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Coseismic potential energy released by global earthquakes during 1976 to 2016

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1. Introduction

The energy budget of global earthquakes, especially great earthquakes is one of the most fundamental subjects in geophysics and seismology, which can provide a meaningful basis for various studies pertaining to global processes, such as the mantle convection, the terrestrial heat flow, Chandler wobble, and plate motions. The total energy release by an earthquake for a self-gravitating, rotating Earth is described as the sum of three main components: kinetic rotational energy *Es*, gravitational potential energy *Eg* and internal elastic energy *Ee*. An earthquake usually produces the static permanent vertical displacements, which correspondingly cause changes in above three components. *Chao et al.* (1995) pointed out the importance of earthquake-induced *Eg* to the global heat flow. Because the coseismic *Eg* change is finally converted into the terrestrial heat flow and assessed quantitatively against the actual heat flow anomalies. The outcomes have important implications in understanding the energetics of the earthquake genesis in relation to the plate tectonic heat engine in the mantle.

We are motivated to develop an alternative method to compute Coseismic changes in *Eg* and *Es* induced by major earthquakes from 1976 to 2016 using the spherical-Earth elastic dislocation theory. We show coseismic changes in *Eg* and *Es*, and details in the core, mantle and crust, and study the relationship between different energy changes and the terrestrial heat flow.

2. Basic Principle and data

2.1 Basic Principle

For a self-gravitating, rotating earth, it is assumed to be quasi-equilibrium in the absence of the earthquakes at the geological time scale, the momentum equation in this situation can be described as:

$$\nabla \cdot \mathbf{T} = \rho \nabla \left(\phi^G + \phi^C \right)$$

Where **T** denotes the stress in the Earth, ρ is the density of the referred Earth model, ϕ is the potential energy. ϕ^G is relative to the gravity and ϕ^C is relative to the centrifugal force.

When an earthquake occurs, the permanent displacement **u** is produced in the whole Earth (V). Multiplying the above equation by permanent displacement and integrating over the whole Earth. Energy balance equation is given:

$$\int \mathbf{T}\nabla \cdot \mathbf{u} dV = \int \rho \mathbf{u} \nabla \phi^G dV + \int \rho \mathbf{u} \nabla \phi^C dV$$

Here we propose an alternative method to compute the energy change based on the elastic spherical-Earth dislocation theory and either the finite fault models/point source. It's noteworthy that horizontal displacements of the spheroidal part and the toroidal have no contribution to coseismic changes in *Eg* and *Es* .

2.2 Data

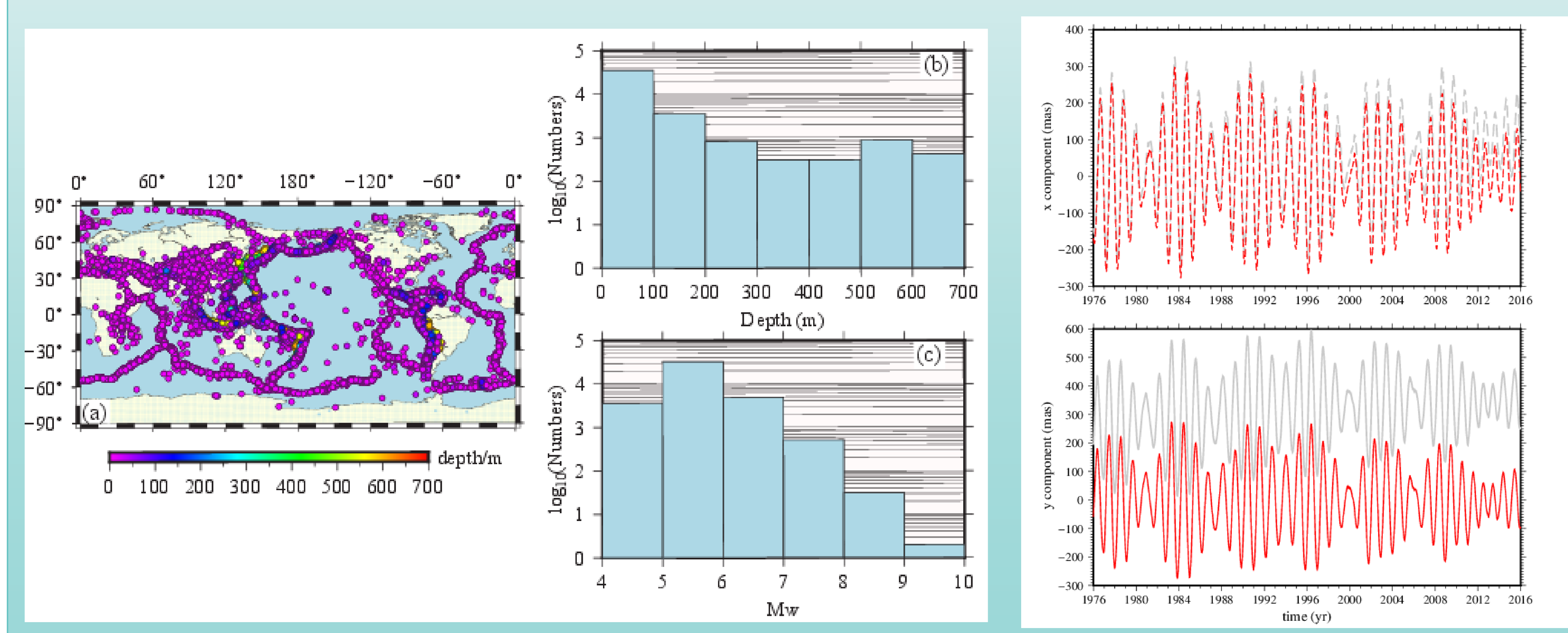

Figure 1: Focal mechanisms from GCMT catalog during 1976 to 2016 (left) and observed polar motion time series adopted from IERS 14 C04 solutions (right).

3.1 Green Functions of coseismic changes in *Eg*

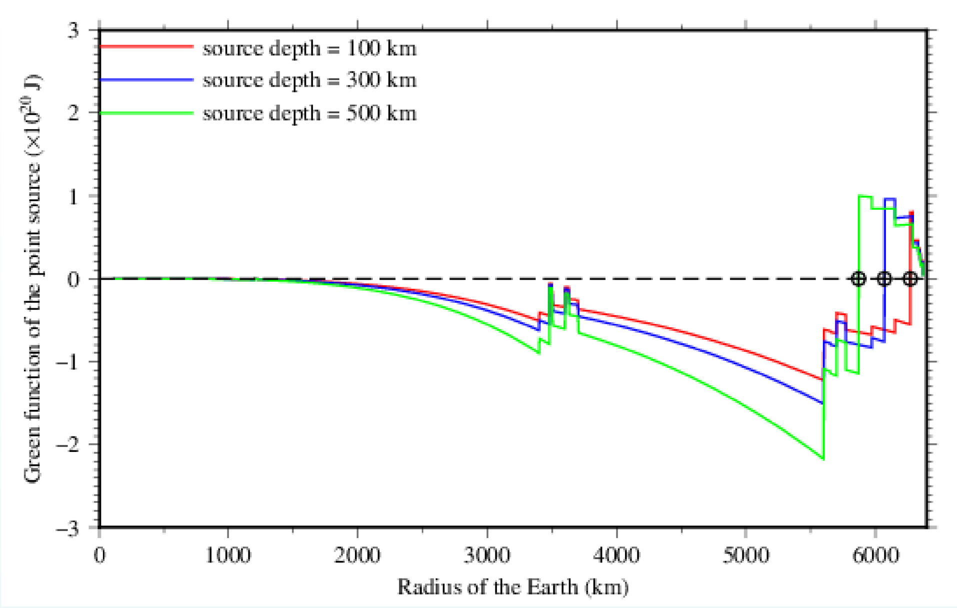

Figure 2: Green functions of coseismic change in *Eg* at three different source depth.

3.2 Real examples

To clearly describe what a great earthquake can do, we selected six great earthquakes to compute the net coseismic E_g change generated by them following the above expressions. The location and focal mechanisms of these earthquakes are listed in Table1.

Event	*lat.*(°)	*lon.*(°)	depth (km)	M_w	$M_o(10^{22} N \cdot m)$	*strike*(°)	*dip*(°)	*rake*(°)
1960 Chile	-38.50	285.50	25.00	9.5	27.00	170	10	80
1964 Alaska	61.00	213.00	50.00	9.2	7.50	155	20	24
1994 Bolivia	-13.84	-67.55	650.50	8.2	0.27	91	81	-98
2004 Sumatra	6.60	93.00	25.00	9.1	6.68	343	6	107
2010 Chile	-35.90	-73.15	24.10	8.8	1.84	18	18	112
2011 Tohoku	37.50	143.10	20.00	9.0	5.30	201	12	89
2013 Okhotsk	54.77	153.33	610.00	8.3	0.38	184	9	262

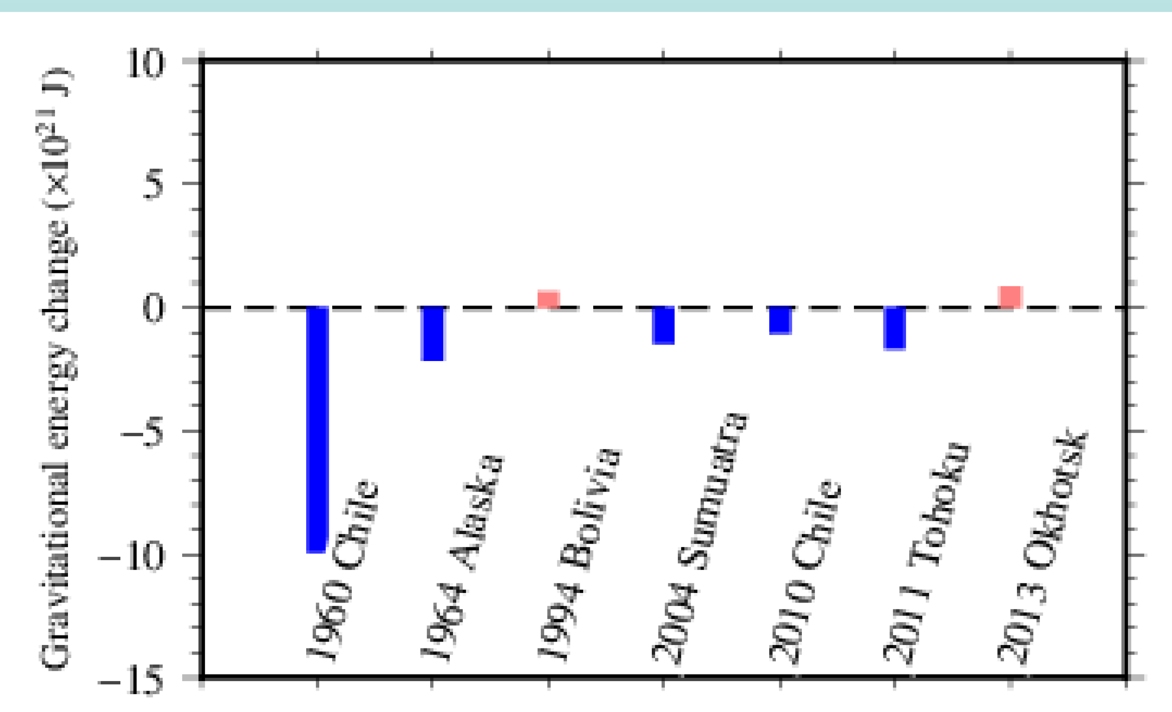

Figure 3: Coseismic gravitational potential energy changes for selected great earthquakes.

4. Cumulative coseismic E_g changes

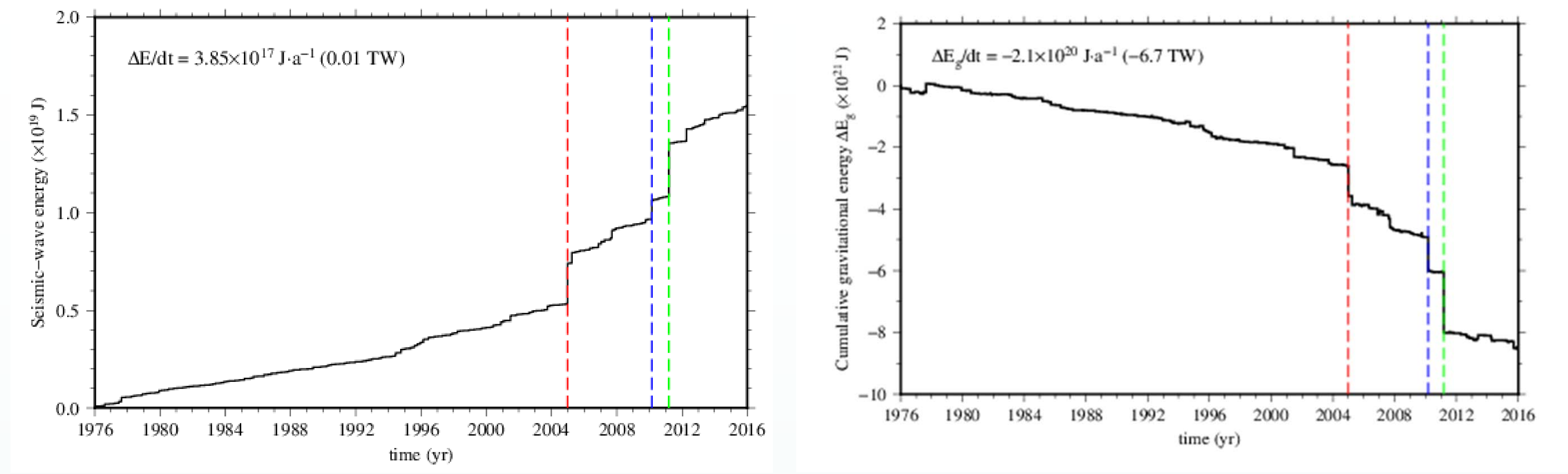

Figure 4 : Cumulative changes in seismic-wave energy and *Eg* from 1976 to 2016

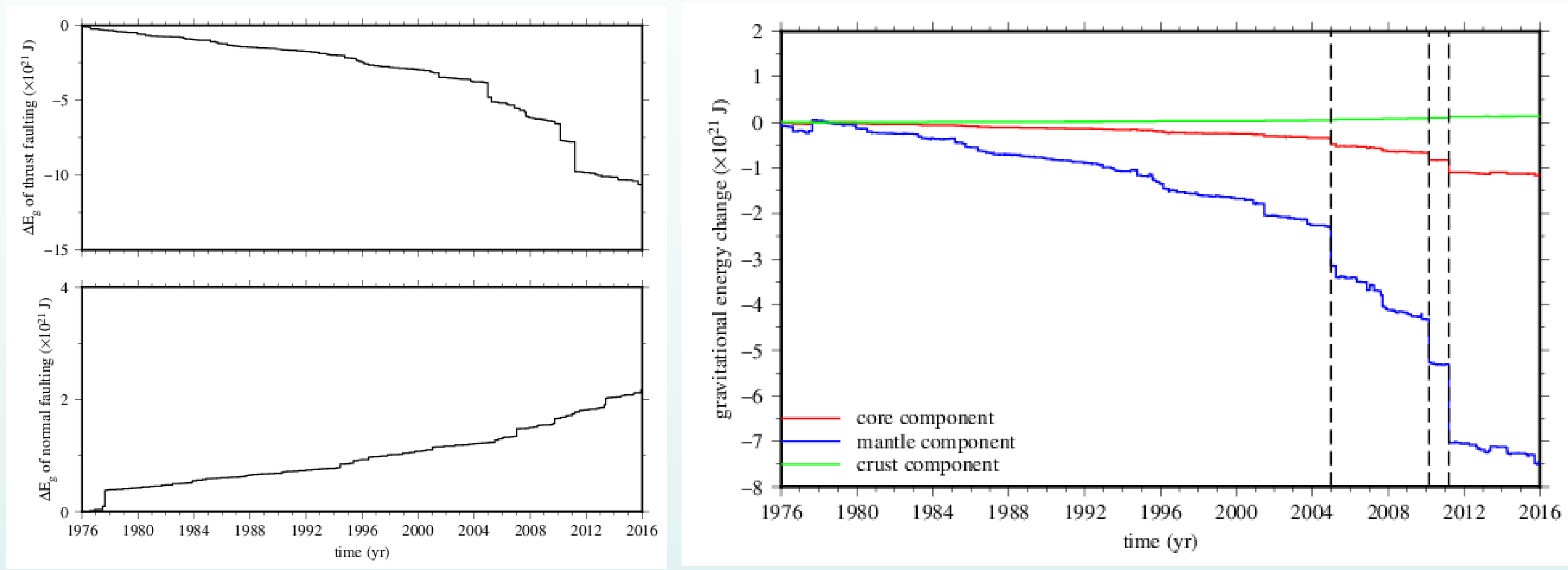

Figure 5: Cumulative changes in *Eg* for two-types faulting (left) and for different parts of the Earth from 1976 to 2016

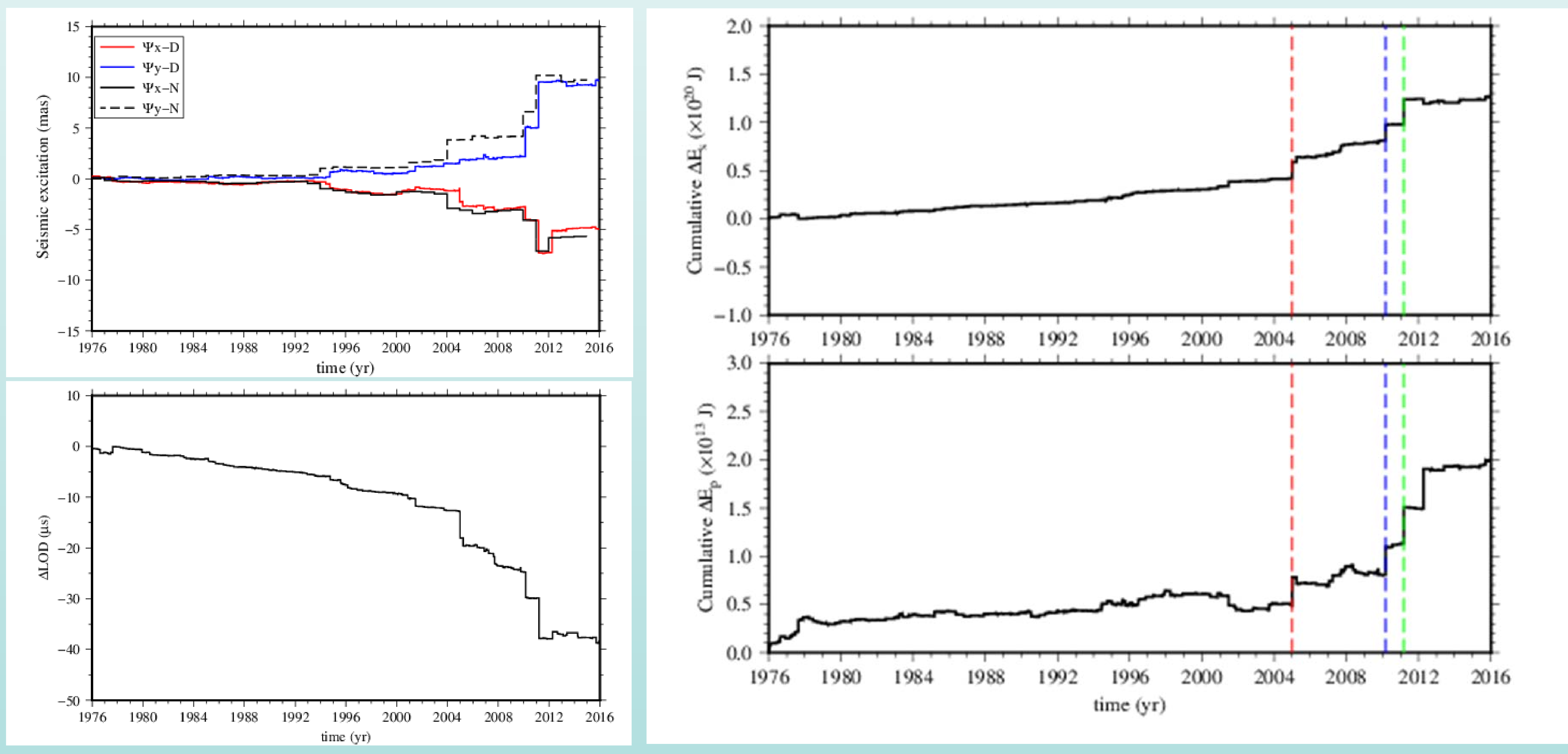

Figure 6: Cumulative changes in earthquake-excited polar motion, excess length of day and kinetic rotational energy from 1976 to 2016

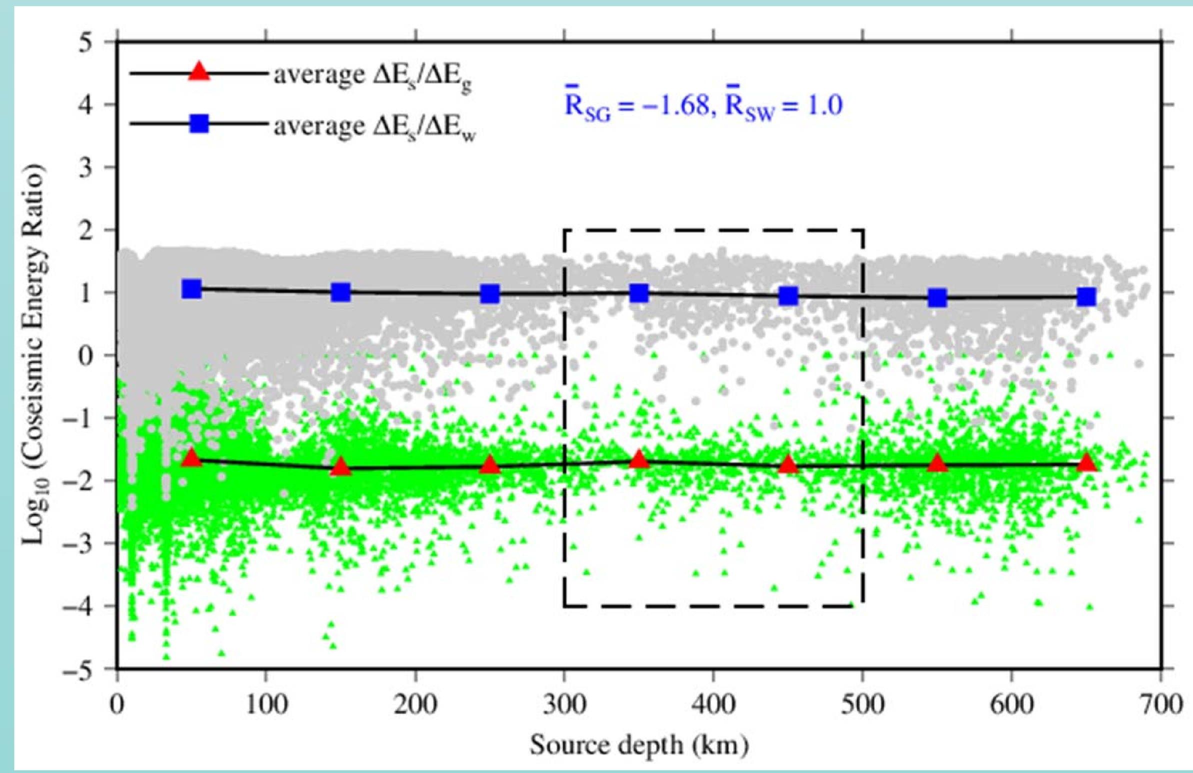

Figure 7: Energy ratio for coseismic changes in *Eg*, *Es* and seismic-wave energy

5. Tectonic signature in coseismic crustal E_g changes

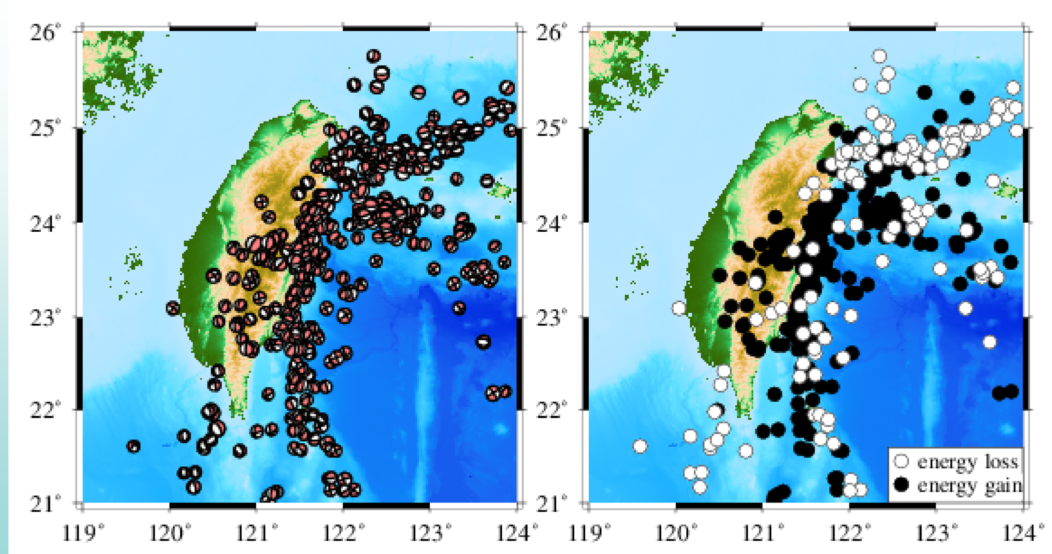

Figure 8: Tectonic signature revealed by coseismic crustal E_g changes

Conclusion

1. We develop an alternative method to compute the coseismic gravitation energy change using the spherical Earth elastic dislocation theory and either the fault model treated as a point source or the finite fault model.
2. The rate of the accumulative E_g loss produced by major earthquakes from 1976 to 2016 is dominated by the thrust-faulting and estimated to be -6.7 TW, amounting to 15% in terrestrial heat flow.
3. The accumulative E_g are mainly lost in the mantle, and also in the core but with a very relative magnitude. By contrast, the crust cumulatively gains coseismic gravitational energy in the last decades.
4. The coseismic crustal E_g change can be treated as a good indicator to reveal the tectonic extensional/compressional features.

Reference

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2. Chao, B. F., R. S. Gross, and D. N. Dong, 1995. Changes in global gravitational energy induced by earthquakes, *Geophys. J. Int.*, *122*, 784–789, doi:10.1111/j.1365-246X.1995.tb06837.x.