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How the choice between nodal planes affects the estimate of tsunami hazard of an earthquake

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Introduction

Usually tsunami warning is issued if a submarine earthquake is registered of magnitude exceeding a threshold, the value of which varies depending on the region where the earthquake took place and on the earthquake depth. Being simple and fast this approach is characterized by quite a low accuracy in the tsunami run-up heights estimate. The forecast accuracy can be improved if, instead of magnitude, one uses the potential energy of the initial elevation in the tsunami source, calculated taking into account the earthquake focal mechanism. Focal mechanisms derived from analysis of the recorded seismic waveforms has two possible solutions, i.e. two nodal planes. Short after an earthquake it is not possible to determine automatically which of the nodal planes is in fact the fault plane. The main purpose of this study is to reveal a difference in estimates of the potential energy of the initial elevation obtained making use of the first (NP1) and the second (NP2) nodal planes.

We processed dataset of the Bulletin of the International Seismological Centre (ISC) 4630 events Mw≥6 (1976 – 2019)

For each event (for NP1 and NP2) we calculated:

1. Vector field of coseismic bottom deformation
   $\vec{u} = (u_x, u_y, u_z)$ [Okada, 1985]
2. Coseismic displacement of the ocean bottom surface
   $\eta(x,y)=\frac{\partial H}{\partial x} u_x + \frac{\partial H}{\partial x} u_x + u_z;$
3. Initial water elevation in a tsunami source
   $\eta(x,y) \rightarrow \mathit{smoothing\ algorithm}[*] \rightarrow \xi(x,y);$
4. Potential energy of initial water elevation
   $E = \frac{\rho g}{2} \int \xi^2 ds\,.$

Nosov M. A., Kolesov S. V. Optimal initial conditions for simulation of seismotectonic tsunamis //Pure and applied geophysics. 2011

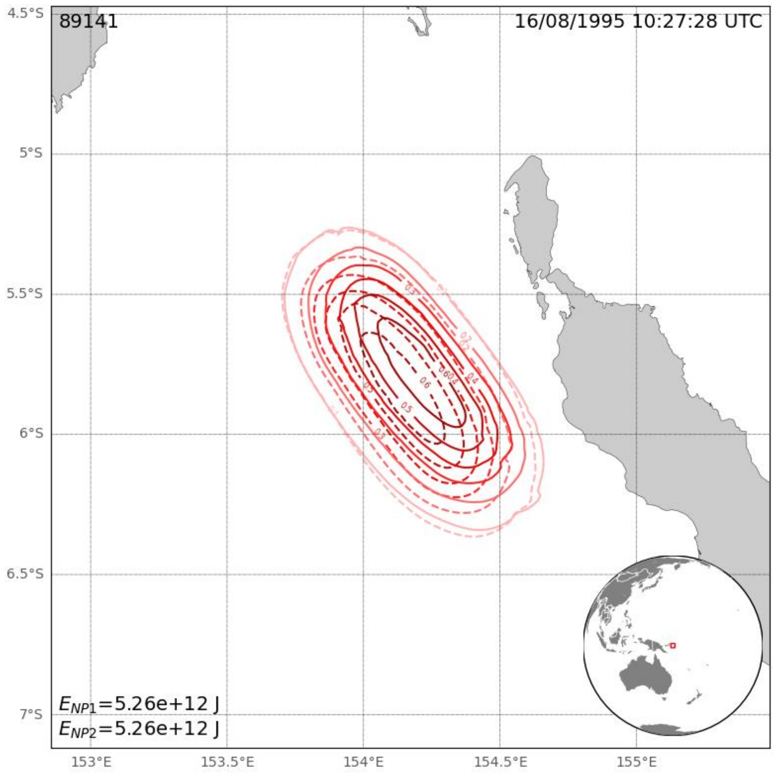
All calculations were made by means of automatic system for estimate of tsunami hazard using focal mechanism which was recently developed[*]

«Tsunami - Observer»

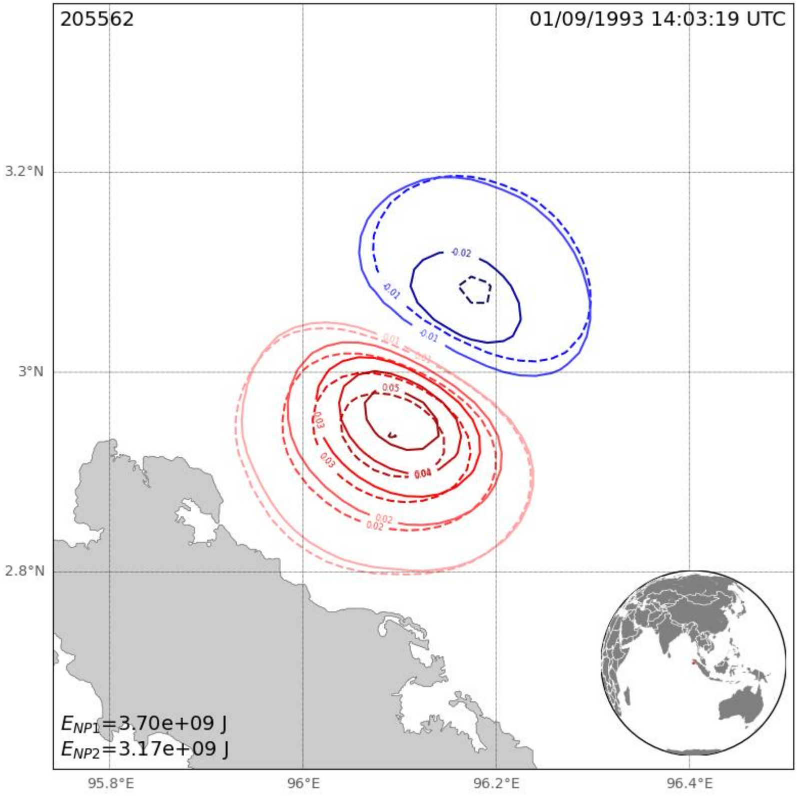
http://ocean.phys.msu.ru/projects/tsunami-observer/

** Kolesov, S.V., Nosov, M.A. The Operating Experience of the Tsunami Observer Automatic System for Assessment of Earthquake Tsunami Hazard. Moscow Univ. Phys. 74, 679–689 (2019). https://doi.org/10.3103/S0027134919060183.*

Examples of initial water elevation in a tsunami source



16.08.1995
Solomon Islands
Mw=7.7
$E_{NP1}/E_{NP2} \approx 1$

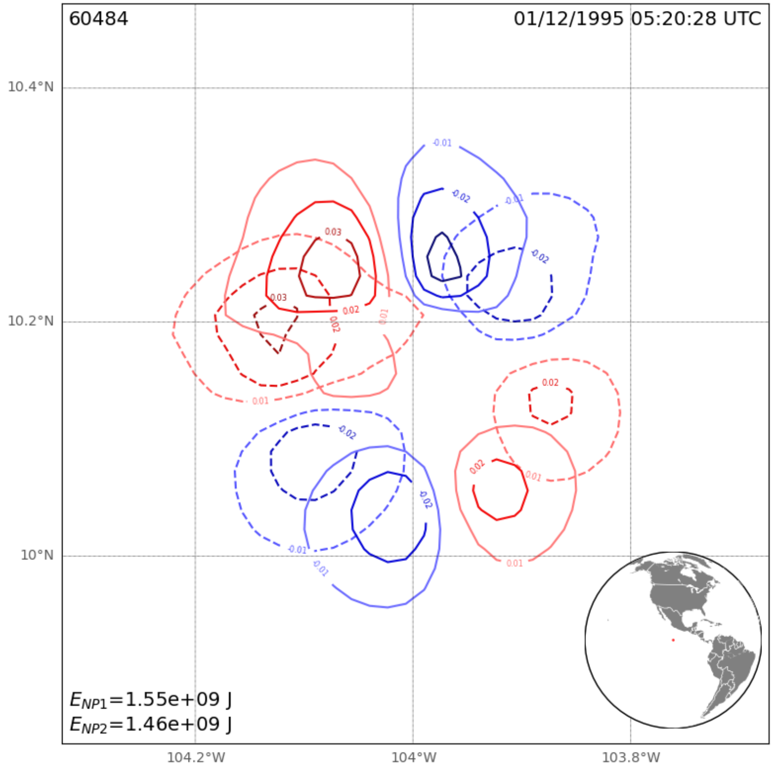


01.09.1993
Northern Sumatra
Mw=6.3
$E_{NP1}/E_{NP2} \approx 1.2$

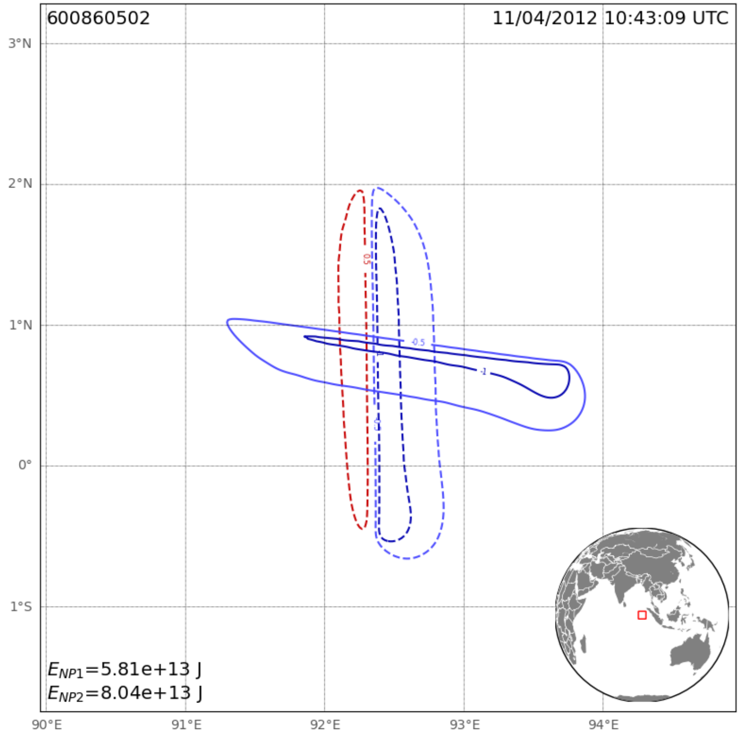
NP1
NP2

Calculations of forms of initial water elevation with use of NP1 and NP2 data sometimes provide very close results

Examples of initial water elevation in a tsunami source



01.12.1995
Mexico
Mw=6.6
$E_{NP1}/E_{NP2} \approx 1.06$

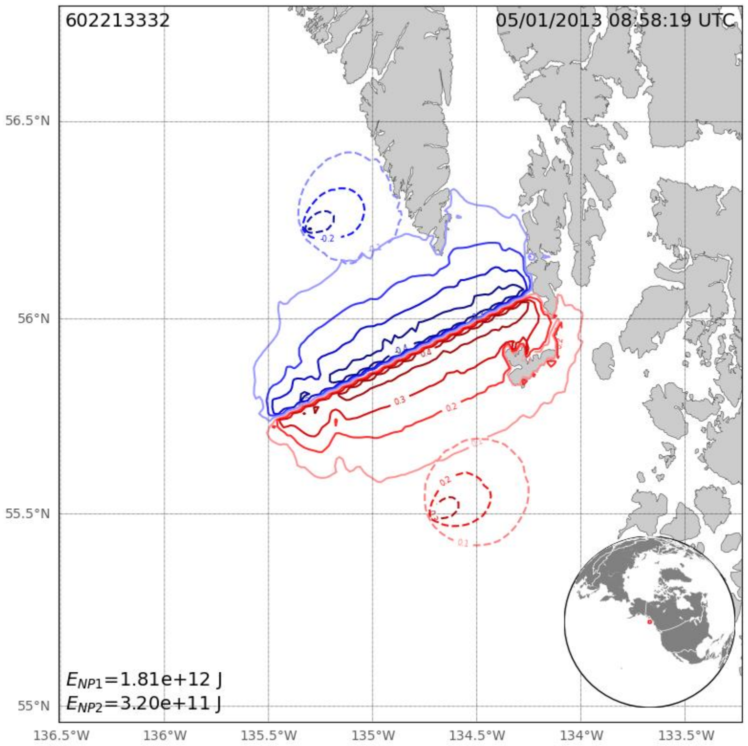


11.04.2012
Northern Sumatra
Mw=8.2
$E_{NP1}/E_{NP2} \approx 0.7$

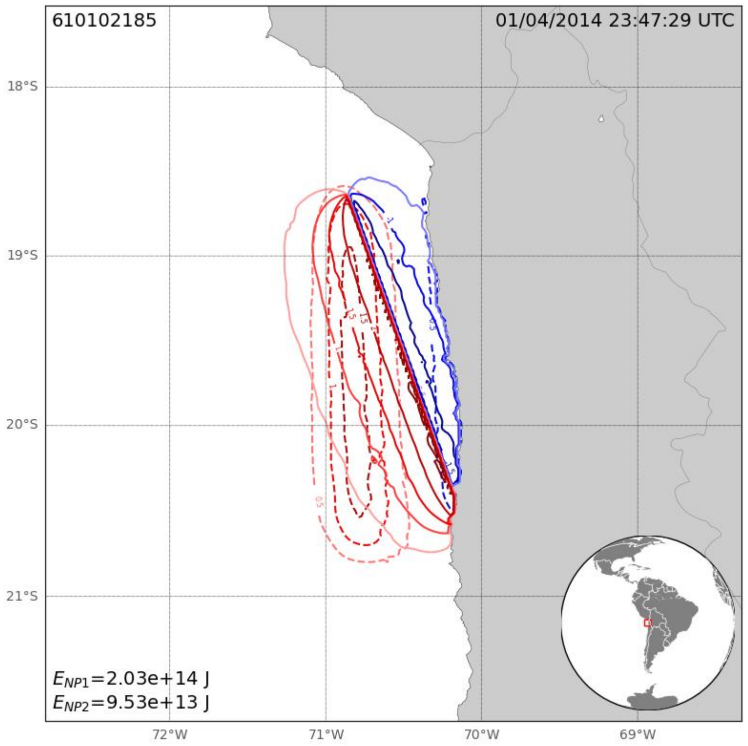
NP1
NP2

Sometimes forms of initial elevation are different while the corresponding potential energies are close

Examples of initial water elevation in a tsunami source



05.01.2013
Alaska
Mw=7.5
$E_{NP1}/E_{NP2} \approx 5.7$

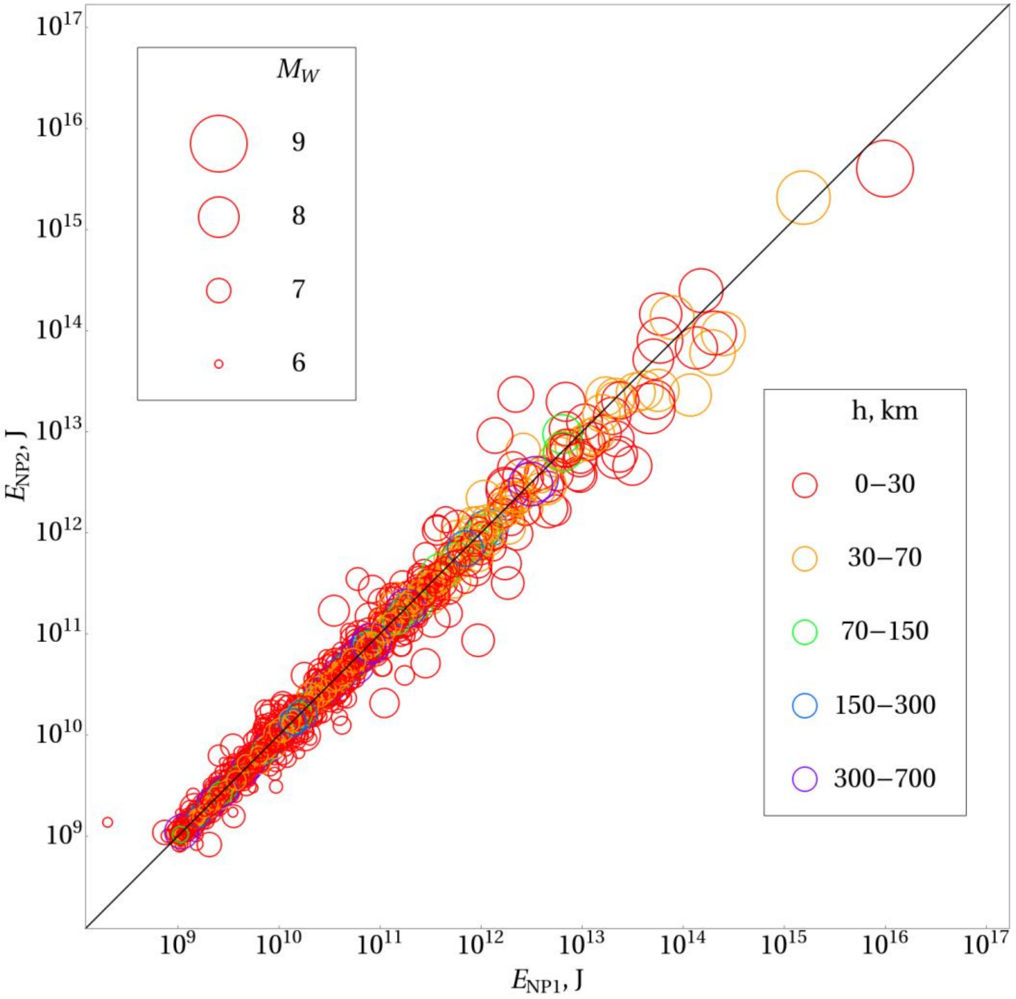


01.04.2014
Chile
Mw=8.1
$E_{NP1}/E_{NP2} \approx 2.1$

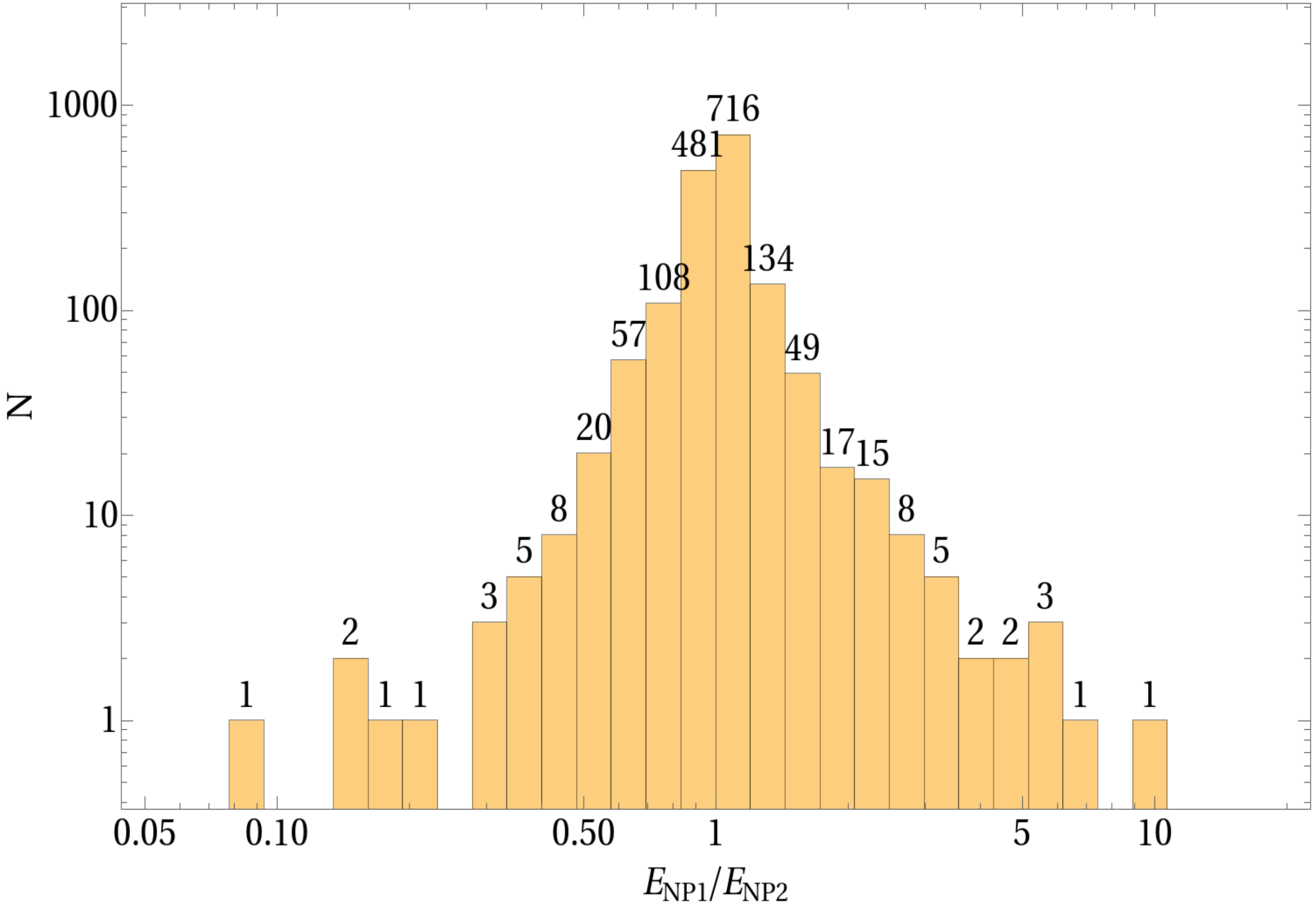
NP1
NP2

Sometimes both forms of initial water elevation and the corresponding potential energies are different

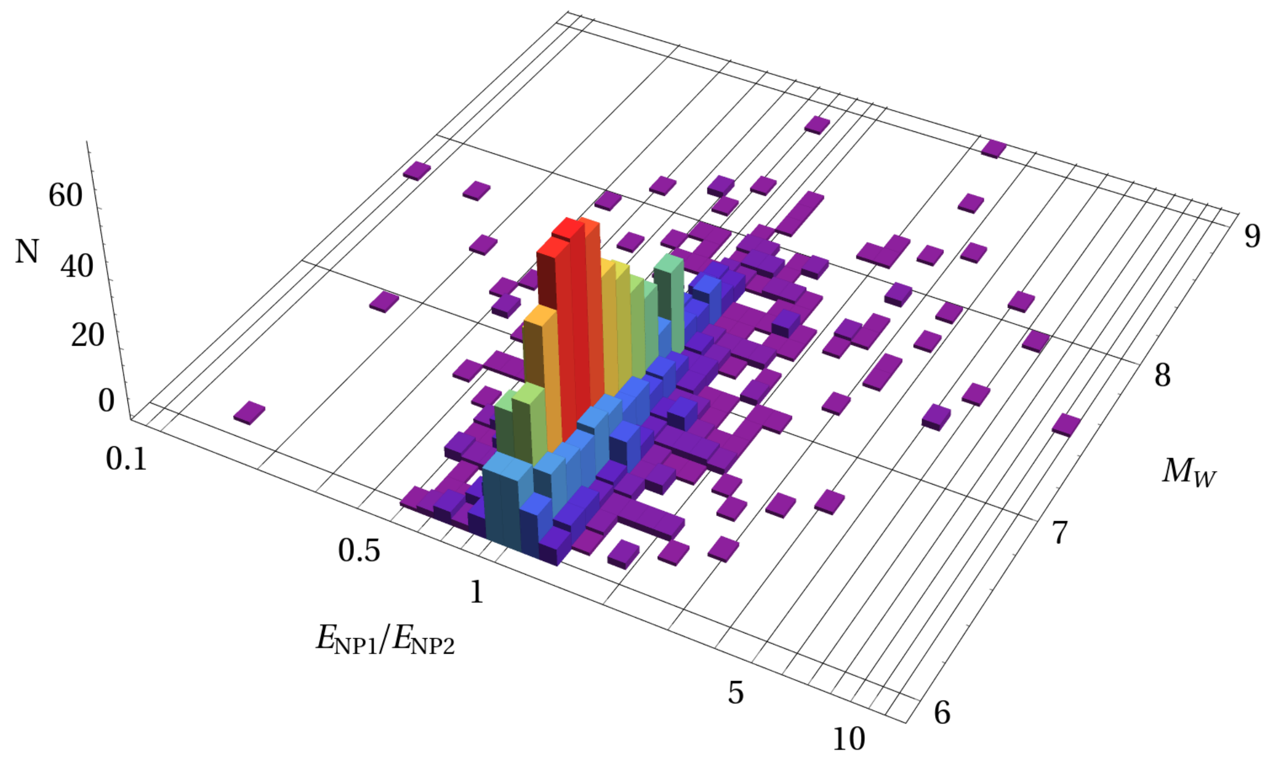
E_{NP1} versus E_{NP2}



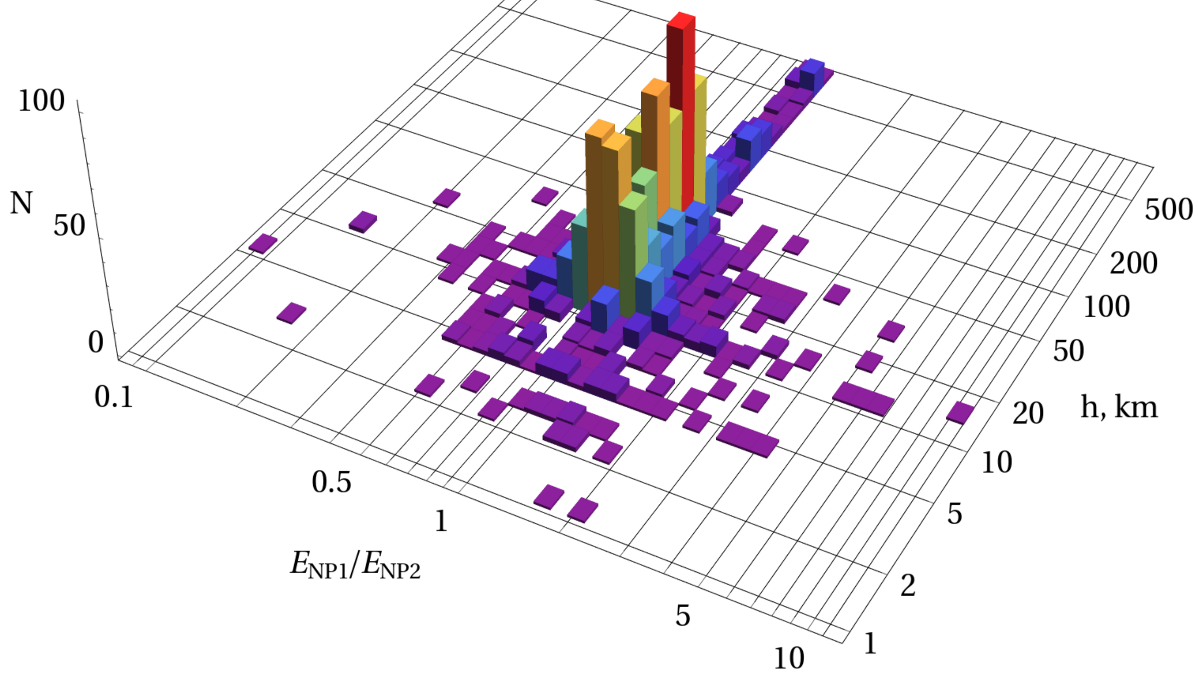
Distributions of the number of events over the ratio E_{NP1}/E_{NP2}



Distributions of the number of events over the earthquake magnitude M_W and the ratio E_{NP1}/E_{NP2}



Distributions of the number of events over the earthquake depth h and the ratio E_{NP1}/E_{NP2}



Conclusions

1. It is shown that for most seismic events the energy estimate weakly depends on the choice of the nodal plane, i.e. for 76% cases the values of E_{NP1} and E_{NP2} differ by no more than 2 times;

2. In some rare cases, energy estimates can differ significantly. As a rule, such significant differences are peculiar to strong shallow earthquakes, i.e., precisely to those seismic events that are capable of effectively generating tsunami waves.