A regionalized seismicity model for subduction zones based on geodetic strain-rates, geomechanical parameters and earthquake-catalog data

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ABSTRACT

The Seismic Hazard Inferred from Tectonics based on the Global Strain Rate Map (SHIFT_GSRM) earthquake forecast was designed to provide high-resolution estimates of global shallow seismicity to be used for seismic hazard assessment. This model combines geodetic strain rates with global earthquake parameters to characterize long-term rates of seismic moment and earthquake activity. Although SHIFT_GSRM properly computes seismicity rates in seismically active continental regions, the raw forecast underestimates earthquake rates in subduction zones by an average factor of approximately 3.

We accordingly present a complementary method to SHIFT_GSRM to more accurately forecast earthquake rates in 37 subduction segments, based on the conservation of moment principle and the use of regional interface seismicity parameters, such as subduction dip angles, corner magnitudes, and coupled seismogenic thicknesses. In six progressive steps, we find that SHIFT_GSRM earthquake-rate underpredictions are mainly due to the utilization of a global probability function of seismic moment release that poorly captures the great variability among subduction megathrust interfaces.

I. INTRODUCTION

Megathrust earthquakes account for approximately 90% of the seismic moment (Pacheco and Sykes, 1992) and 60% of the seismic activity (Bird et al., 2010) worldwide observed.

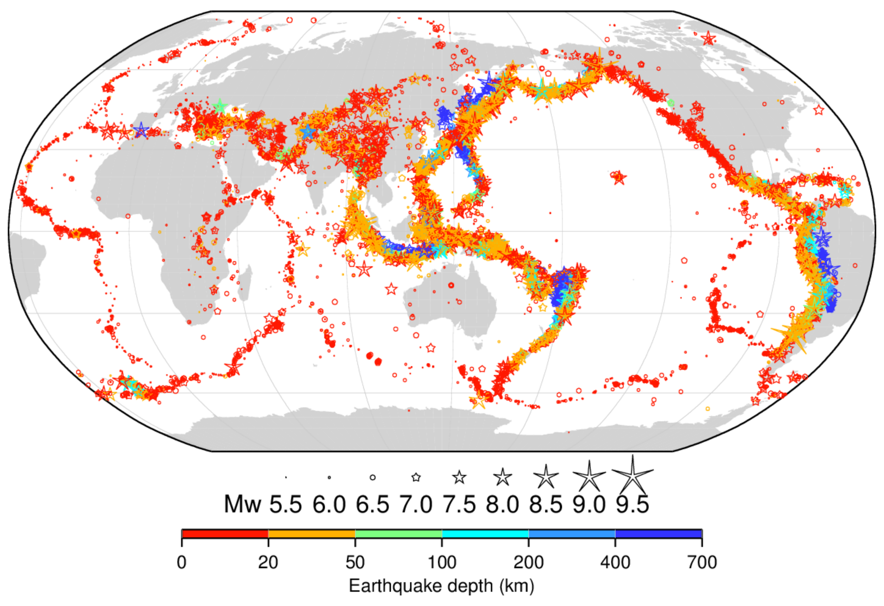


Fig. 1. Hypocentral locations of earthquakes listed in the 1904-2015 ISC_GEM seismicity catalog.

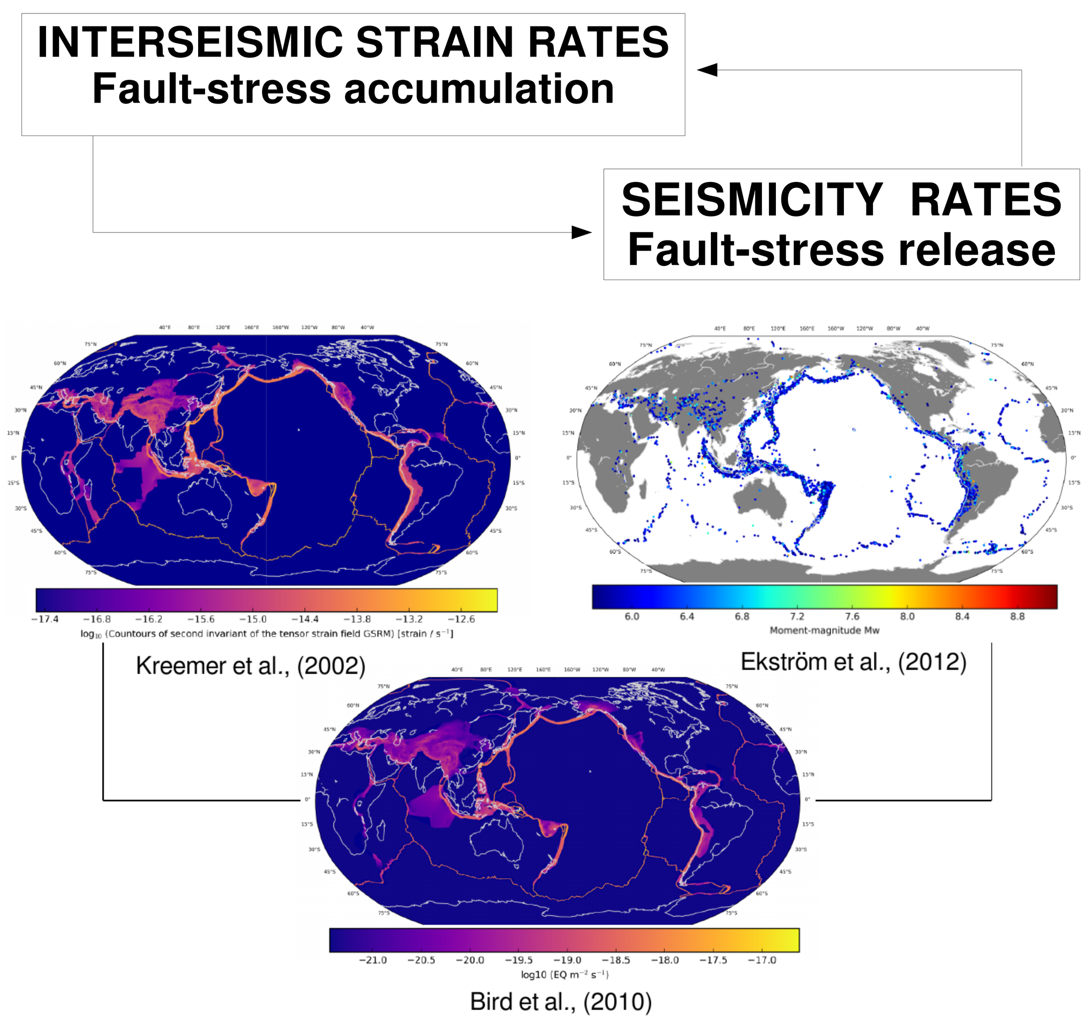


Fig. 2. Construction of seismicity models based on interseismic strain rates and earthquake-catalog data.

Model A: Uncorrected SHIFT_GSRM Seismicity Forecast

Bird et al., (2010) converted the Global Strain Rate Map (GSRM; Kreemer et al., (2003) to an indefinite- term earthquake rate model by applying the hypotheses, assumptions and equations of Bird and Liu (2007). SHIFT_GSRM assumes that the long-term seismic moment rate of any large volume of permanently deforming lithosphere scales linearly with geodetic strain rates as:

1) SEISMIC MOMENT RATE

Grid cell area — Principal strain rates taken from geodetic strain rates

$$\dot{M}_{\mathrm{GEO}} = A_{\mathrm{S}}\ c\ z\ \mu \begin{cases} 2\ \dot{\varepsilon}_3; & \text{if } \dot{\varepsilon}_2 < 0 \text{ or} \\ -2\ \dot{\varepsilon}_1; & \text{if } \dot{\varepsilon}_2 \geq 0 \end{cases}$$

GLOBAL SEISMICITY PARAMETERS

2) PREDICTED SEISMICITY

Computed from the Global CMT catalog

$$\dot{N}(m \geq m_T^{CMT}) = (\dot{M}_{GEO}/\dot{M}^{CMT}) \cdot \dot{N}^{CMT}$$

During the 1977-2009.03 period, the uncorrected SHIFT_GSRM model properly estimates earthquake rates in seismically-active continental regions. However, it underpredicts seismicity rates in subduction zones presumably due to the use of inappropriate geometric parameters.

II. METHODS

Model B: An updated global strain-rate model

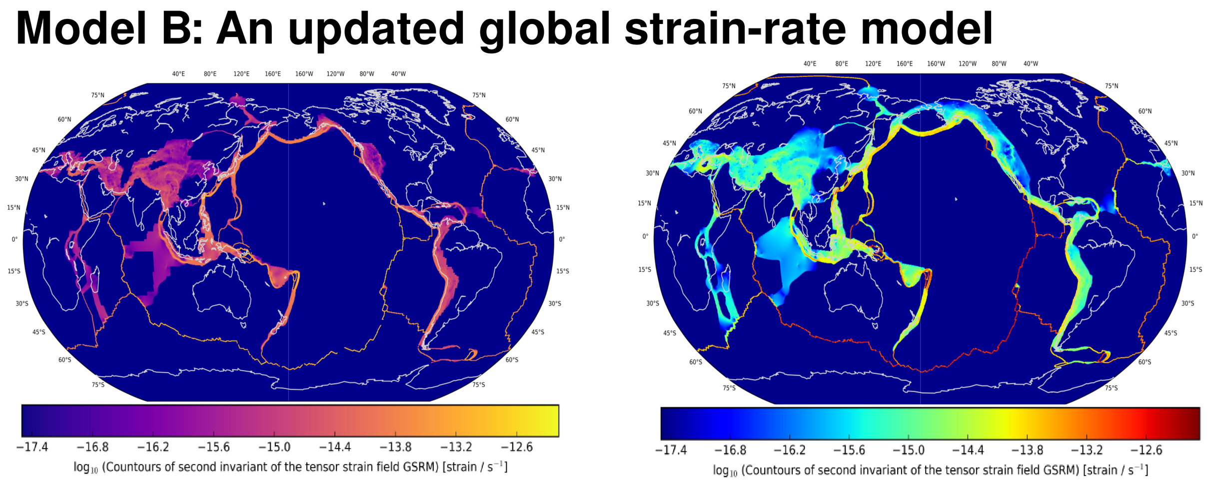


Fig. 2. Global Strain Rate Map (GSRM) used to compute long-term rates of seismic moment and shallow seismicity. Left: GSRMv1.1 (i.e., Kreemer et al., 2003). Right: GSRMv2.1 (i.e., Kreemer et al., 2014).

Model C: A new global regionalization scheme

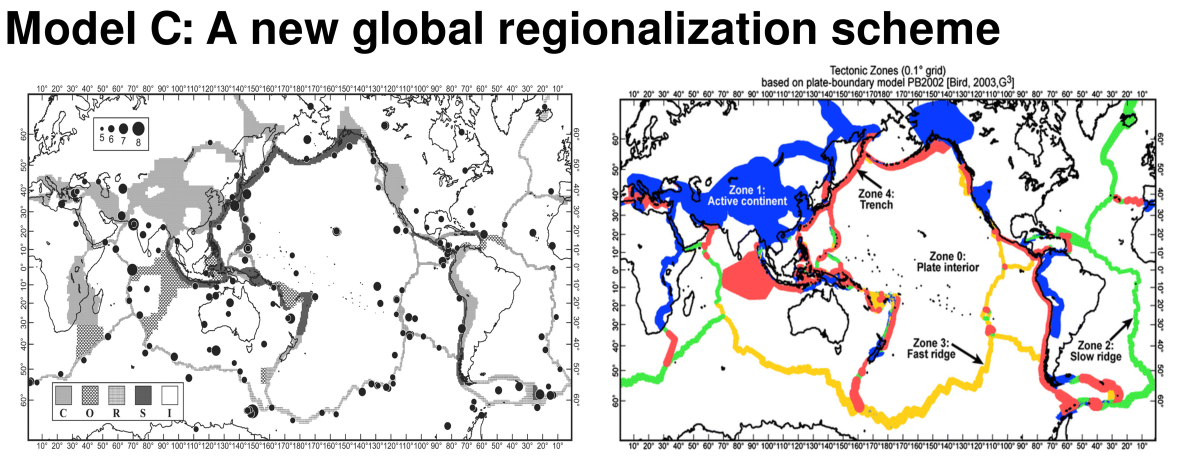


Fig. 3. Global regionalization schemes designed to divide the crust of the Earth into different zones of tectonic styles. Left: The regionalization framework of Kreemer et al. (2002). Right: The global regionalization model of Kagan et al., (2010).

Model D: Regional subduction dip angles

$$\dot{M}_{\mathrm{GEO}} = \frac{A_{\mathrm{X}}\ c\ z\ \mu}{\cos(\theta)\ \sin(\theta)} \begin{cases} \dot{\varepsilon}_3; & \text{if } \dot{\varepsilon}_2 < 0 \text{ or} \\ -\dot{\varepsilon}_1; & \text{if } \dot{\varepsilon}_2 \geq 0. \end{cases}$$

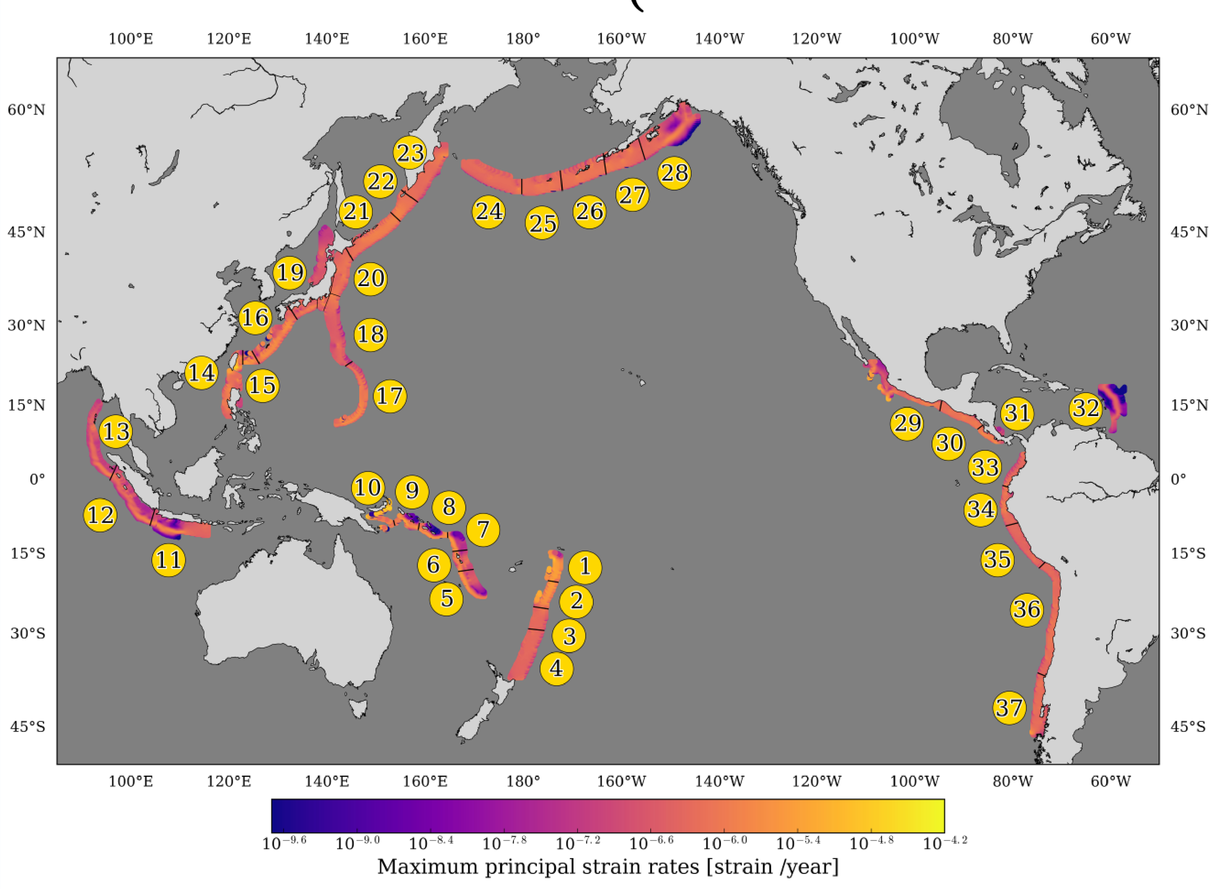
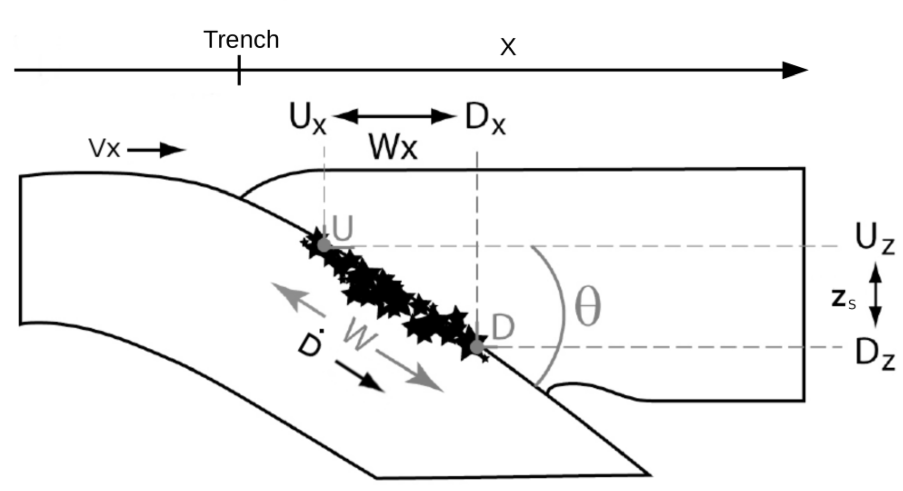


Fig. 4. Map of subduction zones analyzed in this study to computing regional estimates of SHIFT_GSRM seismicity, based on the trench segmentation proposed in Heuret et al., (2011).

Model E: Regional elastic shear moduli



$$\mu_i = v_{si}^2\ \rho_i$$

$$\mu_s = \frac{\sum_{i=1}^{n} \mu_i \Delta z_i}{\sum^{n} \Delta z_i}$$

Fig. 5. Parameters defining the subduction plate interface seismogenic zone geometry derived from the distribution of Mw 5.5–7.0 earthquakes. Modified from Heuret et al., (2011).

Model F: Regional estimates of seismic moment release

$$\dot{M}_{\mathrm{SEIS}} = \frac{\dot{N}(m \geq m_{\mathrm{T}})\ M_{\mathrm{T}}^{\beta}\ \beta}{1-\beta}\ M_{\mathrm{cg}}^{1-\beta}\ \Gamma(2-\beta)\ \xi_{\mathrm{g}}$$

Kagan & Jackson, 2016)

$$\dot{N}(m \geq m_{\mathrm{T}}) = \frac{(1-\beta)\ A_{\mathrm{X}}\ c\ z\ \mu_{\mathrm{s}}\ \dot{\varepsilon}}{M_{\mathrm{T}}^{\beta}\ \beta\ M_{\mathrm{cg}}^{1-\beta}\ \Gamma(2-\beta)\ \xi_{\mathrm{g}}\ \cos(\theta)\ \sin(\theta)}$$

Model G: Regional seismogenic thicknesses

SEISMOLOGICAL — GEO-MECHANICAL

$$c_{\mathrm{H}} = \frac{\dot{N}_{\mathrm{s}} M_{\mathrm{T}}^{\beta} \beta M_{\mathrm{cg}}^{1-\beta} \Gamma(2-\beta) \xi_{\mathrm{g}} \cos(\theta) \sin(\theta)}{(1-\beta) A_X z_{\mathrm{s}} \mu_{\mathrm{s}} \dot{\varepsilon}}$$

III. RESULTS AND DISCUSSION

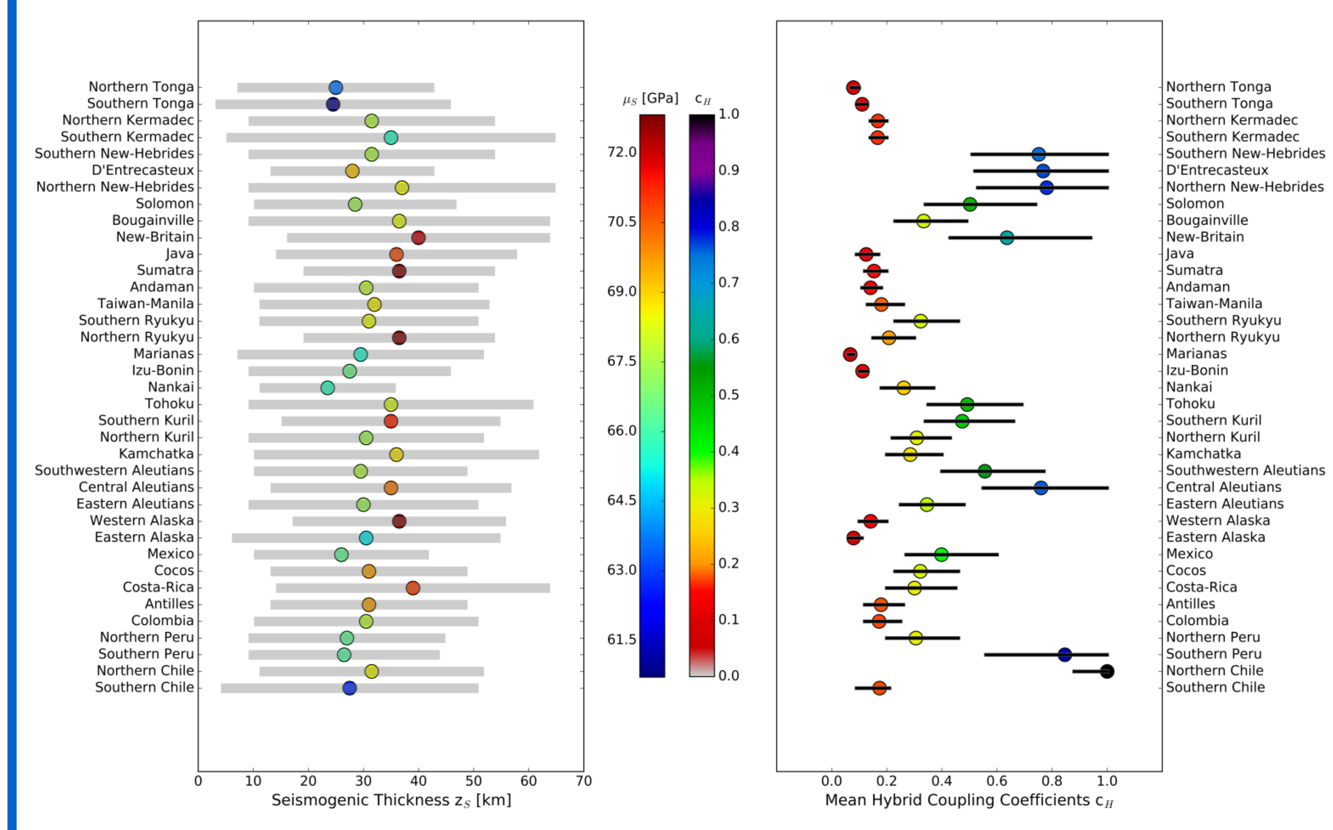


Fig. 6. Mean regional earthquake parameters computed in this study. Left: We present as circles weighted elastic shear moduli, and regional seismogenic thicknesses as gray thick bars. Right: We report mean long-term hybrid coupling coefficients (circles) with their corresponding standard deviations (thin black bars).

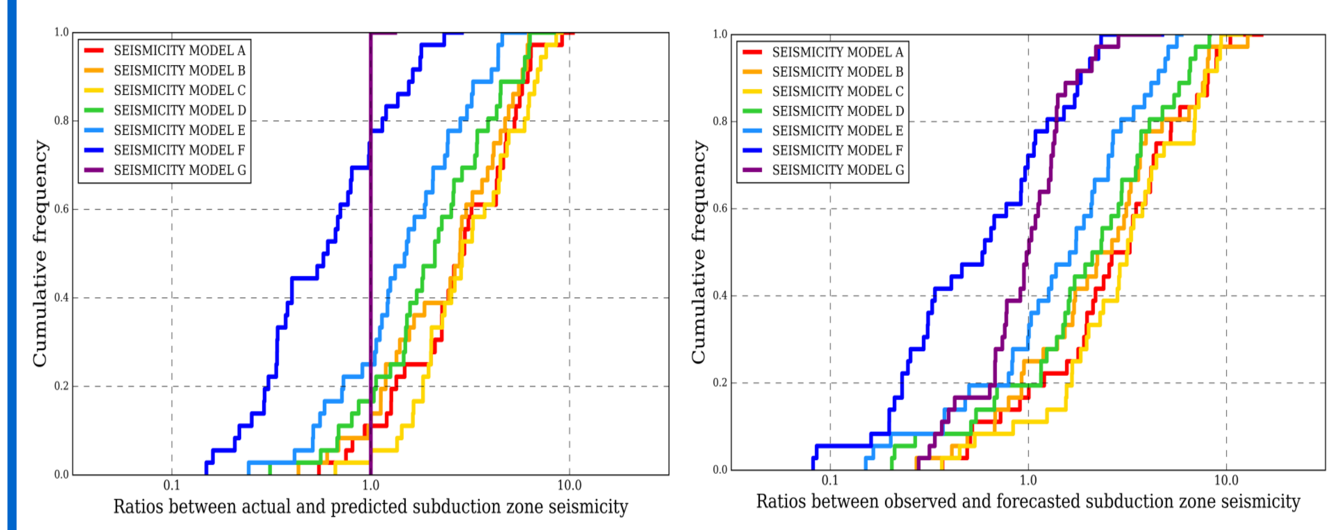


Fig. 7. Cumulative distributions of the ratios between observed and predicted seismicity, according to (Left) retrospective and (Right) pseudoprospective tests. Our periods of observation comprise from 1 January 1977 to 31 December 2014 for calibration and retrospective evaluation and from 1 January 2015 to 31 December 2018 for pseudoprospective testing.

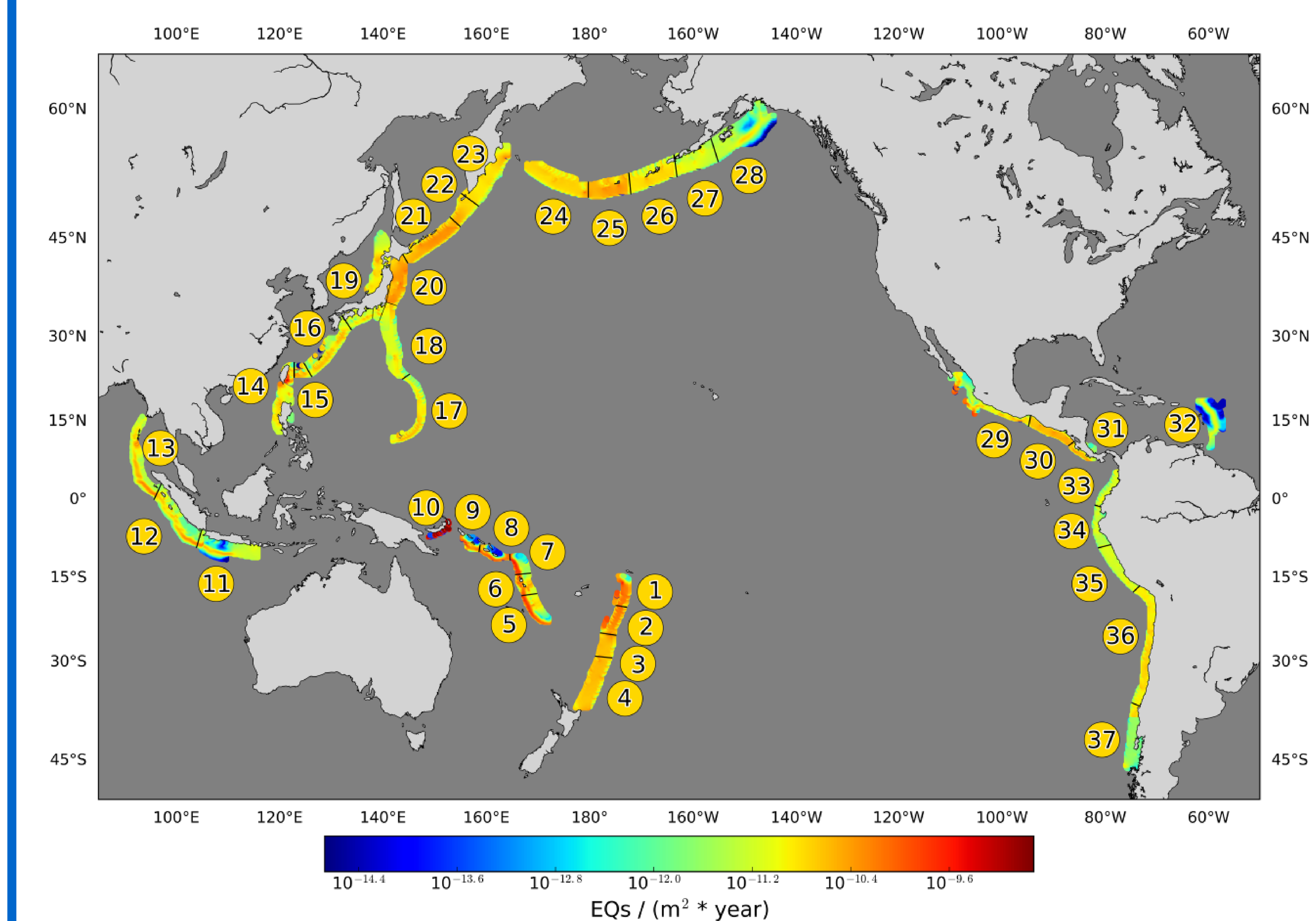


Fig. 8. Long-term rates of shallow seismicity at or above a magnitude threshold $m_T \geq 5.66$ in 37 subduction zones, according to the Subduction Megathrust Earthquake Rate Forecast (SMERF; Bayona Viveros et al., 2019) model.

IV) CONCLUSIONS AND PROSPECTS

- We show in six progressive steps that the uncorrected SHIFT_GSRM forecast underestimates earthquake rates in subduction zones mainly due to the use of a global probability function of seismic moment release, a homogeneous coupling coefficient and a uniform subduction dip angle, which poorly characterize seismicity patterns at regional scales.
- Independent prospective, pseudoprospective and prospective tests are necessary to more reliably describe the capacity of SMERF to properly estimate subduction-zone seismicity.
- We currently evaluate the impact of SMERF on the development, update and improvement of hybrid seismicity models, such as the Global Earthquake Activity Rate (GEAR1; Bird et al., 2015) forecast.

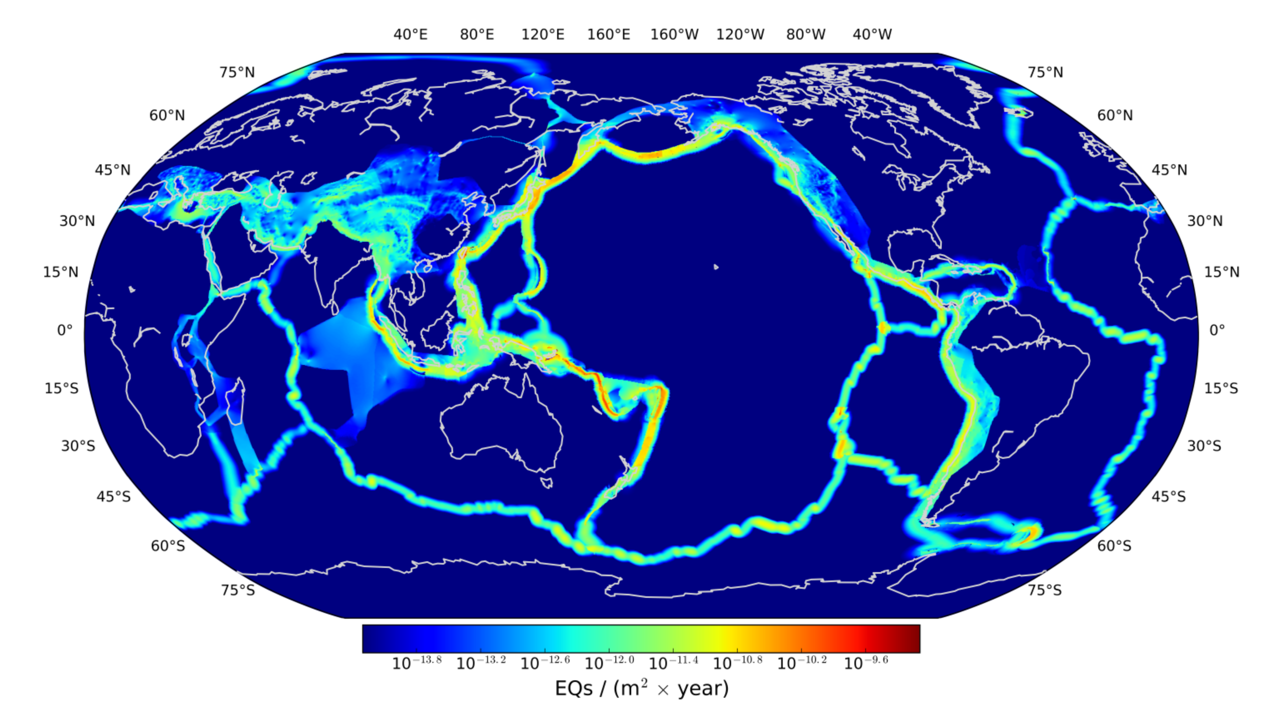


Fig. 9. Global Tectonic Earthquake Activity Model (TEAM) forecast for earthquakes $m_T \geq 5.767$, based on SMERF estimates in 37 subduction zones and SHIFT2f (i.e., Bird and Kreemer, 2015) computations outside of these interface margins.

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