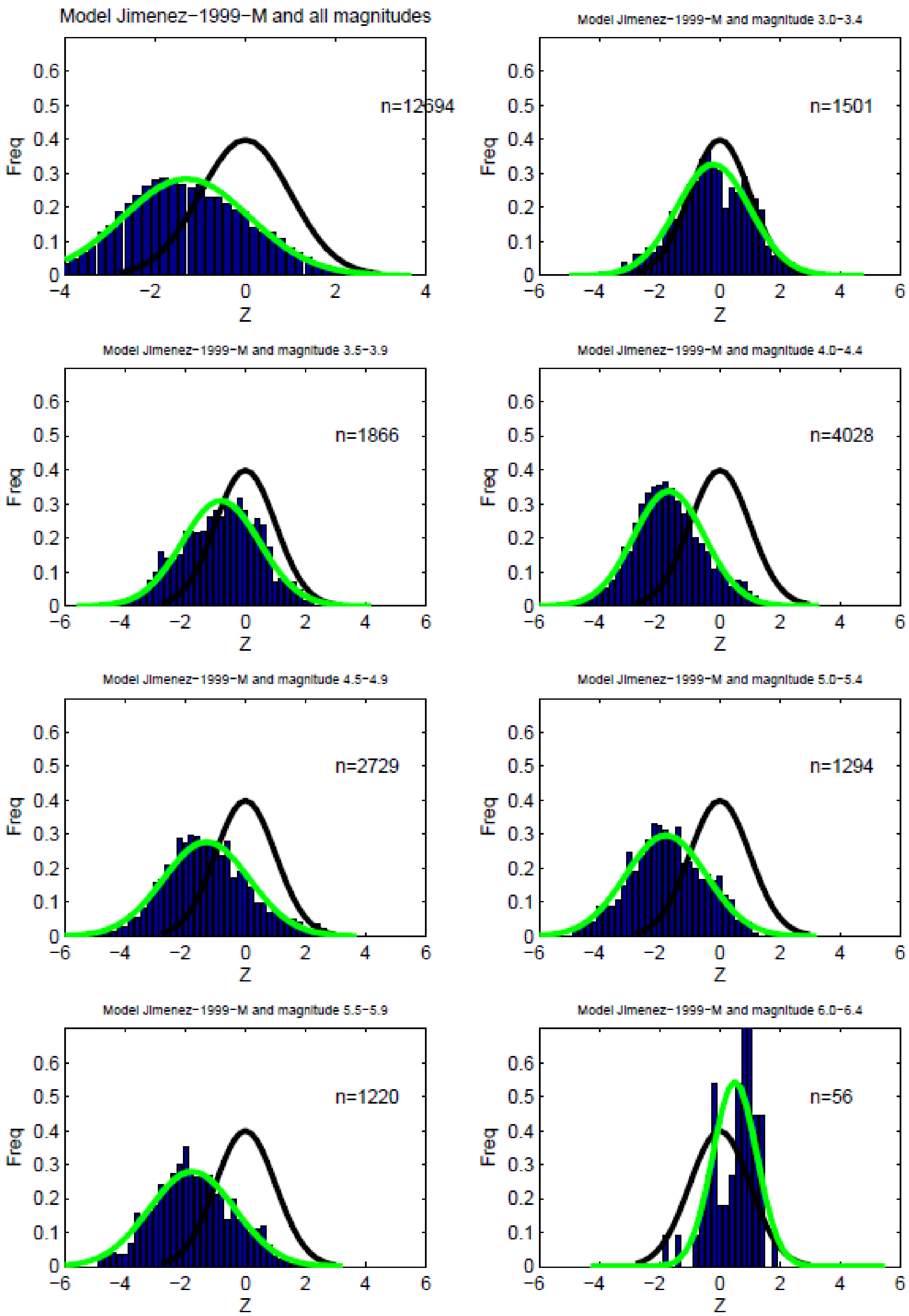



**Figure 29:** *Normalized residuals by magnitude ranges with all data for Jimenez-1999-M.*

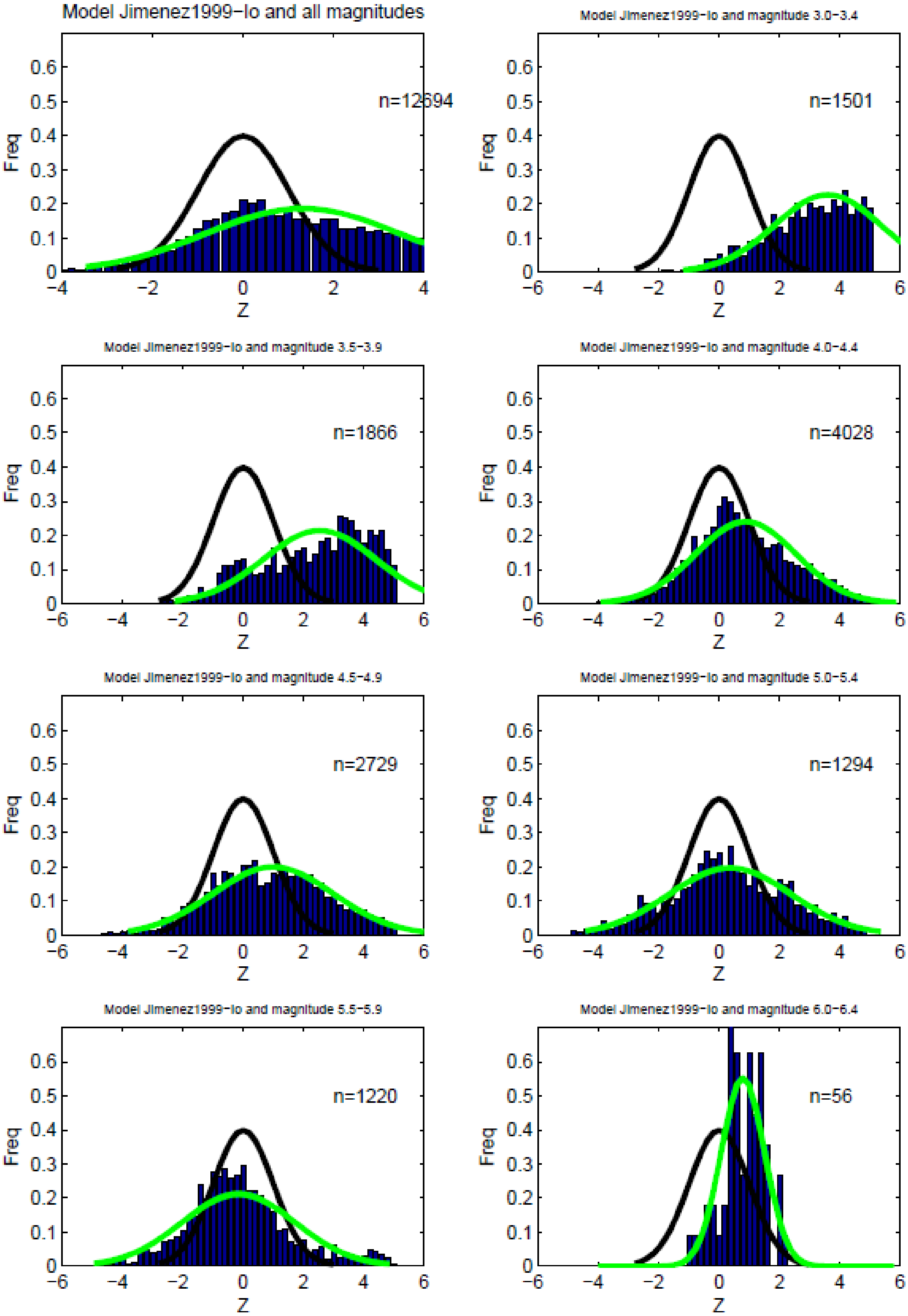



**Figure 30:** *Normalized residuals by magnitude ranges with all data for Jimenez1999-Io.*

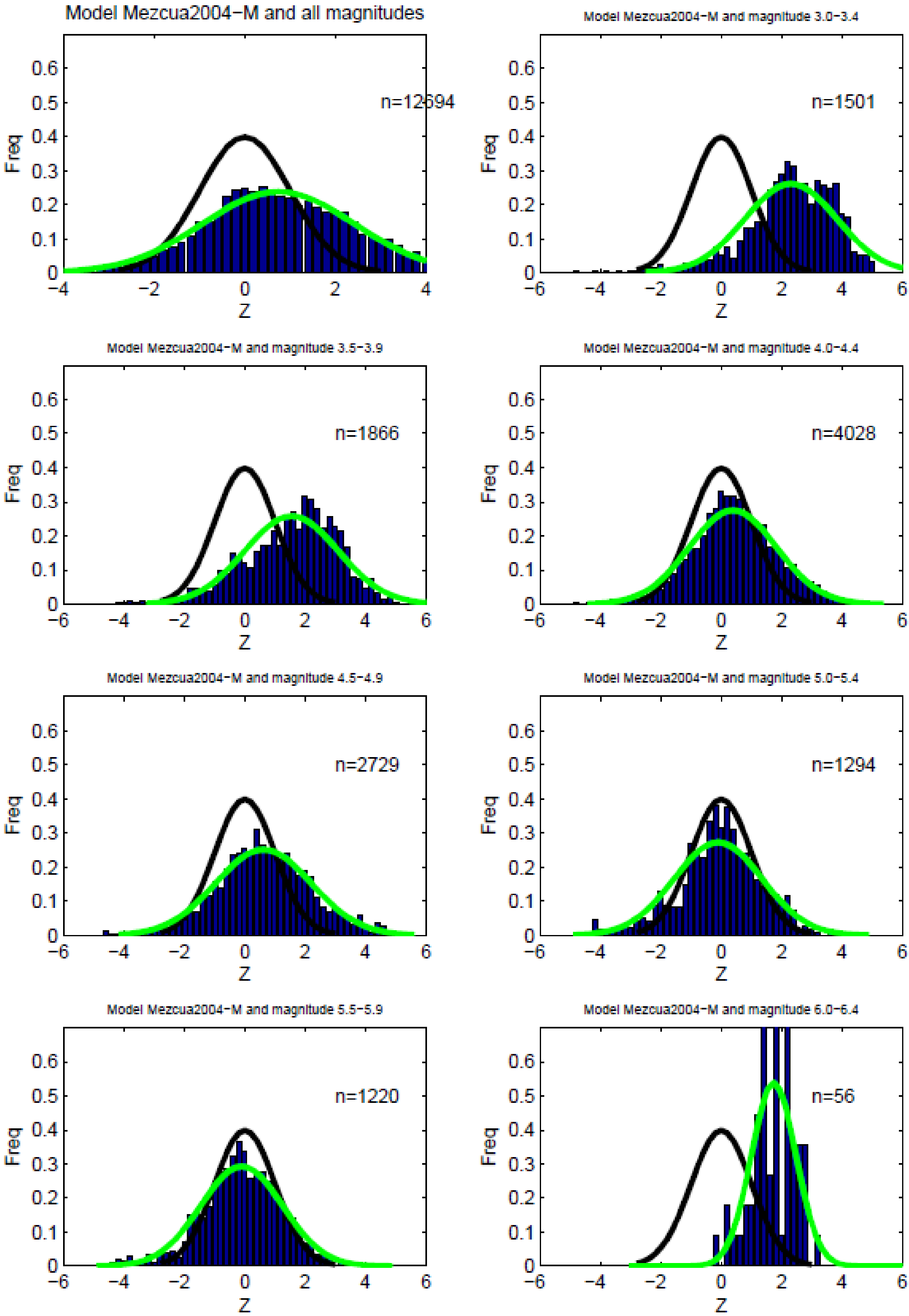



**Figure 31:** *Normalized residuals by magnitude ranges with all data for Mezcua2004-M.*

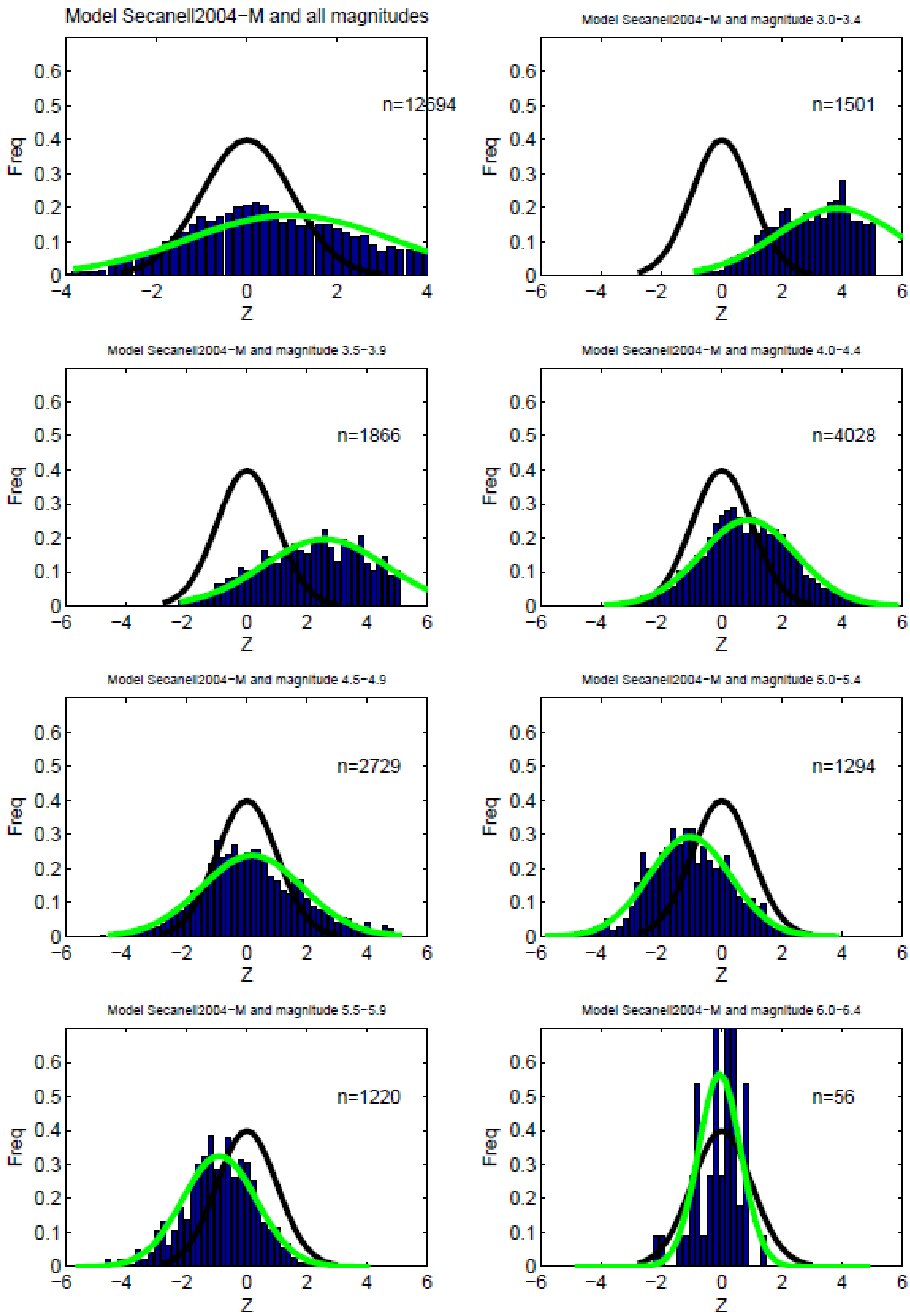



**Figure 32:** *Normalized residuals by magnitude ranges with all data for Secanell2004-M.*

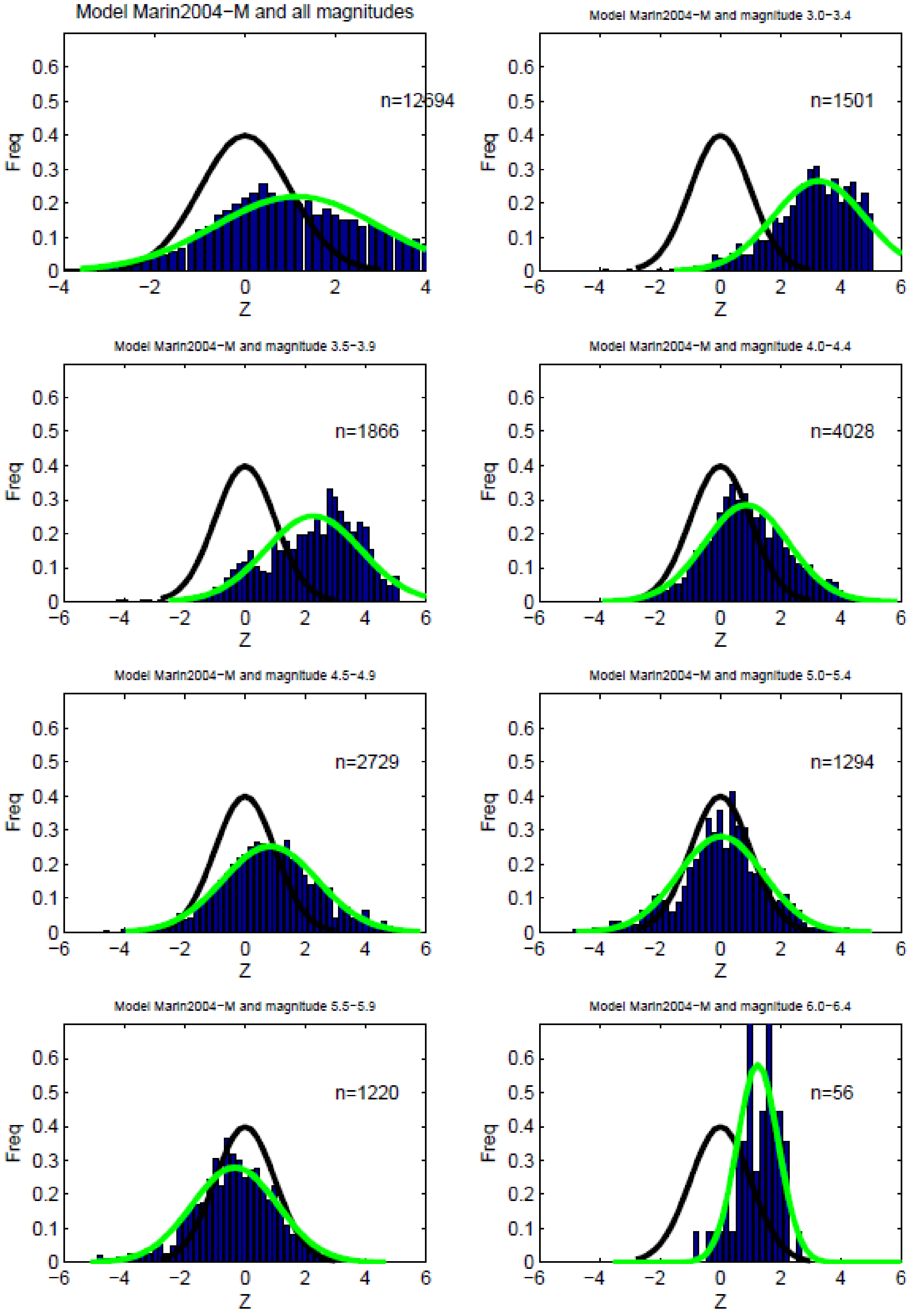



**Figure 33:** *Normalized residuals by magnitude ranges with all data for Marin2004-M.*

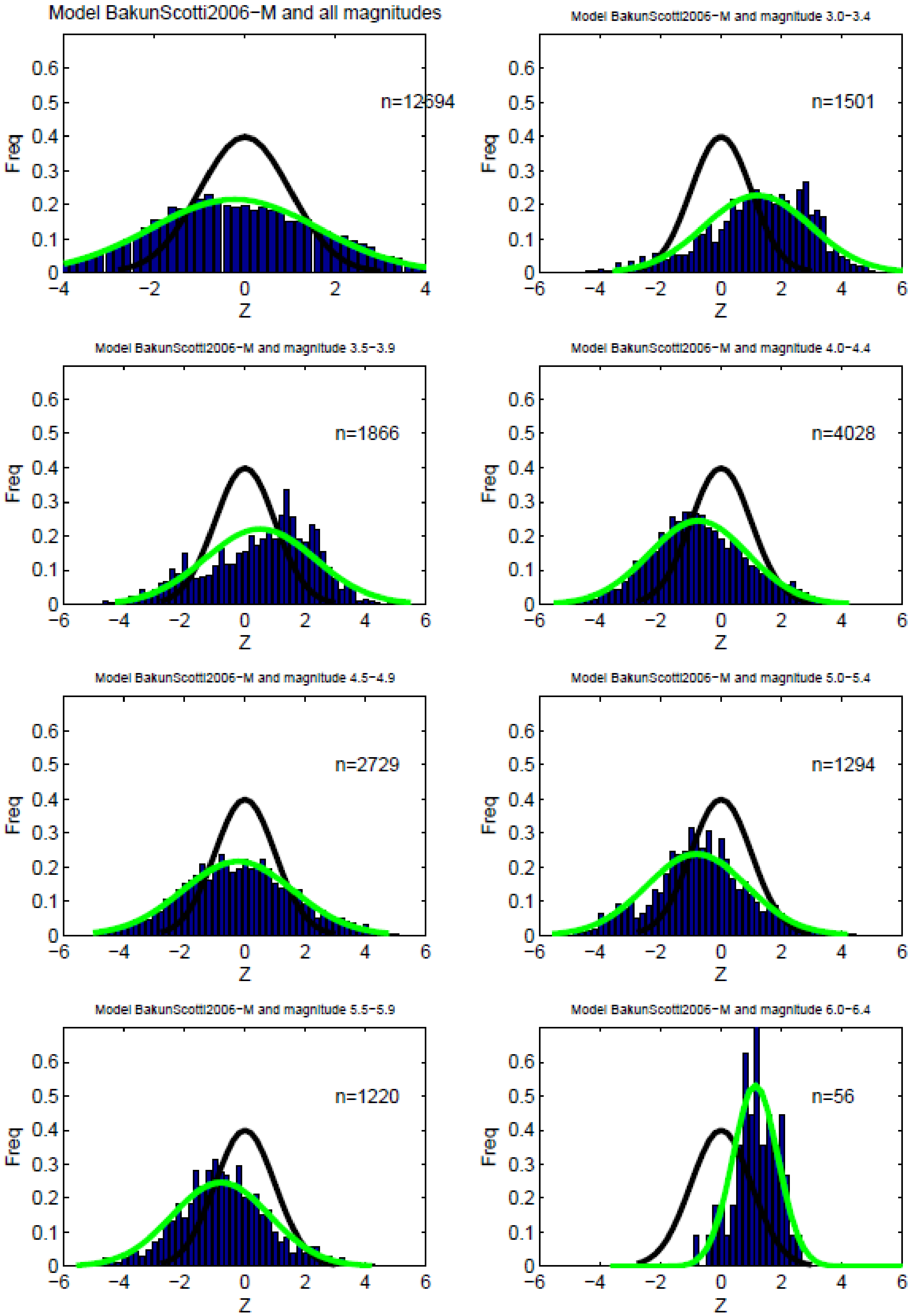



**Figure 34:** *Normalized residuals by magnitude ranges with all data for BakunScotti2006-M.*

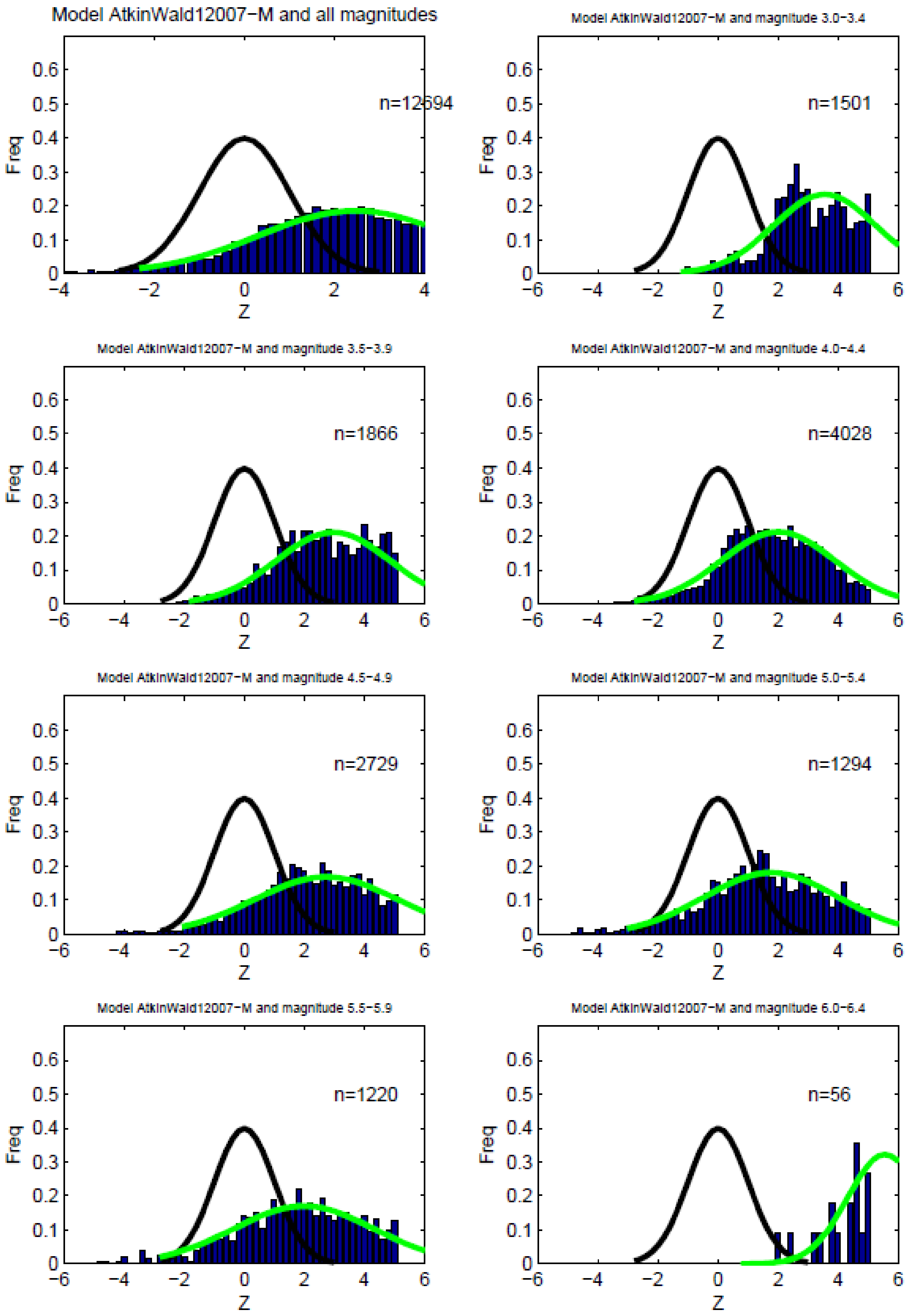



**Figure 35:** *Normalized residuals by magnitude ranges with all data for AtkinWald12007-M.*

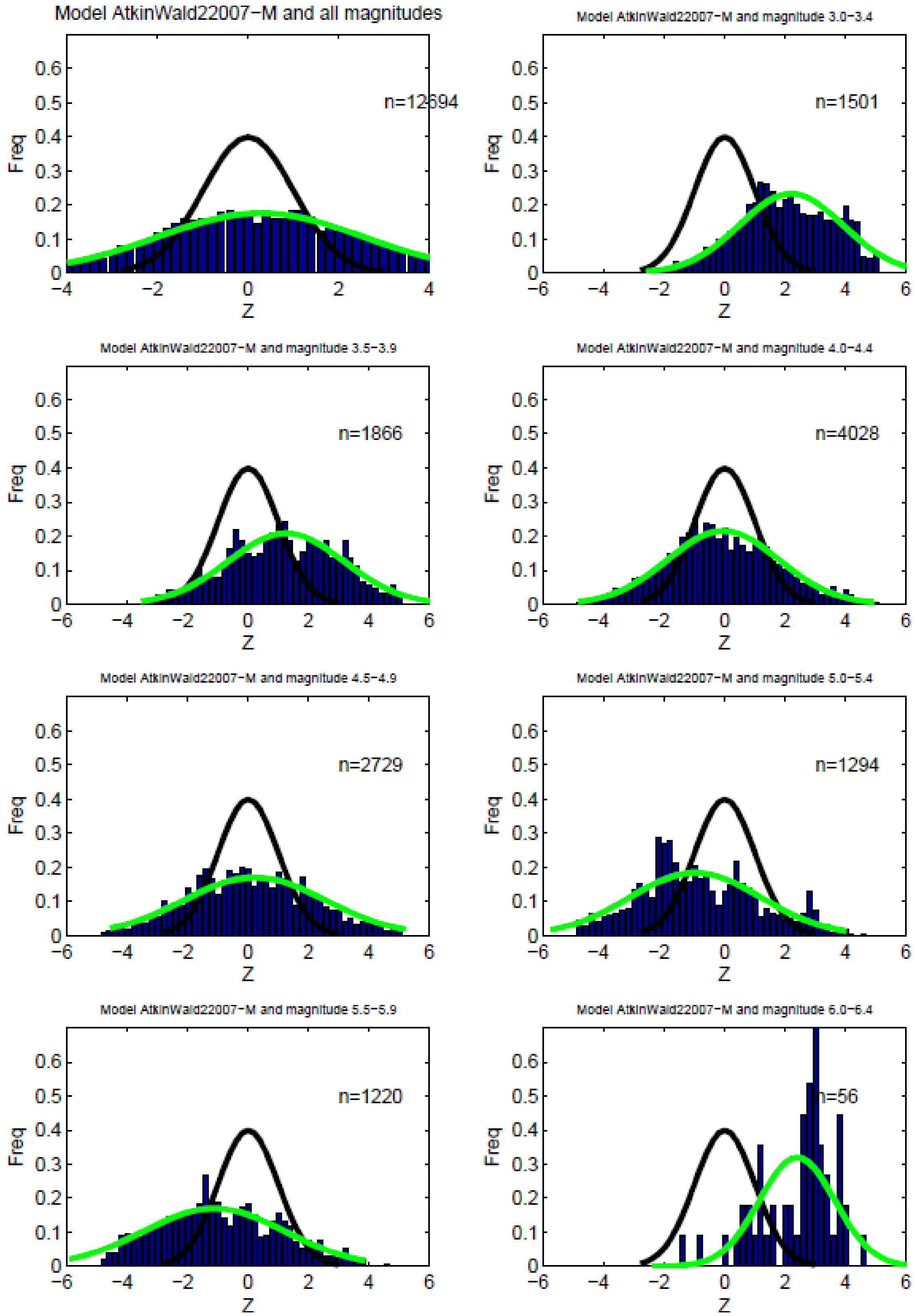



**Figure 36:** *Normalized residuals by magnitude ranges with all data for AtkinWald22007-M.*

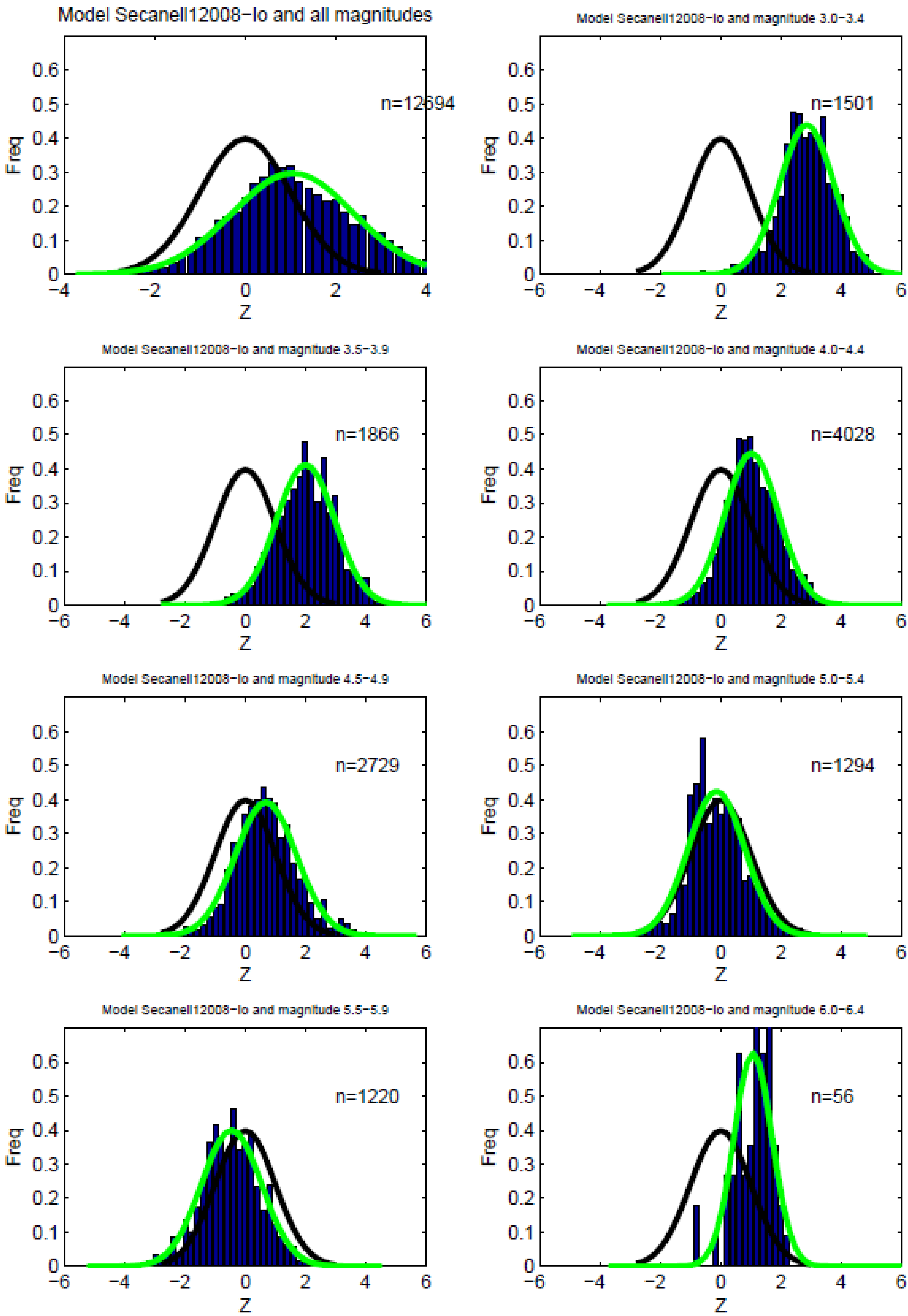



**Figure 37:** *Normalized residuals by magnitude ranges with all data for Secanell1 2008-Io.*

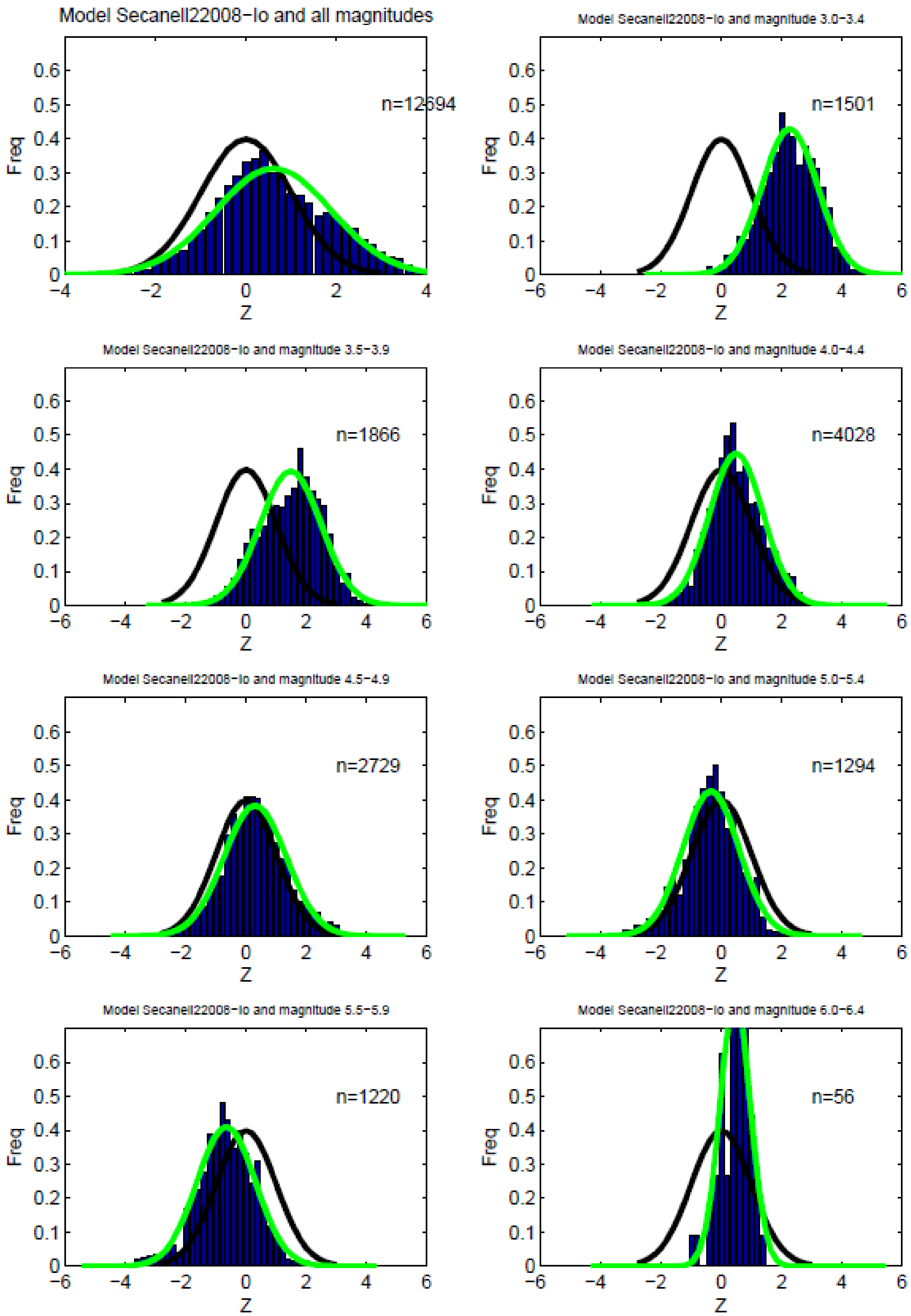



**Figure 38:** *Normalized residuals by magnitude ranges with all data for Secanell22008-Io.*

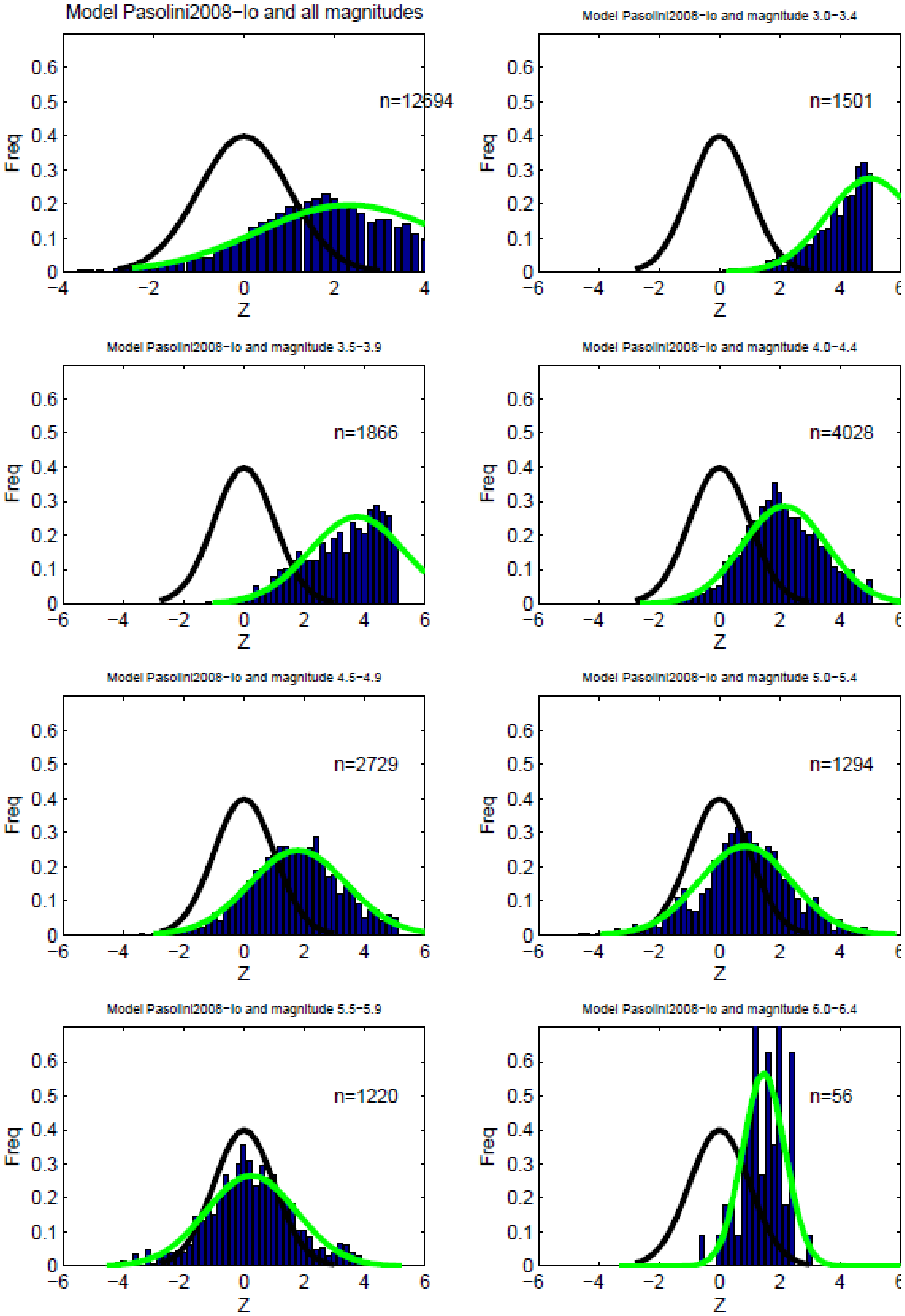



**Figure 39:** *Normalized residuals by magnitude ranges with all data for Pasolini2008-Io.*

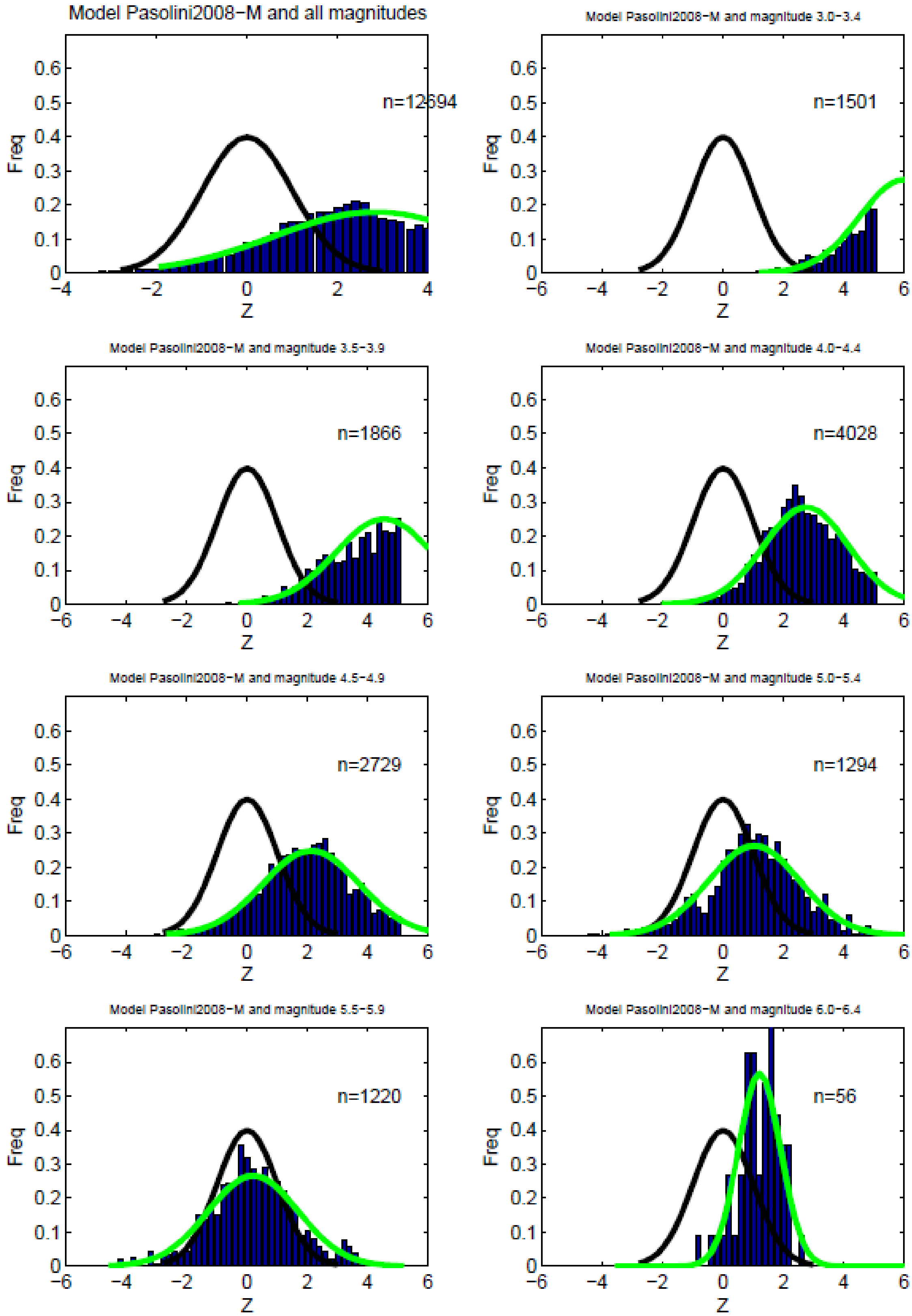



**Figure 40:** *Normalized residuals by magnitude ranges with all data for Pasolini2008-M.*

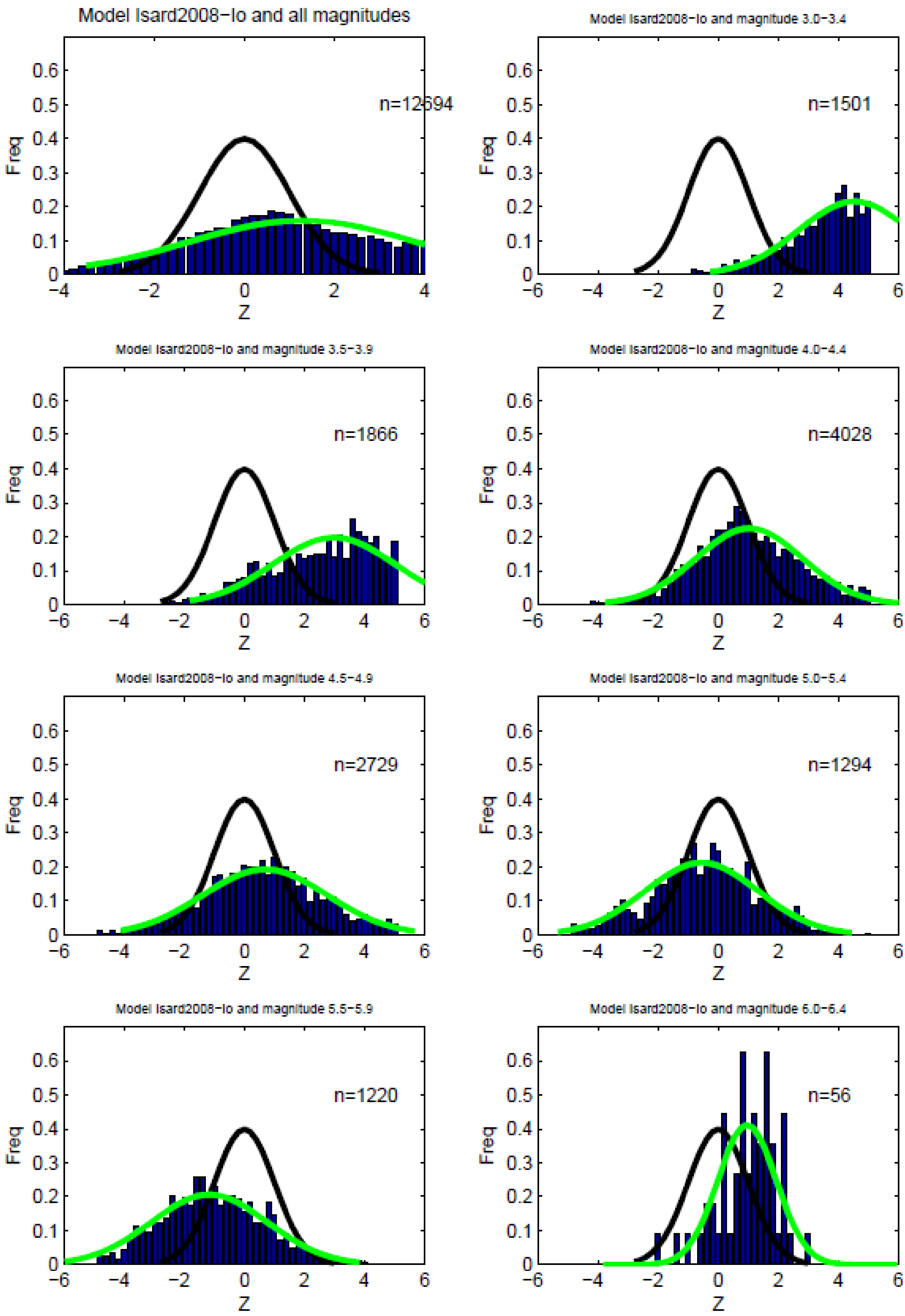



**Figure 41:** *Normalized residuals by magnitude ranges with all data for Isard2008-Io.*

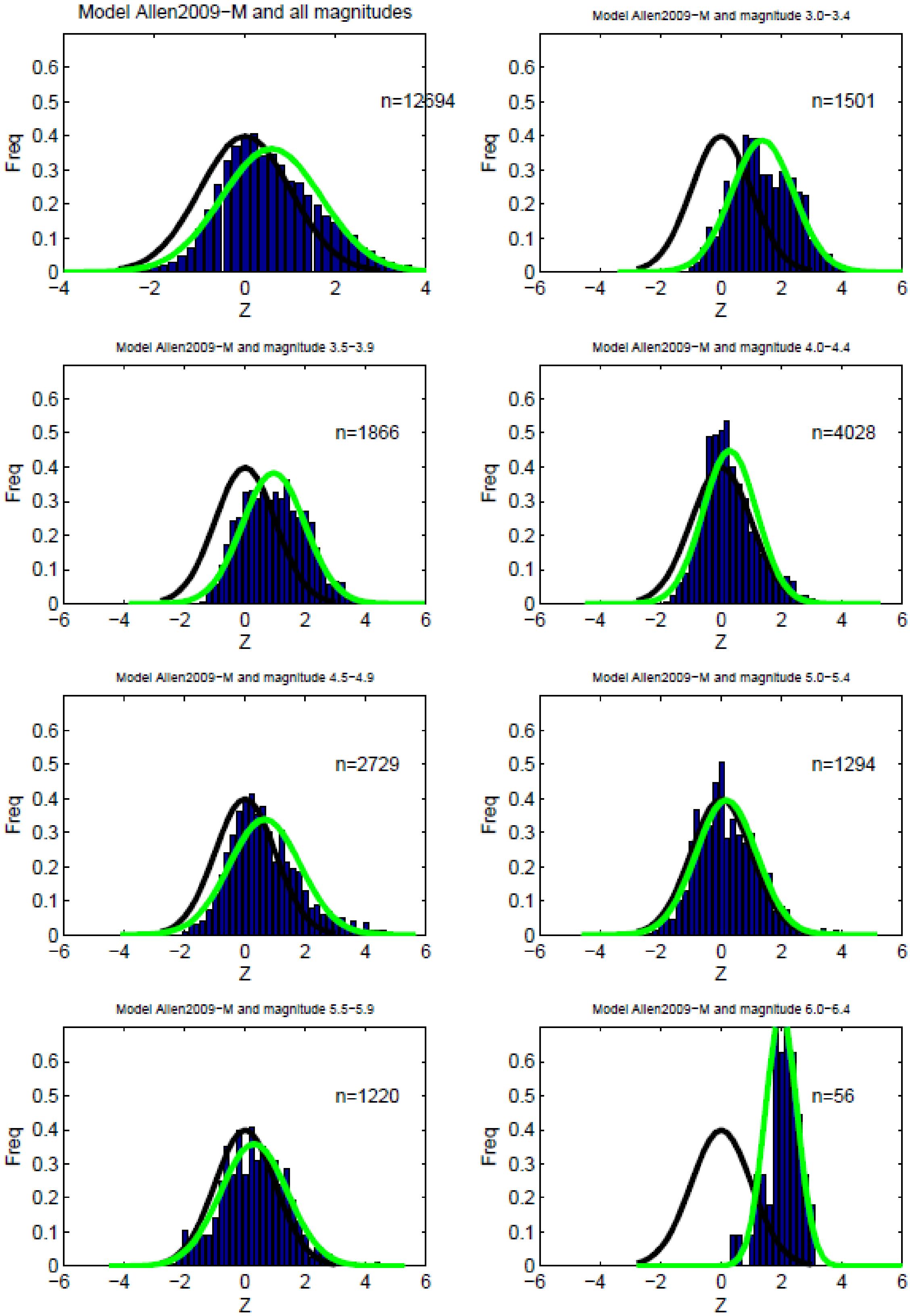



**Figure 42:** *Normalized residuals by magnitude ranges with all data for Allen2009-M.*

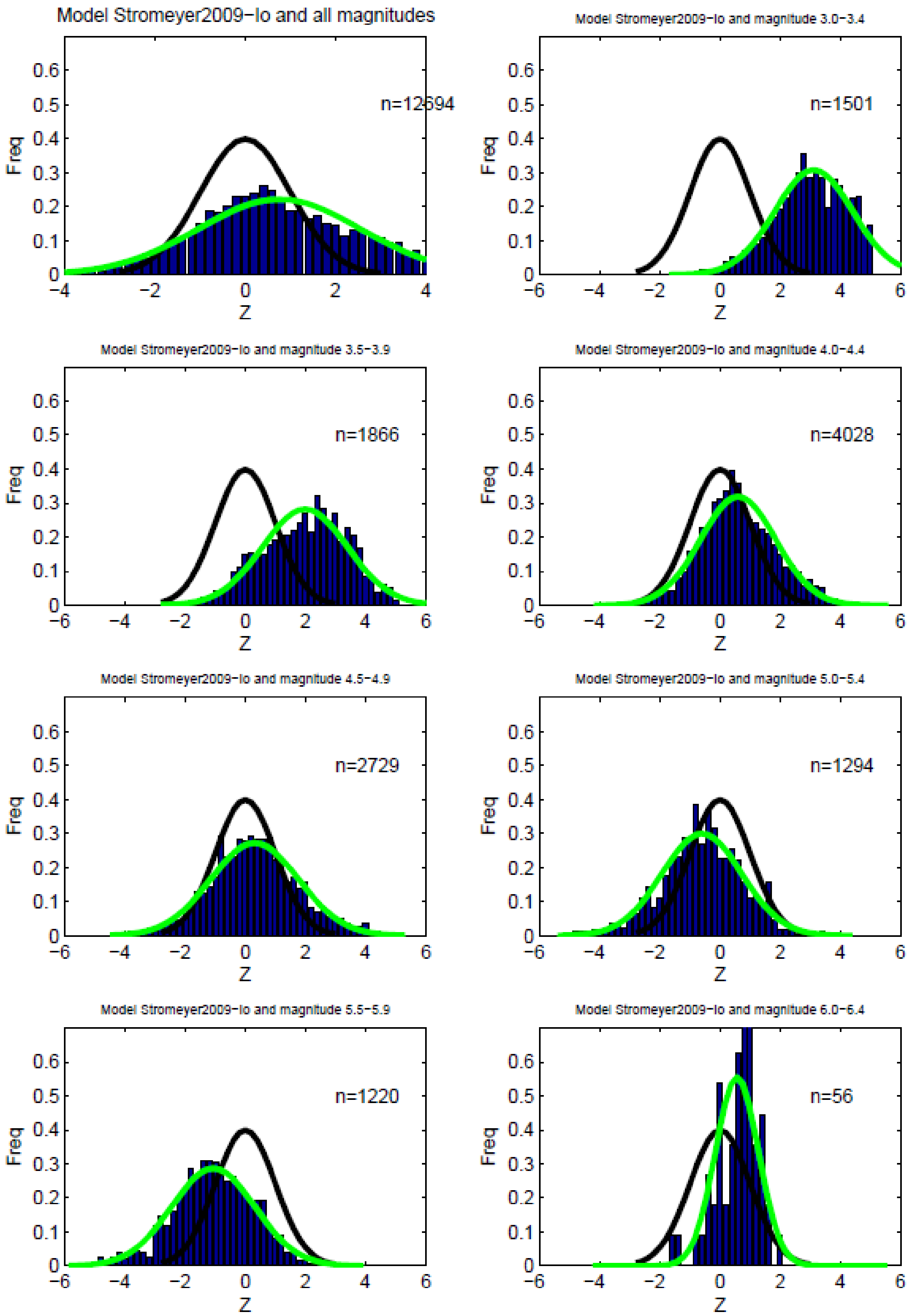



**Figure 43:** *Normalized residuals by magnitude ranges with all data for Stromeyer2009-Io.*

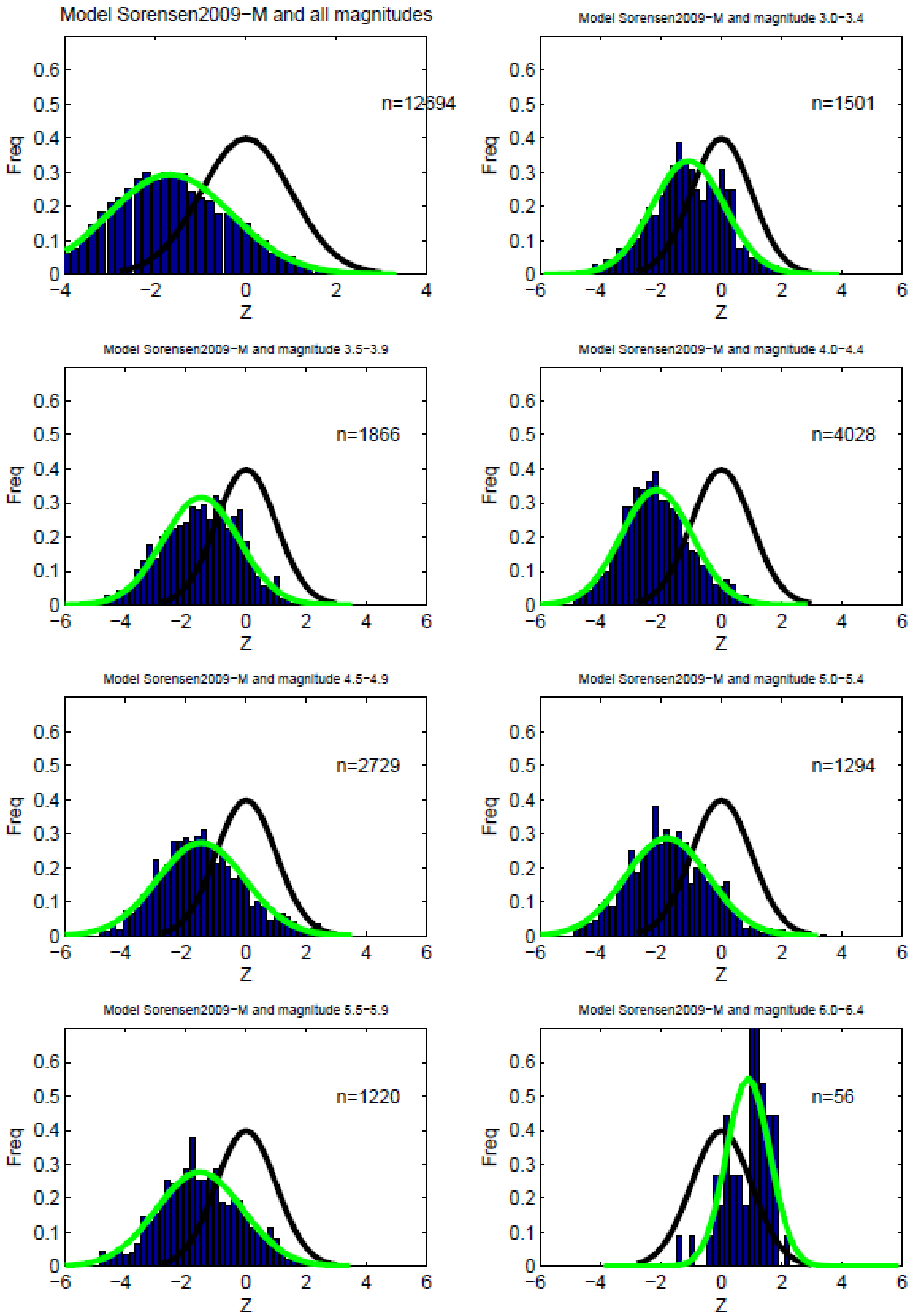



**Figure 44:** *Normalized residuals by magnitude ranges with all data for Sorensen2009-M.*

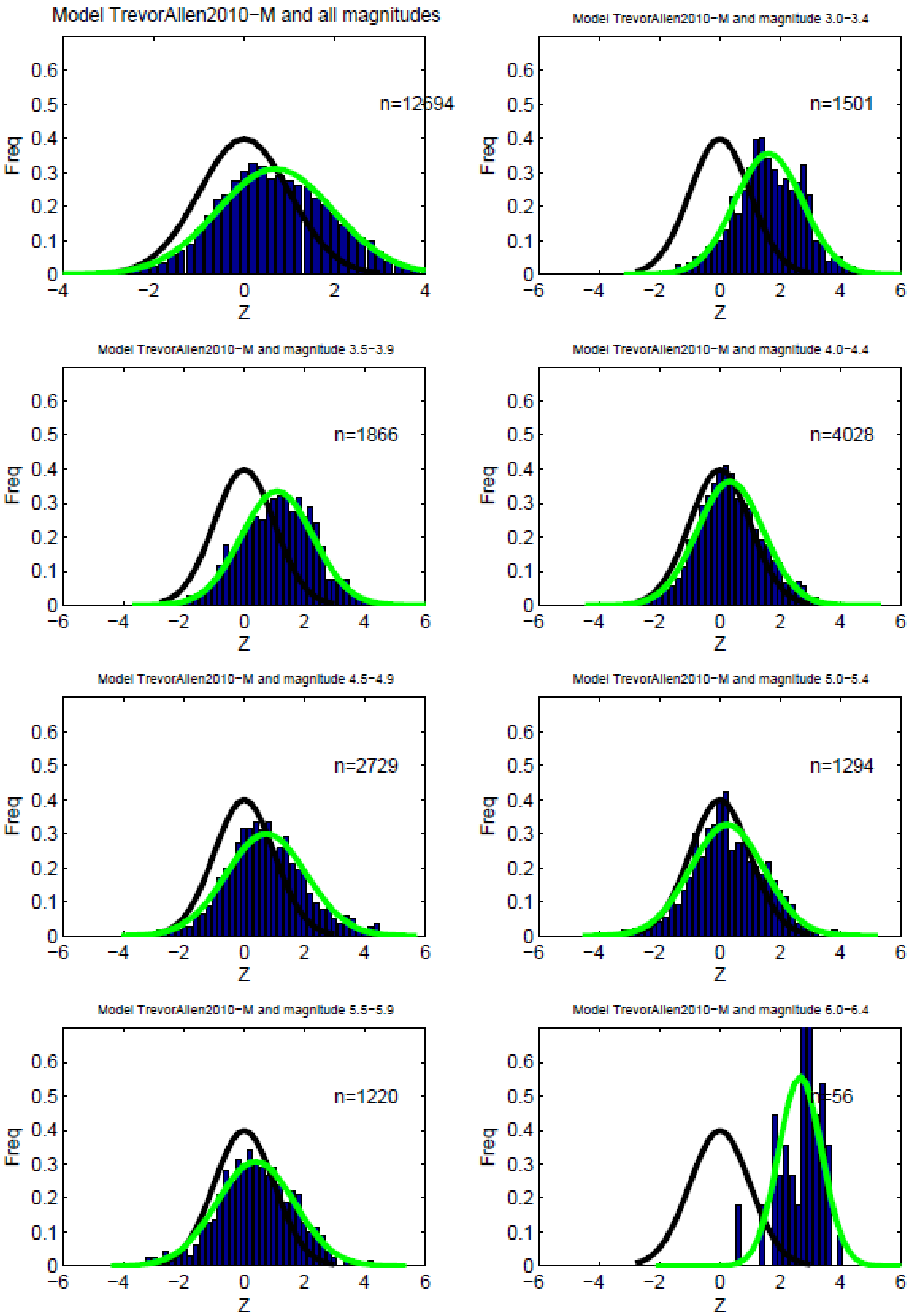



**Figure 45:** *Normalized residuals by magnitude ranges with all data for TrevorAllen2010-M.*

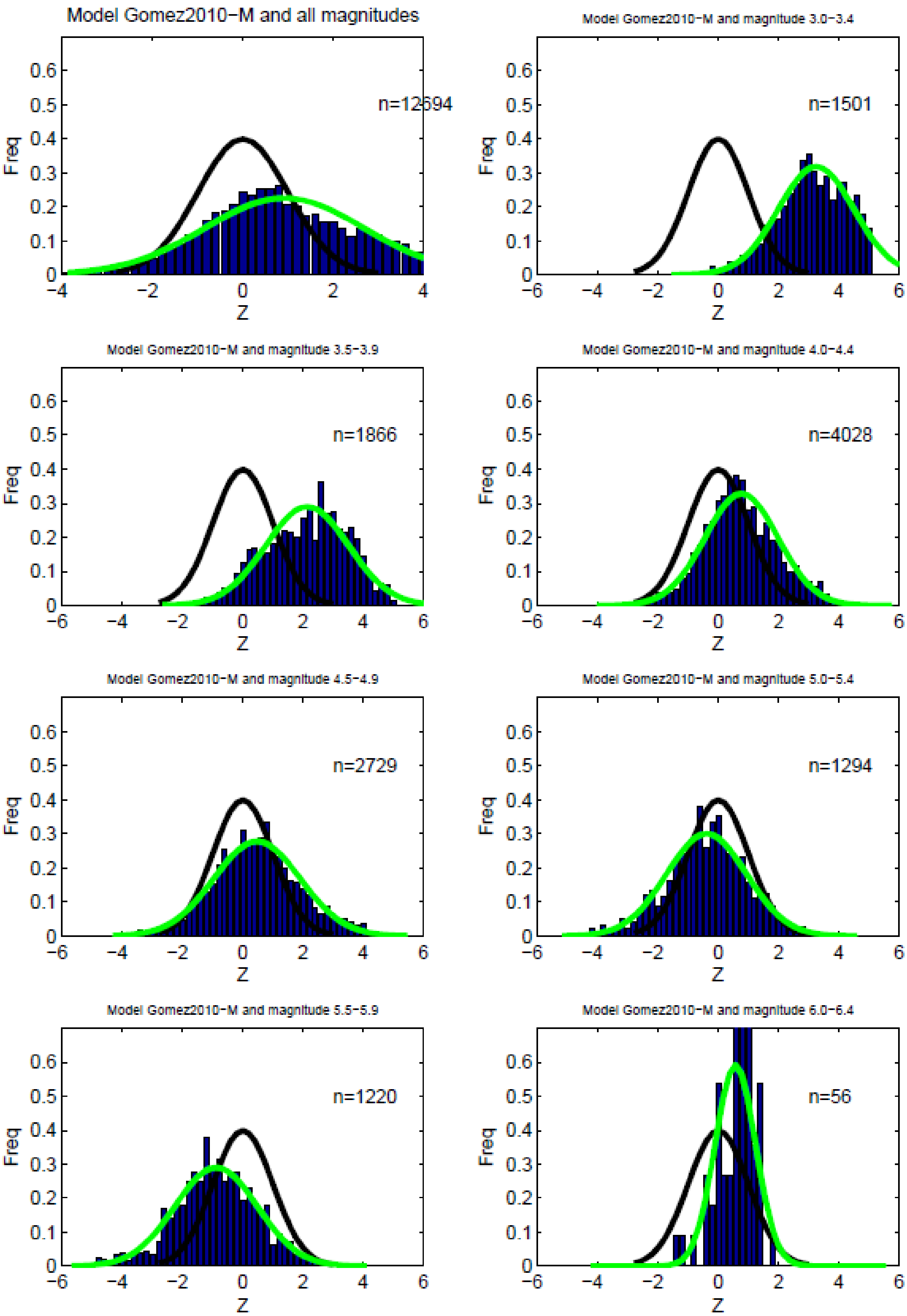



**Figure 46:** *Normalized residuals by magnitude ranges with all data for Gomez2010-M.*

# E Residuals (Y)

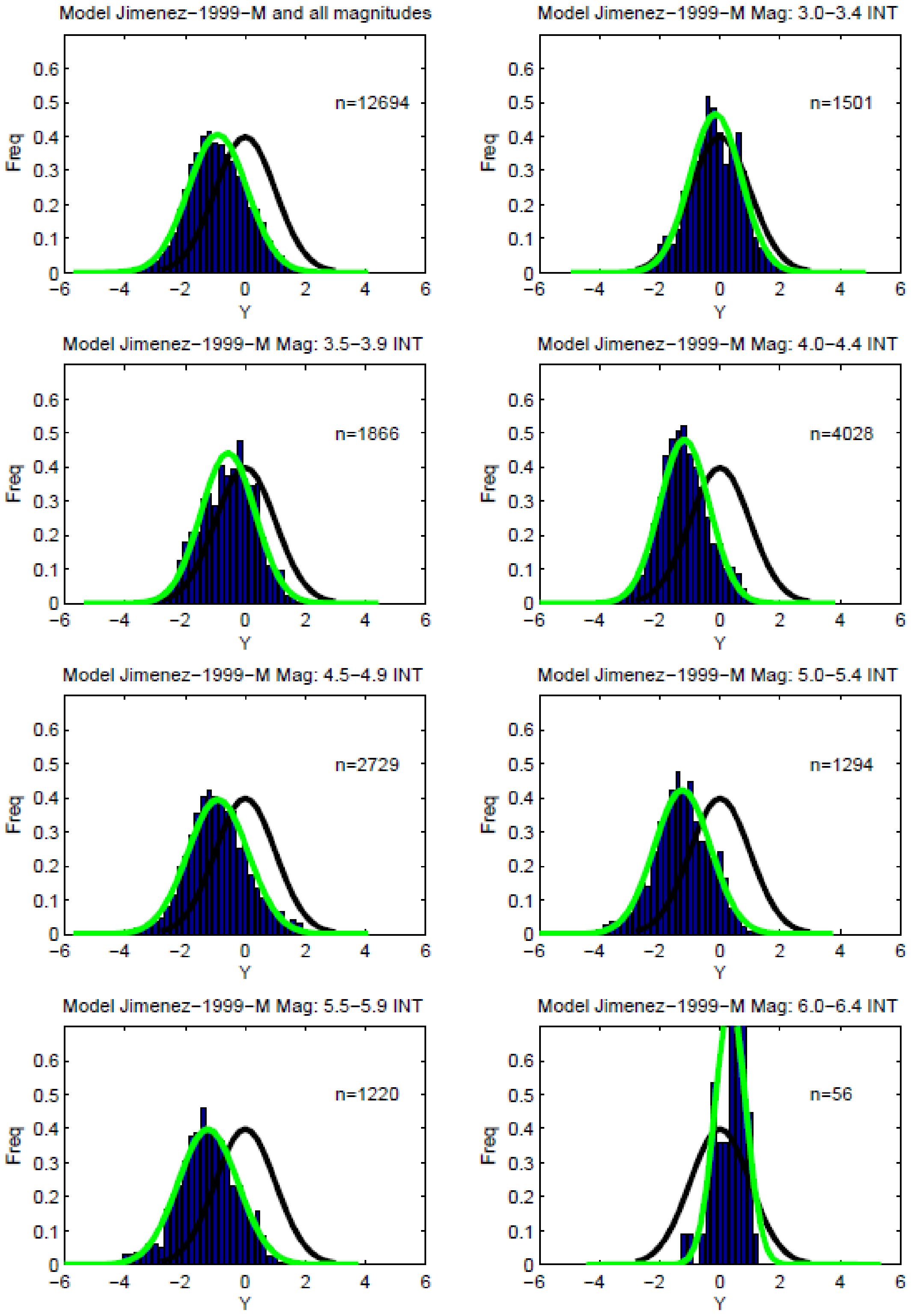



**Figure 47:** *Residuals by magnitude ranges with all data for Jimenez-1999-M.*

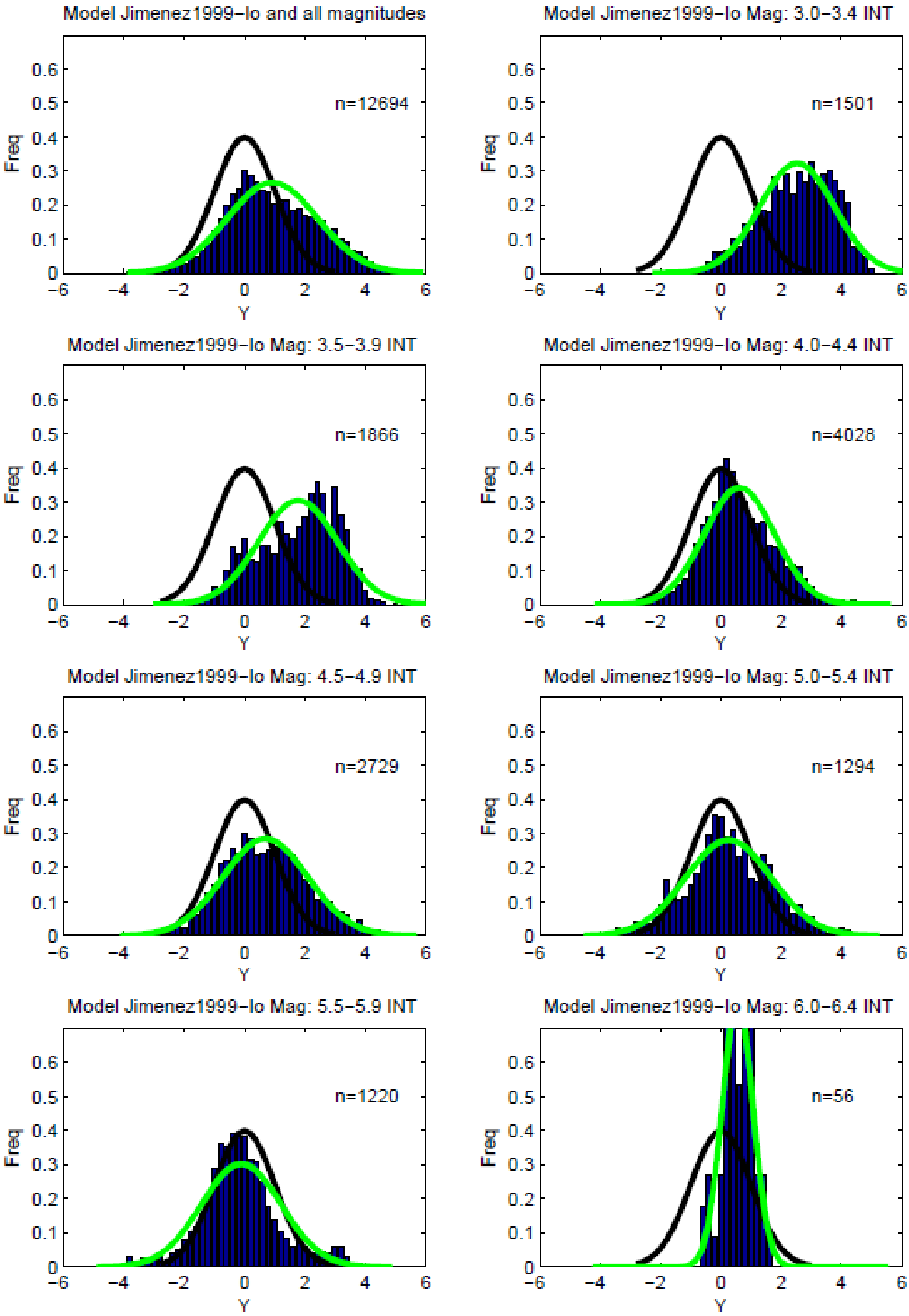



**Figure 48:** *Residuals by magnitude ranges with all data for Jimenez1999-Io.*

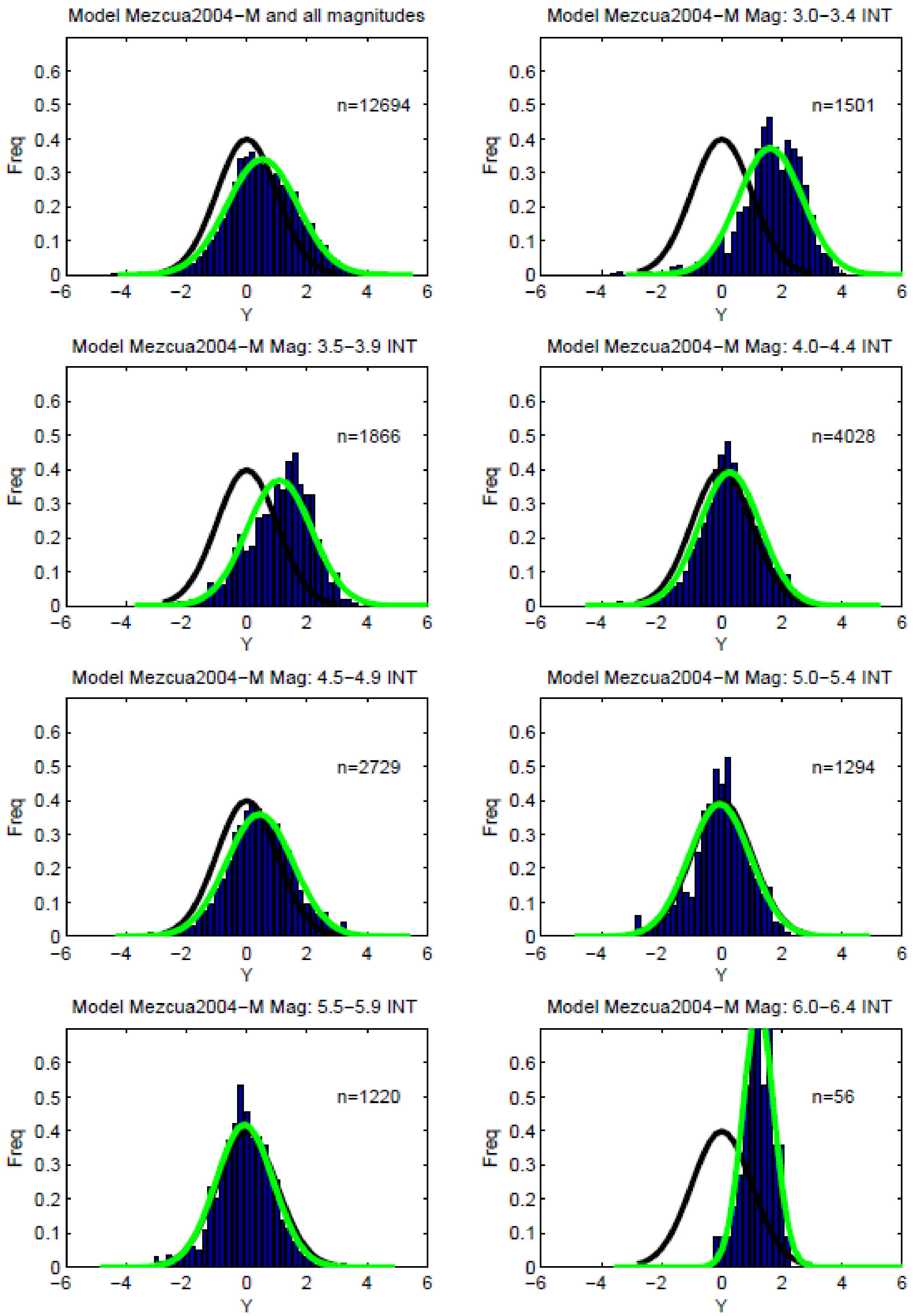



**Figure 49:** *Residuals by magnitude ranges with all data for Mezcua2004-M.*

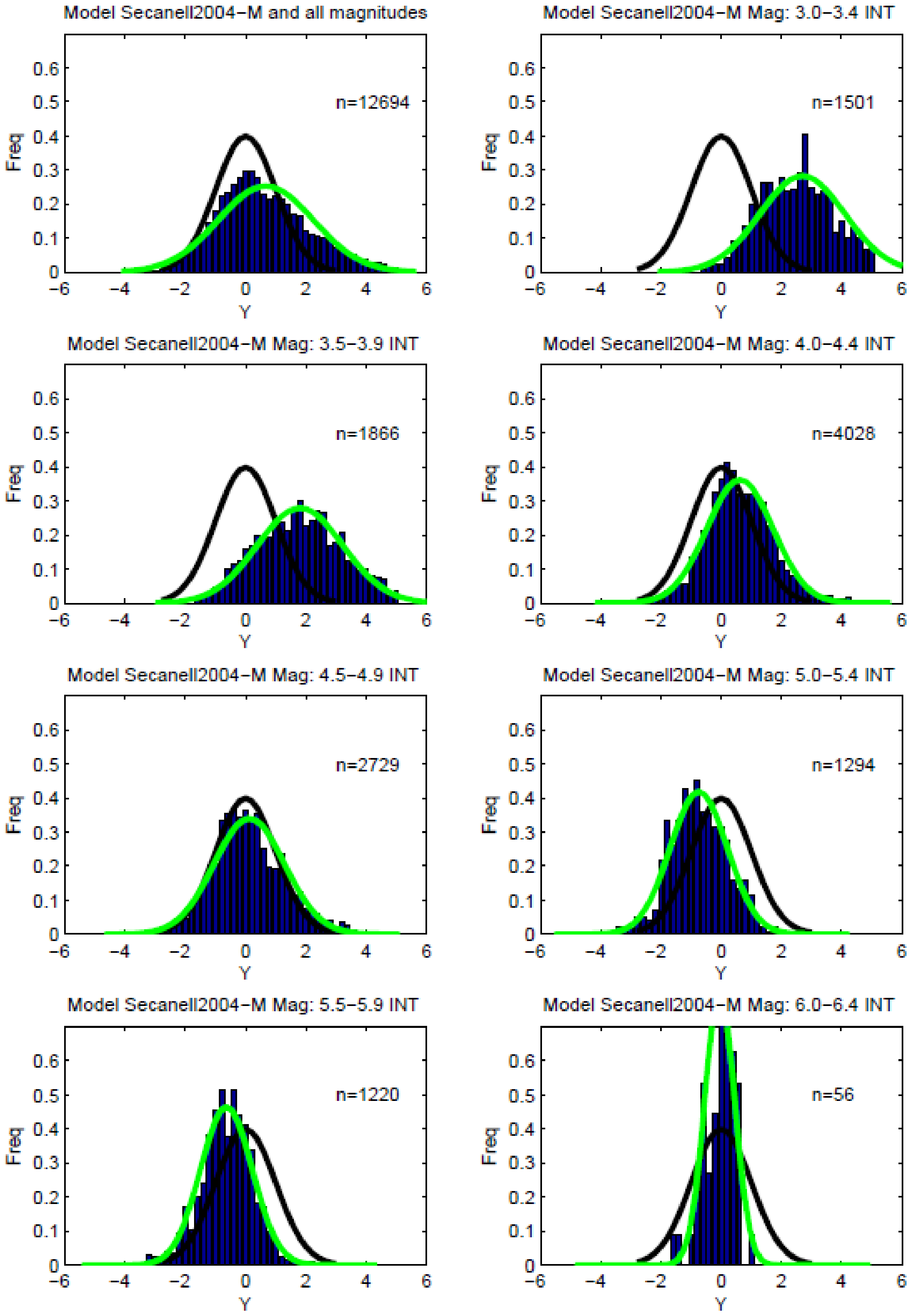



**Figure 50:** *Residuals by magnitude ranges with all data for Secanell2004-M.*

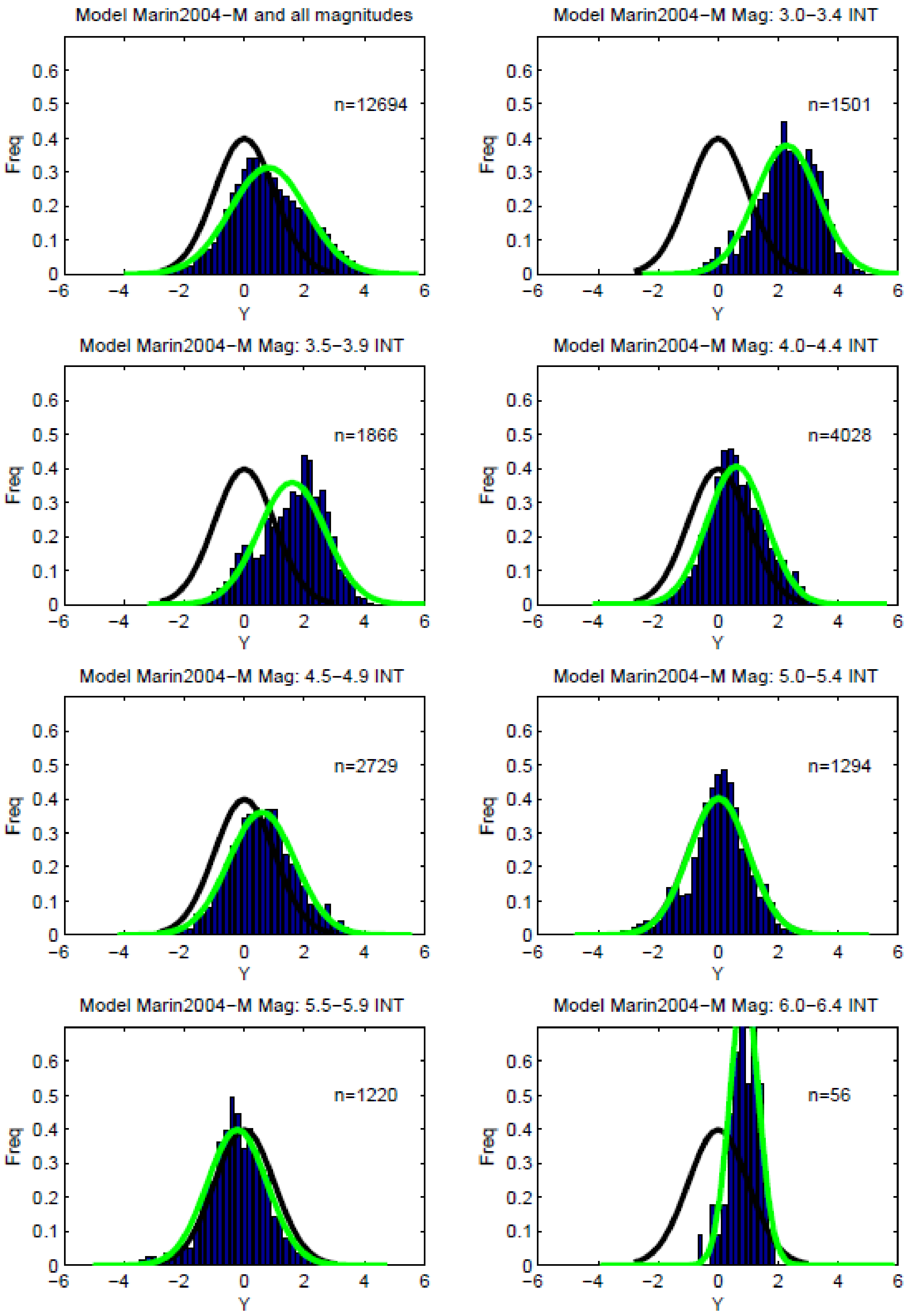



**Figure 51:** *Residuals by magnitude ranges with all data for Marin2004-M.*

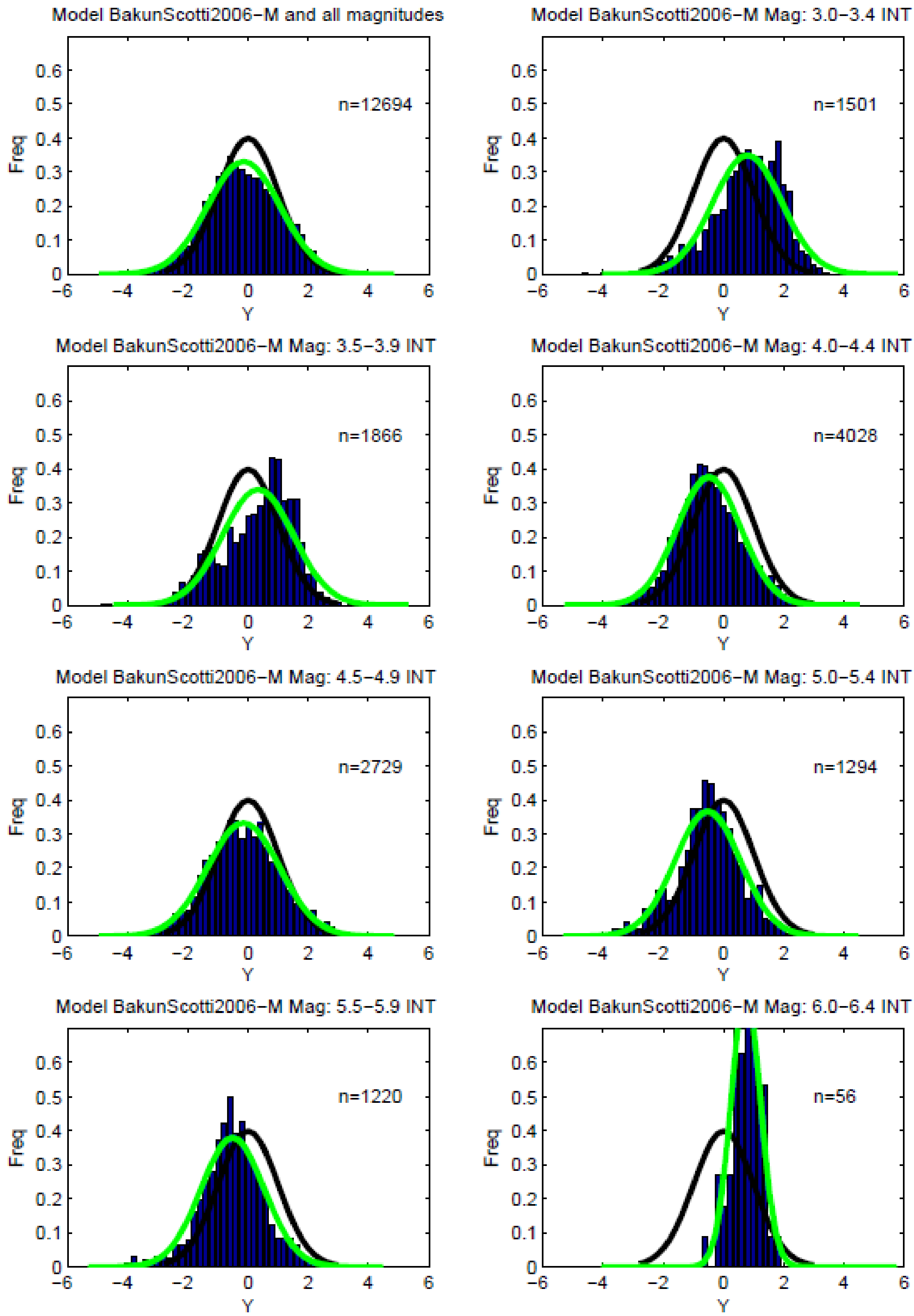



**Figure 52:** *Residuals by magnitude ranges with all data for BakunScotti2006-M.*

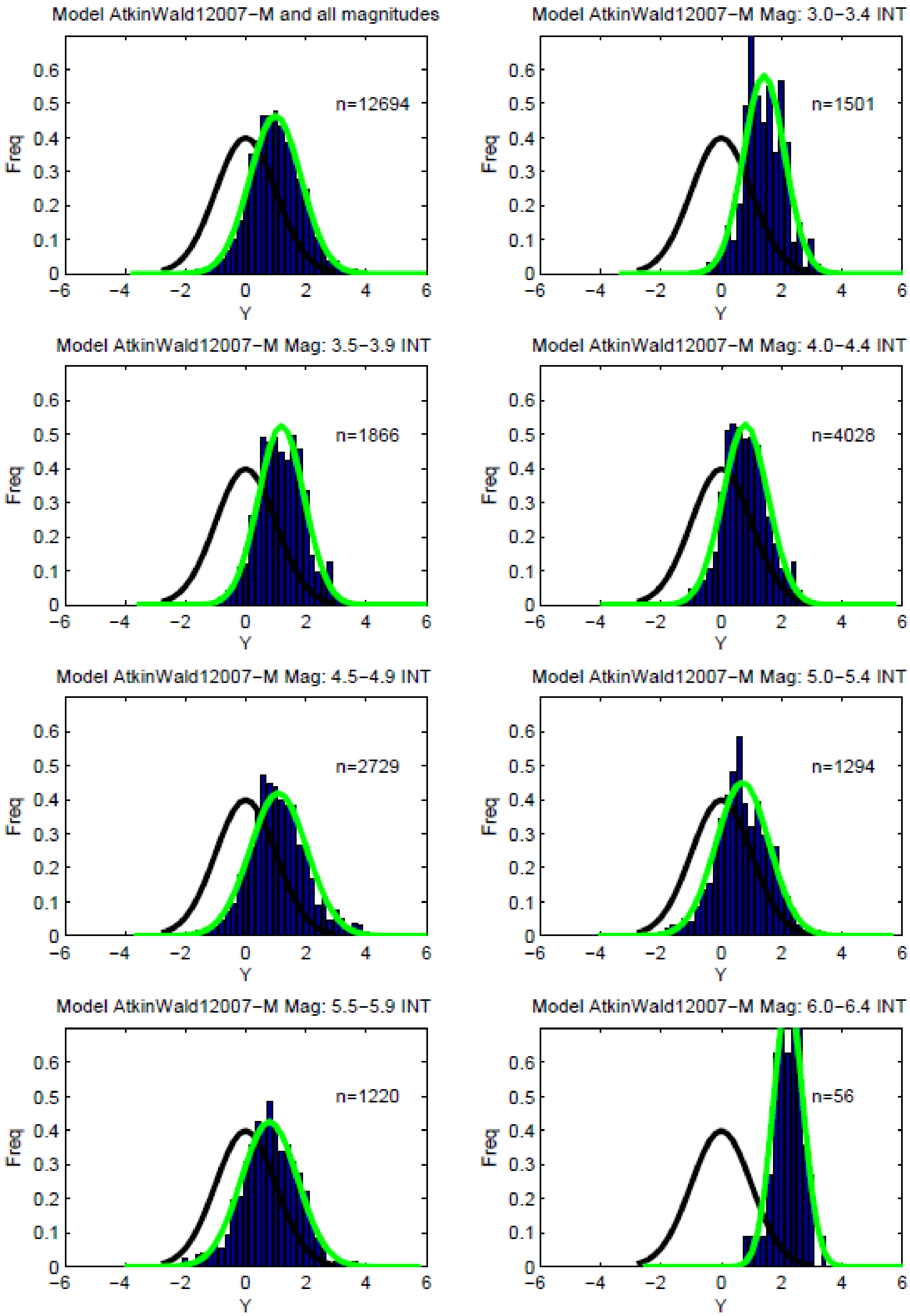



**Figure 53:** *Residuals by magnitude ranges with all data for AtkinWald12007-M.*

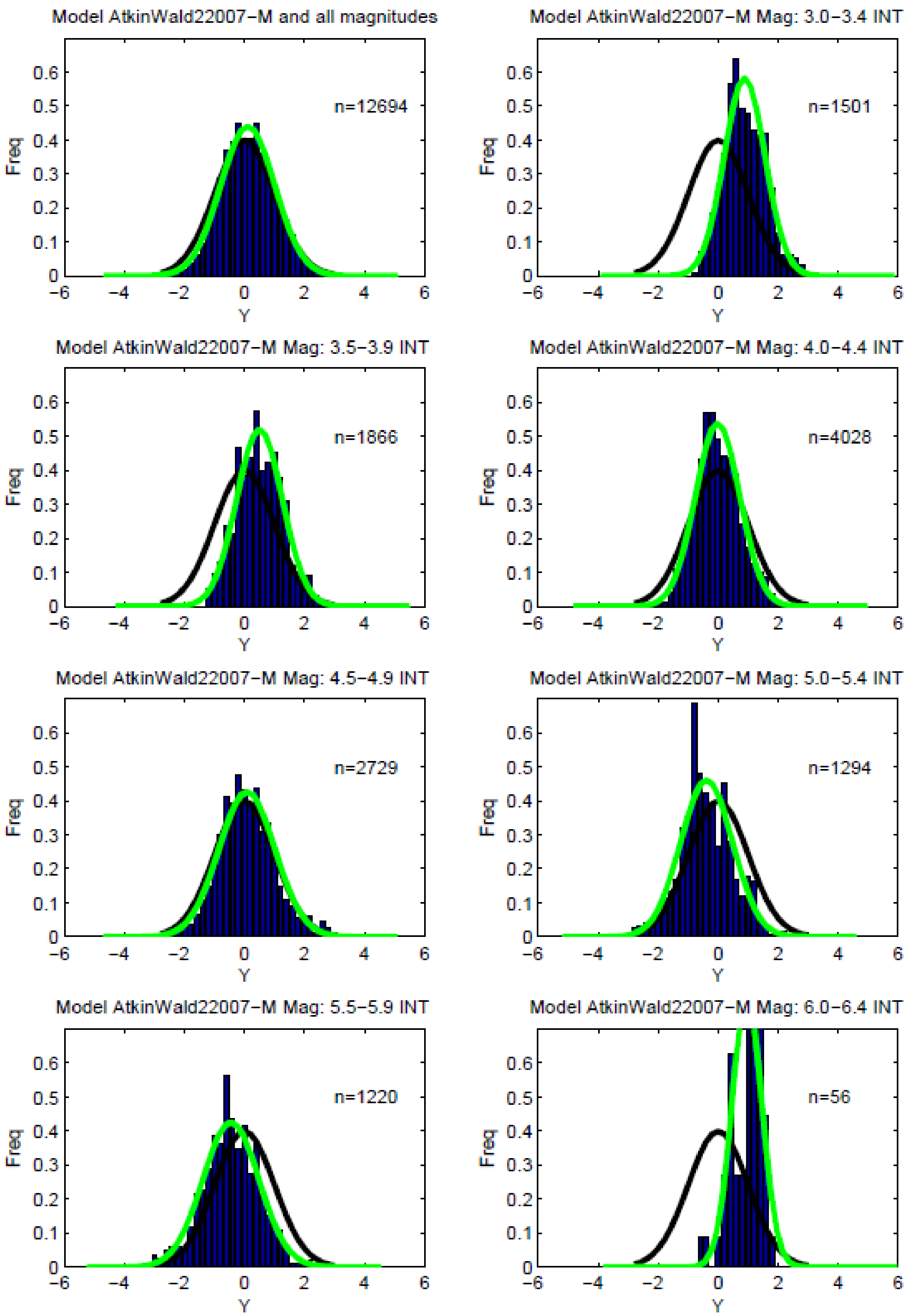



**Figure 54:** *Residuals by magnitude ranges with all data for AtkinWald22007-M.*

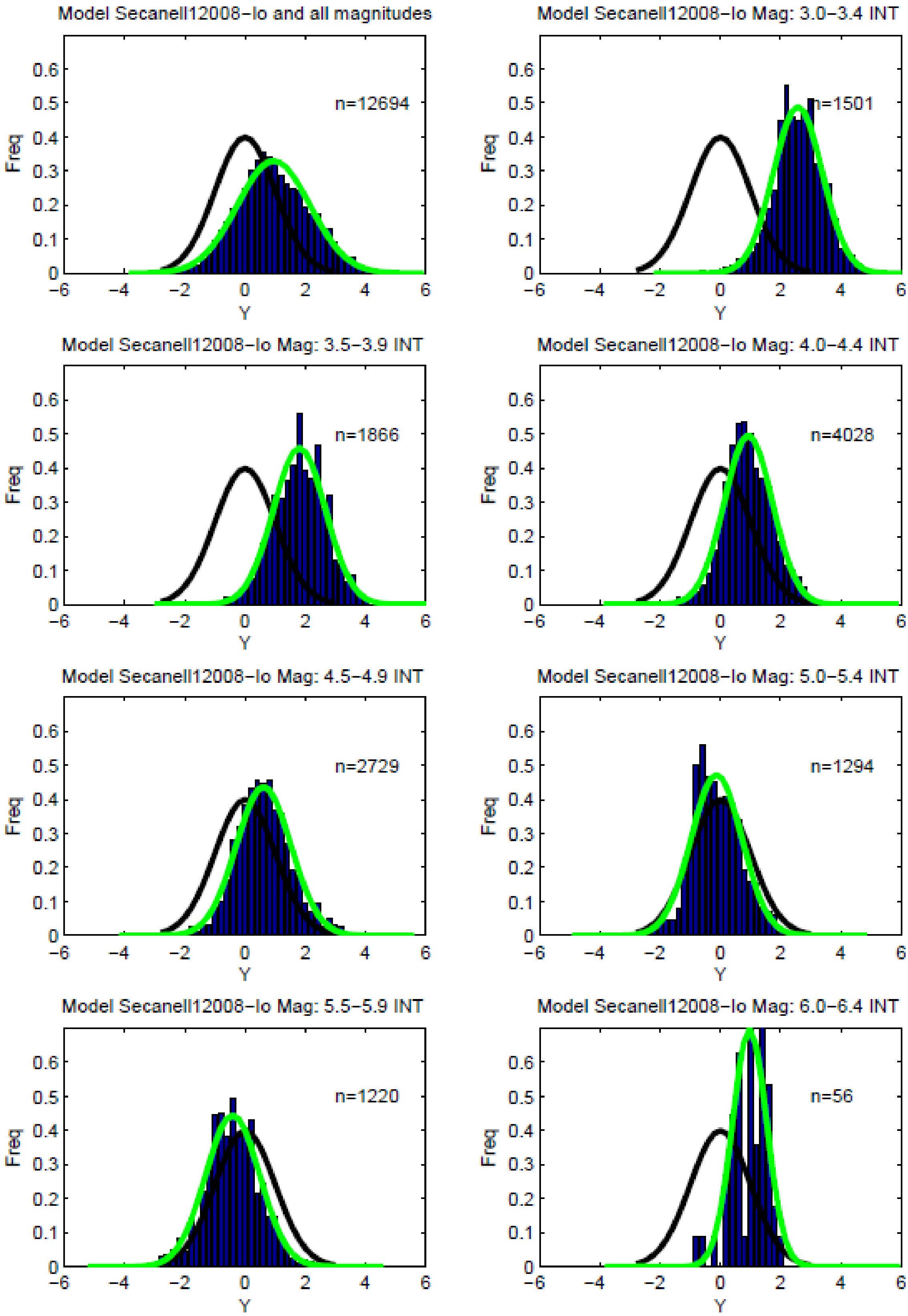



**Figure 55:** *Residuals by magnitude ranges with all data for Secanell12008-Io.*

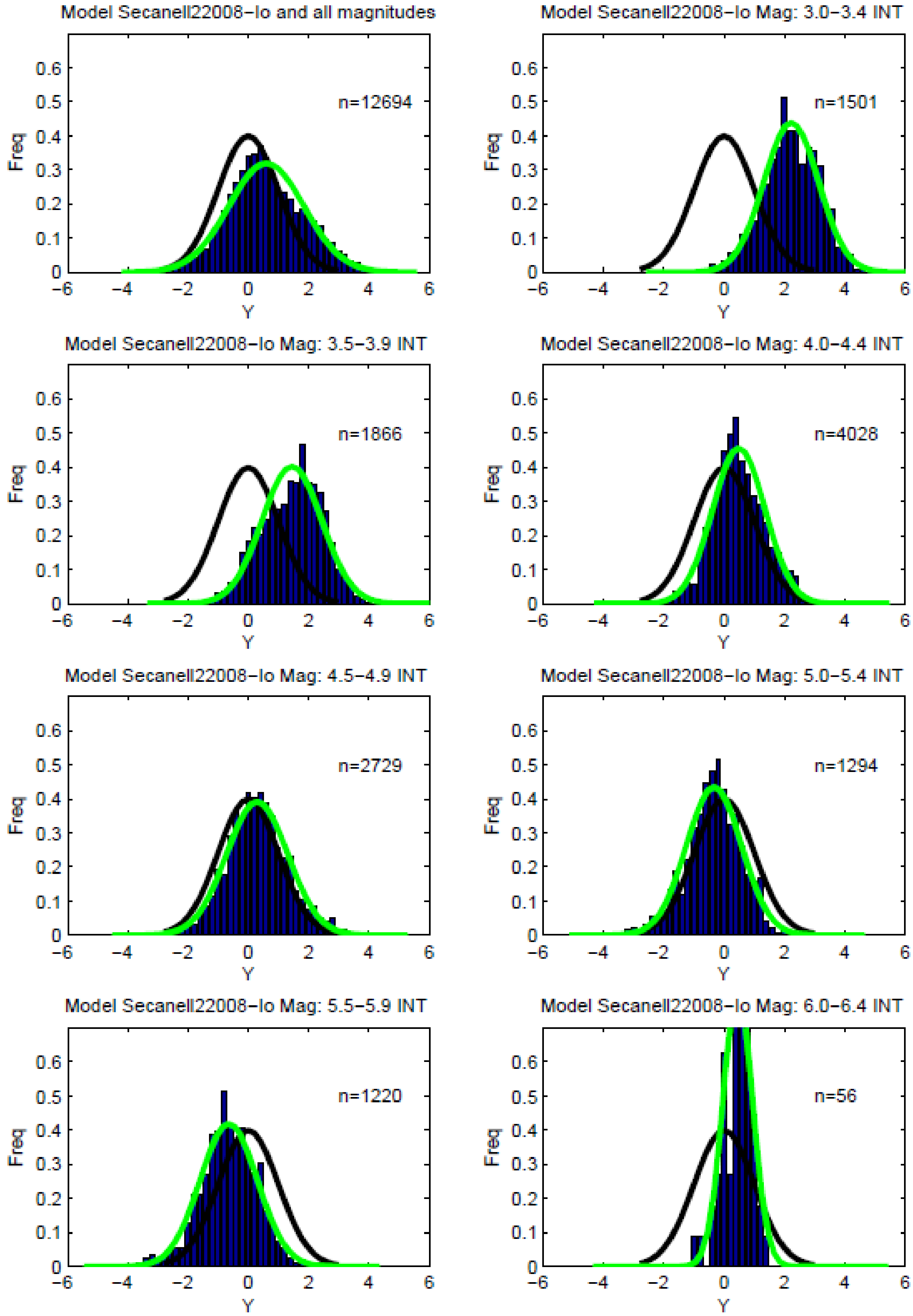



**Figure 56:** *Residuals by magnitude ranges with all data for Secanell22008-Io.*

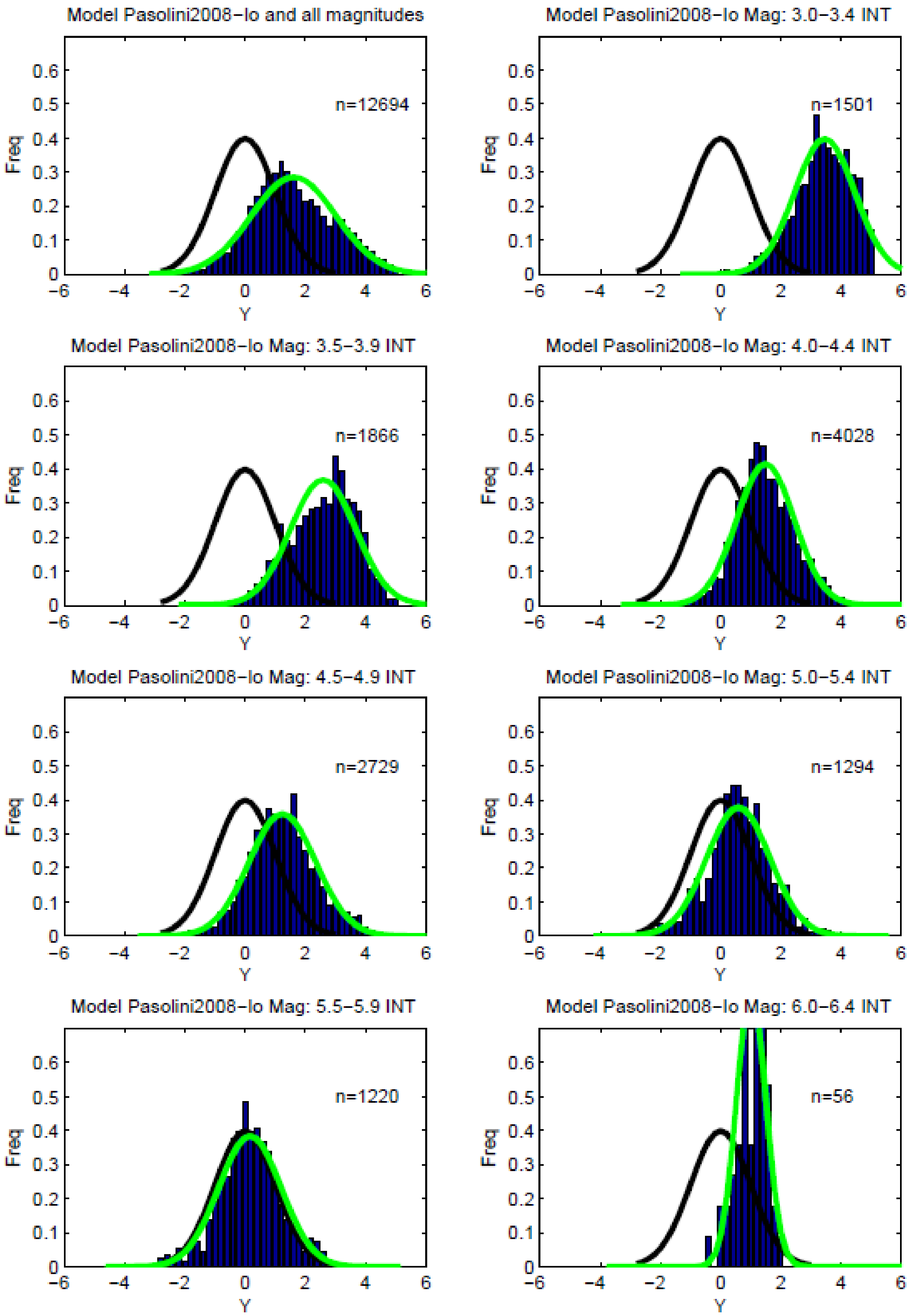



**Figure 57:** *Residuals by magnitude ranges with all data for Pasolini2008-Io.*

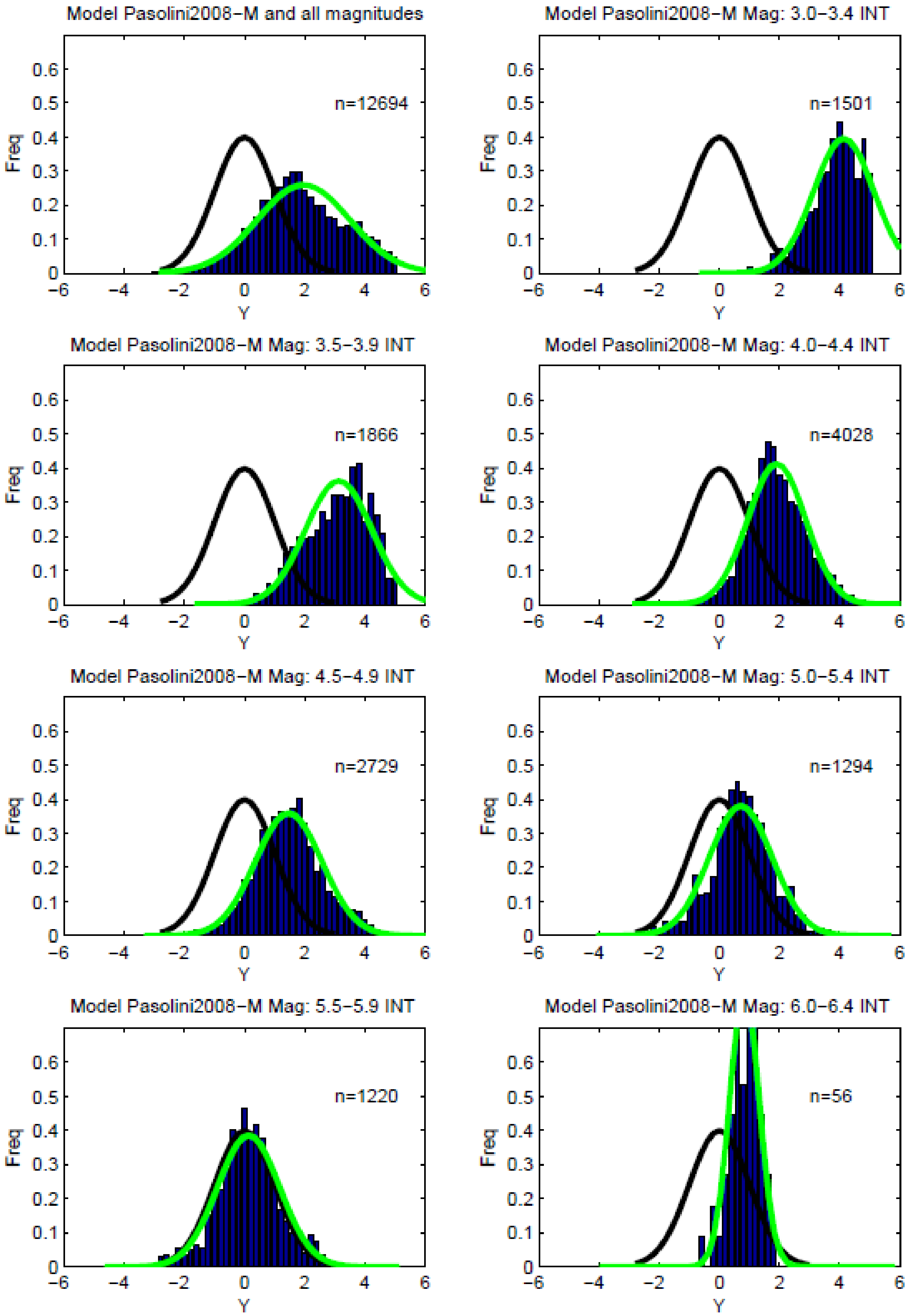



**Figure 58:** *Residuals by magnitude ranges with all data for Pasolini2008-M.*

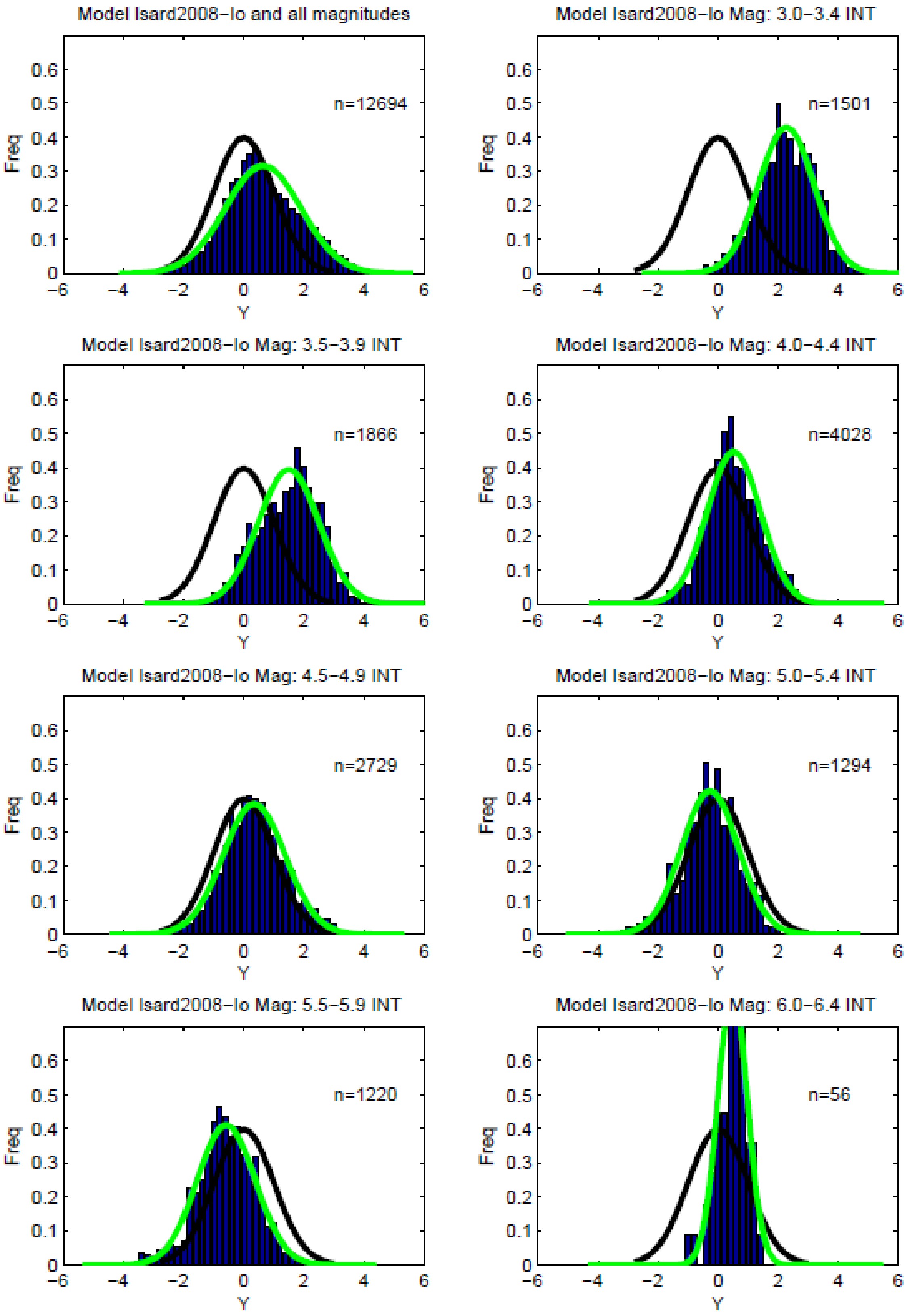



**Figure 59:** *Residuals by magnitude ranges with all data for Isard2008-Io.*

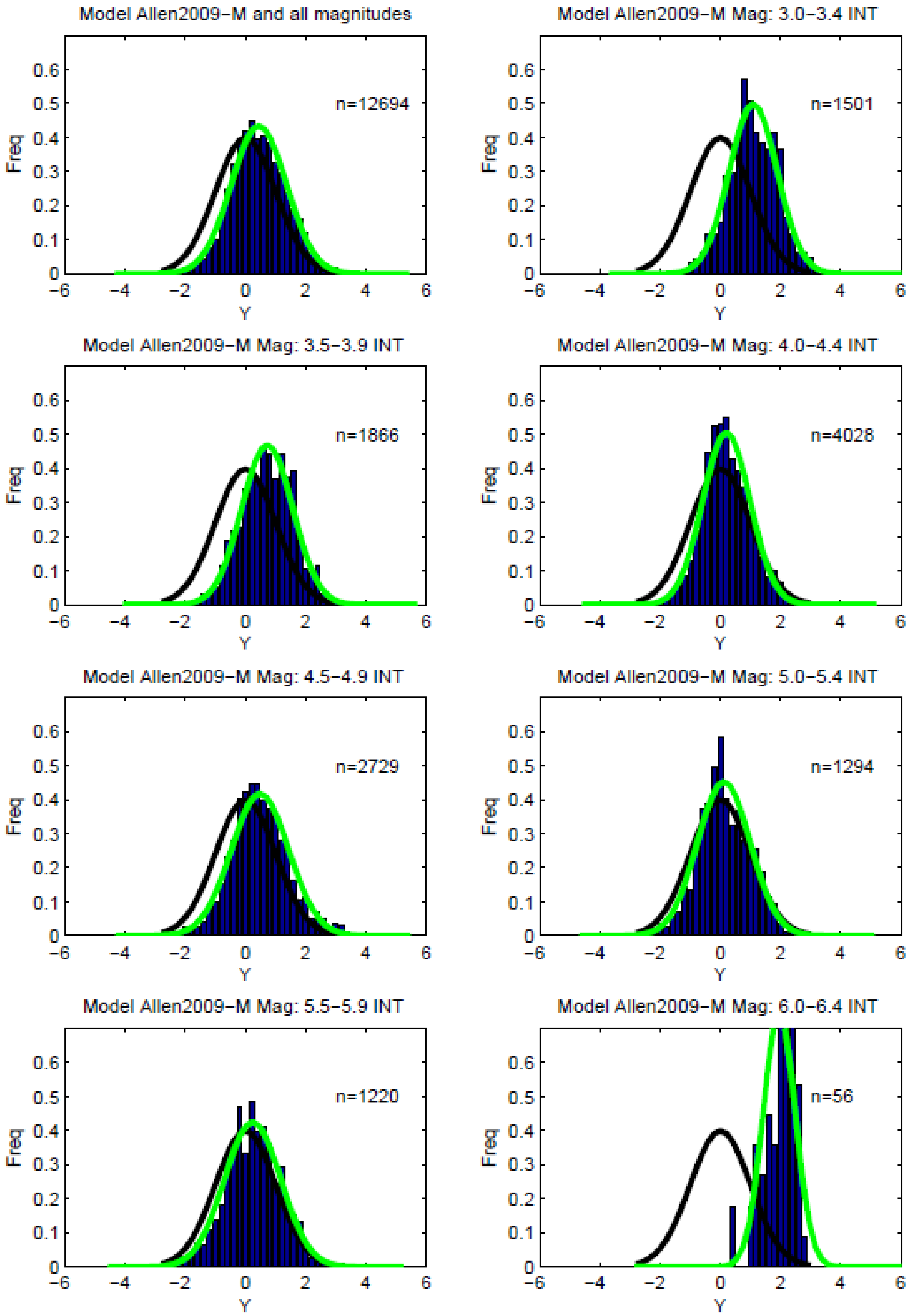



**Figure 60:** *Residuals by magnitude ranges with all data for Allen2009-M.*

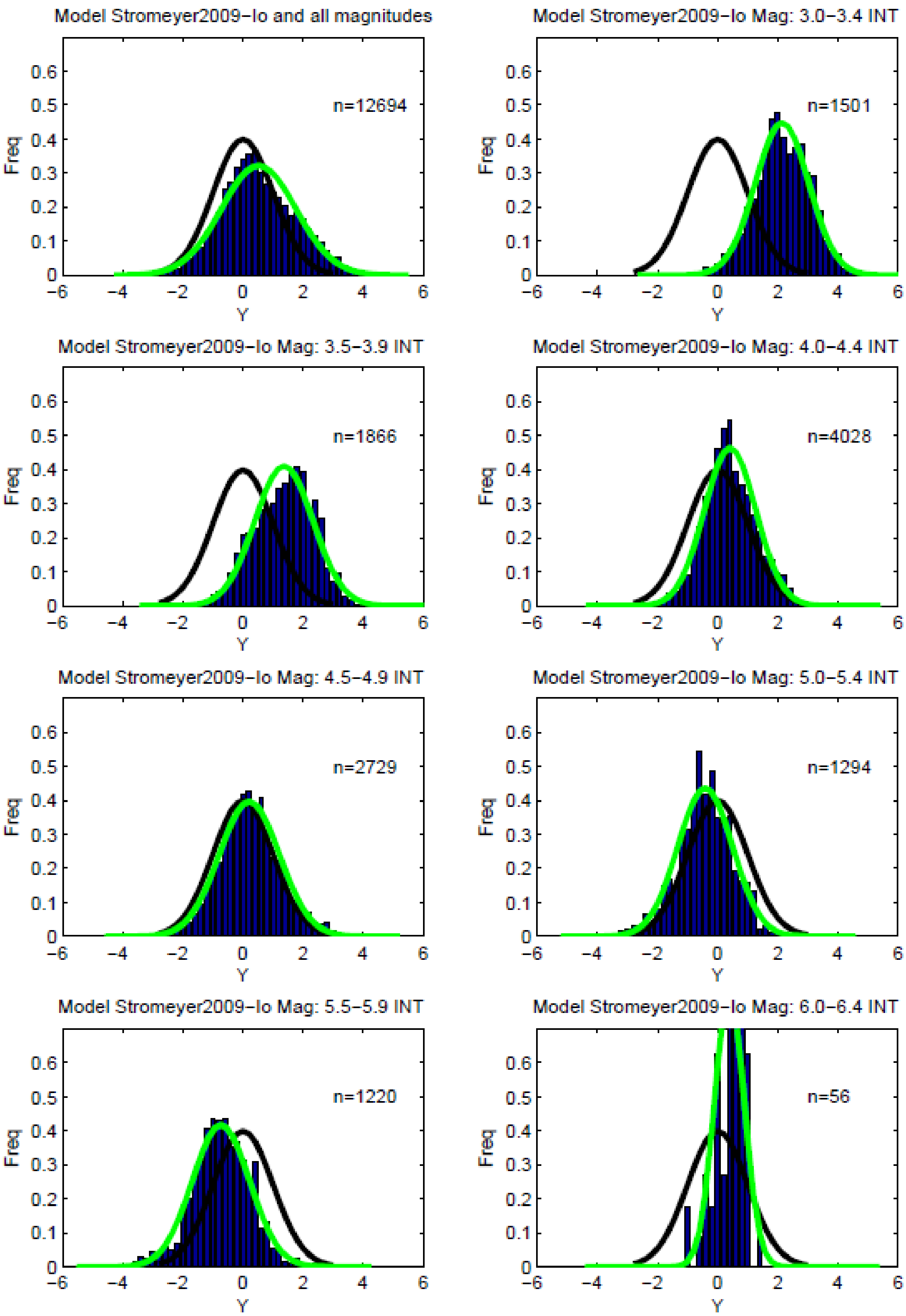



**Figure 61:** *Residuals by magnitude ranges with all data for Stromeyer2009-Io.*

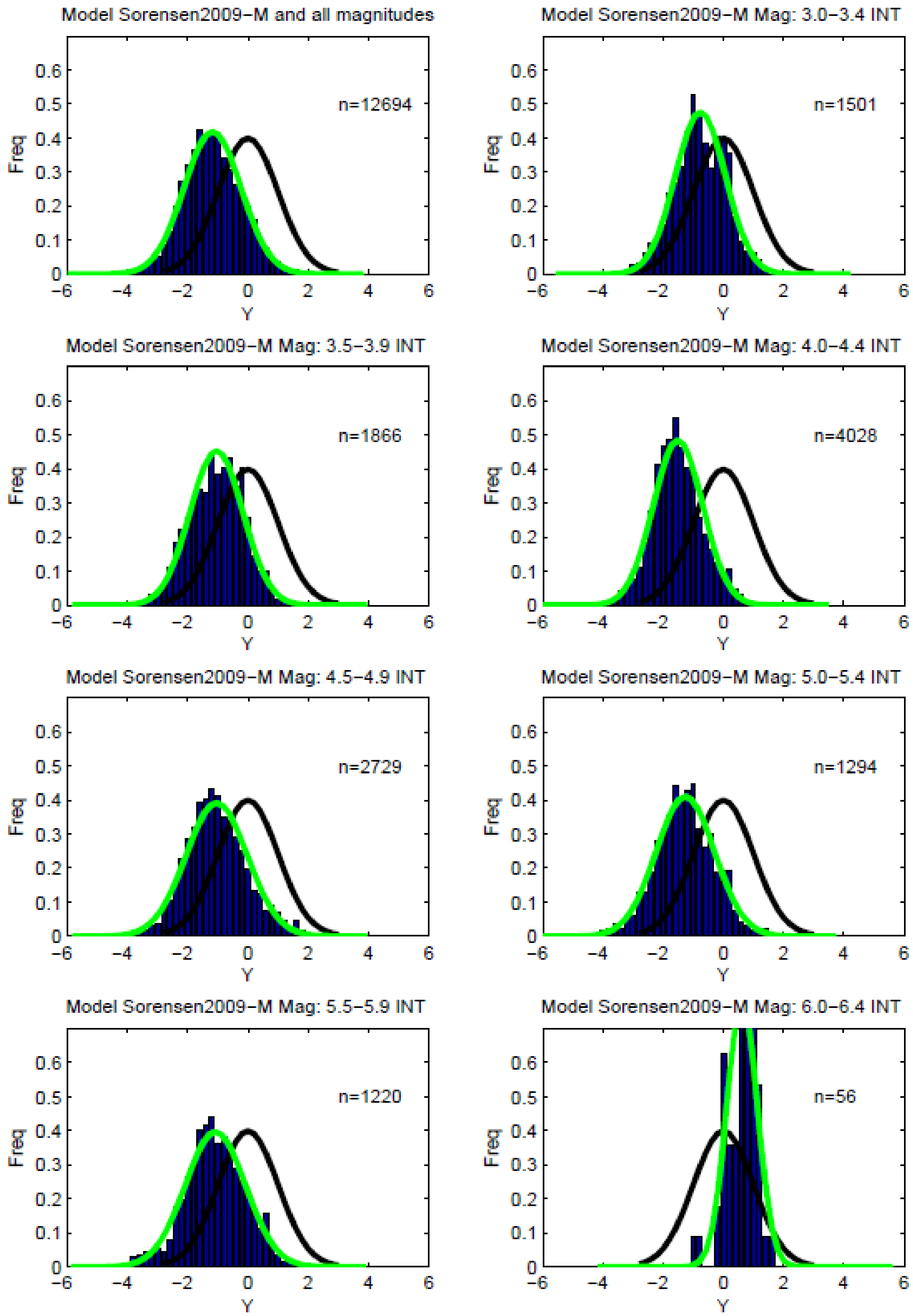



**Figure 62:** *Residuals by magnitude ranges with all data for Sorensen2009-M.*

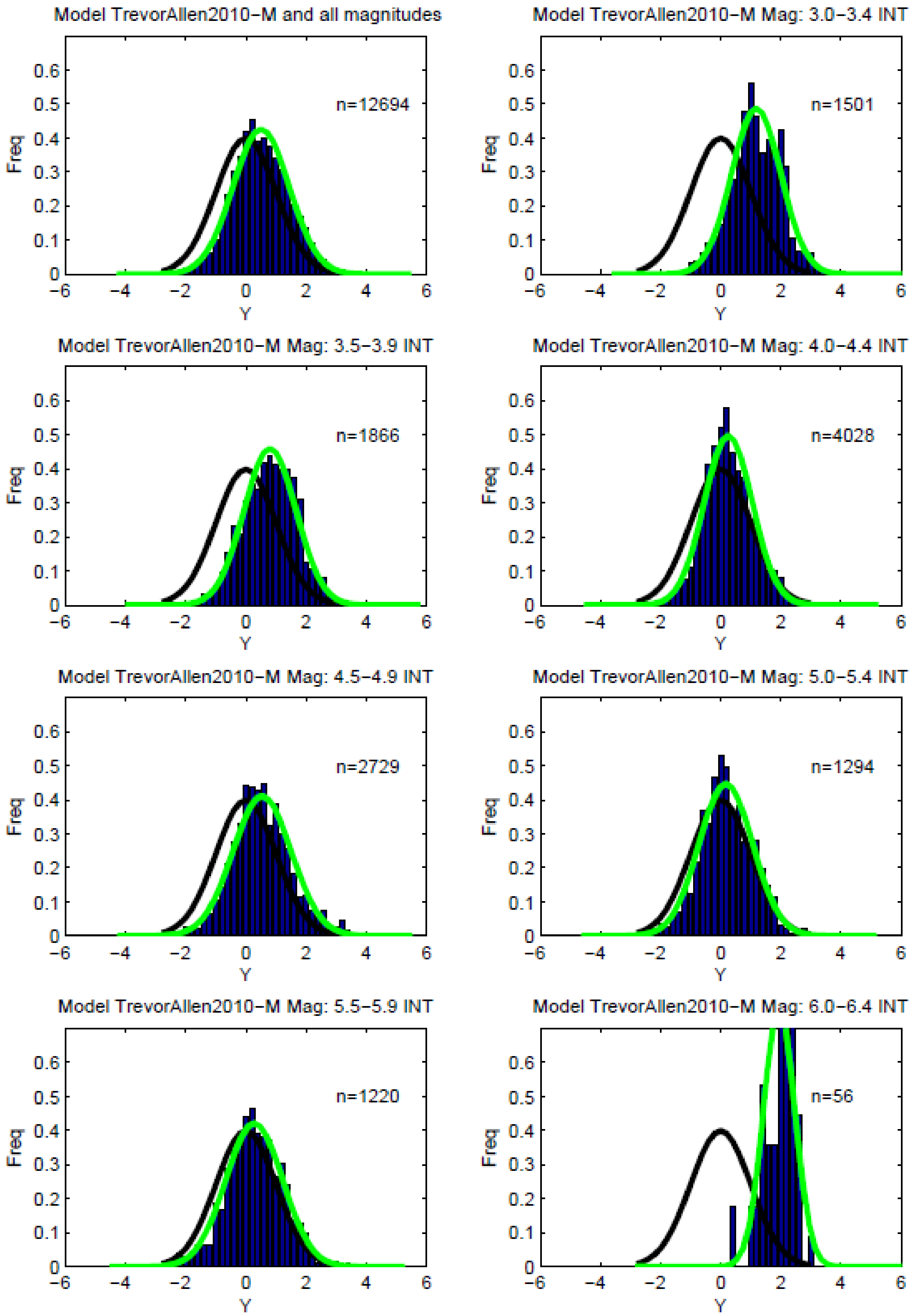



**Figure 63:** *Residuals by magnitude ranges with all data for TrevorAllen2010-M.*

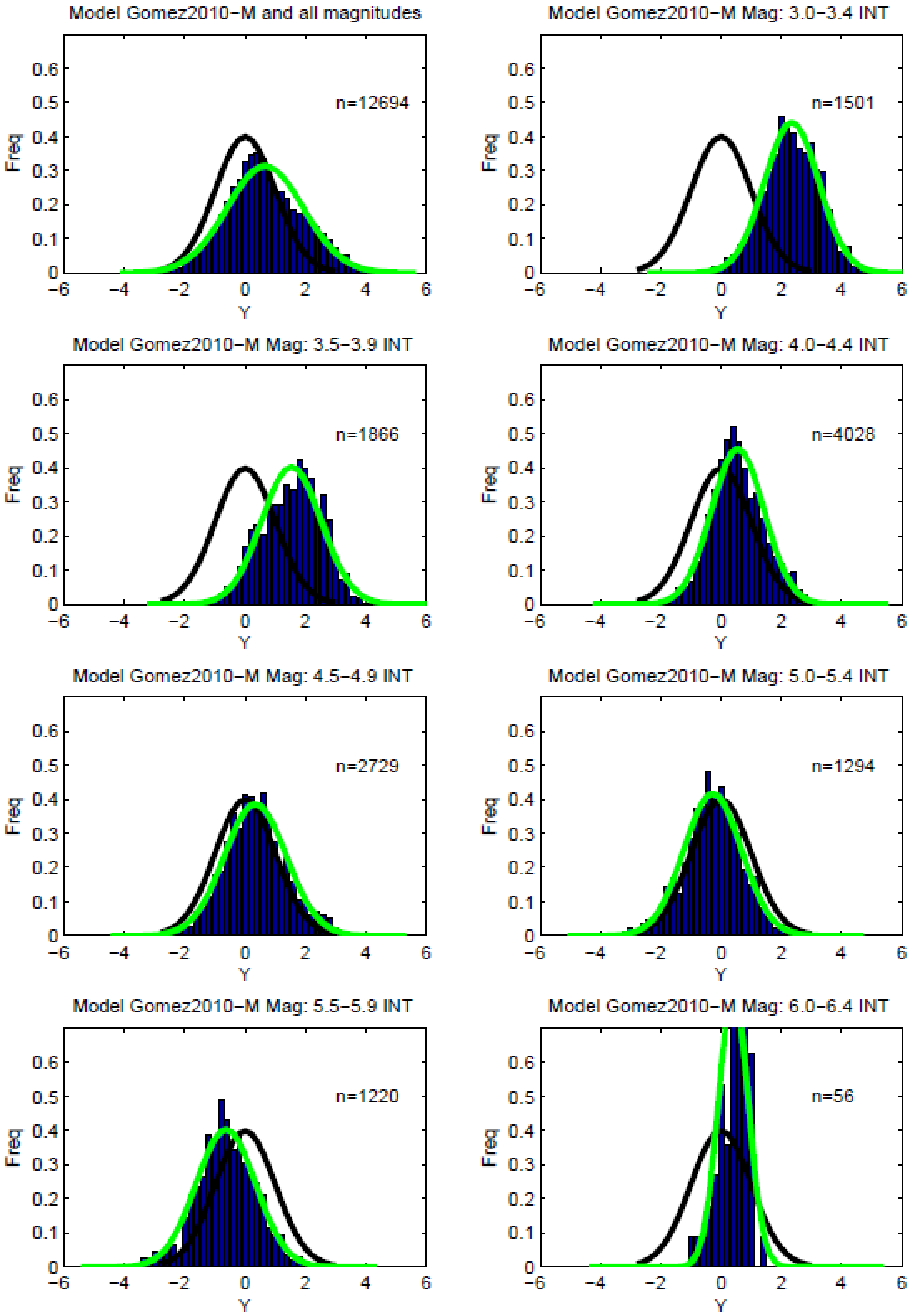
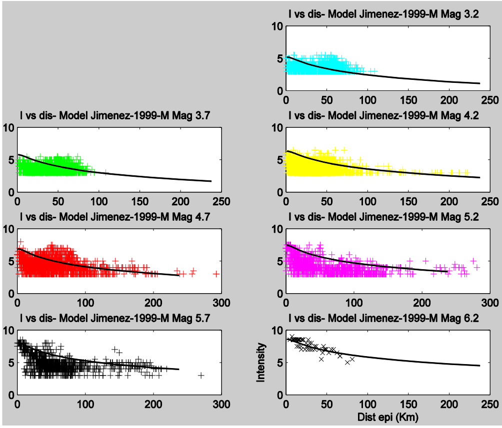
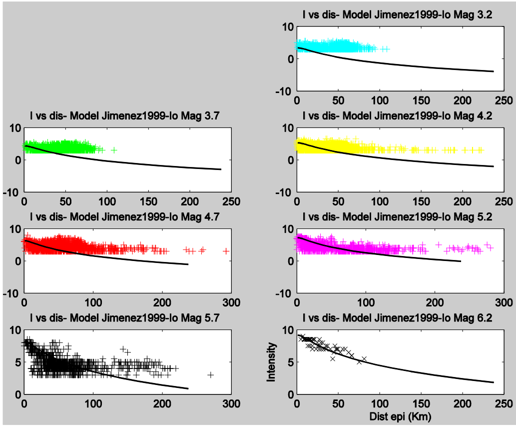
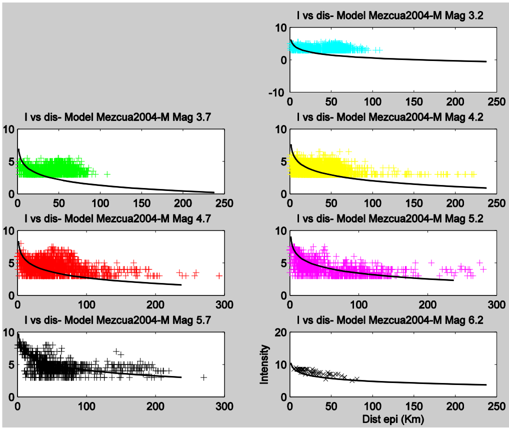


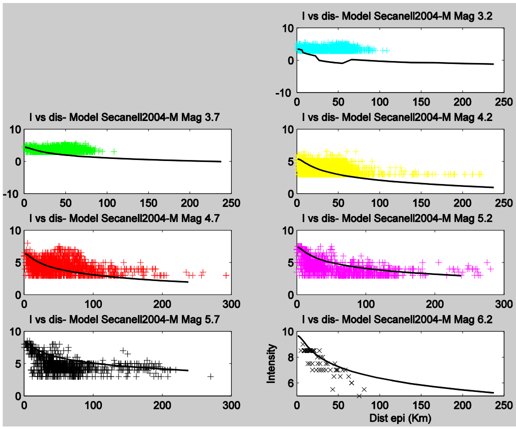

**Figure 64:** *Residuals by magnitude ranges with all data for Gomez2010-M.*

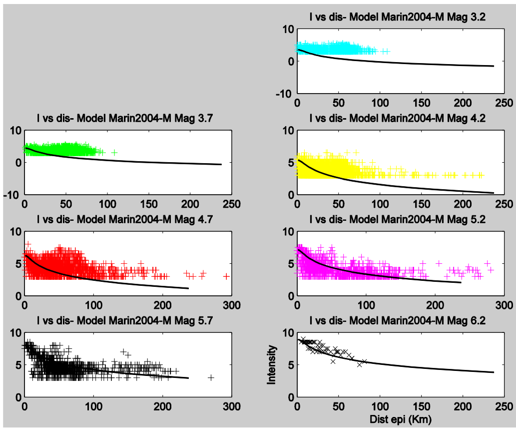
# F First overview of the equations with all the data

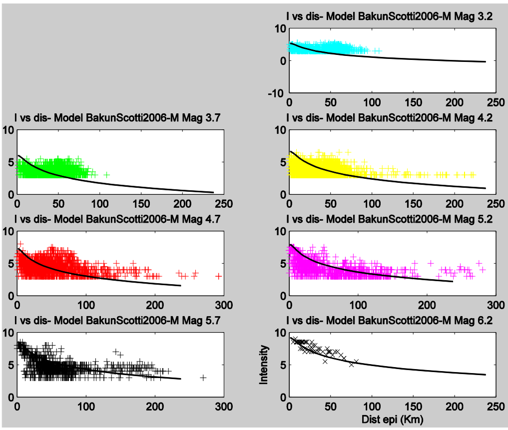


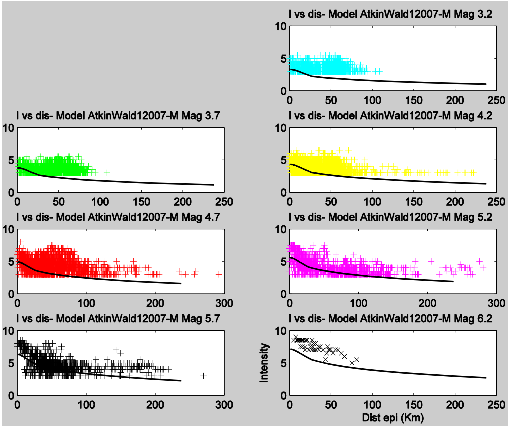

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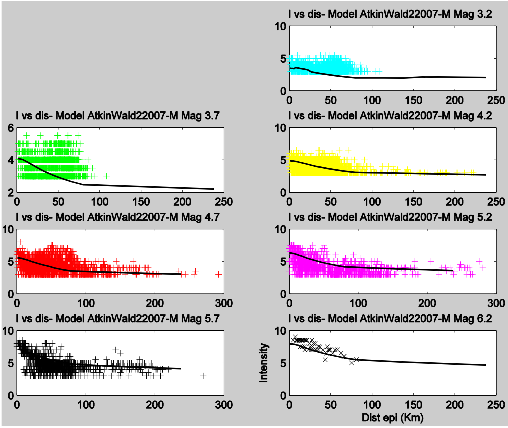
Intensity
Dist epi (Km)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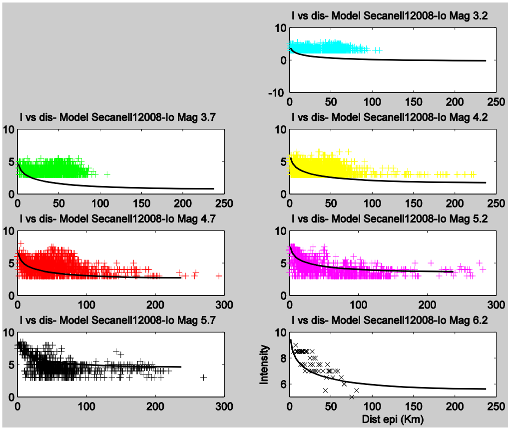
Intensity
Dist epi (Km)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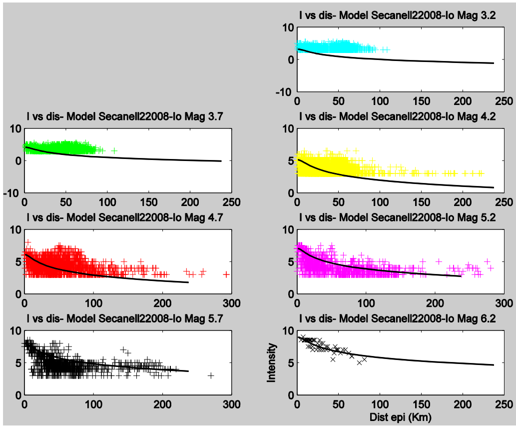
Intensity
Dist epi (Km)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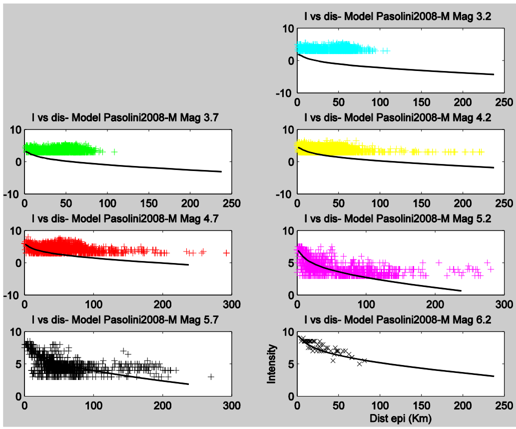
Intensity
Dist epi (Km)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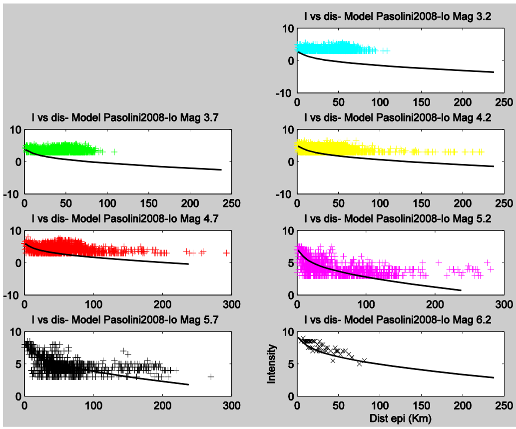
Intensity
Dist epi (Km)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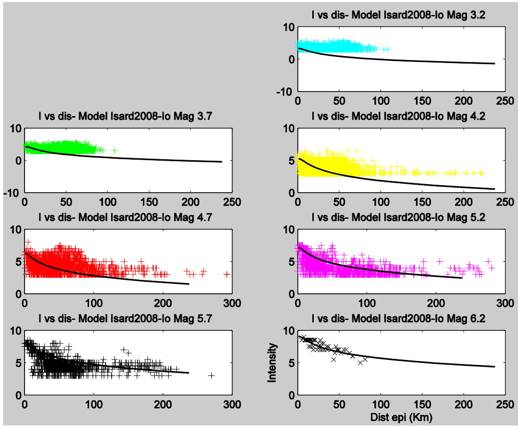
Intensity
Dist epi (Km)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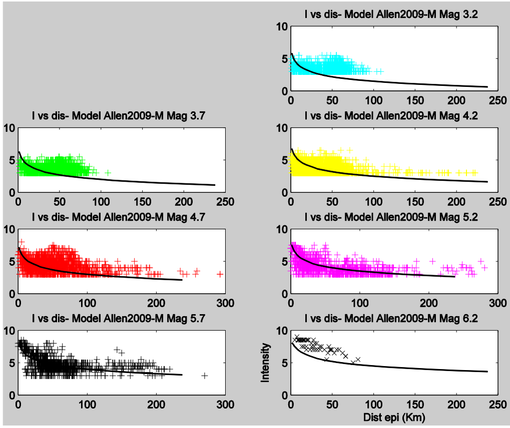
Intensity
Dist epi (Km)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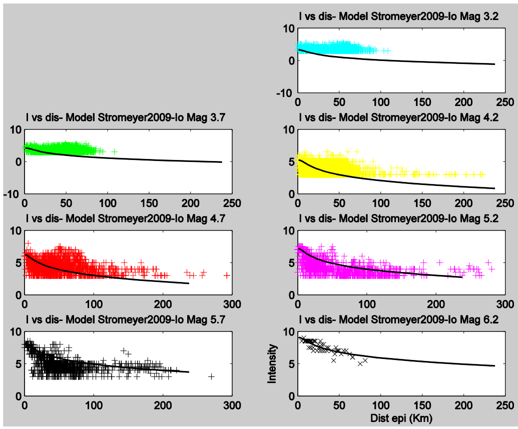
Intensity
Dist epi (Km)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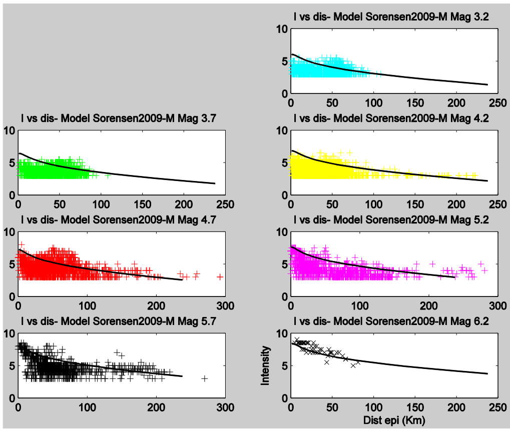
Intensity
Dist epi (Km)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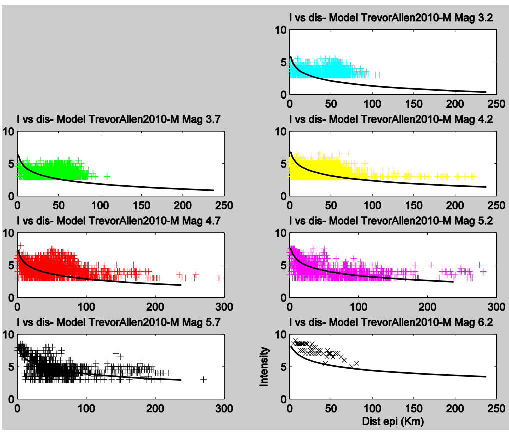
Intensity
Dist epi (Km)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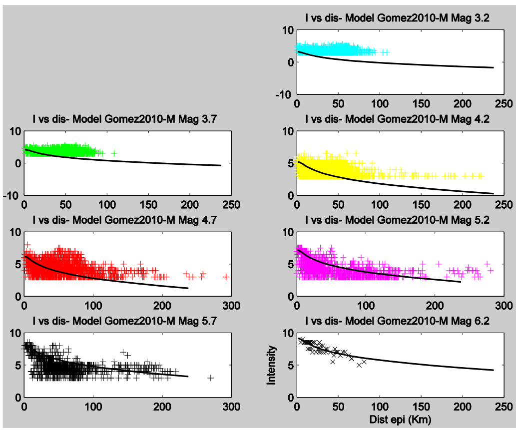
I vs dis- Model TrevorAllen2010-M Mag 5.7
I vs dis- Model TrevorAllen2010-M Mag 6.2
Intensity
Dist epi (Km)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I vs dis- Model Gomez2010-M Mag 5.7
I vs dis- Model Gomez2010-M Mag 6.2
Intensity
Dist epi (Km)

# Shake map: GMICE selection

# Contents



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# List of figures

## List of Tables

# 1. Introduction

Conversion from strong-motion parameters to macroseismic intensities is of major interest for ShakeMaps applications since it allows providing intensity maps few minutes after earthquakes, which constitute for the people involved in the crisis management a much more useful tool than the traditional shake-maps. Traditionally developed in a reverse way (ie. instrumental parameters prediction from intensity values) in order to bypass the lack of seismic stations in some areas or to work on historical events, the problematic has progressively evolved with the quick development of seismic network all around the word and the apparition of the so called “real-time seismology”.

In the frame of the SISPyr project the issue is to identify the most adapted Ground Motion to Intensity Conversion Equations (GMICEs) to the Pyrenean context. Indeed, as for the GMPEs, numerous GMICEs have been elaborated and the choice of the one(s) to use for a specific problematic is not a simple question.

Consequently this study aims at testing a wide sample of GMICEs on a SISPyr instrumental/macroseismic crossed dataset.

# 2. SISPyr crossed dataset

## 2.1. Data origin

The waveform catalogue gathered in the frame of the SISPyr project has been crossed with macroseismic intensity data coming from both side of the France-Spain border. For the French part, macroseismic information are those of the SISFrance macroseismic database (2009 version) managed by BRGM, EDF and IRSN and gathering more than 100.000 intensity data points from 5.500 events that occurred in France (metropolitan) or affected its territory since 463 until today. These intensities are in Medvedev Sponheuer Karnik (MSK) scale.

For the Spanish Pyrenean part, macroseismic data come from IGN and IGC. From IGN due to the no availability of well digitalized data we only use 170 mdps coming from 7 earthquakes. From IGC we use more than 5000 registers coming from 137 earthquakes.

In spite of the fact that available macroseismic data use different macroseismic data scale (MM, MSK and EMS-98) we consider in our analysis that all of them could be confused insofar as their differences are generally lower than the uncertainty linked to the intensity estimation itself ($\pm$ 0.5) (Musson et al., 2009) – cf. Table 1.

| MMI 56 | EMS-98 | MSK | EMS-98 |
|---|---|---|---|
| 1 | 1 | 1 | 1 |
| 2 | 2 | 2 | 2 |
| 3 | 3 | 3 | 3 |
| 4 | 4 | 4 | 4 |
| 5 | 5 | 5 | 5 |
| 6 | 6 | 6 | 6 |
| 7 | 7 | 7 | 7 |
| 8 | 8 | 8 | 8 |
| 9 | 9 | 9 | 9 |
| 10 | 10 | 10 | 10 |
| 11 | –[a] | 11 | 11 |
| 12 | –[a] | 12 | –[a] |

**Table 1:** Comparison of macroseismic intensity scales from Musson et al. (2009).

## 2.2. Crossing approach

Crossing between instrumental and macroseismic observations has been realized per event gathering data by city considering zip-codes. As the municipality code is not assigned to both databases, they are assigned using a GIS software spatial join function. In some cases, multi-points have been encountered consisting of several intensity values or seismic records in a single city. In that cases each possible combination between macroseismic and instrumental observations has been considered as pair since there is generally no way to attribute one value to another for non-joined acquisition system as mentioned in the Auclair & Rey report (2009). That point illustrates the epistemic uncertainty associates to the conversion from strong-motion parameters to intensities. In most of cases we only dispose of a single intensity value per city as the intensity evaluation is generally attributed by town while we can have several seismic stations in this area, but in some cases we can observe reverse situation (Figure 1)

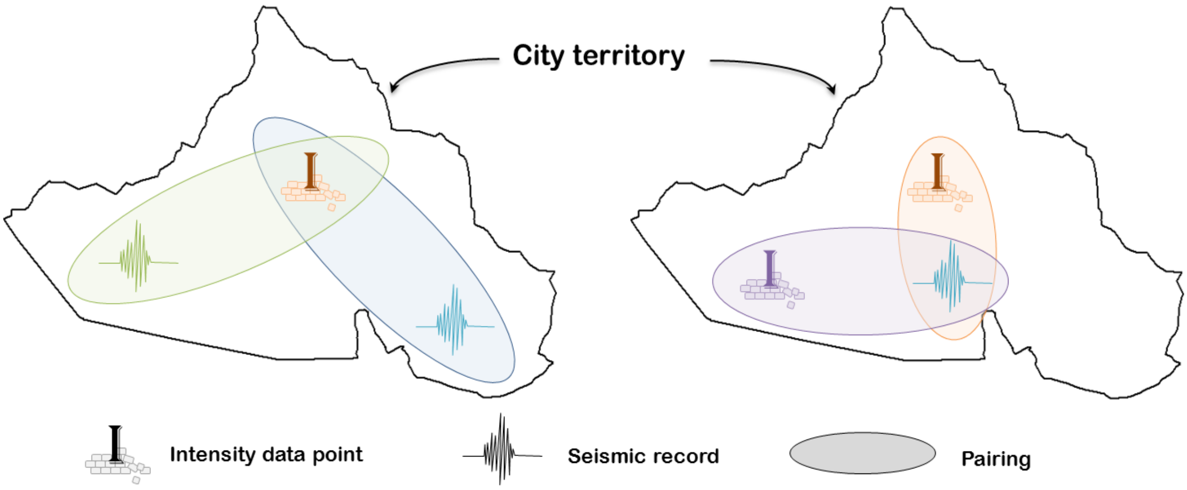


**Figure 1:** Paring approach used to cross instrumental and macroseismic data.

In addition, distance between seismic station and reference coordinates associated to intensity data points (which may be representative of level of intensity since they usually correspond to the urban center of the city) is also attributed to each pair in order to get a first idea of the validity range of associated data. Determine which ones to be discarded.

## 2.3. Data used

Two data sets have been used;

- a first one and well adapted to our region concerns Pyrenean earthquakes. It contains few data and with a maximum felt Intensity of 6
- a second one, extended to the Iberian Peninsula, with more data and maximum felt intensity of 7.

### 2.3.1 Pyrenean data

Concerning the SISFrance database, a quality code has been assigned to all intensity values in order to control the confidence that may be attributed to these values. Thus 3 different codes are defined:

- “A” quality code: high confidence level (uncertainty~0.5);
- “B” quality code: relatively good confidence level (uncertainty ≤ 1);
- “C” quality code: uncertain (uncertainty could be > 1).

When dataset are big enough this kind of qualification of the data allows a weighted approach in order to minimize the influence of bad quality points. Unfortunately, the relatively small dataset gathered for this study combined with the fact that none the IGN’s data nor the IGC ones dispose of such a qualification reduces the usefulness of this code. Indeed, SISFrance’s data only represent 50% of the wall dataset (reduced to 38% considering A and B codes only).

Considering the IGN and IGC dataset we obtain two databases with village’s codes. From this we select the mdps and registers that have the same earthquake code and village code. This could be done thanks to unify all the data with the same catalogue (a unique code for each earthquake).

The final dataset which relates the peak ground parameters with the intensity becomes a 207 registers. Before to work with this dataset some filters have been applied, as minimum intensity value of 2, and a minimum PGA value of $10^{-4}$g because some outliers in the dataset.

For that reason, the final dataset used in all the graphics become from 135 registers, for all the instrumental components, but as ShakeMap do it, we just used the maximum of the horizontal components. The final data set has 45 mdp points with each PGA, PGV, PSA (0.3s, 1s, 3s) values. The magnitude range is from 2.9 to 5, using the IGN magnitude.

Different parameters are shown in the figures 2 and 3. It is clear that the used dataset has a few quantities of values, even for intensity more than 5. These fact causes some problems in the statistical analysis, were becomes difficult to uses the Intensity as a proxy to separate the dataset in two different groups with Intensity<5 and intensity > 5.

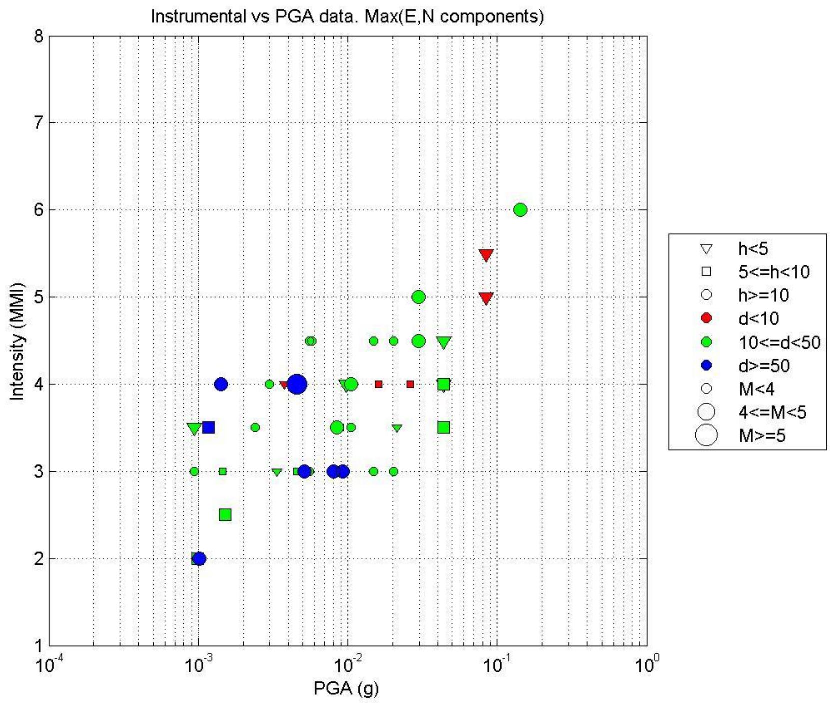


**Figure 2**: Selected data relating Intensity to PGA, with both filters applied. Also the depth, the epicentral distance and the magnitude are shown.

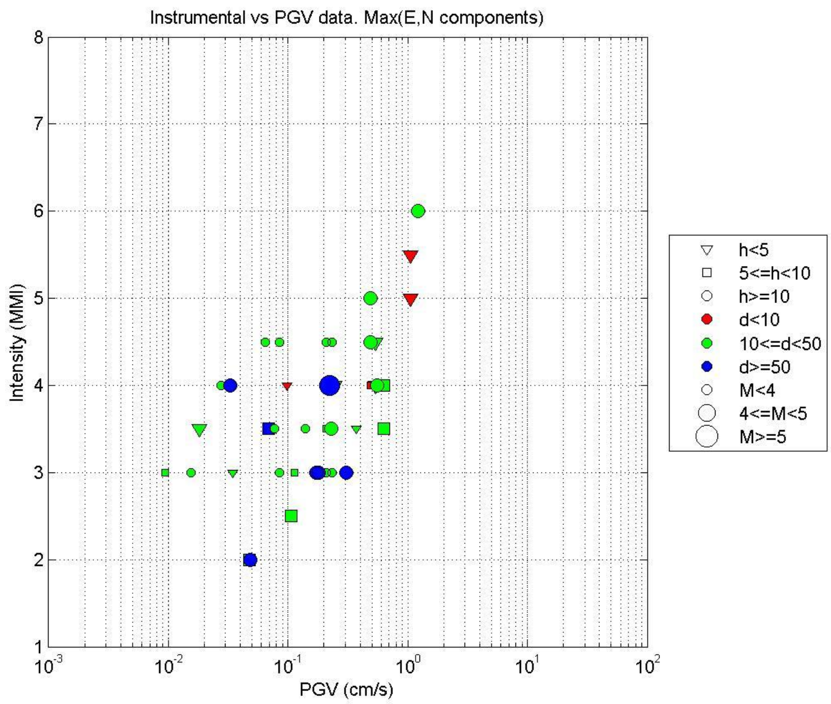


**Figure 3**: Selected data relating Intensity to PGV, with both filters applied. Also the depth, the epicentral distance and the magnitude are shown.

All the gathered data was no uniformly distributed in the Pyrenean zone, as it's show in the figure 4. Also, the magnitude range, show in figure 5, just have values less than 5, so is no possible to have great intensity values.

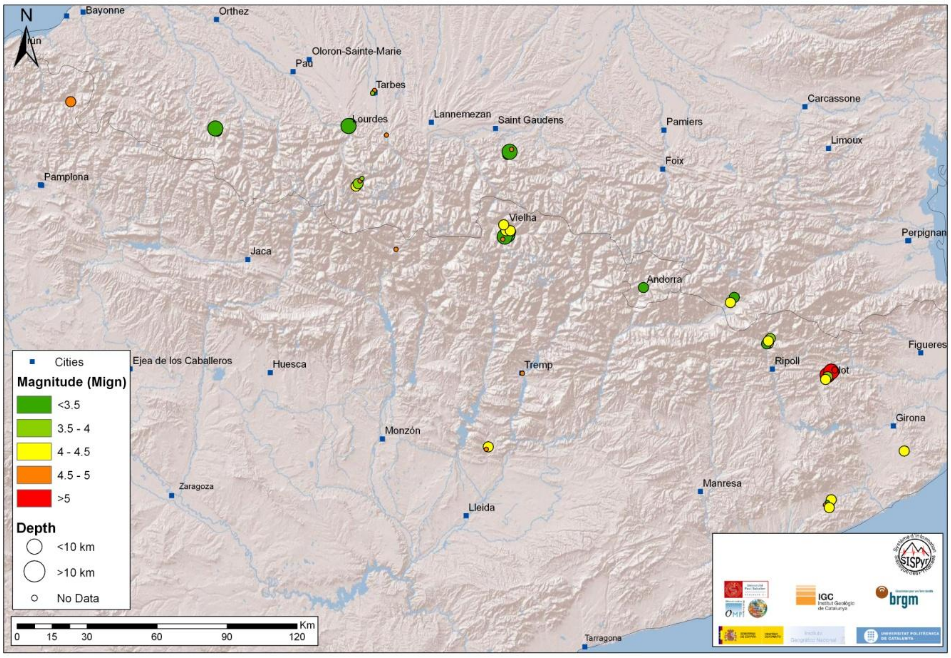


**Figure 4**: Localization of the selected earthquakes in the Pyrenees, with each magnitude.

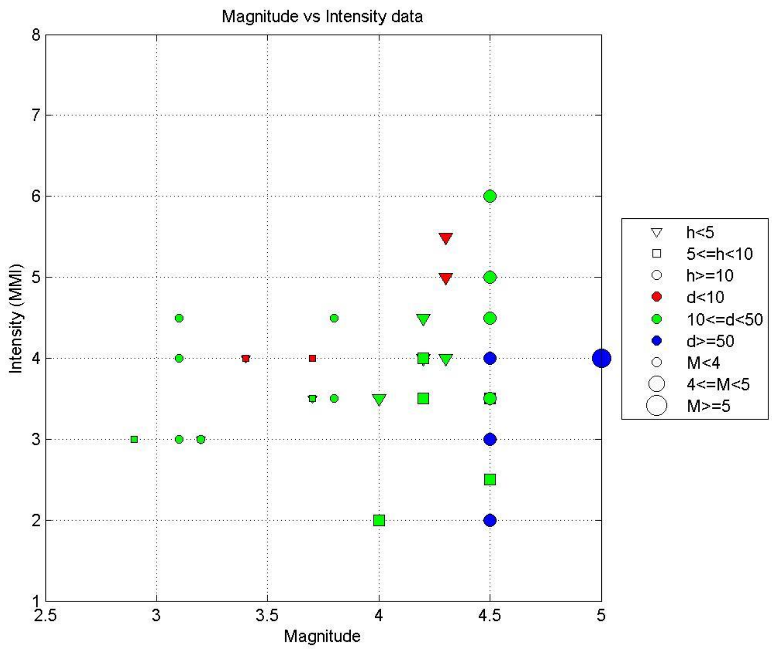


**Figure 5**: Intensity related to IGN Magnitude values. Also the depth, the epicentral distance and the magnitude are shown.

### 2.3.2 Iberian data set

Another dataset was used in some concrete steps of the study, provided by IGN, with events from all the Iberian plate.

These dataset has the same structure as the Pyrenean dataset has; relating Intensity to all the same used parameters.

A total of 614 data points are complied. 581 of them were retained with $I_x > 2$ and PGA > 2 $x10^{-4}$ g (Figure 6 to 8).

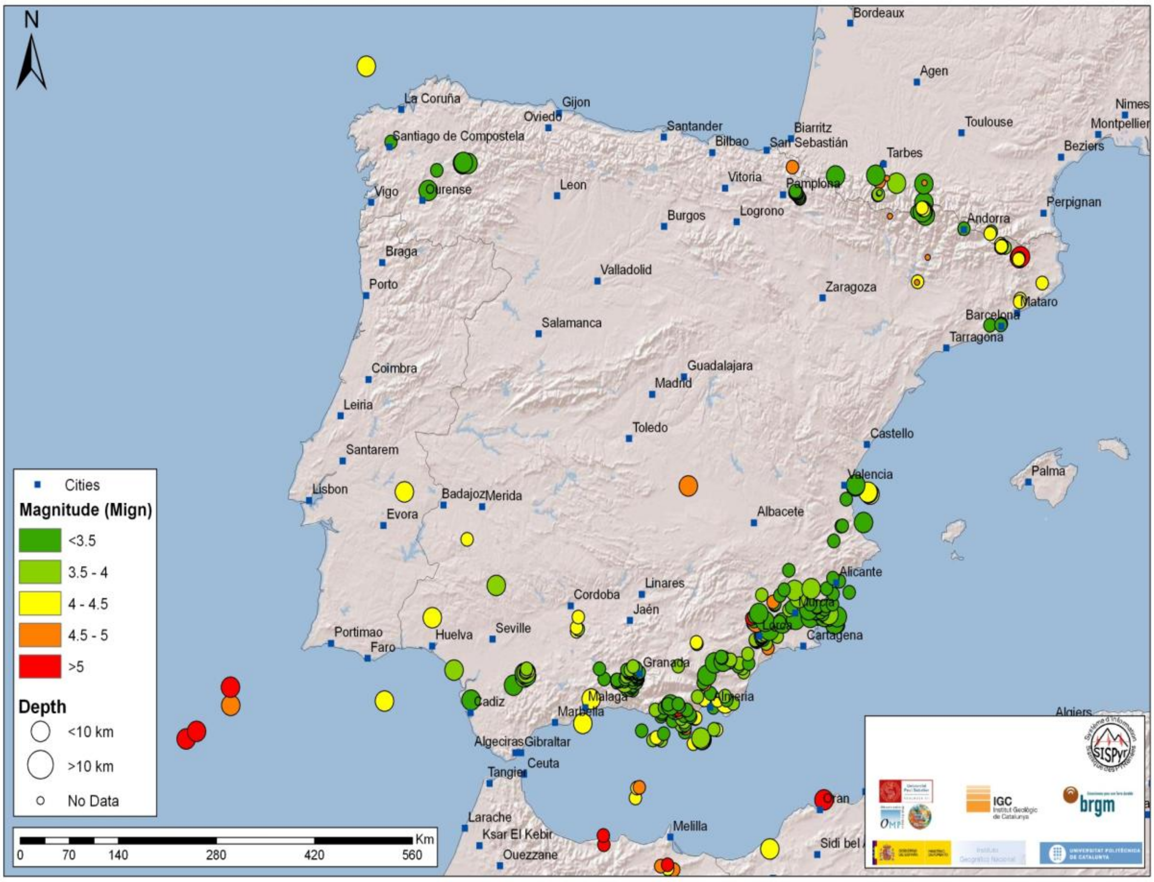


**Figure 6**: Localization of the selected earthquakes in Iberian Peninsula, with each magnitude

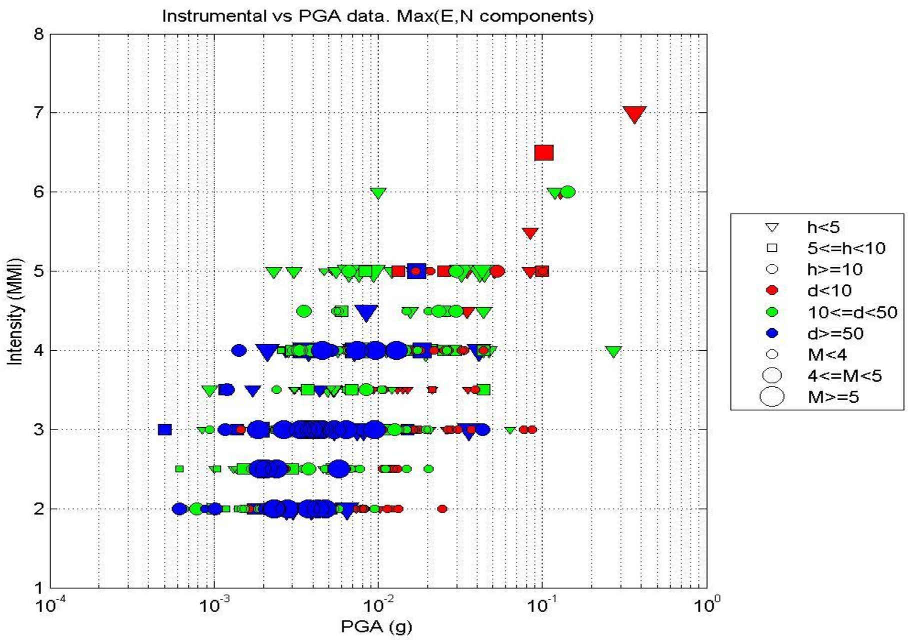


**Figure 7**: Selected data for Iberian earthquakes relating Intensity to PGA, with both filters applied. Also the depth, the epicentral distance and the magnitude are shown.

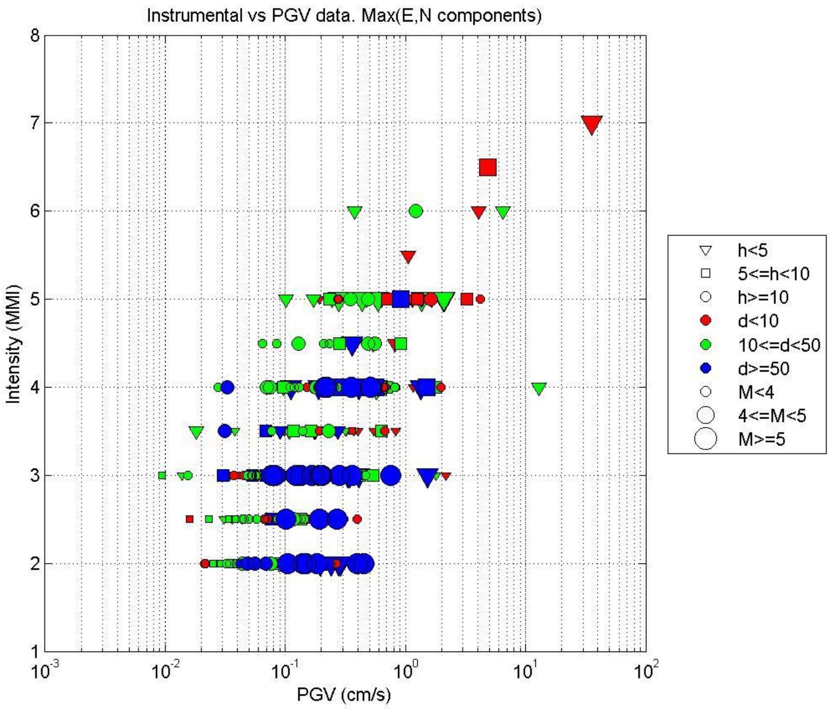


**Figure 8:** Selected data for Iberian earthquakes relating Intensity to PGV, with both filters applied. Also the depth, the epicentral distance and the magnitude are shown**.**

# 3 GMICE Selection

Different strategies have been applied in order to select the most adequate relations between Intensity and Ground motion parameters, PGA, PGV PSA (0,3), PSA (1) and PSA (3). Our options are conditioned by the previous selected GMPE and IPE. Then, the final choice is not conducted by an analogous procedure of applying Sherbaum method to fit to Pyrenean data to existent GMICE, but searching a compromise between the adaptation of GMICE to selected GMPE and IPE and the adaptation of GMICE to the Pyrenean data extended to Iberian data.

To do this we performed the following analysis:

i) pre-selection of GMICE based on Auclair and Rey (2009) comparing a complete list of GMICE with Pyrenean data,

ii) preselected GMICE equations are analyzed with analytical equations and numerical values for different pairs (M, r) deduced from GMPE and IPE in order to study coherence between different equations and Pyrenean and Iberian data,

iii) final selection for GMICE corresponding to Intensity versus PGA, PGV, PSA (0.3), PSA (1) and PSA (3).

## 3.1 GMICE Pre-selection

Recent reports from Auclair & Rey (2009) and Cua et al. (2010) draw up a global overview of existing GMICEs which may be summarized on Table 2 below.

| Reference | Notation | Region | Intensity type | Intensity validity range | Instrumental parameter |
|---|---|---|---|---|---|
| Atkinson & Kaka (2007) | **AK07** | **North America / Central America & California** | **MM** | **II - IX** | **PGA / PGV / PSA** |
| Atkinson & Kaka (2006) | **AK06** | **USA** | **MM** | **II - IX** | **PGA / PGV / PSA** |
| Atkinson & Sonley (2000) | **AS00** | **California** | **MM** | **III - IX** | **PGA / PGV / PGD / PSA** |
| Boatwright & others (2001) | - | California | Itag | V - IX | PGA / PGV / PSV |
| Cabañas & others (1997) | **Cetal97** | **Italy** | **MSK** | **V – VII/VIII** | **CAV / AI** |
| Chernov & Sokolov (1999) | - | word | MSK | IV - IX | FAS |
| Chernov (1989) | - | - | - | - | FAS |
| Davenport (2003) | - | New-Zealand | MM | IV – VIII/IX | PGA |
| Faccioli & Cauzzi (2006) | - | Italy | MCS | IV/V - IX | PGA |
| Faenza & Michelini (2010) | **-** | **Italy** | **MCS** | **II - VIII** | **PGA / PGV** |
| Gerstenberger & others (2010) | - | Califoria | MM | II – VIII/IX | PGA / PGV / PSA |
| ISARD project (2008) | **ISARD** | **Pyrenees** | **MSK** | **-** | **PGA / PGV** |
| Kaestli & Faeh (2006) | **KF06** | **Europe** | **EMS98 - MSK - MCS** | **I - VII** | **PGA / PGV** |
| Kaka & Atkinson (2004) | **KA04** | **USA + Canada** | **MM** | **II - VIII** | **PGV / PSA** |

| | | | | | |
|---|---|---|---|---|---|
| Koliopoulos & others (1998) | **Ketal98** | **Greece** | **MM** | **III – VIII/IX** | **PGA / PGV / CAV / AI /** etc. |
| Levret & Mohammadioun (1984) | - | France | MSK | V - IX | PSV |
| Margottini & others (1992) | - | Italy | MSK | IV – VIII/IX | PGA / AI |
| Marin & others (2004) | **Metal04** | **France** | **MSK** | **-** | **PGA** |
| Sokolov & Chernov (1998) | - | word | MM/MSK | IV - IX | FAS |
| Sokolov & Wald (2002) | - | word | MM | III - XII | FAS |
| Sokolov (2002) | - | word | MM/MSK | III - XII | FAS |
| Sorensen & others (2007) | - | Romania | EMS98 | V - VIII | PGA / PGV |
| Souriau (2006) | **S06** | **France** | **EMS98** | **II - V/VI** | **PGA** |
| Theodulidis & Papazachos (1992) | - | Greece | MM | IV - VIII | PGA / PGV |
| Trifunac (1989) | - | - | MM | - | FAS |
| Tselentis & Danciu (2008) | **TD08** | **Greece** | **MM** | **IV - VIII** | **PGA / PGV / CAV / AI** |
| Wald & others (1999) | **Wetal99** | **California** | **MM** | **V - IX** | **PGA / PGV** |
| Wu & others (2003) | - | Taiwan | It | I - VII | PGV |

**Table 2:** Main existing GMICEs. With PGA, PGV & PGD: peaks ground acceleration, velocity and displacement respectively, CAV: Cumulative Absolute Velocity, AI: Arias Intensity, FAS: Fourier Amplitude Spectrum. Bold lines correspond to GMICEs tested in the frame of the present study.

A test on our raw data set (i.e. without any consideration about data quality) of numerous GMICEs (bold relations on table 1) has been performed in order to have a first idea of their applicability in Pyrenees as intensity prediction tools. These calculations have been done using GMICEs on their proper intensity validity range only – as reported on Table 1–, and considering for each of them the adapted combination of both horizontal components as defined in original articles and reports (maximum parameter from 2 horizontal components, geometrical mean, etc.).

Results show several kinds of behavior depending on authors and/or instrumental proxy considered. First of all we may notice that, considering a given instrumental parameter, predicted intensities from different GMICEs are in some cases very different with an interval of more than one intensity unit. Consequently some relations succeed relatively well in predicting intensities from Pyrenean seismic records while others do not which is not surprising given the investigated intensity range (III to VI) knowing that GMICEs presents strong dispersions for lowest intensities (≤ V) as shown for PGA and PGV on Figure 9 extracted from the 2010-4 GEM report from Cua et al. (2010).

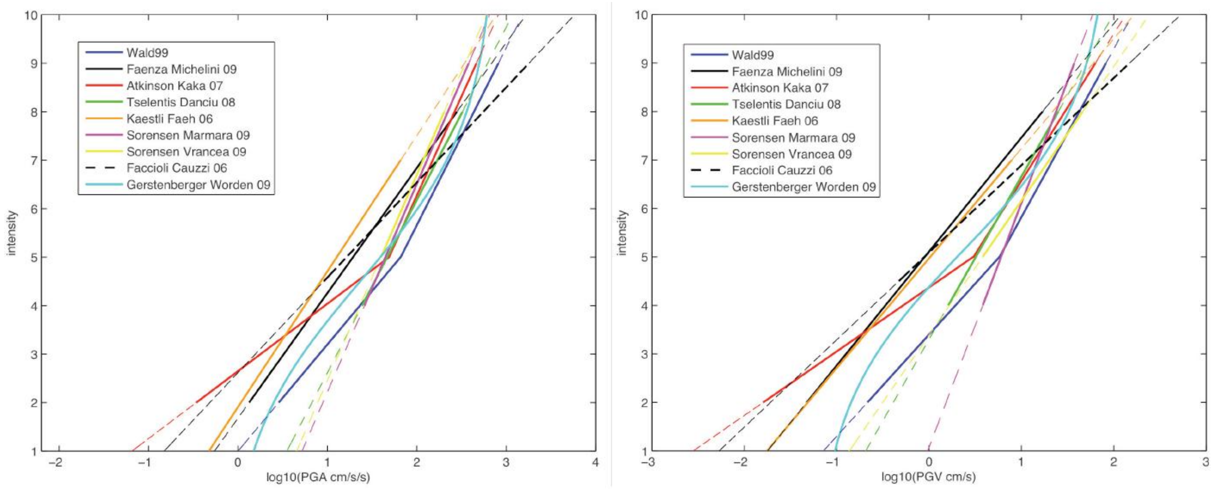


**Figure 9:** Functional forms of PGA and PGV to intensity relationships derived from various regions (from Cua et al., 2010)

The repartition of residuals (defined as $I_{predicted} – I_{observed}$) in function of observed intensity for each GMICE permit to retain four of them which show good results:

1. <u>Tselentis and Danciu (2008) PGA relation:</u> As it can be seen on Figure 10a, while the Tselentis and Danciu PGA relation is clearly not adapted to predict low intensity values in Pyrenees due to a large over-estimation until intensity IV, it seems to be more adapted for higher values (IV-V to VI). By the past this relation has been tested at different occasions on several data-sets such as the Aquila earthquake's one (cf. Auclair and Rey, 2009) and it has been shown that it is generally quite reliable also for intensities notably higher than VI.
2. <u>Souriau (2006) PGA relation:</u> The Souriau's relation is one of the rare GMICE specifically defined for low intensities (ie. no destruction: I ≤ VI). Moreover it has been built using Pyrenean data. Consequently it may be considered as a "region specific" relation a-priori quite adapted to Pyrenees. The fact is that this hypothesis is comforted by the test performed on our data set (cf. Table 3 and Figure 10b).
3. <u>Kaka and Atkinson (2004) PGV relation:</u> Even though this relation is not based on Pyrenean data it exhibits results very close to the ones got with the relation of Souriau (cf. Table 1 and Figure 1c). That is very interesting because PGV is generally considered as a high-intensities proxy when PGA is privileged for low-intensities.
4. <u>Kaka and Atkinson (2004) PSA-10Hz relation:</u> It is quite interesting to notice that, contrary to the test led by Auclair & Rey on Aquila earthquake for high intensity values, the PSA-10Hz GMICEs of Kaka and Atkinson shows relatively good results for the moderate intensities of the Pyrenean data set (cf. Table 3 and Figure 1d). Indeed this relation exhibited bad results in the case of Aquila while the Atkinson and Kaka (2007) PSA-1Hz relation appeared promising. That observation underlines the fact that low intensities dominated by human perception and effects on objects are not sensitive to the same parameters (such as frequency) that strongest ones dominated by damages on buildings.

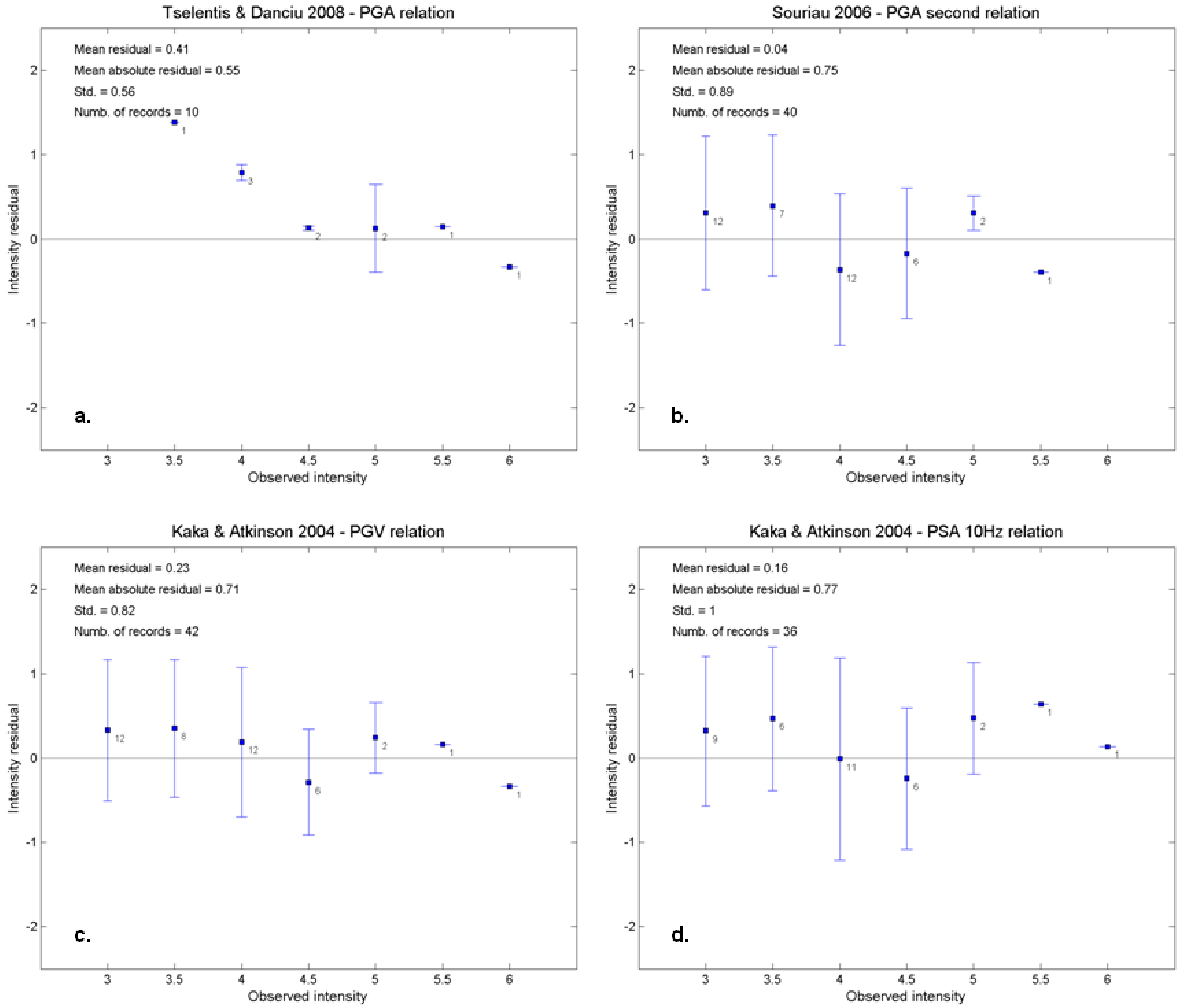


**Figure 10:** Residuals of four selected GMICEs from test performed on Pyrenean instrumental/macroseismic crossed data.

However, good results got by these GMICEs in our test stage have a limited signification because of the low number of pairs used (no more than 2 pairs available per class of observed intensity greater than IV). However, this is a delicate issue to conclude about the reason of this mismatch since GMICEs are not fully responsible of it. Indeed, instrumental/macroseismic common data points cannot be considered as unbiased reference data because they are note based on a true common acquisition and then intensity associated to each seismic record is not really representative of the local effects induce by the earthquake at the site of the station. Moreover we remind that intrinsic uncertainty attributed to intensity due to its estimation is typically around half a unity.

At this stage we will incorporate some more equations to be analyzed:

- Wald et al. (1999), because it is used in worldwide standard shakemaps
- NCSE02 BOE nº 244 (2002), because is the equation used in the Spanish seismic rules for construction
- Faccioli and Cauzzi (2006), because is one of the few european equations for PGV
- Atkinson and Kaka (2006, 2007), because they propose equations for PSA at frequencies necessaries for Shakemap

The retained GMICE for further analysis are listed in Table 3

| Reference | Region | Intensity type | Intensity validity range | Instrumental parameter |
|---|---|---|---|---|
| Atkinson & Kaka (2007) | North America / Central America & California | MM | II - IX | PGA / PGV / PSA |
| Atkinson & Kaka (2006) | USA | MM | II - IX | PGA / PGV / PSA |
| Atkinson & Sonley (2000) | California | MM | III - IX | PGA / PGV / PGD / PSA |
| Faccioli & Cauzzi (2006) | Italy | MCS | IV/V - IX | PGA |
| Faenza & Michelini (2010) | Italy | MCS | II - VIII | PGA / PGV |
| ISARD project (2008) | Pyrenees | MSK | - | PGA / PGV |
| Kaka & Atkinson (2004) | USA + Canada | MM | II - VIII | PGV / PSA |
| Marin & others (2004) | France | MSK | - | PGA |
| Souriau (2006) | France | EMS98 | II - V/VI | PGA |
| Tselentis & Danciu (2008) | Greece | MM | IV - VIII | PGA / PGV / CAV / AI |
| Wald & others (1999) | California | MM | V - IX | PGA / PGV |
| NCS E02. BOE nº244 (2002) | Spain | EMS98 | II - IX | PGA |

**Table 3**: Pre-selected GMICES for analysis of coherence with GMPE and IPE

## *3.2* Coherency of GMICE with GMPE and IPE

The aim of this section is to analyze the compatibility of pre-selected GMICE's with selected GMPE and IPE together with the used data.

Two set of data and two procedures to obtain (Int, PGM) from combination of GMPE and IPE, are used, one analytical and a second one, numerical.

In the Figures 11 to 19 the plots corresponding to Pyrenean data set and Iberian data set for Intensity versus GM parameters: PGA, PGV, PSA (0,3s), PSA (1s) and PSA (3s) are shown with some pre-selected GMICE's and (Int, PGM) obtained from selected GMPE and IPE.

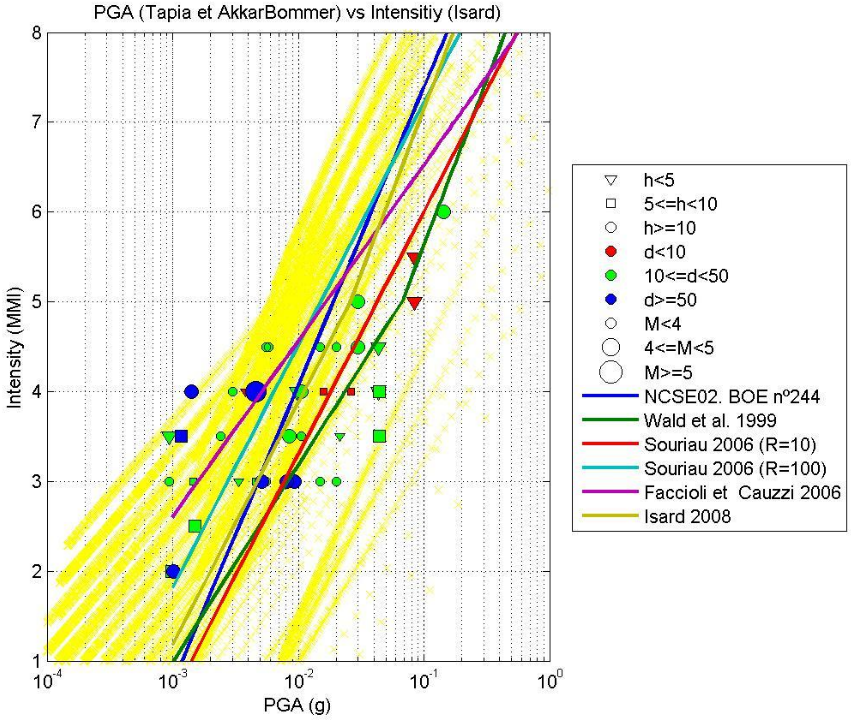


**Figure 11**: Int/ PGA: Pyrenean data, selected GMICE's and numerical values of (Int, PGA) from selected GMPE and IPE.

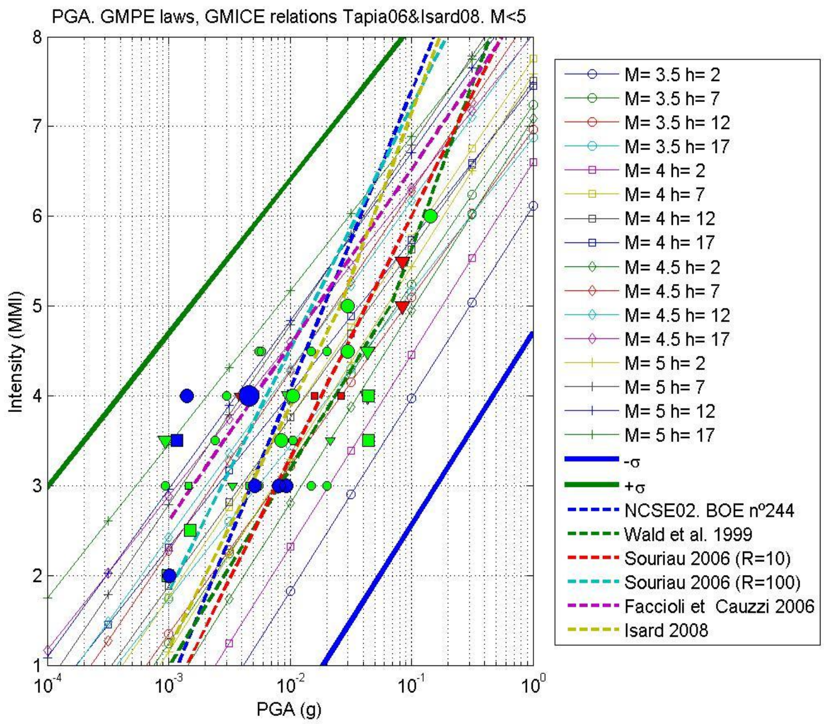


**Figure 12**: Int/ PGA: Pyrenean data, selected GMICE's and analytical values of (Int, PGA) from selected GMPE and IPE.

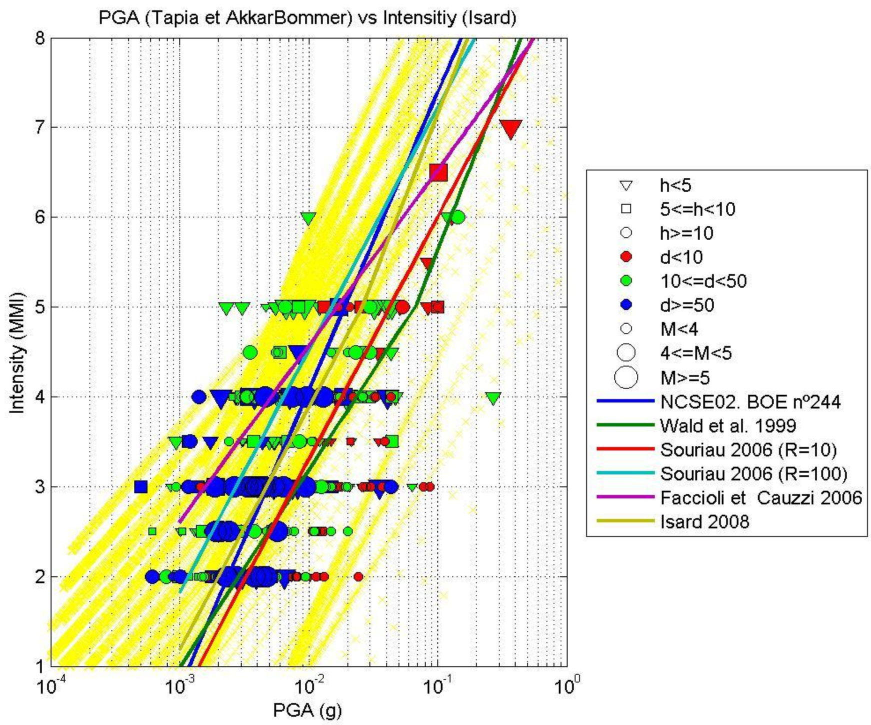


**Figure 13:** Int/ PGA: Iberian data, selected GMICE's and numerical values of (Int, PGA) from selected GMPE and IPE.

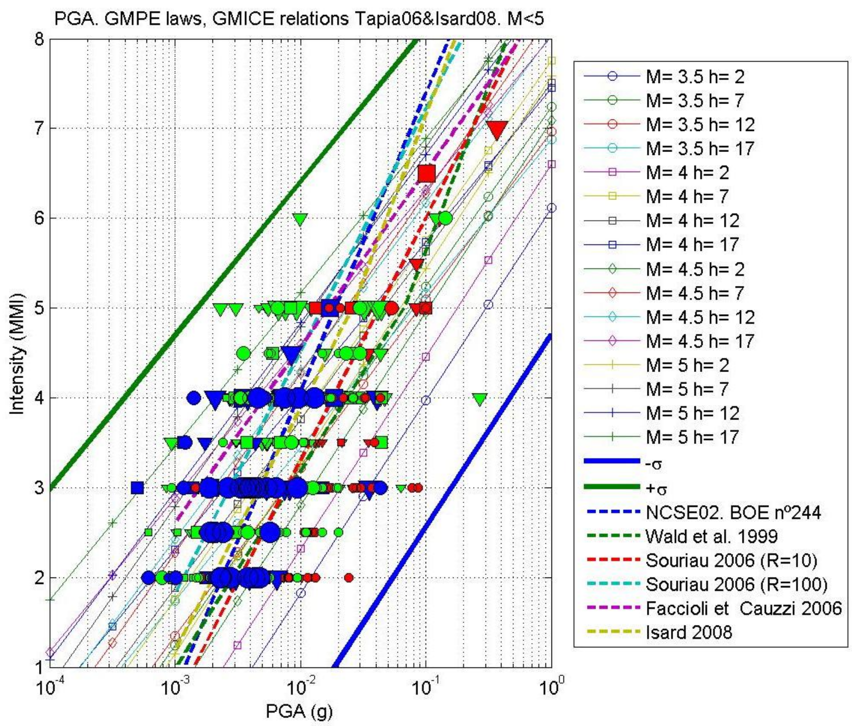


**Figure 14:** Int/ PGA: Iberian data, selected GMICE's and analytical values of (Int, PGA) from selected GMPE and IPE.

From the plots of Int/PGA, we can do the following observations:

- Great dispersion in Pyrenean and Iberian data set. Major part of data corresponds to intensities up to 5. Even for Iberian data set, only few data are present for greater intensities.
- Data points related to selected GMPE and IPE, both from numerical and analytical combinations show a big dispersion, in agreement with observed data for both data sets.
- Selected GMICE show the following tendencies:
  + NCSE02 fits well data for lower intensities, but greater intensities correspond to very low values of PGA, for example I=7 corresponds to PGA<0,1g. The slope of this equation corresponds to an increment of 1 degree of Intensity when PGA is doubled. This slope is the same that the one proposed by Wald et al 1999 for Intensities greater than 5, but very different from the slope of the other equations.
  + Faccioli and Cauzzi (2006) present a slope very different to the previous equation. For lower intensities, related PGA's are lower than the mean observed data. At the contrary for higher intensities, related PGA values are high. For example I=7 corresponds to PGA=0.2 g, near the few observed data for Iberian data set.
  + Wald et al (1999) shows high values of PGA for lower intensities, greater than the mean observed values. This tendency is also observed for higher intensities, but slope is modified. This last portion of equation fits well the few observed data for Iberian data set.
  + Souriau (2006), is dependent on epicentral distances. Slope is the same for all distances. If we take distances between 10 and 100km equations fit well the whole data sets, for low and high intensities. For example I=7 corresponds to a PGA rang of 0.1-0.25g.

The equations for these 4 GMICE are the following:

- NCSE02 (g) : I= 1.4427*ln(PGA) + 10.709
- Wald et al (1999a); V a VIII (cm/s$^2$) : I= 2.20*$\log_{10}$ (PGA) + 1
- Souriau (2006) (7, D = free); II a V (m/s$^2$) : I= 4.8108 + 2.7027*$\log_{10}$ (PGA) + 1.2162*log10(D),
- Faccioli et Cauzzi (2006); IV a IX (m/s$^2$) : I= 5*$\log_{10}$(PGA) + 6.54

For the Intensity versus PGV analysis very few equations have been found in literature. We have retained 3 equations:

- Wald et al.(1999); V a VIII (cm/s): I = 2.1$\log_{10}$ (PGV) + 3.40;
- Faccioli and Cauzzi (2006); IV a IX (cm/s): I = 5.09 + 1.80*$\log_{10}$ (PGV)
- Kaka and Atkinson (2004); II a VIII (mm/s): I= 3.96+1.79$\log_{10}$ (PGV)

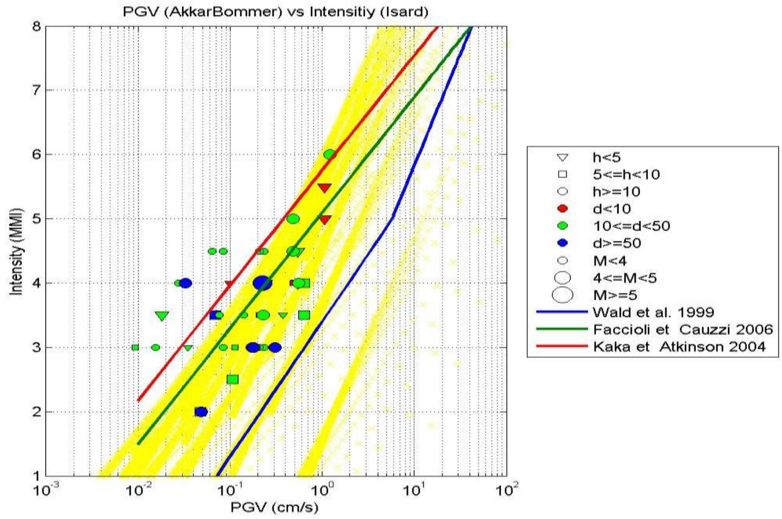


**Figure 15**: Int/ PGV: Pyrenean data, selected GMICE's and numerical values of (Int, PGV) from selected GMPE and IPE.

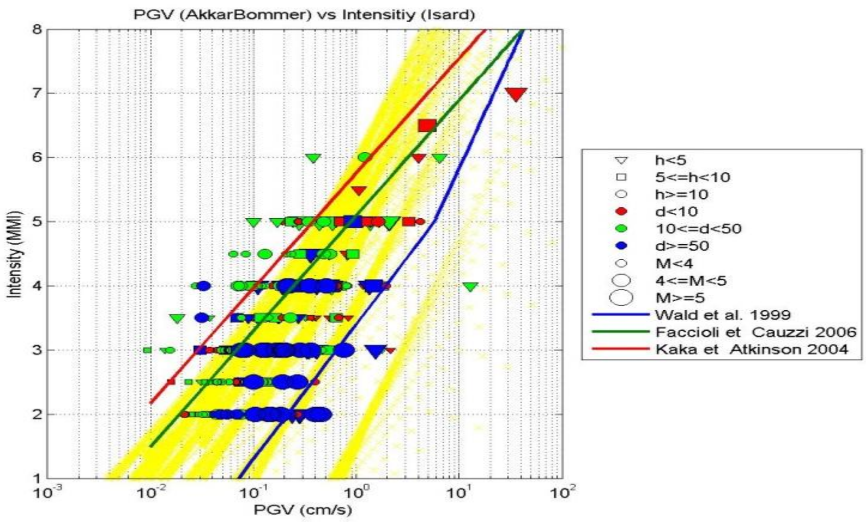


**Figure 16**: Int/ PGV: Iberian data, selected GMICE's and numerical values of (Int, PGV) from selected GMPE and IPE.

From the Int/PGV plots we can do the following observations:

- As we have observed in the Int/PGA analysis we observe a great dispersion in Pyrenean and Iberian data set. Data points related to selected GMPE and IPE, both from numerical and analytical combinations, show a big dispersion, in agreement with observed data for both data sets.
- Concerning GMICE, those proposed by Kaka and Atkinson (2004) and by Wald et al (1999) are placed in the higher part and in the lower part of the data respectively. Faccioli and Cauzzi (2006) equation seems to fit the best both data sets.

For Intensity versus PSA (0.3s); PSA (1s) and PSA (3s) we have found very few equations in literature.

For Int/ PSA (0,3s) we have plotted data for Iberian data set with equations of Atkinson and Kaka (2006, 2007). Equation Kaka and Atkinson (2004) is not proposed for 0.3s but for 0.2s.

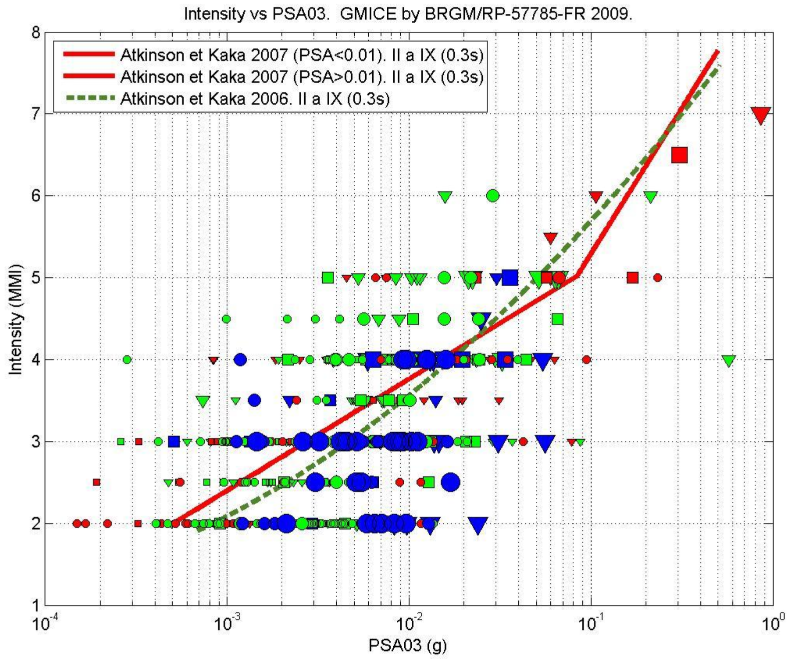


**Figure 17**: Int/ PSA (0,3s): Iberian data and GMICE's of Atkinson and Kaka (2006, 2007)

For Int / PSA (1s) we have plotted data for Iberian data set with equations of Atkinson and Kaka (2006, 2007) and equation Kaka and Atkinson (2004)

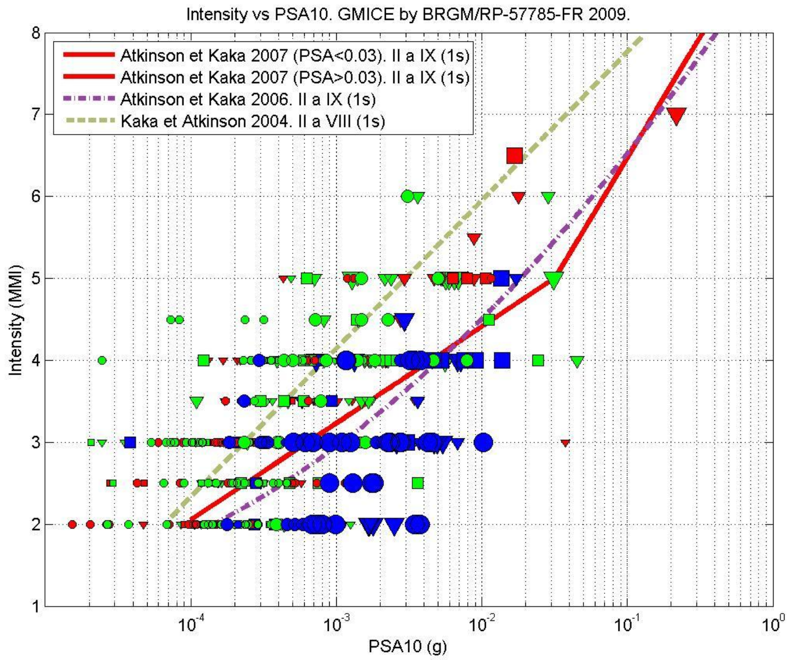


**Figure 18**: Int/ PSA (1s): Iberian data and GMICE's of Atkinson and Kaka (2006, 2007) and Kaka and Atkinson (2004)

For Int / PSA (3s) we have plotted data for Iberian data set with equations of Atkinson and Kaka (2006, 2007) for PSA (2s).

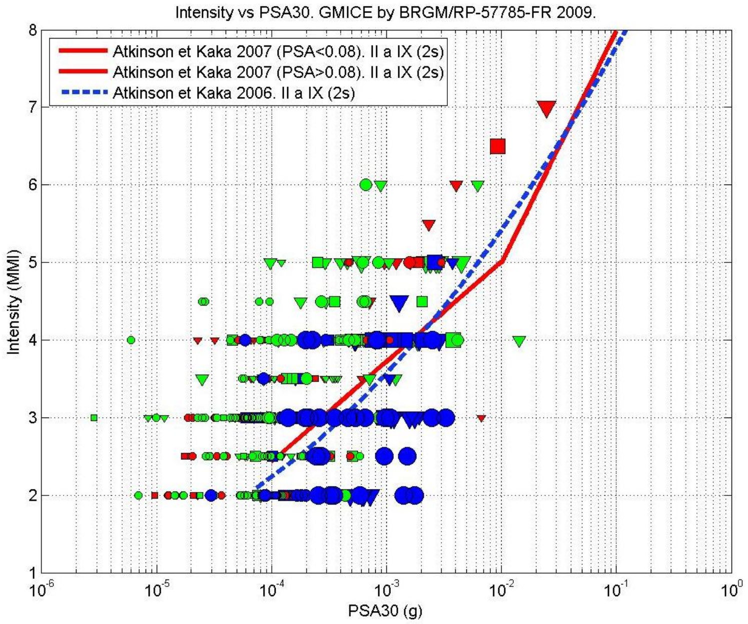


**Figure 19:** Int/ PSA (3s): Iberian data and GMICE's of Atkinson and Kaka (2006, 2007) for PSA (2s).

## 3.3 Final selection

From the previous analysis a final decision has been taken as following:

- For Int/PGA, the equation of Souriau (2006) has been taken, with a value of R fitting the best the Iberian data, i.e. R=22km. Fig 20 shows the average values of PGA for each Intensity class (Iberian data set), with the different GMICE's analyzed and retained

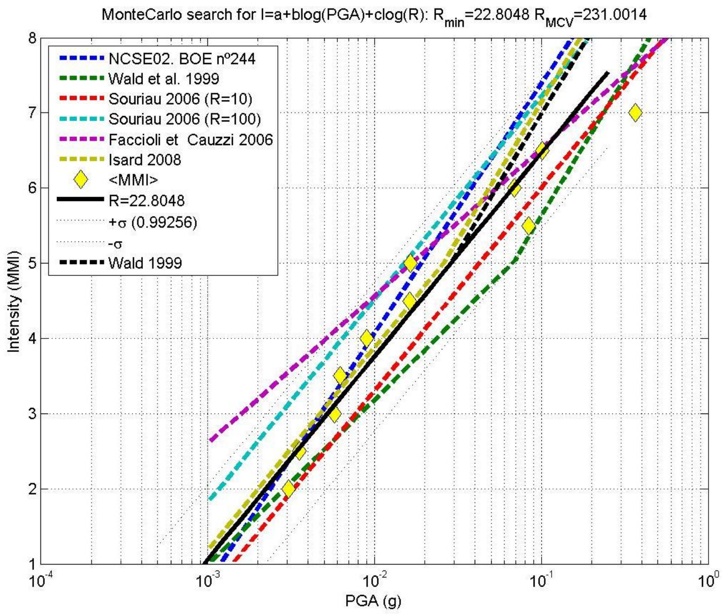


**Figure 20**: Int/ PGA: average PGA values from Iberian data set with analyzed and retained GMICE's

- For Int/PGV, fig 21 shows the average values of PGV for each Intensity class (Iberian data set), with different GMICE’s analysed. Differences between equation proposed by Faccioli and Cauzzi, (2006) and the equation fitting the best the data (black line) are very low. In consequence Faccioli and Cauzzi (2006) has been retained.

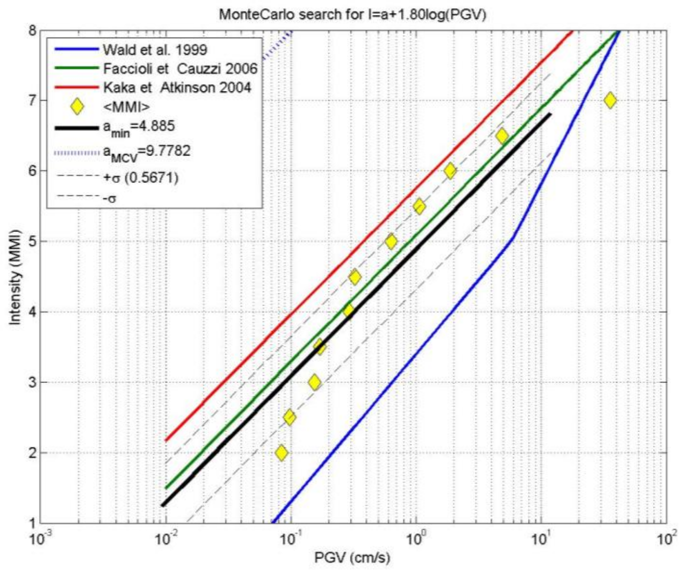


**Figure 21:** Int/PGV: average PGV values from Iberian data set with analyzed, best fitting and retained GMICE’s.

- For Int/PSA (0,3s), fig 22 shows the average values of PSA (0,3s) for each Intensity class (Iberian data set), with the different GMICE’s analyzed, i.e. Atkinson and Kaka (2007), Kaka and Atkinson (2004) for PSA (0,2s) and a linear best fitted equation to average values (black line). We decided to retain GMICE of Kaka and Atkinson (2004) for 0,2s because the difference with the best estimate equation is not very big.

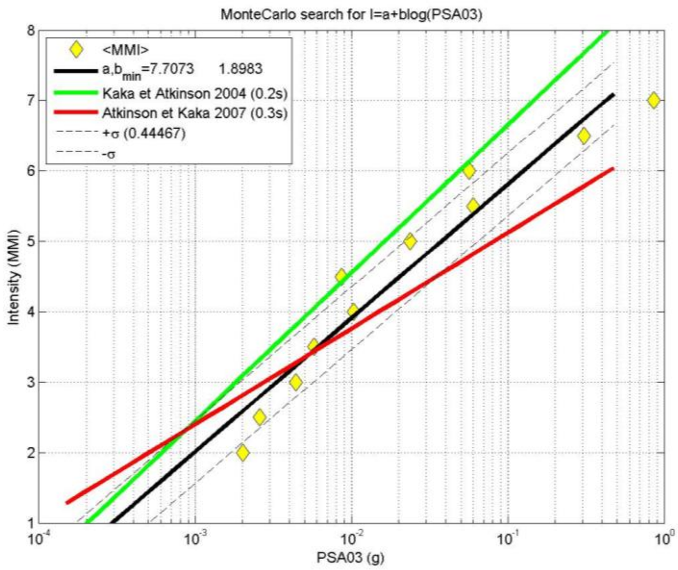


**Figure 22:** Int/PSA (0,3s): average PSA (0,3s) values from Iberian data set with analyzed, best fitting and retained GMICE’s

- For Int/PSA (1s), fig 23 shows the average values of PSA (1s) for each Intensity class (Iberian data set), with the different GMICE's analyzed, i.e. Atkinson and Kaka (2007), Kaka and Atkinson (2004) and a linear best fitted equation to average values (black line). We decided to retain GMICE of Kaka and Atkinson (2004) because the difference with the best estimate equation is not very big.

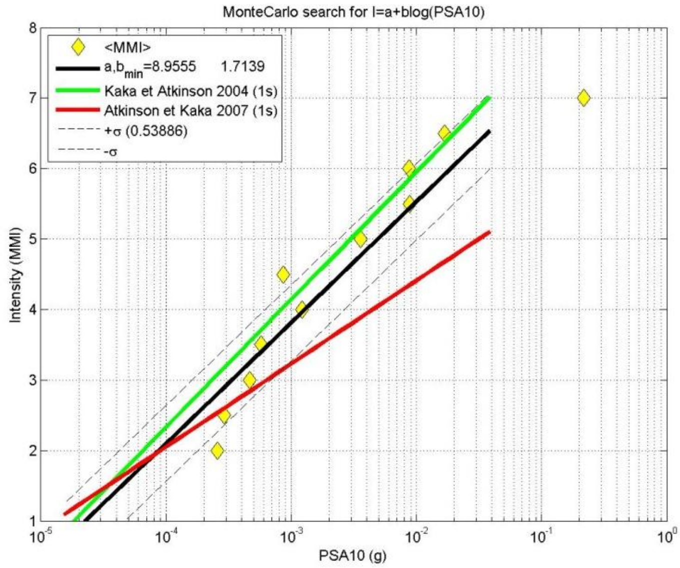


**Figure 23**: Int/PSA (1s): average PSA (1s) values from Iberian data set with analyzed, best fitting and retained GMICE's

- For Int/PSA (3s), fig 24 shows the average values of PSA (3s) for each Intensity class (Iberian data set), with the GMICE analyzed, i.e. Atkinson and Kaka (2007) and the linear best fitted equation to average values (black line). We decided to retain best fitted equation to represent this GMICE, because existing GMICE is not well adapted to data of PSA for period of 3s.

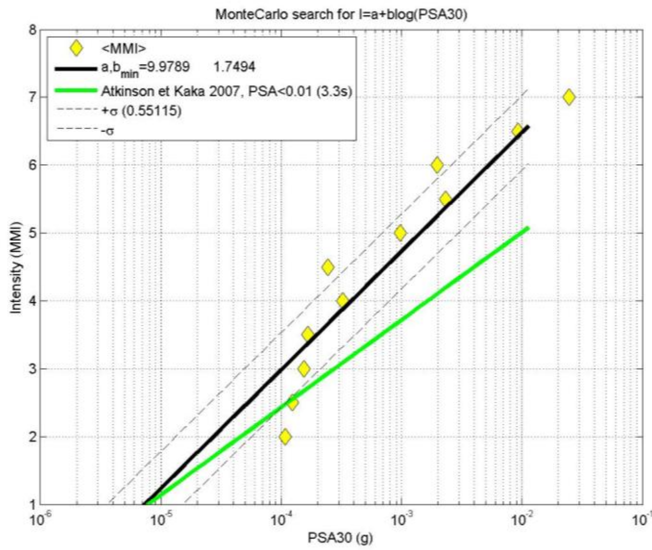


**Figure 24:** Int/PSA (3s): average PSA (3s) values from Iberian data set with analyzed and best fitting retained GMICE

# 4 Conclusions

Conversion from strong-motion parameters to macroseismic intensities (GMICE) is of major interest for ShakeMaps applications since it allows providing intensity maps few minutes after earthquakes. GMICE has been adapted for Pyrenees from existing equations analyzing the adaptation to 2 sets of data, from Pyrenees and from Iberia. Moreover the equations to be representative of this conversion needs to be compatible with attenuation relationships adapted for GM parameters (GMPE) and Intensity (IPE). A compromise solution has been found in order to find this compatibility and to best fitting data set observations for each GMICE.

In table 4, GMICE equations retained for different parameters are shown with their standard deviation and units to be used.

| PGM | **GMICE** | | Units PGM |
|---|---|---|---|
| PGA | Souriau 2006 adapted to SISPyr dataset (R = 22,8km) from Monte-Carlo search | $I_{PGA} = 4.8108 + 2.70257\log_{10}(PGA) + 1.2162\log_{10}(22.8) \pm 0.484$ | $m/s^2$ |
| PGV | Faccioli et Cauzzi 2006 adapted with Monte-Carlo search to SISPyr dataset | $I_{PGV} = 5.09 + 1.799\log_{10}(PGV) \pm 0.567$ | cm/s |
| PSA (0.3 s) | Kaka and Atkinson 2004 (0.2s) | $I = 2.45+2.10\log_{10}(PSA) \pm 0.283$ | cm/s2 |
| PSA (1s) | Kaka and Atkinson 2004 (1s) | $I = 4.14+1.81\log_{10}(PSA) \pm 0.332$ | cm/s2 |
| PSA (3s) | Linear fit to SISPyr dataset (3s) | $I = 9.978+1.7494\log_{10}(PSA) \pm 0.551$ | g |

**Table 4:** Retained GMICE to be used in Shakemap, adapted to the Pyrenean and Iberian context.

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