Physics of the Earth and Planetary Interiors 232 (2014) 61–71

Contents lists available at ScienceDirect

Physics of the Earth and Planetary Interiors

journal homepage: www.elsevier.com/locate/pepi

Assessing the scalar moment of moderate earthquake and the effect of lateral heterogeneity on normal modes—An example from the 2013/04/20 Lushan earthquake, Sichuan, China

Xiao Gang Hu [a],*, Ying Jiang [a,b], He Ping Sun [a]

[a] Laboratory of Geodesy and Earth's Dynamics, Institute of Geodesy and Geophysics, Chinese Academy of Sciences, Wuhan 430077, China
[b] College of Earth Sciences, University of Chinese Academy of Sciences, Beijing 100949, China

ARTICLE INFO

Article history:
Received 2 March 2014
Accepted 20 April 2014
Available online 28 April 2014

Keywords:
Normal modes
Scalar seismic moment
Lateral heterogeneity

ABSTRACT

Medium-frequency normal modes in the frequency range of 2.0–6.0 mHz excited by moderate earthquakes ($6.0 < M_w < 7.0$) are weak seismic signals and seldom concerned in academic study. We show that the validity of predicted M_0 (scalar seismic moment) for a complex moderate earthquake can be effectively assessed by a systematic comparison of observed and synthetic medium-frequency spheroidal modes, and the effect of lateral heterogeneity on normal-mode amplitudes can also be well assessed in the comparison. For a complex moderate earthquake, the differences between predicted M_0 derived from different inversion methods are significant, in some cases as large as factors of 1.56–3.18. In this study we focus on the Lushan earthquake, a moderate thrust event on 20 April 2013 in the Western Sichuan, China. Five reported M_0 for the earthquake differ significantly from 0.4×10^{19} to 1.06×10^{19} N m, up to about 2.5 times difference. To assess the validity of reported M_0, we compare observed with synthetic modes corresponding to five centroid moment tensor solutions at 17 stations, which located within epicentral distances of 5–30° and distributed in a wide range of source-receiver azimuths. Synthetic modes corresponding to moment tensor solutions derived from long-period waveforms show good agreement to observations. However, synthetics corresponding to moment tensor solutions derived from body waves display significant deviations of amplitudes from observations. We show underestimate of M_0 is the main cause for such a large deviation. Another important result obtained from the comparison is that lateral heterogeneity has very little effects on the amplitudes of spherical modes at frequencies below 6.0 mHz. This observational result is inconsistent with previous theoretical result of lateral structure perturbations to normal modes.

1. Introduction

Inversion of centroid moment tensor solutions for a seismic source depend on details of individual inversion methodologies, including data pre-processing, frequencies and phases of seismograms used and the Green's functions calculations. But estimates of scalar seismic moment M_0 by different procedures should be accordant with each other for a moderate earthquake. In fact, for moderate earthquakes with magnitude $6.0 < M_w < 7.0$ in the significant earthquake archive of USGS (U.S. Geological Survey), in most cases predicted M_0 derived from global CMT project is accordant with that from body waves. However, we note that in a few cases predicted M_0 from the two inversion methods are discordant significantly, as large as factors of 1.56–3.18. The large discrepancy may not be caused by the method difference but by the source complexity. We list these anomaly cases in Table 1. The significant difference between predicted M_0 by different inversion methods for a moderate earthquake should not be neglected but need be appraised.

Scalar seismic moment defined as $M_0 = \mu \cdot A \cdot \overline{D}$, measures the size and strength of a seismic source quantitatively on the basis of final static displacement and rupture area after an earthquake (e.g. Brune, 1968), where μ is the average shear modulus of the medium around the source, A the rupture area the and $\overline{D}$ the average displacement. Estimate of M_0 is usually derived from a moment tensor inversion of observed seismograms after an earthquake. Following Aki (1967) and Brune (1970) for a

---

* Corresponding author. Tel.: +86 2768881301.
E-mail addresses: hxg432@whigg.ac.cn (X.G. Hu), jiangyingchen@126.com (Y. Jiang), heping@whigg.ac.cn (H.P. Sun).

http://dx.doi.org/10.1016/j.pepi.2014.04.005
0031-9201/© 2014 Elsevier B.V. All rights reserved.

Table 1
Moderate earthquakes with significant different predicted M_0.

Event & epicenter[1]	Solutions[2]	M_w	M_0	Ratio[3]
2013/10/12	GCMT	6.7	1.42×10^{19}	1.73
PLATANOS, GREECE	UBODY	6.4	8.19×10^{18}	
35.514 23.252				
2013/09/04	GCMT	6.5	7.21×10^{18}	1.76
ATKA, ALASKA	UBODY	6.3	4.09×10^{18}	
51.557 174.767				
2012/11/11	GCMT	6.4	5.47×10^{18}	2.49
OFFSHORE GUATEMALA	UBODY	6.2	2.20×10^{18}	
14.156–92.188				
2012/06/04	GCMT	6.3	3.18×10^{18}	1.99
SOUTH OF PANAMA	UBODY	6.1	1.60×10^{18}	
5.507–82.457				
2012/04/11	GCMT	6.7	1.20×10^{19}	2.00
MICHOACAN, MEXICO	UBODY	6.5	6.00×10^{18}	
18.311–102.699				
2012/04/11	GCMT	6.0	1.06×10^{18}	2.26
OFF THE COAST OF OREGON	UBODY	5.7	4.70×10^{17}	
43.623–127.514				
2011/10/14	GCMT	6.5	6.19×10^{18}	1.88
NEW GUINEA REG., P.N.G.	UBODY	6.3	3.30×10^{18}	
–6.593 147.929				
2010/12/20	GCMT	6.5	8.26×10^{18}	2.50
SOUTHEASTERN IRAN	UBODY	6.3	3.3×10^{18}	
28.498 59.098				
2010/03/05	GCMT	6.7	1.57×10^{19}	2.15
KEP. MENTAWAI REGION, INDONESIA	UBODY	6.5	7.3×10^{18}	
–3.805 100.922				
2010/03/08	GCMT	6.1	1.55×10^{18}	1.65
EASTERN TURKEY	UBODY	5.9	9.4×10^{17}	
38.788 39.994				
2010/04/13	GCMT	6.9	2.53×10^{19}	1.95
SOUTHERN QINGHAI, CHINA	UBODY	6.7	1.3×10^{19}	
33.156 96.529				
2009/05/16	GCMT	6.5	7.38×10^{18}	1.85
KERMADEC ISLANDS REGION	UBODY	6.3	4.0×10^{18}	
–31.337–178.044				
2008/10/06	GCMT	6.4	4.23×10^{19}	2.23
EASTERN XIZANG,CHINA	UBODY	6.1	1.9×10^{18}	
29.702 90.269				
2008/11/10	GCMT	6.3	3.60×10^{19}	2.25
NORTHERN QINGHAI, CHINA	UBODY	6.1	1.6×10^{18}	
37.588 95.833				
2008/10/16	GCMT	6.6	1.10×10^{19}	2.11
OFFSHORE CHIAPAS, MEXICO	UCMT	6.6	1.2×10^{19}	
14.421–92.387	UBODY	6.4	5.7×10^{18}	
2008/11/09	GCMT	6.6	1.46×10^{19}	1.61
KERMADEC ISLANDS REGION	UBODY	6.4	9.1×10^{18}	
–30.965–176.876				
2008/10/05	GCMT	6.6	1.11×10^{19}	2.36
KYRGYZSTAN	UBODY	6.4	4.7×10^{18}	
39.562 73.766				
2008/05/07	GCMT	6.8	2.34×10^{19}	1.95
EAST COAST OF HONSHU, JAPAN	UBODY	6.6	1.2×10^{19}	
36.243 141.455				
2008/02/21	GCMT	6.0	1.30×10^{18}	1.91
NEVADA	UBODY	5.8	6.8×10^{17}	
41.083–114.730				
2008/02/21	GCMT	7.1	4.88×10^{19}	3.17
MACQUARIE ISLAND REGION	UBODY	6.8	1.9×10^{19}	
–55.490 158.511				
2008/02/14	GCMT	6.9	2.70×10^{19}	3.18
SOUTHERN GREECE	UBODY	6.6	8.5×10^{18}	
36.52 21.67				
2008/06/08	GCMT	6.3	3.89×10^{18}	1.56
SOUTHERN GREECE	UBODY	6.2	2.50×10^{18}	
38.000 21.468				

[1] The information of scientific and technical of earthquakes is from the significant earthquake archive of USGS.

[2] GCMT and UBODY indicate that the predicted M_0 is derived from the Global CMT Project Moment Tensor Solution and the USGS Body-Wave Moment Tensor Solution, respectively.

dislocation source model, the source displacement spectrum is flat and proportional to M_0 below a certain frequency, the corner frequency of the source spectrum, but it decays as ω^{-1} or ω^{-2} above the corner frequency. Therefore, seismic seismograms used to access predicted M_0 for a seismic source should be in a frequency range below the corner frequency.