NGA-Subduction Research Program

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As part of NGA-Subduction Research Group

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Outline

- NGA-Sub database
- Scope and status of NGA-Sub ground motion models
- Summary



The project has 33 contributors

1	Norm Abrahamson	18	Nicolas Kuehn
2	Sean Ahdi	19	Dong Youp Kwak
3	Tim Ancheta	20	Annie Kwok
4	Ralph Archuleta	21	Po-Shen Lin
5	Gail Atkinson	22	Harold Magistrale
6	David Boore	23	Sanaz Rezaeian
7	Yousef Bozorgnia	24	Silvia Mazzoni
8	Ken Campbell	25	Sifat Muin
9	Brian Chiou	26	Saburoh Midorikawa
10	Victor Contreras	27	Grace Parker
11	Robert Darragh	28	Hongjun Si
12	Nick Gregor	29	Walter Silva
13	Zeynep Gulerce	30	Jon Stewart
14	I.M. Idriss	31	Melanie Walling
15	Chen Ji	32	Katie Wooddell
16	Ronnie Kamai	33	Bob Youngs
17	Tadahiro Kishida		



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Acknowledgements

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- FM Global
- USGS
- Caltrans
- PG&E



NGA-Sub database

- The database span:
 - 1,880 worldwide events
 - **71,340** three-component recordings
 - Over **214,020** records
 - Over 6,000 recording stations
 - Magnitudes from 4 to 9.1
 - Interface, Intraslab ("slab") classifications

This is the largest database among all NGA programs

NGA-Sub database

- The database includes:
 - Acceleration, velocity & displacement time series
 - Pseudo-spectral acceleration (PSA) for periods: 0.01-10 sec
 - For 11 damping values between 0.5% and 30%
 - We will expand to 70% damping ratio
 - Fourier amplitude spectra (FAS) for frequencies from 0.1 to 100 Hz
 - Significant durations based on Arias Intensity

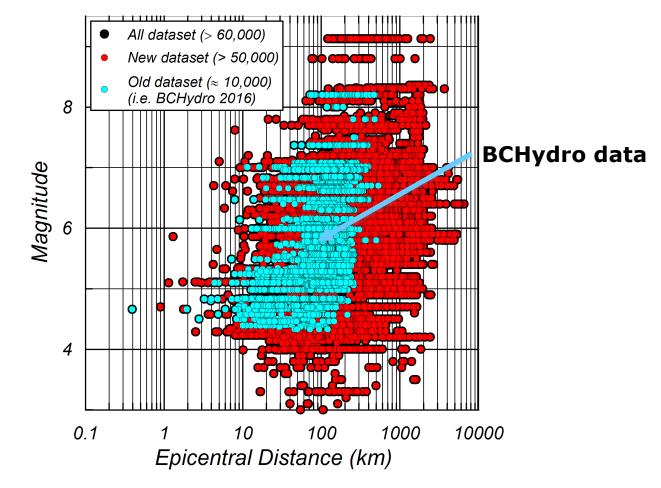


NGA-Sub database: Event distribution

- Database includes events and ground motions recorded since early 1970s to present, including recent significant earthquakes:
 - 2010 Maule, Chile (M8.8)
 - 2011 Tohoku, Japan (M9.1)
- Database includes more data than any previously compiled databases (e.g. BCHydro 2016)



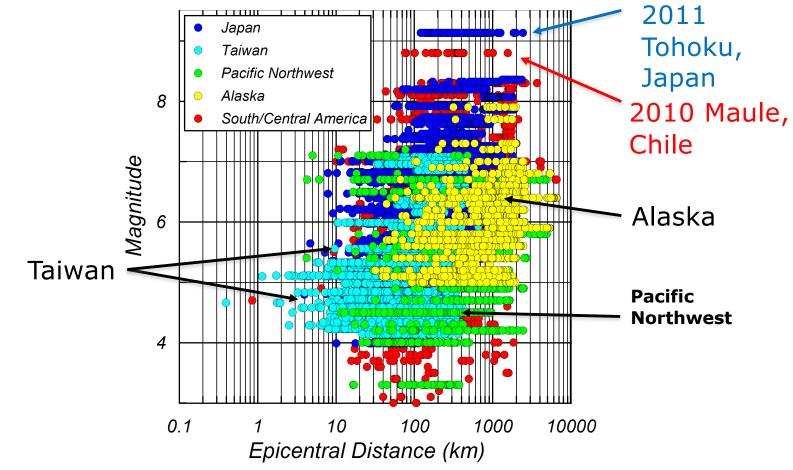
NGA-Sub database: M-R distribution





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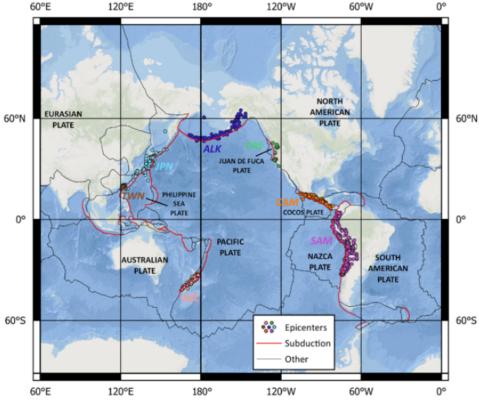
NGA-Sub database: M-R distribution



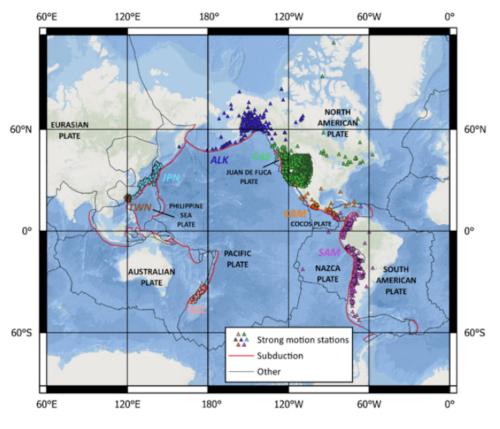


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Worldwide epicenters and recording stations



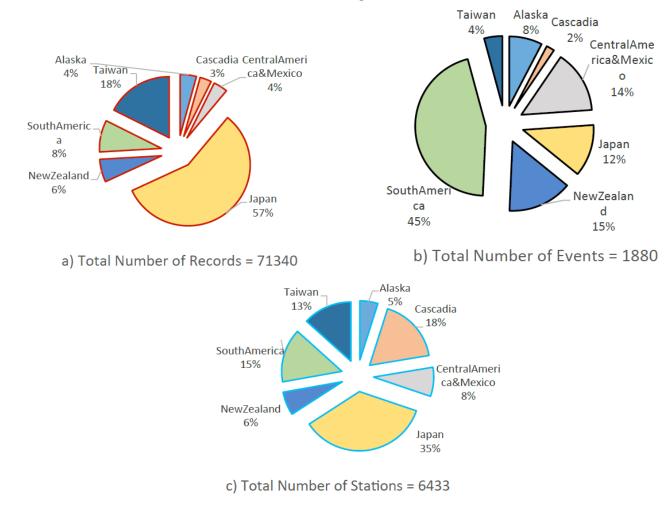
Epicenters



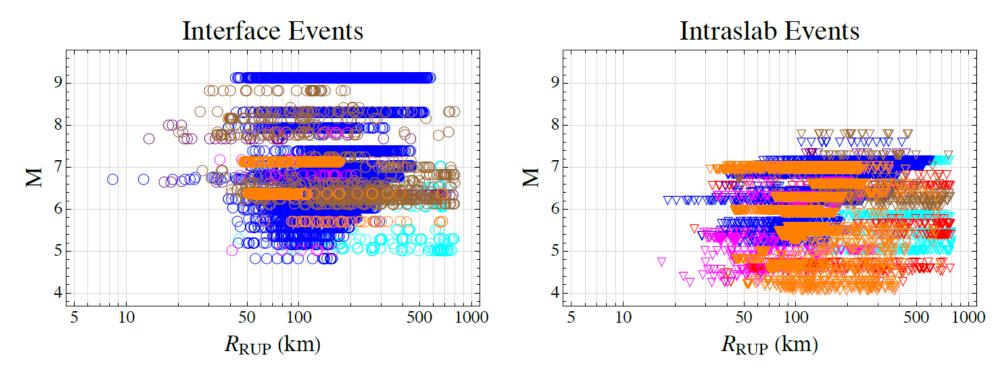
Stations



Distribution of records, events and stations



Modelers can select a subset of data for their analysis: An example of selected recordings





NGA-Sub: Relational database

Metadata:

- Source
- Site
- Path
- Event Class

Data:

- Peak GM values
- PSA
- Duration
- FAS

		NGAsubDb_RecordMapDb						
	¥ NGA	subRSN						
		baseRegion						
		subEQID						
		subSSN						
	Orig	inalFlatfile_RSN						
	Orig	inalFlatfile_RSNstring	DbData_EventClassData_E	an				
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			OriginalFlatfile_EQID					
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NGAsubDb_SourceDb	NGAsubDb_SiteDb	1	NGAsubDb_EventClassDb	NGAsubDb_TimeSeriesDb	NGAsubDb_DurationMetricsDb	-		V NGAsubRSN
% NGAsubEQID •	VIGAsubSSN	NGAsubRSN A	§ NGAsubEQID	🖇 NGAsubRSN 🔺	VGAsubRSN A	NGAsubRSN	VGAsubRSN A DatabaseRegion	DatabaseRe
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OriginalFlatfile_EQID •	Station_Name -		OriginalFlatfile_EQID	OriginalFlatfile_RSN	OriginalFlatfile_RSN	accFilePathH2	EQFolder	EQFolder
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YEAR	Station_Longitude_deg	Dip_ClosestSegment_deg Rake_ClosestSegment_deg	C1EQID_M1_Rcutoff10km	EQfolder	H1_End_Time_Opt1	FileH1Exists	File2	File2
MODY HRMN	Station_Elevation_m Sensor_Depth_m	EpiD_km	C1NGAsubEQID_M1_Rcutoff10km Rclosest_M1_Rcutoff10km	Filename_H1	H1_End_Time_Opt15 H1_End_Time_Opt2	FileH2Exists	DampingRatio	DampingRa
Earthquake_Magnitude	Geomatrix_Site_Code_1st_Letter	HypD_km	C1C2Class_M1_Rcutoff20km	Filename_H2	H1_End_Time_Opt25	FileVExists	SpectrumComponent	SpectrumCo
Hypocenter_Latitude_deg	OriginalFlatfile_Station_ID_No	Rjb_km	C1EQID_M1_Rcutoff20km	Filename_V accFilePathH1	H1_End_Time_Opt3	HeaderDataH1	PGA_g	PGA_g
Hypocenter_Longitude_deg	Vs30_Selected_for_Analysis_m_s	Rsei_km	C1NGAsubEQID_M1_Rcutoff20km	accFilePathH2	H1_End_Time_Opt35	HeaderDataH2	PGV_cm_sec	PGV_cm_sec
Hypocenter_Depth_km	Sigma_of_Vs30_Selected_for_Analy	ClstD_km	Rclosest_M1_Rcutoff20km	accFilePathV	H1_End_Time_Opt4	HeaderDataV	PGD_cm	PGD_cm
Strike_deg	NEHRP_Category_Based_on_Vs30	Rx_km	C1C2Class_M1_Rcutoff40km	Instrument_Type	H1_End_Time_Opt45	nptsH1	T0pt010S	T0pt010S
Dip_deg	Vs30_Measured_Inferred_Class	Ry_km	C1EQID_M1_Rcutoff40km	Instrument_Period_sec	H1_End_Time_Opt5	nptsH2	T0pt020S	T0pt020S
Rake_deg	Vs30_Code	Ry0_km	C1NGAsubEQID_M1_Rcutoff40km	Natural_Freq	H1_End_Time_Opt55	nptsV	T0pt022S	T0pt022S
Ztor_km	Measured_Vs30_m_s	Ztor_ClosestSegment_km	Rclosest_M1_Rcutoff40km	Accelerograph_Seismograg	H1_End_Time_Opt6	dtH1	T0pt025S	T0pt025S
Intra_Inter_Flag	Vs30_m_s_Boore_et_al_2011	U_km	C1C2Class_M1_Rcutoff80km	Instrument_Damping_Rati	H1_End_Time_Opt65	dtH2	T0pt029S	T0pt029S
Fault_Author	Vs30_m_s_Dai_et_al_2013	T_km	C1EQID_M1_Rcutoff80km	Number_of_Usable_Record	H1_End_Time_Opt7	dtV	T0pt030S	T0pt030S
Preferred_Fault_Plane	Vs30_m_s_Midorikawa_and_Nogi_2	LocalStrikeParallelDirection	C1NGAsubEQID_M1_Rcutoff80km	Average_H_V_for_PSA_H_V	H1_End_Time_0pt75	TimeSeriesMaxH1	T0pt032S	T0pt032S T0pt035S
Magnitude_Author	Vs30_m_s_Wang_and_Wang_2015	Rvol_km	Rclosest_M1_Rcutoff80km	Frequency_of_max_H_V_fo	H1_End_Time_Opt8	TimeSeriesMaxH2	T0pt0355	T0pt036S
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Number_of_Seismic_Moment	Vs30_from_fpeak_m_s_Hassani_anc	Seg1_Joyner_Boore_Dist_km	C1NGAsubEQID_M2_Rcutoff10km	Location	H1_End_Time_0pt95	SpectrumT0pt0105_rotD50 SpectrumT0pt0105_V	T0pt0425	T0pt044S
Number_of_Magnitude	Vs_Class	Seg1_Rsei_Dist_km	Rclosest_M2_Rcutoff10km	fcButterHP	H1_End_Time_1	SpectrumT0pt0105_rotD50/Tin		T0pt0455
Hypocenter_Author	Distance_to_PD8_Profile_m	Seg1_Rx Seg1_Ztor_km	FractC2WithinRmax_M2_Rcutoff10km	f_iniLP	H1_Duration_0pt05_0pt1	SpectrumT0pt0105_V/TimeSeri		T0pt046S
Finite_Fault_Model	Vsz_m_s Profile_depth_Zp_m	Seg2_ClstD_km	C1C2Class_M2_Rcutoff20km C1EQID_M2_Rcutoff20km	References	H1_Duration_0pt05_0pt15 H1_Duration_0pt05_0pt2	PGAcaseH	T0pt048S	T0pt048S
Multiple_Event	Travel_time_from_0_to_Zp	Seg2_Joyner_Boore_Dist_km	C1EQID_M2_Reutom20km C1NGAsubEQID_M2_Reutoff20km	SouthAmericaStationFlag	H1_Duration_0pt05_0pt2 H1_Duration_0pt05_0pt25	PGAcaseV	T0pt050S	TOpt0505
Number_of_Segment Length_km	Original_Reported_Vs30_m_s	Seg2_Rsei_Dist_km	Rclosest_M2_Rcutoff20km	H1_azimuth_angle H2_azimuth_angle	H1_Duration_0pt05_0pt3	PGAcaseFlagH	T0pt0555	T0pt0555
Width_km	Source_of_Vs_Profile	Seg2_Rx	FractC2WithinRmax_M2_Rcutoff20km	Unfiltered_PGA_H1_g	H1_Duration_0pt05_0pt35	PGAcaseFlagV	T0pt060S	T0pt060S
HypN	Inferred_Vs30_by_Elevation_m_s_O	Seg2_Ztor_km	C1C2Class_M2_Rcutoff40km	Unfiltered_PGA_H2_g	H1_Duration_0pt05_0pt4		T0pt065S	T0pt065S
HypE	Inferred_Vs30_by_Geomatrix_3rd_L	Seg3_CistD_km	C1EQID_M2_Rcutoff40km	Unfiltered_PGA_V_g	H1_Duration_0pt05_0pt45		T0pt067S	T0pt067S
Source_review_flag	Inferred_Vs30_by_Terrain_Categori	Seg3_Joyner_Boore_Dist_km	C1NGAsubEQID_M2_Rcutoff40km	fc.HP_H1	H1_Duration_0pt05_0pt5		T0pt070S	T0pt070S
Source_review_Comments	Inferred_Vs30_by_Terrain_Categori	Seg3_Rsei_Dist_km	Rclosest_M2_Rcutoff40km	fc_HP_H2	H1_Duration_0pt05_0pt55		T0pt075S	T0pt075S
Fault_Type	Terrain_Category_Mean_Vs30_m_s_	Seg3_Rx	FractC2WithinRmax_M2_Rcutoff40km	fc_HP_V	H1_Duration_0pt05_0pt6		T0pt080S	TOpt0805
Subduction_Zone_Name	Terrain_Category_Sigma_In_Vs30_Y	Seg3_Ztor_km	C1C2Class_M2_Rcutoff80km	fc_UP_H1	H1_Duration_0pt05_0pt65		T0pt085S	T0pt0855
Preferred_Fault_maximum_widtl	PNW_Terrain_Category_Mean_Vs30	Seg4_CistD_km	C1EQID_M2_Rcutoff80km	fc_LP_H2	H1_Duration_0pt05_0pt7		T0pt090S	T0pt090S T0pt095S
Alternate_Fault_maximum_widtl	PNW_Terrain_Category_Sigma_In_V	Seg4_Joyner_Boore_Dist_km	C1NGAsubEQID_M2_Rcutoff80km	fc_UP_V	H1_Duration_0pt05_0pt75		T0pt0955	T0pt0955 T0pt1005
Preferred_Saturation_Magnitud	Inferred_Vs30_from_Slope_m_m_Se	Seg4_Rsei_Dist_km	Rclosest_M2_Rcutoff80km	Month	H1_Duration_0pt05_0pt8		T0pt100S T0pt110S	T0pt100S
Alternate_Saturation_Magnitud	Inferred_Vs30_from_Slope_m_m_30	Seg4_Rx	FractC2WithinRmax_M2_Rcutoff80km	Day 👻	H1_Duration_0pt05_0pt85 v		idpt1105 ¥	Toperios
	Inferred_Vs30_from_Slope_m_m_W	Seg4_Ztor_km +						



NGA-Sub flatfile and time series

- All data have been stored & managed in a relational database
 - Relational database will improve update and expansion
 - Relational database can be queried by other databases, such as NGL (liquefaction)
- Time series of NGA-Sub:
 - About 500 time series were selected and released to the public



- Scope:
 - GMMs for horizontal components of ground motions
 - Vertical GMMs may be developed in 2020
 - 5%-damped PSA for T=0 to 10 sec
 - Interface: Magnitude range 5.0-9.5
 - Slab: Magnitude range 5.0-8.5
 - Rrup: 10 1000km
 - Ztor:
 - Interface: < 50 km
 - Slab: < 200 km
 - Vs30: 150-1500 m/sec



- There are "Global" and Regionalized models
 - Two global and regionalized models are final and reports are being published
 - Kuehn-Bozorgnia-Campbell-Gregor
 - Parker-Stewart-Boore-Atkinson-Hassani
 - One more global and regionalized model is being finalized
 - Abrahamson-Gulerce
- Two Japan-specific models are final and reports are being drafted
 - Si-Midorikawa-Kishida
 - Youngs-Chiou-AlAtik



- Seven regions are considered
 - Alaska (AK)
 - Central America and Mexico (CAM)
 - Cascadia (CASC)
 - Japan (JP)
 - New Zealand (NZ)
 - South America (SA)
 - Taiwan (TW)



- Heavy focus on regionalization (or lack of regionalization) on terms, including:
 - Vs30 scaling
 - Anelastic attenuation
 - Regional effects of amplification (constant term)
 - Regionalized magnitude scaling for slab & interface events (some models)



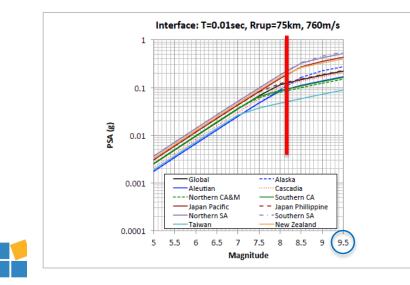
<u>General</u> characteristics of GMMs (besides regionalization)

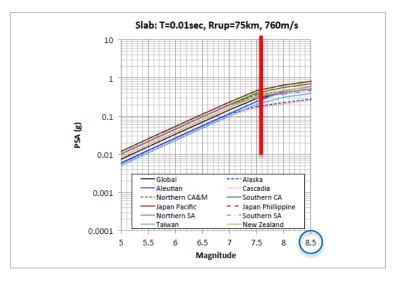
- Interface and slab geometrical spreadings are different
- Interface and slab anelastic attenuation is the same
- Interface and slab magnitude scaling below the break point are different
- Slope of mag scaling beyond break point is the same for slab and interface
- Some models: Forearc-backarc are for Japan, Central and South America
- Some models: Basin effects are for: Japan, Cascadia (Z2.5); Taiwan and NZ (Z1.0)



Break in magnitude scaling

- Investigation by UC Santa Barbara researchers for "Slab" events:
 - Break point in magnitude scaling for in-slab events is a function of the slab thickness. This feature is being incorporated into ground motion models
- Campbell generalized it for Interface events





Example of Break in magnitude scaling for In-Slab events

	Subduction Zone	Saturation Magnitude	Fault Maximum Width
	Aleutian	7.95	53
_	Alaska	7.2	22.5
	Cascadia	7.2	22
	Central America South	7.6	36
	Central America North	7.4	28
	Japan Pacific	7.65	38.5
	Japan Philippines	7.55	36
	New Zealand North	7.6	37.5
	New Zealand South	7.4	30.5
	South America North	7.3	25
_	South America South	7.25	24
L	Taiwan	7.7	42

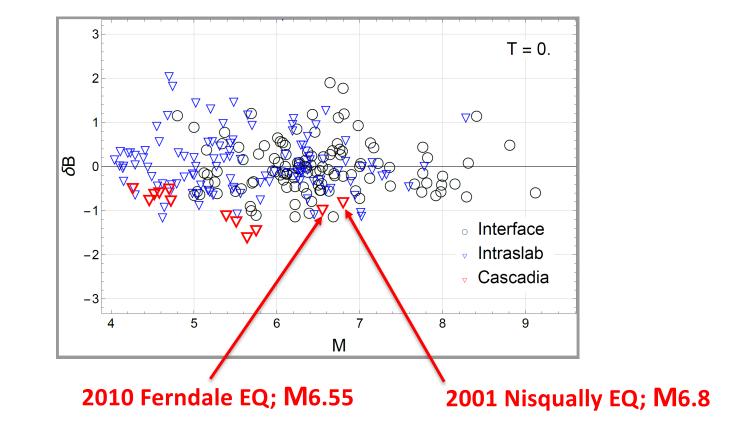


NGA-Sub Ground Motion Models: Cascadia

- Special attention on Cascadia:
 - No <u>recorded</u> large magnitude interface event in the region
 - Few in-slab events. Most of them have lower motions than global model
 - Thus, if you do "purely statistical" analysis of small magnitude in-slab events, you get much lower prediction of motion in Cascadia
 - NGA-Sub did major, multiple, internal discussions on modeling for Cascadia

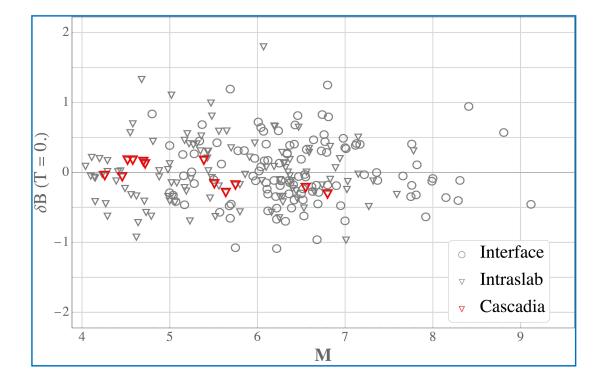


Cascadia events before regionalization





Cascadia events after regionalization





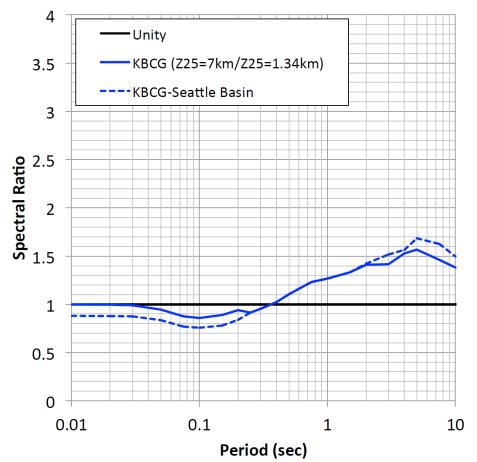
Assumptions for Cascadia GMMs

- Slab: Model constant is calculated from two largest all events (Nisqually and Ferndale). This leads to a somewhat increase in prediction compared to all Cascadia events
- Interface: No recorded interface events. Interface constant is determined by correlation between interface and slab constants globally
- Slab and Interface: Anelastic attenuation and Vs30-scaling for Cascadia are the same for interface and intraslab, and are determined from all events in Cascadia



Basin effects in Seattle: An example (KBCG model)

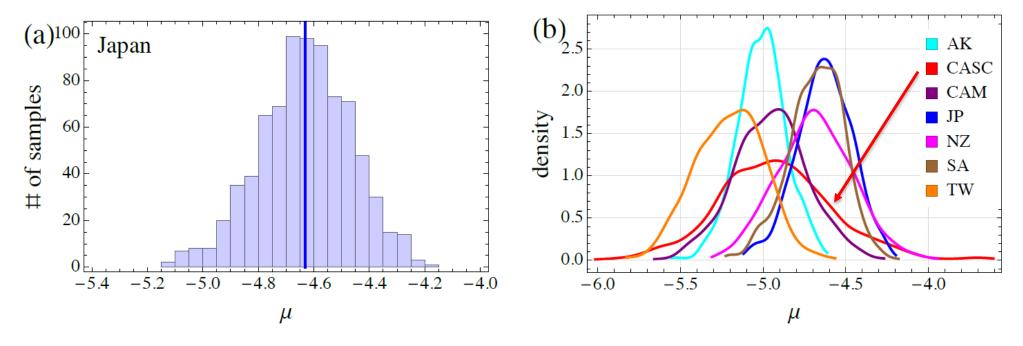
Interface Cascadia: M8, Rrup=100km, Vs30=400m/s, Z25=7km





Possible In-Model Epistemic Uncertainty

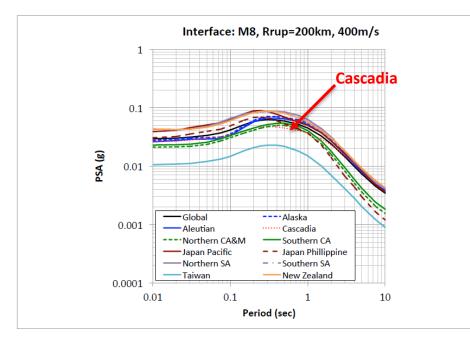
Epistemic uncertainty of median prediction

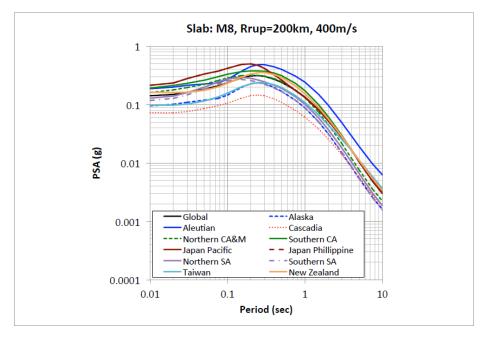


Example: M = 6, Rrup = 100 km, Vs30 = 400, ZTOR = 10 km, Interface and Forearc



Example results







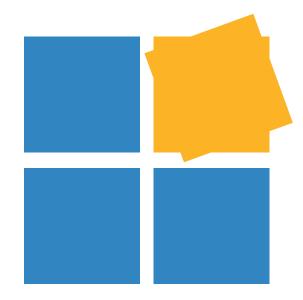
Summary and NGA-Sub status

- Two global and regionalized models are final
 - They include basin effects
 - They include Cascadia and Alaska as regions
 - Reports to be published in February 2020
- One more global and regionalized model is being finalized
- Two Japan-specific GMMs are being finalized and documented
- Two other reports will be published in Feb 2020:
 - Database report
 - Comparisons of NGA-Sub GMMs and existing models
- Journal publications will follow the reports, to be submitted in 2020
- Damping scaling for NGA-Sub is being developed (Rezaeian, et al)
- Duration model for subduction is being developed (Walling-Kuehn-Abrahamson)
- CAV models are being developed (Macedo-Abrahamson, Campbell-Bozorgnia,...)
- Vertical GMMs for NGA-Sub may be developed in 2020 (depends on the funding)



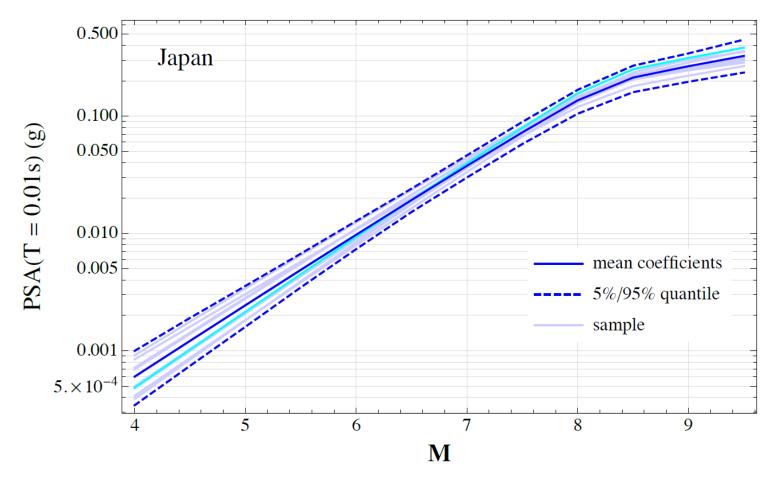
The B. John Garrick Institute for the Risk Sciences





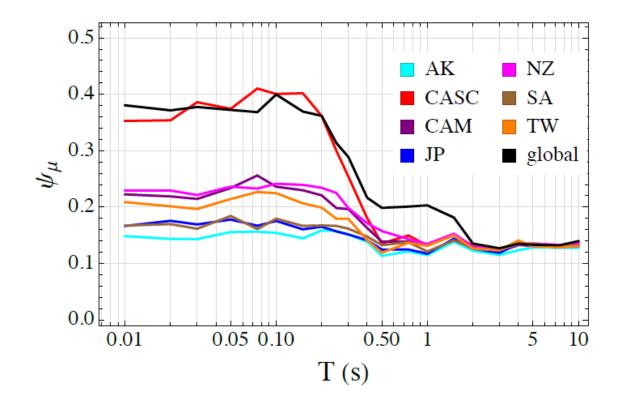
Thank You

Example of epistemic uncertainty for magnitude scaling (Japan, Interface)





Standard deviation of median prediction (epistemic) for each region (M = 6, RRUP = 100 km, VS30 = 400, ZTOR = 10 km, Interface and Forearc)





Attenuation of Interface and slab events

