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Rupture model of a Hikurangi Mw 8.6 megathrust earthquake

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ABSTRACT

We have developed a multi-segment M8.6 rupture model of a Hikurangi megathrust event, including unilateral rupture with propagation towards the northeast, in accordance with Schellart and Rawlinson (2012). We used the Graves and Pitarka hybrid Irikura method (Pitarka et al., 2018; GP-IM) for developing the source model. This method combines the Irikura and Miyake (2011) asperity-based kinematic rupture generator with the Graves and Pitarka (2015) rupture generation methods for stochastic spatial variability and background slip in shallow crustal earthquakes. We adapted these for use with subduction earthquakes using the Skarlatoudis et al. (2016) scaling for the corner wavenumbers in the along strike and down-dip directions for great interface subduction earthquakes. We also modified the perturbations to the rupture times for large earthquakes to make them smoother, and modified the parameters that control the average rupture speed and rise time. Relationships between seismic moment, rupture area, asperity area, and stress parameters were based on work by Murotani et al. (2008), Tajima et al (2013) and Miyake (2018). The maximum slip over the rupture planes was found to be approximately 14 m, and the average slip is approximately 3.5 m. Both of these values are broadly consistent with the scaling relations developed by Tajima et al. (2013) and Skarlatoudis et al. (2016). We are also performing simulations to assess the importance of slip randomness, asperity number and location, and hypocentre location in influencing the simulated ground motions.

1 INTRODUCTION

We develop a multi-segment M8.6 rupture model of a Hikurangi megathrust event, including unilateral rupture with propagation towards the northeast, in accordance with Schellart and Rawlinson (2012). We use the Graves and Pitarka hybrid Irikura method (Pitarka et al., 2018; GP-IM) for developing the source model.

This method currently applies to planar faults, but the resulting planar models could potentially be draped over non-planar surfaces. The maximum slip over the rupture planes is approximately 14 m, and the average slip is approximately 3.5 m. Both of these values are broadly consistent with the scaling relations developed by Tajima et al., (2013) and Skarlatoudis et al. (2016). In future work, we will develop additional rupture models and will perform simulations to assess the importance of slip randomness, asperity number and location, and hypocentre location on the synthetic ground motions.

2 RUPTURE GEOMETRY

We use the geometric model from GNS Science (Stirling et al., 2012) as the basis for the Hikurangi rupture geometry, shown in Figure 1. The full Hikurangi scenario is composed of three segments: northern (Raukumara), central (Hawke's Bay), and southern (Wairarapa) as identified in Wallace et al., (2009). The GNS northern and central segments have identical dip angle and down-dip extent. The GNS southern segment has a steeper dip angle and extends to greater depth. The parameter values are listed in Table 1.

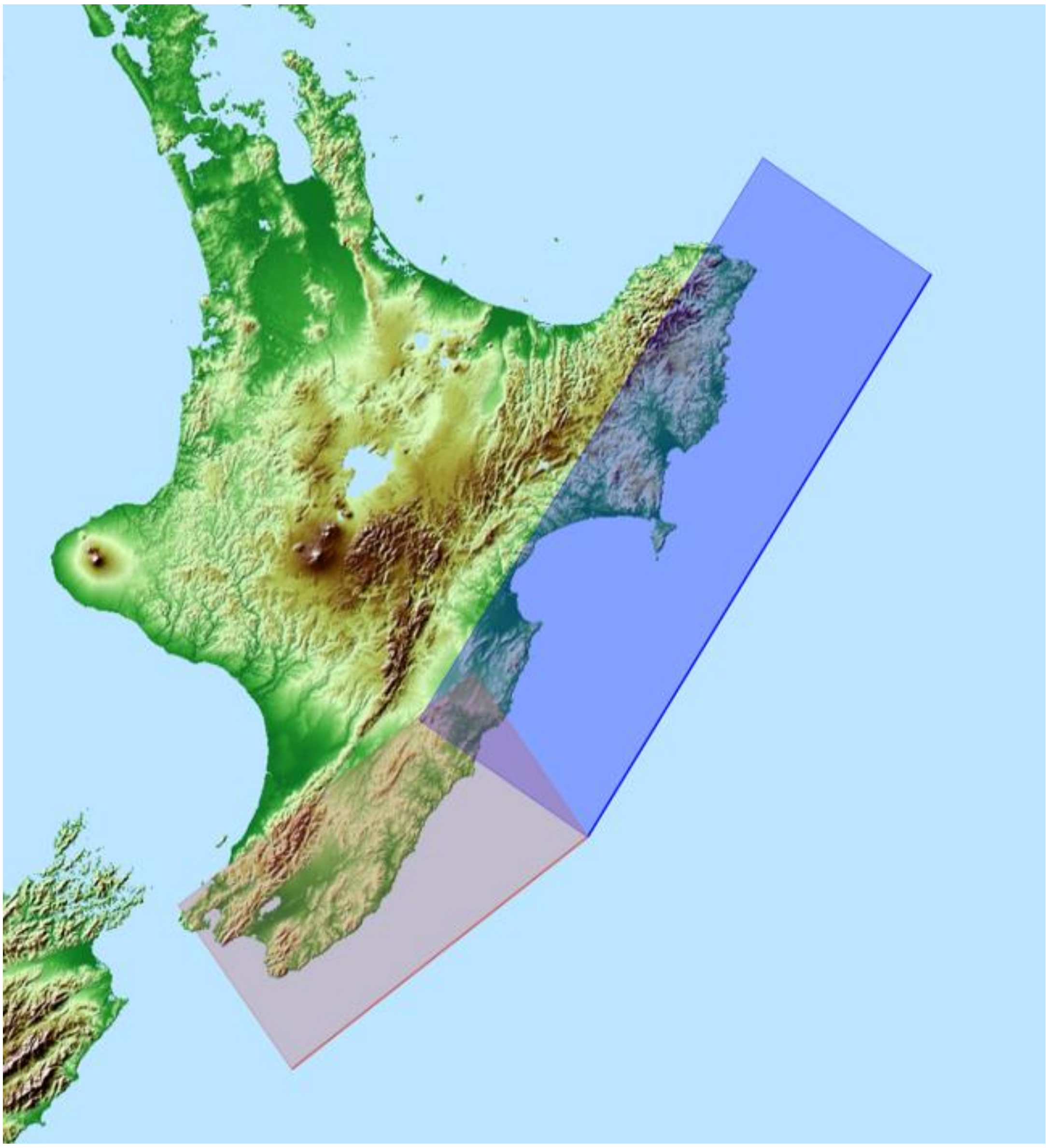

Figure 1: The northern and central segments are shown in blue, and the southern segment is shown in red. The solid lines identify the surface traces and the filled areas are the surface projections of the rupture planes.

Table 1: Parameters of the Hikurangi fault model.

Rupture Scenario	Dip Angle (deg)	Depth to Top of Rupture (km)	Depth to Bottom of Rupture (km)	Length (km)	Strike Angle (deg)	Characteristic M
Northern	8.5	5	20	200	209.5	8.3
Central	8.5	5	20	200	209.5	8.3
Southern	10	5	30	224	224.7	8.4
Combined	9.0	5	24	624	Varies	9.0

3 SEISMIC VELOCITY MODEL

We developed a generic 1D seismic velocity and density model for the Hawke's Bay region, shown in Figure 2. This model was created by averaging profiles from the Eberhart-Phillips et al. (2010) model sampled within 100km of the Hawke's Bay earthquake fault plane, and modified in the upper 1.5 km to have a smooth transition to Vs30=863 m/s. This is the 1D model we adopt for generating the Hikurangi source.

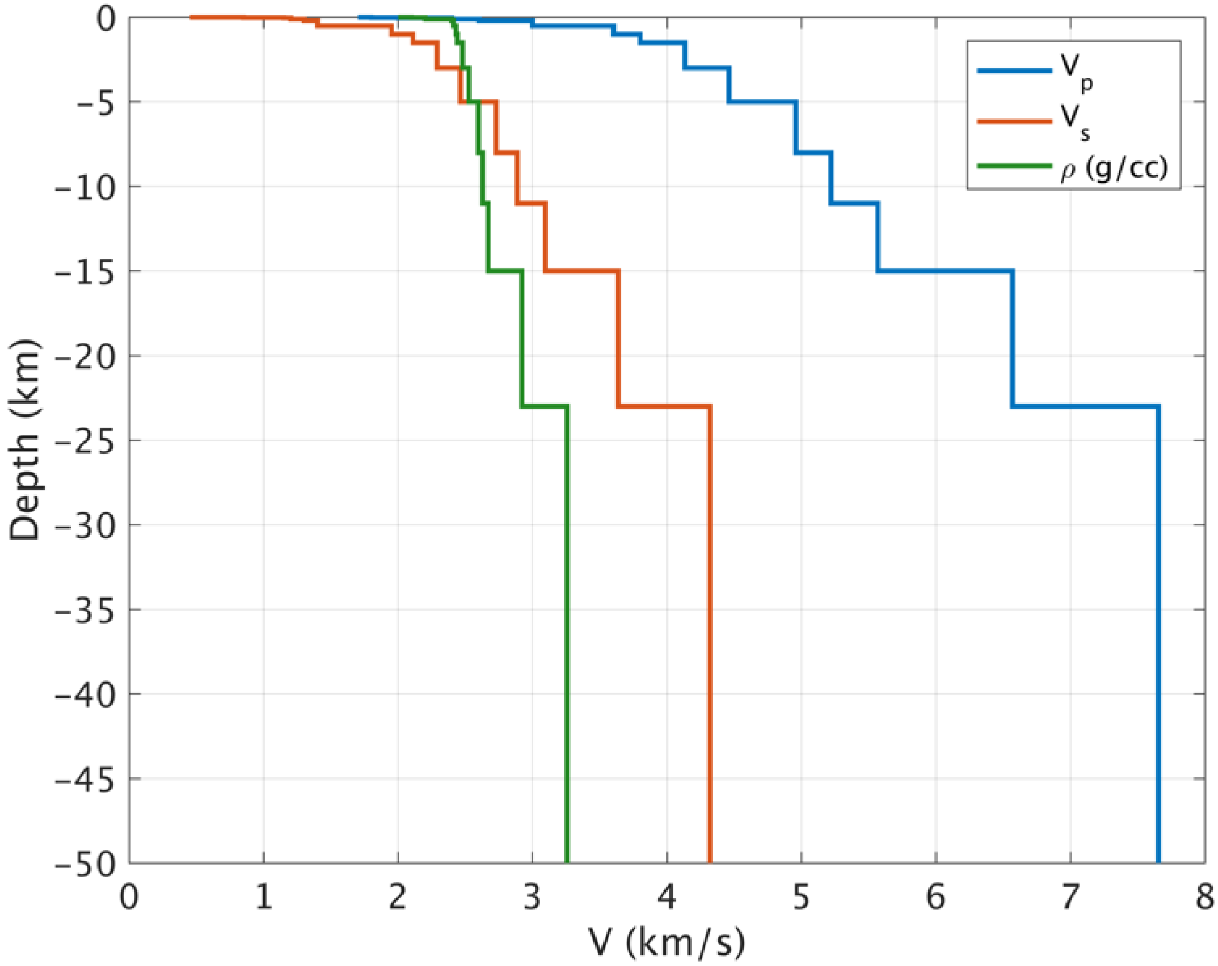

Figure 2: The 1D seismic velocity model used to represent the north island region.

4 EARTHQUAKE MAGNITUDE

We use the Skarlatoudis et al. (2016) self-similar magnitude scaling relationship for subduction earthquakes to determine the scenario magnitude, using the rupture area from GNS. The Skarlatoudis relationship is given as

M = 3.72 + log10(Rupture Area). Using the combined rupture geometry from Table 1, the total rupture area is 75,816 square km, which yields **M**8.6.

5 GP-IM RUPTURE MODEL CODE

The Pitarka et al. (2018; GP-IM) method combines the Irikura and Miyake (2011) asperity-based kinematic rupture generator with the Graves and Pitarka (2015) rupture generation methods for stochastic spatial variability and background slip.

Up to now, the model input parameters have been only calibrated for crustal earthquakes. Rob Graves and Arben Pitarka have not used the model extensively with subduction events and recommend that the model should be validation with recordings. Based on our communication with them, we have made the following modifications to the model:

- Used the Skarlatoudis et al. (2016) scaling for the corner wavenumbers.
- Modified magnitude dependence for deltaT perturbations to rise time.
- Modifications for multi-segment rupture with continuous slip velocity.

We define the scenario SMGA areas based on advice from Hiroe Miyake (pers. comm.) and on the Murotani et al., (2008) and Skarlatoudis et al., (2016) relationships. The model has four asperities (as shown in Figure 3): three with area 1,805 km^2 (each approximately **M**7.0) and one with area 5,984 km^2 (approximately **M**7.5). They are placed in the deeper portion of the rupture plane, consistent with the assumptions used in Wirth et al., (2017).

Table 2: GP-IM Code (v5.4.0-asp) Parameters

Parameter	Value	Description
SLIP1_SCOR	0.999	Controls the amount of stochastic variability in the slip distribution.
MASTER_RVFRAC	0.80	Vr/Vs ratio. Vs is the local shear wave velocity given in the 1D crustal model.
RISETIME_COEF	1.95	Coefficient that controls the rise time, where the actual rise time is calculated as: RISETIME_COEF *1.0e-09*exp(log(Moment)/3.0);
RUP_DELAY	0.0	No rupture delay.
SLIP_COV	0.85	Controls the slip distribution roughness.
DT	0.0125	Time step in the source time function.
ALPHA_ROUGH	0.0	Controls the fault geometry roughness.
TSFAC_MAIN	max { -0.5 * 1.0e+09 * Mo^(1/3) - 0.1, -2.0 }	Magnitude dependent perturbations to the rupture times.
Kx, Ky	Skarlatoudis et al., (2016)	Corner spatial wavenumbers

6 RUPTURE MODEL SUMMARY

The Hikurangi megathrust scenario rupture model we developed is shown in Figure 3. This figure shows the slip on the fault plane in shades of red, with rupture initiation contours (black lines) at 10 s intervals. The break between the northern and southern segments is identified by the dashed blue line.

The maximum slip over the rupture planes is approximately 14 m, and the average slip is approximately 3.5 m. Both of these values are broadly consistent with the interface subduction earthquake scaling models by Tajima et al., (2013) and Skarlatoudis et al. (2016), shown in Figures 4 and 5 respectively.

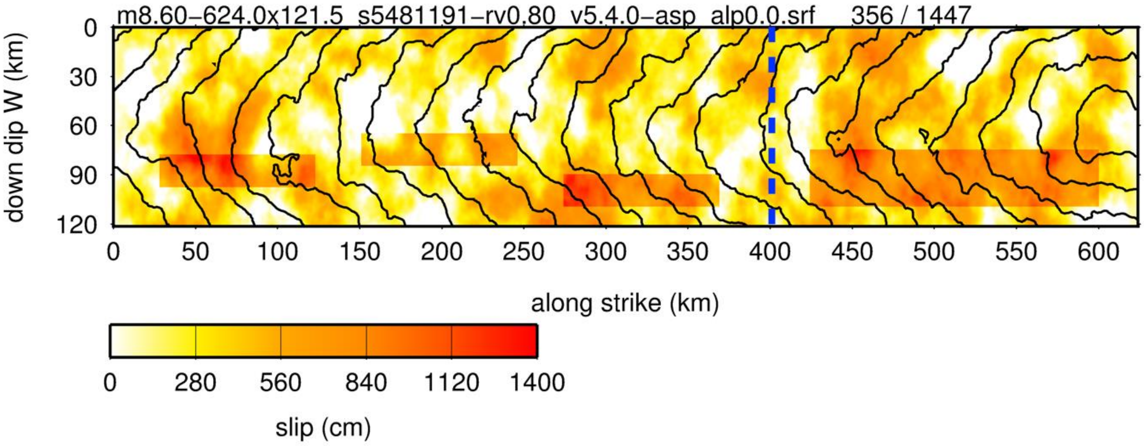

Figure 3: The developed Hikurangi earthquake rupture model

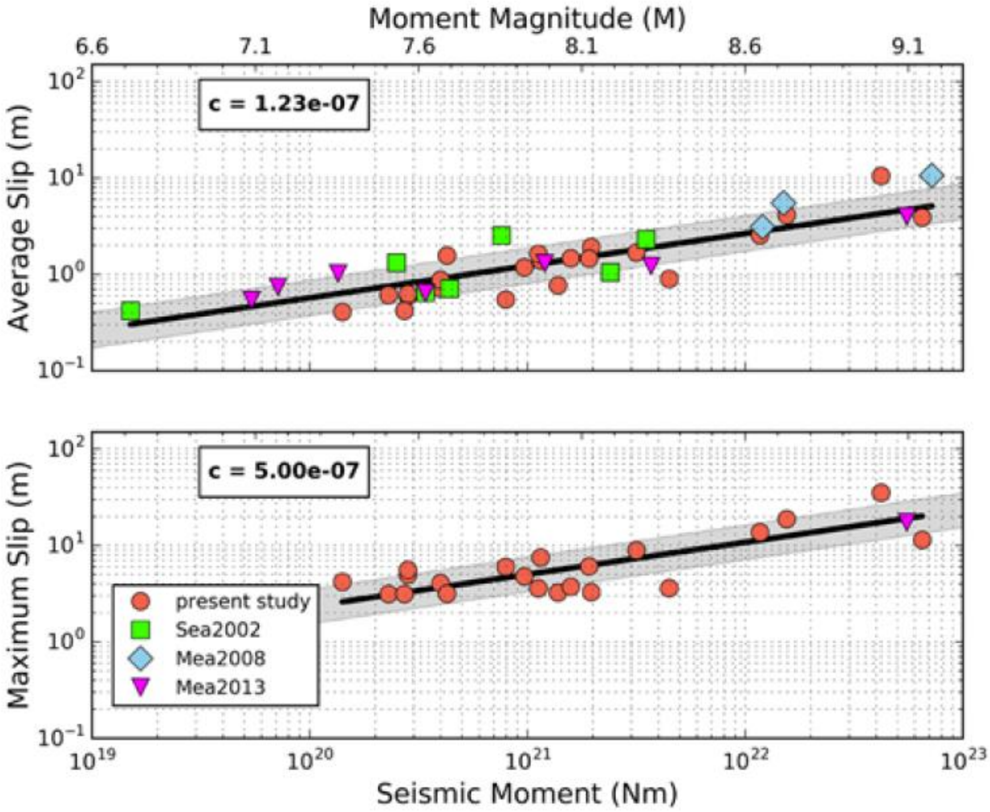

Figure 4: Scaling of average and maximum slip with seismic moment. Source: Skarlatoudis et al., 2016.

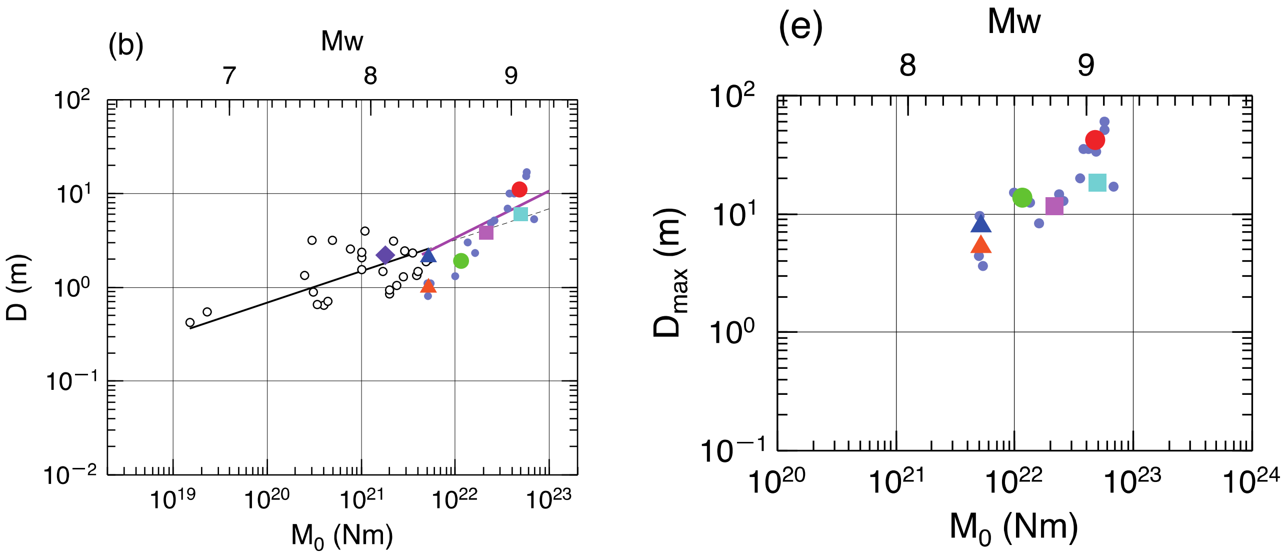

Figure 5: Scaling of average and maximum slip with seismic moment. Source: Tajima et al., 2013

7 ACKNOWLEDGMENTS

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