Constraints on earthquake nodal planes obtained from regional and teleseismic data

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Status of earthquake mechanisms in the ISC Bulletin (1993-2013)

$m_b = 4.0 - 5.5$

$N = 226988$
Discrepancies in reported earthquake mechanisms in the ISC Bulletin

Event  601993246 Taiwan region

2012/11/20 17:09:00       22.6000  121.5000f          5.0      NIED
03815750
(MOMTENS sc  M0  fCLVD  MRR  MTT  MPP  MRT  MTP  MPR  NST1  NST2  Author )
(#  eM0  eCLVD  eRR  eTT  ePP  eRT  eTP  ePR  NCO1  NCO2  Duration )
(#  16  1.860  NIED )
(#FAULT_PLANE Typ  Strike  Dip  Rake  NP  NS  Plane  Author )
(#  BDC  69.00  62.00  169.00  NIED )
(+  165.00  80.00  29.00 )
(Epicenter information from JMA Focal Mechanism Solution Determined Manually Variance reduction = 63.20%)

2012/11/20 17:09:01.80   0.20       22.4300  121.3900        22.8  0.7  228  90      GCMT
05250176
(CENTROID)
(MOMTENS sc  M0  fCLVD  MRR  MTT  MPP  MRT  MTP  MPR  NST1  NST2  Author )
(#  eM0  eCLVD  eRR  eTT  ePP  eRT  eTP  ePR  NCO1  NCO2  Duration )
(#  16  6.486  5.370  0.035 -5.400 -1.760 -3.200 -0.880  49  90  GCMT )
(#  0.275  0.151  0.182  0.223  0.094  0.225  68  160  0.90 )
(FAULT_PLANE Typ  Strike  Dip  Rake  NP  NS  Plane  Author )
(#  BDC  9.00  40.00  66.00  GCMT )
(+  219.00  54.00  109.00 )
(PRINAX sc  T_val  T_azim  T_pl  B_val  B_azim  B_pl  P_val  P_azim  P_pl  Author )
(#  16  5.899  182.00  73.00  1.180  28.00  15.00 -7.073  296.00  7.00  GCMT )
Discrepancies in reported earthquake mechanisms in the ISC Bulletin

Event 14703080 Northern Algeria

2010/05/14 12:29:22.30 0.10 35.9000 4.1400 1.112 1.112 -1 12.0f 369 115 GCMT
00123887
(#CENTROID)
(MOMTENS sc M0 fCLVD MRR MTT MPP MRT MTP MPR NST1 NST2 Author )
(# eM0 eCLVD eRR eTT ePP eRT eTP ePR NCO1 NCO2 Duration )
(# 17 1.297 0.133 0.223 -0.350 0.275 -1.230 -0.051 88 115 GCMT )
(# 0.017 0.018 0.019 0.043 0.014 0.043 151 218 1.10 )
(FAULT_PLANE Typ Strike Dip Rake NP NS Plane Author )
(# BDC 83.00 85.00 167.00 GCMT )
(+ 174.00 77.00 5.00 )
(PRINAX sc T_val T_azim T_pl B_val B_azim B_pl P_val P_azim P_pl Author )
(# 17 1.252 38.00 13.00 0.090 241.00 76.00 -1.343 129.00 5.00 GCMT )

2010/05/14 12:29:22.30 0.40 35.9200 4.0700 2.224 2.224 -1 12.0f 81 47 MED_RCMT
06111660
(#CENTROID)
(MOMTENS sc M0 fCLVD MRR MTT MPP MRT MTP MPR NST1 NST2 Author )
(# eM0 eCLVD eRR eTT ePP eRT eTP ePR NCO1 NCO2 Duration )
(# 17 1.450 0.190 0.300 -0.490 -0.360 -1.300 -0.440 4 47 MED_RCMT )
(# 0.030 0.030 0.030 0.090 0.020 0.070 6 75 1.20 )
(FAULT_PLANE Typ Strike Dip Rake NP NS Plane Author )
(# BDC 83.00 79.00 -166.00 MED_RCMT )
(+ 350.00 77.00 -11.00 )
(PRINAX sc T_val T_azim T_pl B_val B_azim B_pl P_val P_azim P_pl Author )
(# 17 1.270 216.00 2.00 0.370 121.00 72.00 -1.630 307.00 17.00 MED_RCMT )
Enhancing the earthquake mechanism catalogue in the ISC Bulletin

Continuous effort to collect new parametric data sets

- First motion polarities
- Focal mechanism solutions
- Moment tensors and best double couple mechanisms

(Re-)determination of earthquake mechanisms by combining all the available parametric data (e.g., reported polarities, amplitudes) and seismic waveforms
Focal mechanisms based on first motion polarities

First motion polarities reported to the ISC

Parameter search of best fitting nodal planes ("hash", Hardebeck & Shearer, 2002)

Automatic picking (Lomax et al., 2012) of first motion polarities from waveforms of stations in the International Registry (IR)

Manual inspection of first motion polarities (optional)

Earthquake location uncertainties (ISC locator)

Optimal (or preferred) and acceptable nodal plane parameters
Earth's structure effect

Source depth: 2km

Source depth: 12km

Source depth: 33km

Source depth: 39km

Takeoff angle [°]

Δ [°]

Takeoff angle [°]

Δ [°]

Takeoff angle [°]

Δ [°]

Takeoff angle [°]

Δ [°]

Takeoff angle [°]

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Earthquake mechanisms – Benchmark tests

Selected earthquakes from the GCMT catalogue (2010 – 2013)

$N = 719$

$M_w = 4.7 – 9.0$
Earthquake mechanisms – Benchmark tests

*** Output from ISC_MECA ***

Event id: 17433354
Date: 2011-10-27
Time: 00:15:24.00
Magnitude [mb]: 5.31
Latitude: -17.94°
Longitude: -179.43°
Depth: 605.01 km

Exponent for moment tensor: 25 units: dyne-cm

Mrr     Mtt     Mpp     Mrt     Mrp     Mtp
CMT    -0.403   0.462  -0.059   0.501  -0.848  -0.369
Error   0.007   0.011   0.011   0.011   0.010   0.011

Mw = 6.0 Scalar Moment = 1.14e+25

Fault plane: strike=85  dip=23  slip=-149
Fault plane: strike=326  dip=78  slip=-70

Eigenvector: eigenvalue: 1.16  plunge: 31  azimuth: 40
Eigenvector: eigenvalue: -0.05  plunge: 19  azimuth: 142
Eigenvector: eigenvalue: -1.11  plunge: 52  azimuth: 259

Earthquake mechanism comparisons:

Benchmark mechanism vs. Calculated mechanism

Multiple solutions:
- Best fitting nodal plane \((\varphi, \delta)\)
- Best fitting mechanism \((\varphi, \delta, \lambda)\)
Earthquake mechanisms – Benchmark tests

**Best fitting mechanism**

- **Azimuthal gap [°]**
  - Δφ
  - Δδ
  - Δλ

- **Takeoff angle gap [°]**
  - Δφ
  - Δδ
  - Δλ

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Earthquake mechanisms – Benchmark tests (Az. gap < 90°/ Tk. gap < 60°)

Best fitting mechanism
Earthquake mechanisms – Benchmark tests (Az. gap < 90°/ Tk. gap < 60°)

Best fitting mechanism

22% of cases within the 95% confidence interval

- Plane 1
  - $\mu = 2°$
  - $M = 0°$
  - $\sigma = 37°$

- Plane 2
  - $\mu = 4°$
  - $M = 1°$
  - $\sigma = 45°$

24% of cases within the 95% confidence interval

- Plane 1
  - $\mu = 0°$
  - $M = 0°$
  - $\sigma = 22°$

- Plane 2
  - $\mu = 6°$
  - $M = 3°$
  - $\sigma = 69°$

19% of cases within the 95% confidence interval

- Plane 1
  - $\mu = 0°$
  - $M = 0°$
  - $\sigma = 22°$

- Plane 2
  - $\mu = 6°$
  - $M = 1°$
  - $\sigma = 145°$

17% of cases within the 95% confidence interval

- Plane 1
  - $\mu = 3°$
  - $M = 7°$
  - $\sigma = 69°$

- Plane 2
  - $\mu = 3°$
  - $M = 3°$
  - $\sigma = 21°$
Earthquake mechanisms – Robustness criteria (2°-90°)

- Selected mechanisms according to quality parameters
- $|\Delta \phi| \leq 30^\circ$ & $|\Delta \delta| \leq 30^\circ$
- $|\Delta \phi| \leq 30^\circ$ & $|\Delta \delta| \leq 30^\circ$ & $|\Delta \lambda| \leq 30^\circ$

**Strength of quality parameters**

- Weak
- Strong
Earthquake mechanisms – Robustness criteria (0°-90°)

Selected mechanisms according to quality parameters
- Black: $|\Delta \phi| \leq 30^\circ$ & $|\Delta \delta| \leq 30^\circ$
- Green: $|\Delta \phi| \leq 30^\circ$ & $|\Delta \delta| \leq 30^\circ$ & $|\Delta \lambda| \leq 30^\circ$

Bar chart showing the number of earthquakes (%):
- azgap $\leq 360^\circ$
- tkgap $\leq 90^\circ$
- fpu $\leq 90^\circ$
- stdr $\geq 0$

Legend:
- Weak
- Strong

Strength of quality parameters

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Earthquake mechanisms – Robustness criteria

2010/04/05 22:36:57.20 0.10 -20.0700 -69.3200 1.112 1.112 -1 124.5 0.7 514 131 GCMT 00123555

#FAULT_PLANE Typ Strike Dip Rake NP NS Plane Author
(# BDC 183.00 15.00 -58.00 GCMT )
(+ 330.00 77.00 -98.00 )

#PRINAX sc T.val T.azim T.pl B.val B.azim B.pl P.val P.azim P.pl Author
(# 17 5.922 67.00 32.00 0.043 332.00 8.00 -5.961 230.00 57.00 GCMT )

*** Output from ISC_MEGA ***

Event id: 14591168
Date: 2010-4-5
Time: 22:36:57.00
Magnitude [ mb ]; 5.64
Latitude: -19.97°
Longitude: -69.05°
Depth: 106.17 km

Error in latitude: +/- 0.02°
Error in longitude: +/- 0.04°
Error in depth: +/- 1.80 km
Number of polarities: 476
Azimuthal gap: 132°
Takeoff angle gap: 19°

Foc. Mech. # 1

Plane 1 strike: 110.59°
Plane 1 dip: 12.83°
Plane 1 rake: -123.81°
Plane 2 strike: 325.08°
Plane 2 dip: 79.37°
Plane 2 rake: -82.78°
P-axis azimuth: 244.01°
P-axis plunge: 55.08°
T-axis azimuth: 48.92°
T-axis plunge: 33.98°
Plane 1 uncertainty: 22.69°
Plane 2 uncertainty: 10.59°
Foc. mech. quality: D
Close to solution prob.: 0.62

Foc. Mech. # 2

Plane 1 strike: 315.61°
Plane 1 dip: 74.38°
Plane 1 rake: -115.60°
Plane 2 strike: 196.27°
Plane 2 dip: 23.71°
Plane 2 rake: -32.81°
P-axis azimuth: 194.65°
P-axis plunge: 53.57°
T-axis azimuth: 65.33°
T-axis plunge: 25.07°
Plane 1 uncertainty: 12.36°
Plane 2 uncertainty: 30.28°
Foc. mech. quality: D
Close to solution prob.: 0.29
Earthquake mechanisms – Robustness criteria

\[
\Delta u = \frac{\sum \left( k_1 |Azi_i - (u_i + b)| + k_2 \frac{\Delta r_i}{r_0} \right)}{360 \, N}
\]

\[ b = \bar{Azi} - \bar{u} \]

\[ u_i = \frac{360 \, (i-1)}{N} \]

\( r_0 \): maximum allowed distance between nodal plane and station

\( N \): number of polarities within maximum allowed distance between nodal plane and station

\( Azi_i \): station azimuth

\( \Delta r_i \): distance difference between nodal plane and station

\( k_1, k_2 \): normalization factors
Conclusions

- The determination of focal mechanisms based on first motion polarities can be a demanding task.
- At least one nodal plane ($\phi$, $\delta$) can be constrained in most cases.
- Despite large uncertainties in theoretical 1D takeoff angle calculations, local data can improve well constrained mechanisms.
- The routine determination of focal mechanisms could help on the identification of systematic station polarity reversals.
- Constraints on some of the fault parameters can be useful for earthquake source model determinations.
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