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Subduction Zone *b*-values: a Global and Regional Comparison

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Introduction

- *b*-value is the slope of a log-normal distribution of seismic events & describes the frequency of earthquake distribution
- A high *b*-value suggests that small mag. earthquakes dominate & a low *b*-value suggests large mag. earthquakes dominate
- This study classifies earthquake catalogs into upper plate, interface, & intraslab, & calculates *b*-value for each resulting catalog for all Slab2 subduction regions

Methods

Earthquake Catalog:

- A global mb (short-period body wave) catalog from the USGS Preliminary Determination of Epicenters (PDE) bulletin was collected from 01/01/1973-12/15/2020 with a magnitude cutoff at 4.5
- While moment tensors are not determined from mb magnitudes but are used in classifying events, moment tensors from other magnitude sources (e.g., Mww, Mwr, Mwb) within the PDE catalog were taken when available
- This global mb catalog was broken down into Slab2 regions & run through a catalog separation code

Catalog Separation Code:

- A probabilistic earthquake classification scheme (following (Worden et al., 2005 and Thompson et al., in prep.) was devised to classify earthquakes into upper plate, interface, & intraslab events
- A simple ramp function (a) is used to scale probabilities between 0 and 1, such that the total probability, P(x), is given by,

$$P(x) = \begin{cases} p_1 & \text{for } x < x_1, \\ p_1 + \dfrac{p_2 - p_1}{x_2 - x_1}(x - x_1) & \text{for } x_1 \le x \le x_2, or \\ p_2 & \text{for } x > x_2. \end{cases}$$

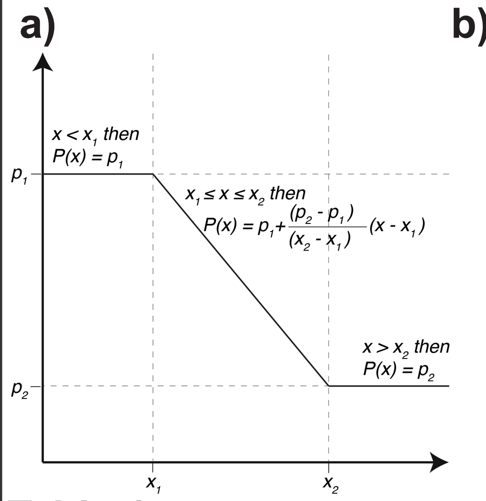
(x represents some variable, x_1 and x_2 are associated parameters used to define the ramp, and p_1 and p_2 give the probabilities of those parameters; see Table 1 for details)

- Probability that each earthquake was an upper plate, interface, or intraslab event was calculated by,

$$P_{interface} = p_{sz} * p_{fx} * p_{kagan}$$
$$P_{upper} = (1 - P_{interface}) * p_{diff} * p_{moho}$$
$$P_{slab} = 1 - (P_{interface} + P_{upper})$$

- *b*-value was calculated using the maximum likelihood method (Aki, 1965; Utsu, 1965, 1966) where the magnitude of completeness was estimated using the procedure of Wiemer and Wyss (2000)

a)



b)

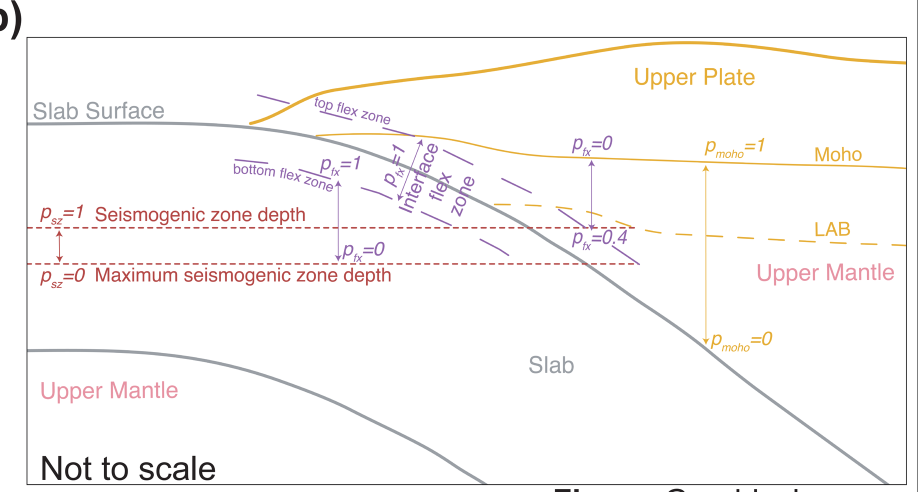


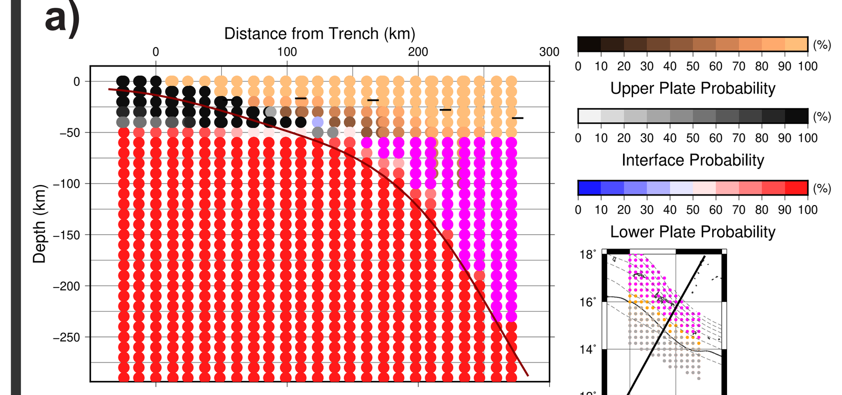
Table 1

Parameter	x	x_1	x_2	p_1	p_2
p_{sz}	Earthquake depth	Seismogenic zone depth	Maximum seismogenic zone depth	1.0	0.0
p_{fx}	Earthquake depth	Bottom interface flex zone	Maximum seismogenic zone depth	1.0	0.0
	Earthquake depth	Moho depth	Seismogenic zone depth	0.0	0.4
p_{kagan}	Kagan angle	30	53	1.0	0.25
p_{diff}	Earthquake depth – slab depth	-20	20	1.0	0.0
p_{moho}	Earthquake depth	Moho depth	Slab depth	1.0	0.0

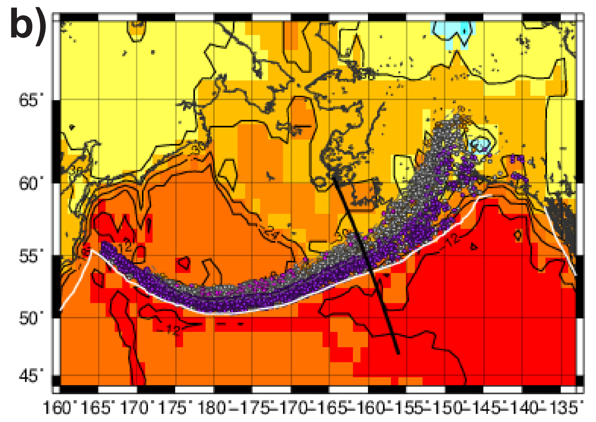
Fig. a - Graphical representation of the probabilistic ramp function
Fig. b - Cartoon of parameters & probabilities used in the earthquake classification scheme
Table 1 - Parameters used in the probabilistic ramp functions

Results: Catalog Separation

a)



b)



Basemap: Moho depth (CRUST1.0)

c)

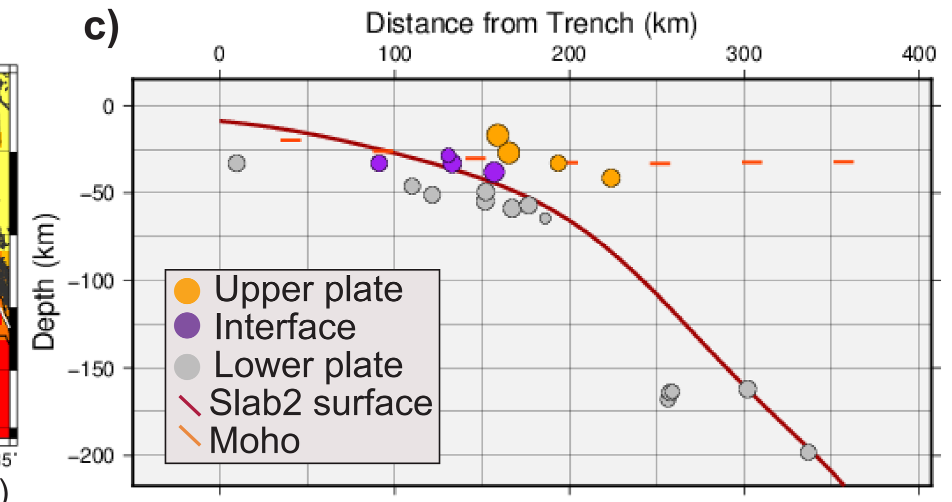
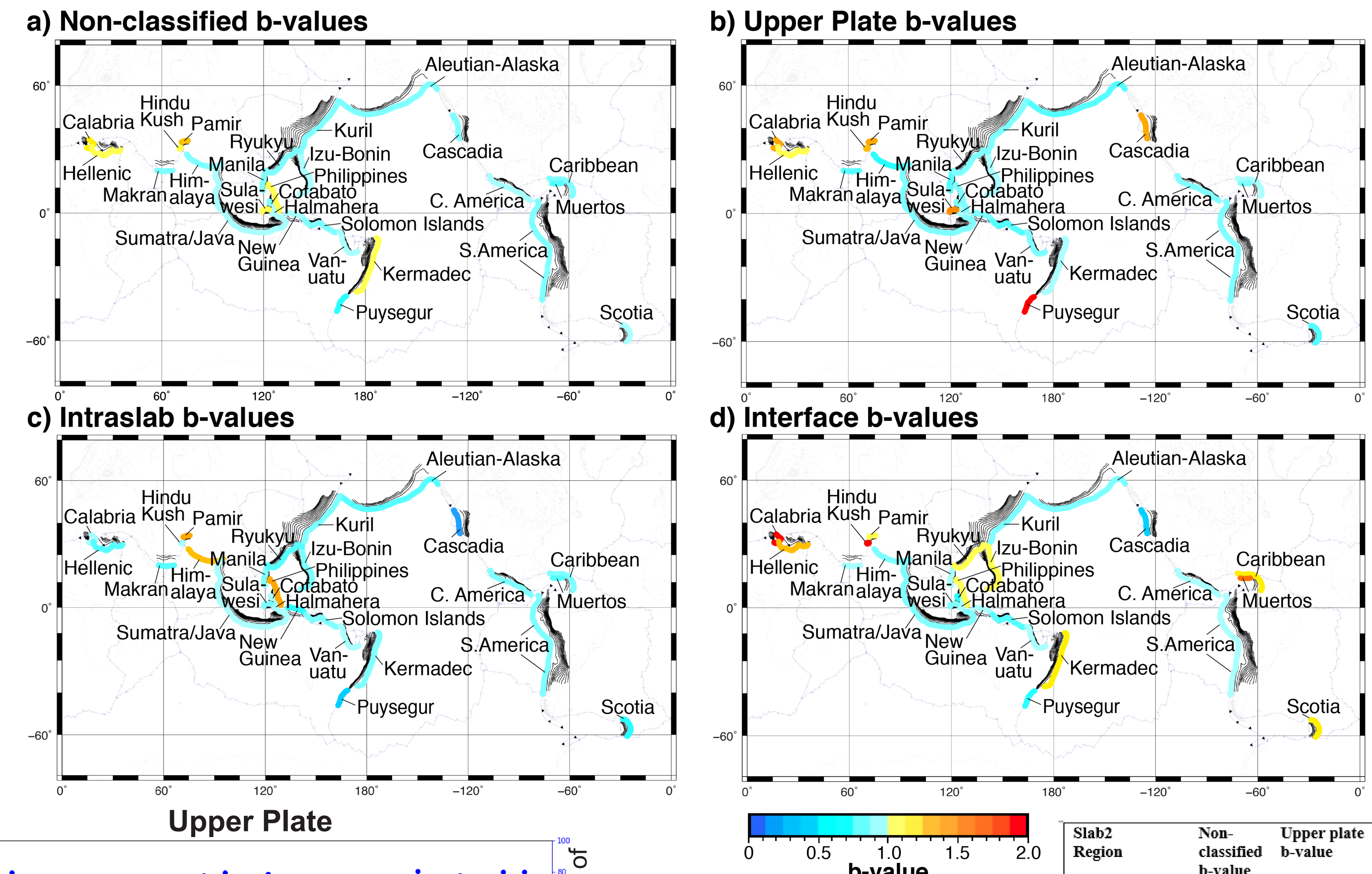
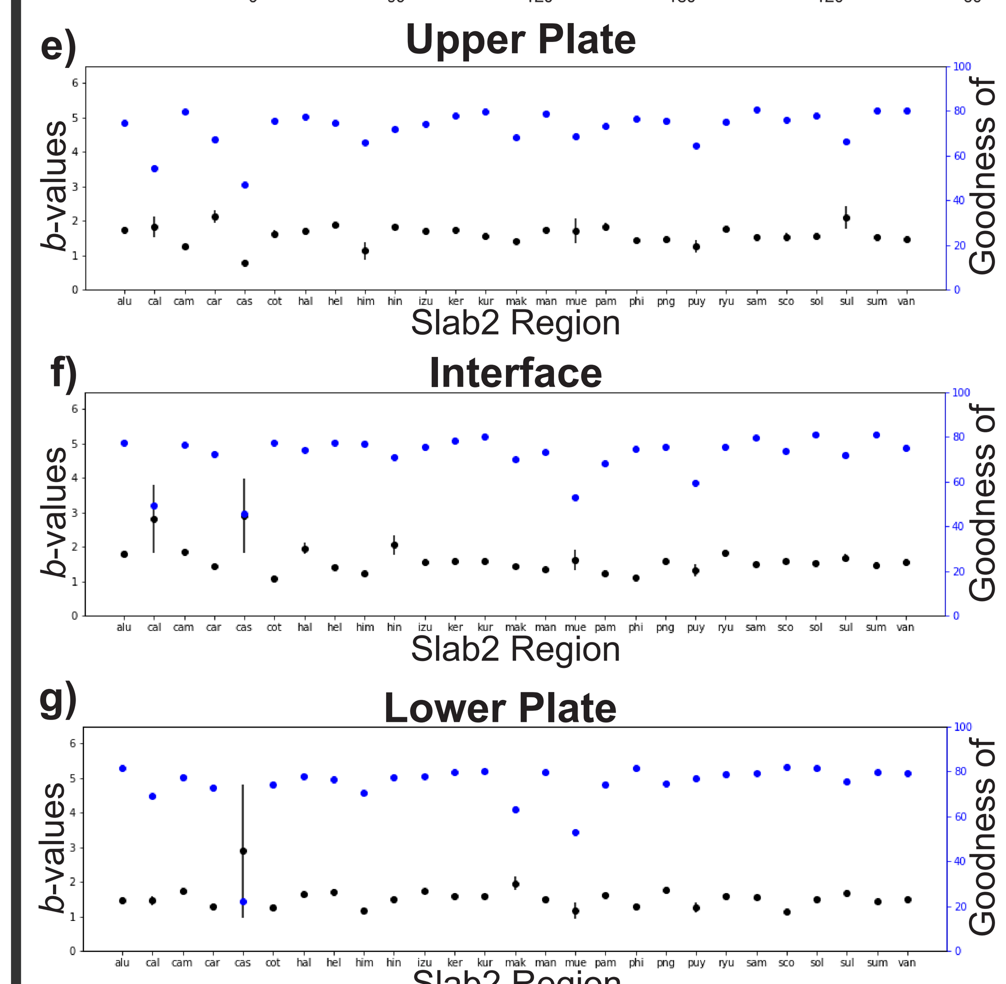


Fig. a - Results from running test events through catalog separation code (purple: flagged as mantle events)
Fig. b - map view of separated Aleutian-Alaska catalog
Fig. c - Cross-section view of separated catalog in (b)

Results: Global *b*-values





Figs. a-d - *b*-values for each Slab2 subduction zone for non-classified & classified (separated) catalogs

Figs. e-g - *b*-values & goodness of fit for classified Slab2 regions

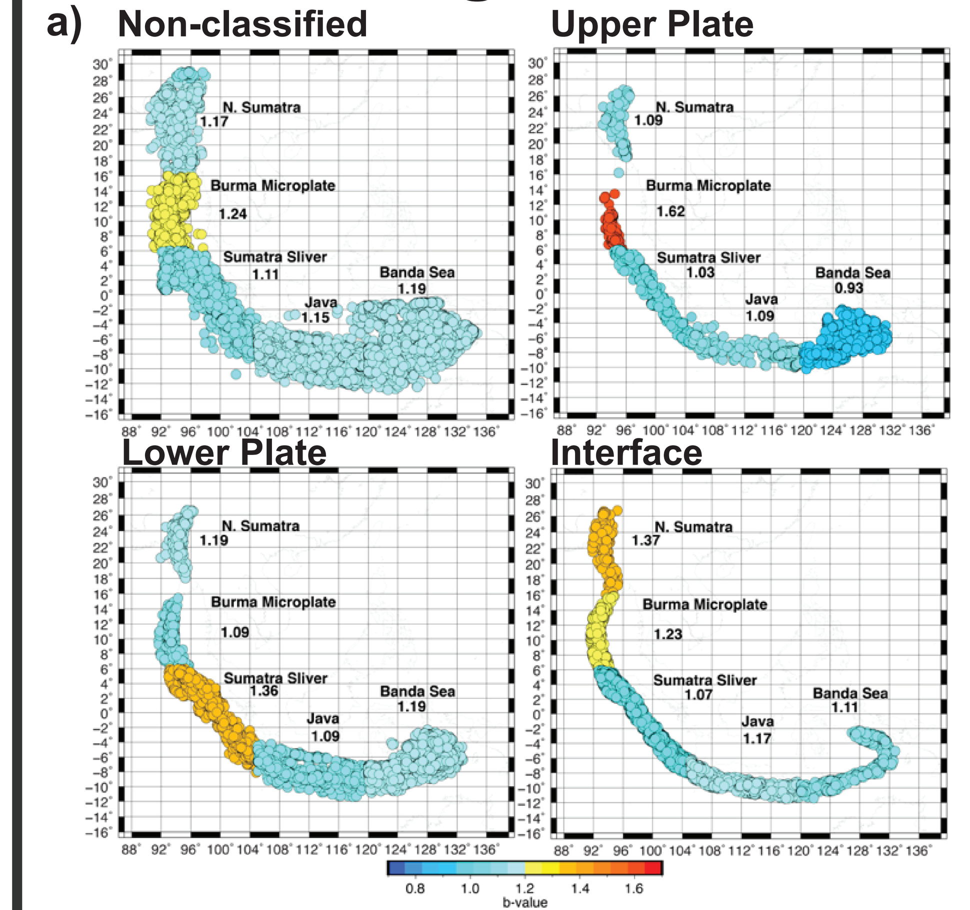
Table 2 - *b*-values for Slab2 regions. * denotes *b*-values with a goodness of fit ≥ 80% & a minimum of 2000 events

Table 2

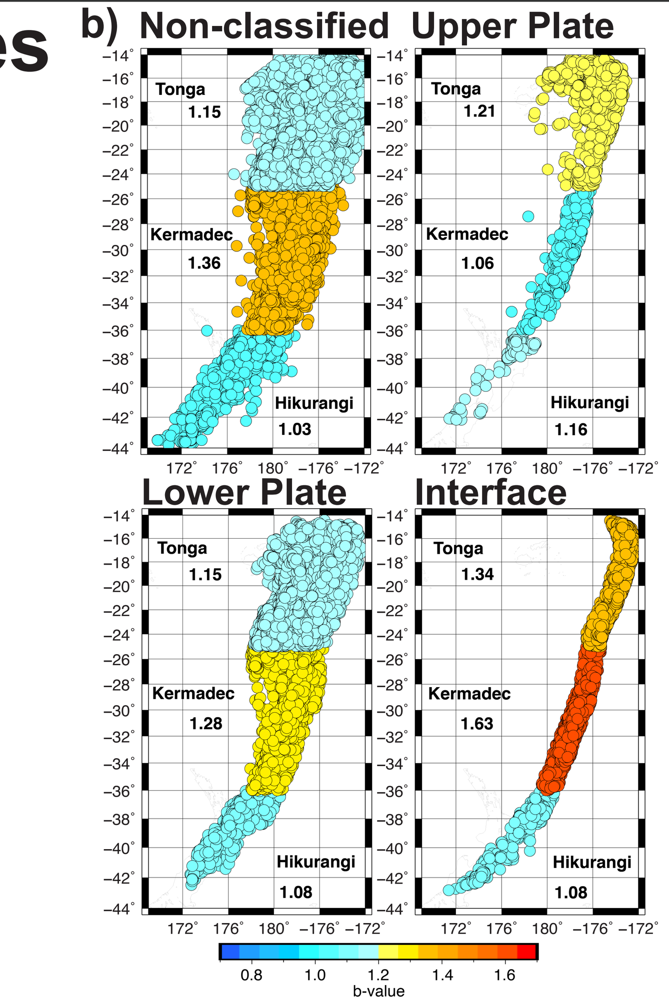
Slab2 Region	Non-classified b-value	Upper plate b-value	Interface b-value	Intraslab b-value
Aleutians	*1.0733	0.9901	*1.0806	1.0333
Calabria	1.3823	1.2368	4.3429	1.6084
Caribbean	1.1279	1.2333	1.4096	1.1188
Cascadia	1.0803	1.5953	0.8188	0.6461
Central America	*1.1753	1.1417	*1.2423	*1.1558
Cotabato	1.0866	1.1090	0.9312	1.1752
Halmahera	*1.2059	*1.2070	1.2119	*1.2204
Hellenic	1.2893	1.3009	1.4423	1.0313
Himalaya	1.1549	0.9047	1.0831	1.4476
Hindu	1.2952	1.5266	2.0530	1.2471
Izu-Bonin	*1.2480	1.2142	*1.2585	*1.1040
Kermadec	*1.2727	*1.1772	*1.3835	*1.1344
Kuril	*1.1232	1.0992	*1.1365	*1.0734
Makran	1.0662	1.0415	1.1719	1.0503
Manila	*1.1055	0.9882	1.1738	1.0665
Muertos	1.0125	1.1030	1.7882	1.0366
New Guinea	*1.1741	1.0744	1.2327	0.9336
Pamir	1.4578	1.6085	1.2645	1.5383
Philippines	*1.2566	1.0642	1.2836	1.5453
Puysegur	0.8884	1.9066	0.9437	0.8352
Ryukyu	*1.1314	1.1495	1.3426	1.0598
Scotia	*1.2299	0.9934	1.3765	0.9453
Solomon	*1.1049	0.9754	*1.0044	*1.1527
South America	*1.0753	*1.0997	*1.1724	*1.0817
Sulawesi	1.3078	1.6716	1.1533	1.0778
Sumatra	*1.1999	*1.0759	*1.0677	*1.2268
Vanuatu	*1.1811	1.0793	*1.1836	*1.1962
All regions	1.1196	1.0348	1.1668	1.1148
Average	1.1743	1.2199	1.3538	1.1248

Results: Regional *b*-values

a)



b)



- Sumatra, Kermadec, & South America meet our *b*-value requirements for both the non-classified and classified catalogs (see Table 2 caption)
- These regions were split up based on local tectonics to investigate how *b*-values vary along strike

Fig. a - *b*-values along the Sumatra subduction zone
Fig. b - *b*-values along the Kermadec subduction zone

Conclusions & Future Work

- With a few exceptions, most subduction zones have *b*-values around 1.0 for both non-classified and classified catalogs
- Regions with large *b*-values occur due to a low number of events and poor goodness of fit
- Regional comparisons show that b-values vary spatially & with earthquake classification, suggesting that such variations should be considered in products that use *b*-values (e.g., aftershock forecasts, seismic hazard analysis)
- Future plans include updating the earthquake catalog to use events dated to 2023, possibly updating parameters used in the catalog separation code, & further investigation of regional *b*-value variations

Acknowledgments

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Selected References

Aki, K. (1965). Maximum likelihood estimate of b in the formula log N= a-bM and its confidence limits. Bull. Earthq. Res. Inst., Tokyo Univ., 43, 237-239.
Hayes, G. P., Moore, G. L., Portner, D. E., Hearne, M., Flamme, H., Furtney, M., & Smoczyk, G. M. (2018). Slab2, a comprehensive subduction zone geometry model. Science, 362(6410), 58-61. https://dx.doi.org/10.1126/science.aat4723
Thompson, E. M., Hearne, M. G., Hayes, G. P., Worden, C. B., Wald, D. J., & Deweu, J. (in prep.). A Heuristic and Probabilistic Earthquake Regionalization Scheme. TBD.
Utsu, T. (1965). A method for determining the value of" b" in a formula log n= a-bm showing the magnitude-frequency relation for earthquakes. Geophys. Bull. Hokkaido Univ., 13, 99-103.
Wiemer, S., & Wyss, M. (2000). Minimum Magnitude of Completeness in Earthquake Catalogs: Examples from Alaska, the Western United States, and Japan. Bulletin of the Seismological Society of America, 90(4), 859-869. https://dx.doi.org/10.1785/0119990114