Ground Motion to Intensity Conversion Equations (GMICEs) for Chilean Megathrust Earthquakes

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What are GMICEs?

Ground motion to intensity conversion equations (GMICEs) are predictive equations that describe the empirical relationship between instrumentally measured ground motions, such as peak acceleration (PGA) and peak velocity (PGV), and observed intensities (MMI). They are routinely used shortly following an earthquake to produce online maps of *instrumental* intensities—intensities calculated from instrumentally measured ground motions, as opposed to traditional intensities determined from human observations.

Purpose and Methodology

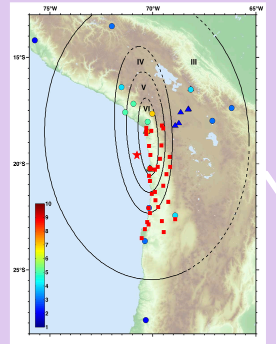
We determine ground motion to intensity conversion equations (GMICEs) for three recent interplate Chilean megathrust earthquakes: the November 14, 2007 *Mw* 7.7 Tocopilla, the February 27, 2010 *Mw* 8.8 Maule, and the April 1, 2014 *Mw* 8.2 Iquique earthquakes. Most great earthquakes (M≥8), like these, occur within subduction zones. Yet, few GMICEs exist for subduction earthquakes. The most commonly used GMICEs were developed from earthquakes in active crustal regions, not subduction zones.

We pair instrumental peak ground acceleration (PGA) and velocity (PGV) with intensities derived from on-site surveys of earthquake damage and volunteered felt reports. We fit linear equations to predict MMI intensity from PGA and PGV using a weighted ordinary least squares scheme. We use a weighting scheme to express the uncertainty on assigned MMIs based on a station's proximity to the nearest intensity observation: *high quality* pairings, with MMIs assigned from nearby field observations, are given greater weight than *low quality* pairings, with MMIs estimated from isoseismal maps.

Data

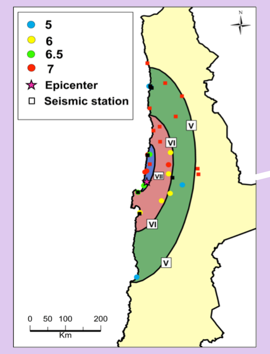
Our data set enables for the first time the study of the relationship between intensity and instrumental ground motion for Chilean megathrust earthquakes.

2014 M_W 8.2 Iquique Earthquake



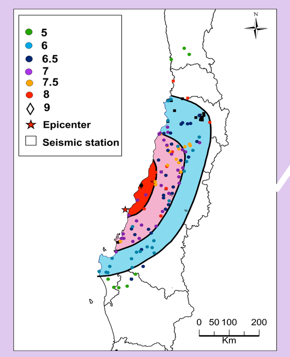
- North end of 1877 M 8.8 seismic gap, largest in gap since 1877
- 41 strong-motion stations, mostly digital
- Limited field survey of damage
- Over 200 point samples at approximately 10 localities
- Over 100 *Did You Feel It* reports, aggregated in 17 cities
- Isoseismal regions approximated using kriging (this study)

2007 M_W 7.7 Tocopilla Earthquake



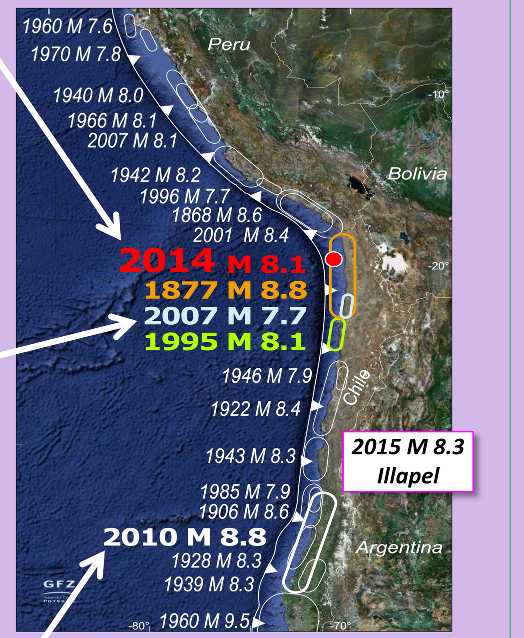
- South end of 1877 M 8.8 seismic gap, second largest since 1877
- 20 strong-motion stations, mostly digital
- Extensive field survey of damage within 5 days
- Approximately 20 localities visited
- Aggregate of 20 samples at each locality
- Published isoseismal map (Astroza and others, 2008)

2010 M_W 8.8 Maule Earthquake



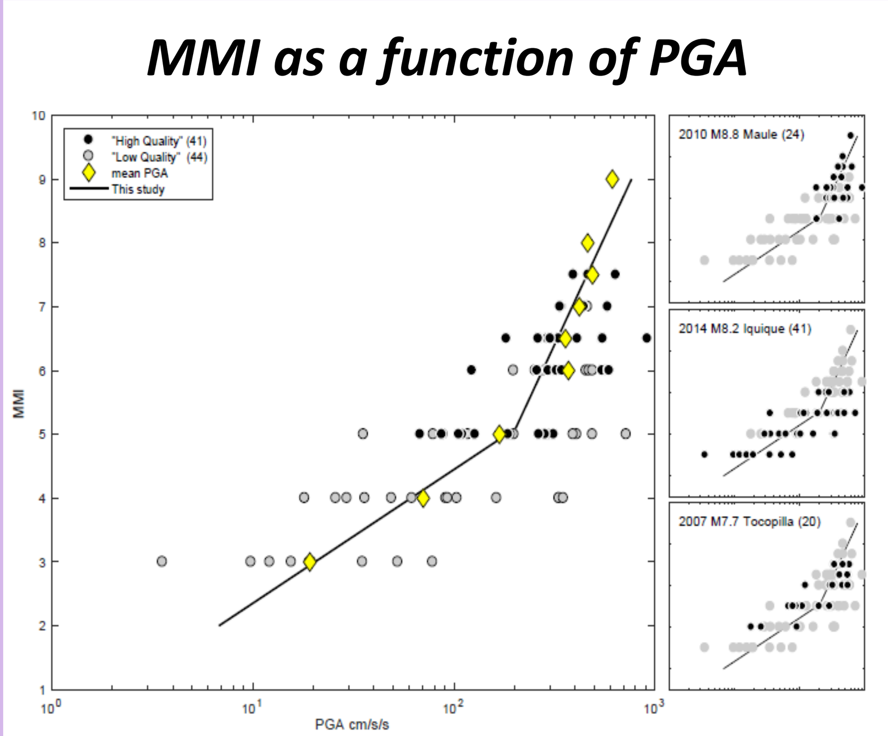
- Largest earthquake with recorded strong motions at the time
- 24 strong-motion stations, half digital
- Extensive field survey of damage within 3 weeks
- Over 100 localities visited
- Aggregate of 20 samples at each locality
- Published isoseismal map (Astroza and others, 2010)

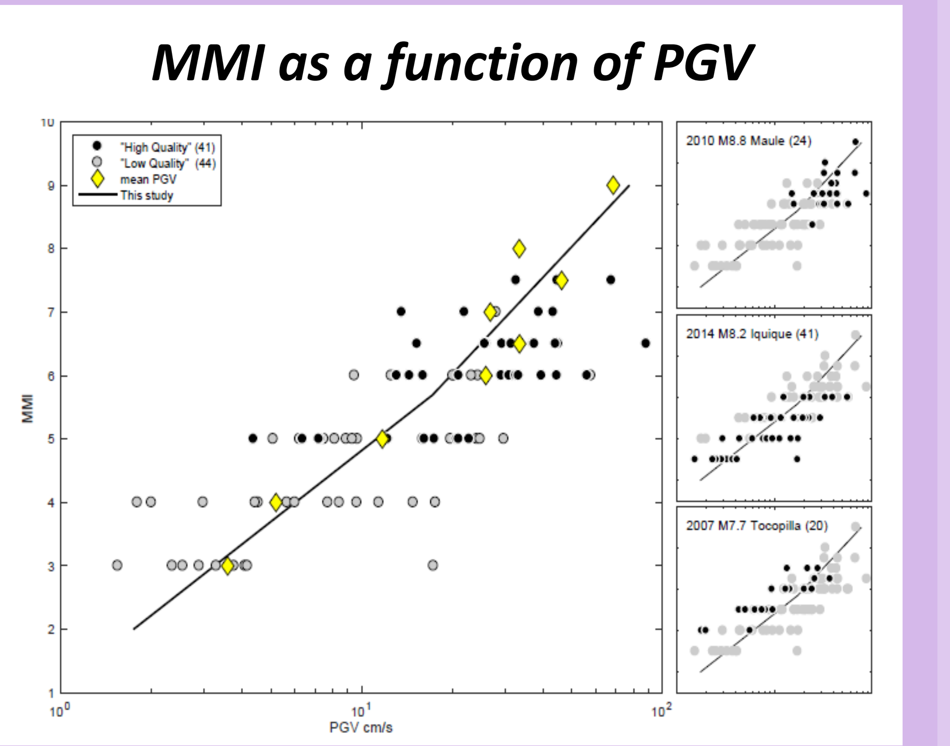
These are the three most recent M≥7 Chile earthquakes prior to the September 16, 2015 M_W 8.3 Illapel earthquake.



All three were megathrust earthquakes, located on the interface between the Nazca and South American plates.

Results





Pairings of peak ground motions (PGA, PGV) with intensities (MMI).

Main panel

Black dots are *high quality* pairings, grey dots are *low quality* pairings; the number of pairings in each category is in parentheses. Diamonds are the weighted geometric means of the peak ground motions for each MMI unit. The black line is the segmented fit of MMI to the means.

Side panels

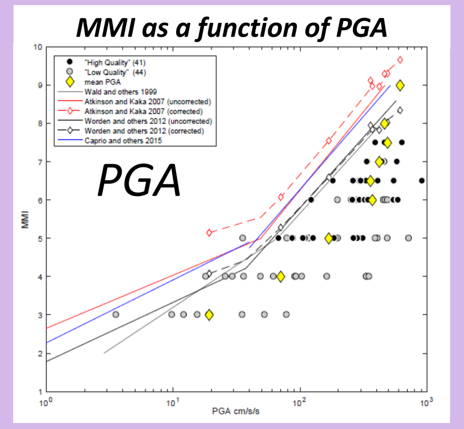
Sources of the pairings.

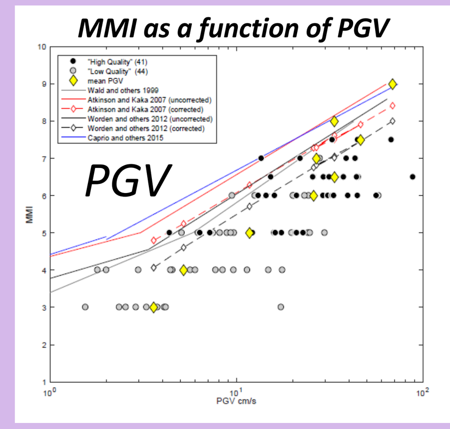
- 41 *high quality* pairings (stations within 16 km of an intensity field observation)
- 44 *low quality* pairings (intensity estimated from an isoseismal map)
- High quality pairings are assigned greater weight than low quality pairings
- Pairings with MMIs estimated from published isoseismal maps (2007, 2010) are assigned greater weight than pairings with MMIs estimated from isoseismal regions approximated using kriging (2014)
- Weighted geometric mean of peak ground motions (PGA, PGV) for each magnitude unit
- Segmented least squares fit of MMI to the weighted geometric means with a hinge at MMI=V

Comparison with Existing GMICEs

Developed for active crustal regions, not subduction zones

GMICEs

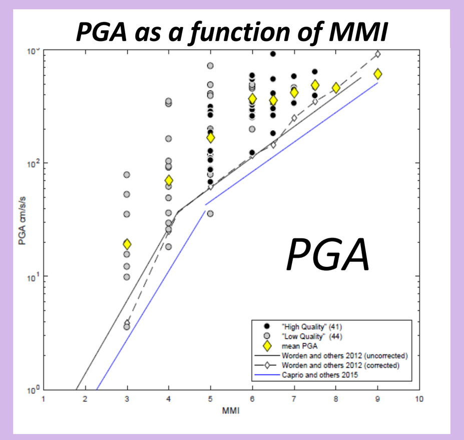


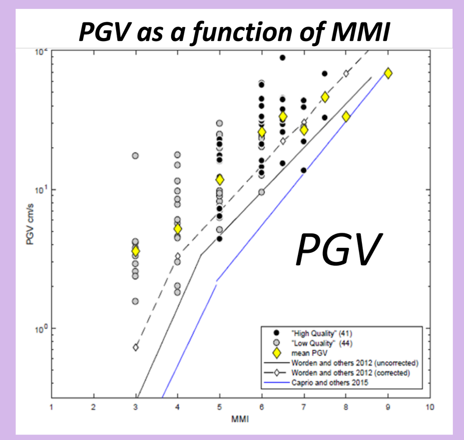


Intensities are over predicted

Corrections alter the MMI location of the hinge

Inverse GMICEs

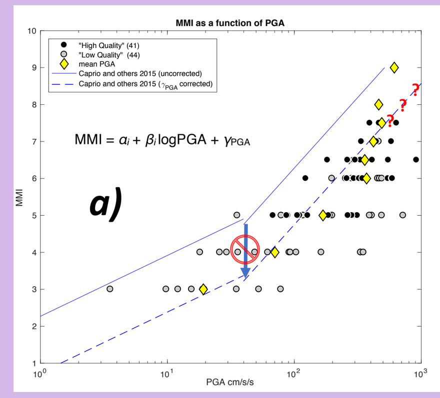




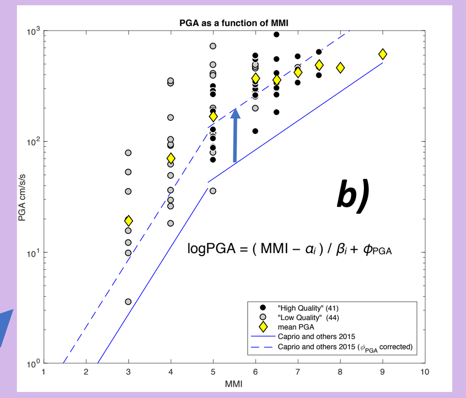
Peak ground motions are under predicted

Improving Regional Corrections for Global GMICEs

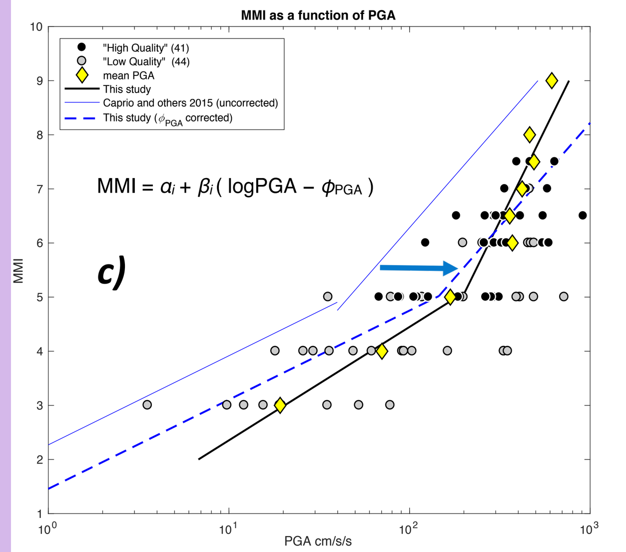
- Caprio and others (2015) use two different equations to make region-specific corrections to their global GMICEs. For GMICEs, an adjustment $\boldsymbol{\gamma}_{PGM}$ is made to MMI (fig. *a*). For inverse GMICEs, an adjustment $\boldsymbol{\varphi}_{PGM}$ is made to logPGM (fig. *b*).
- When region-specific corrections are made to MMI, the line segments move up or down, moving the hinge out of position.
- The MMI location of the hinge is a stable feature of all existing GMICEs. Caprio and others (2015) interpret the MMI location of the hinge as the threshold between only felt shaking and the physical effects of the earthquake. They also showed the statistical significance of the improved fit provided by a segmented relation compared to a linear relation.
- We recommend an alternative adjustment for GMICEs that preserves the MMI location of the hinge. We take advantage that Caprio and others' (2015) relations are reversible and apply their inverse GMICE adjustment $\boldsymbol{\varphi}_{PGM}$ to logPGM before computing MMI, not after (fig. *c*). This single, reversible equation can be used to adjust both forward and inverse GMICEs.



- It is unclear what meaning to ascribe to the MMI location of the hinge after the $\boldsymbol{\gamma}_{PGA}$ adjustment is made
- The corrected GMICE is essentially linear, abandoning the improved fit of a segmented GMICE
- Assumes extrapolation of the relation is valid for PGAs above the range of the corrected GMICE
- The corrected GMICE is no longer reversible with the corrected inverse GMICE (fig. *b*)



We hypothesize that what makes one region different from another—the underlying mechanism behind Caprio and others' (2015) region-specific corrections—may be the relative efficiency of the radiation of high frequency seismic waves for the same effect (intensity) due to the different properties of the faults and the geologic structure in each region. That implies regional corrections should be made to PGM rather than to MMI.



- Uses Caprio and others' (2015) equation that adjusts logPGA by $\boldsymbol{\varphi}_{PGA}$, solved for MMI
- Preserves the MMI location of the hinge and the segmented relation
- Adjusts PGA to be in the valid range of the GMICE
- A single, reversible equation corrects both GMICEs and inverse GMICEs

Conclusions

- Existing GMICEs are not a good match for the Chilean data.
- Our results are in agreement with the low-intensity values found in previous studies of other great interplate earthquakes (Astroza and others, 2012).
- Our results are in agreement with the larger-than-expected ground motions predicted by Ground Motion Prediction Equations (GMPEs) for Chilean interface earthquakes (Contreras and Boroschek, 2012).
- We propose that our novel GMICEs should be used for ground motion intensity prediction in subduction zones, and the Chilean region in particular.

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