A new ground motion prediction equation (attenuation relation) for Japan based on the 2011 Tohoku-oki earthquake records

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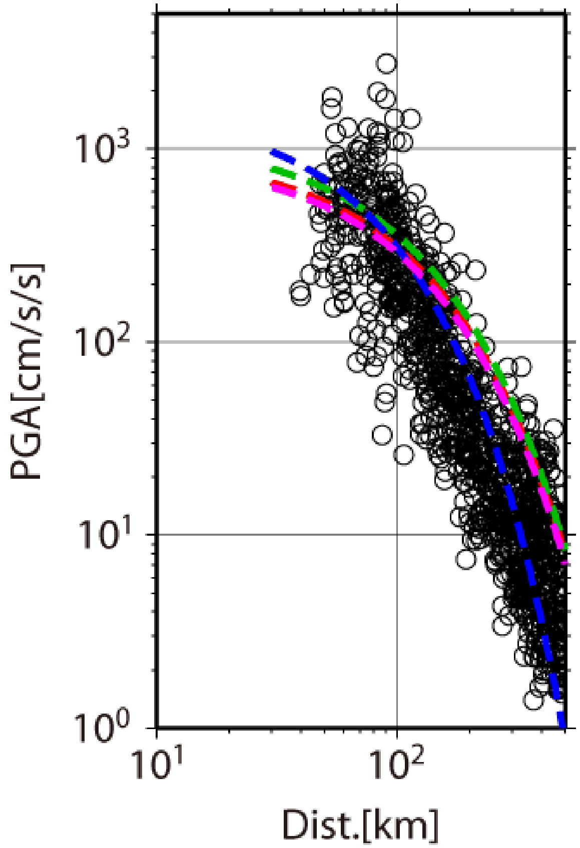
Background

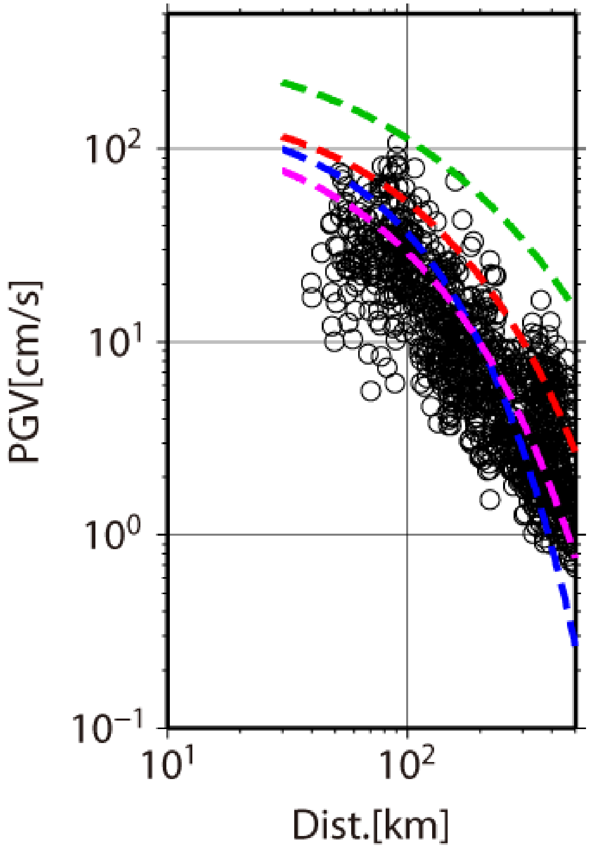
- We have constructed a database of strong-motion records and have obtained a new attenuation relation. (Kanno et al., 2006; BSSA)
- The Tohoku-oki mega-earthquake (Mw=9.0) on March 11, 2011, is the largest event which many strong-motion records were obtained. (over 2,000 records in Japan)
- We must consider Mw9-class mega-earthquakes (e.g. Nankai trough earthquake) in our seismic hazard assessment.

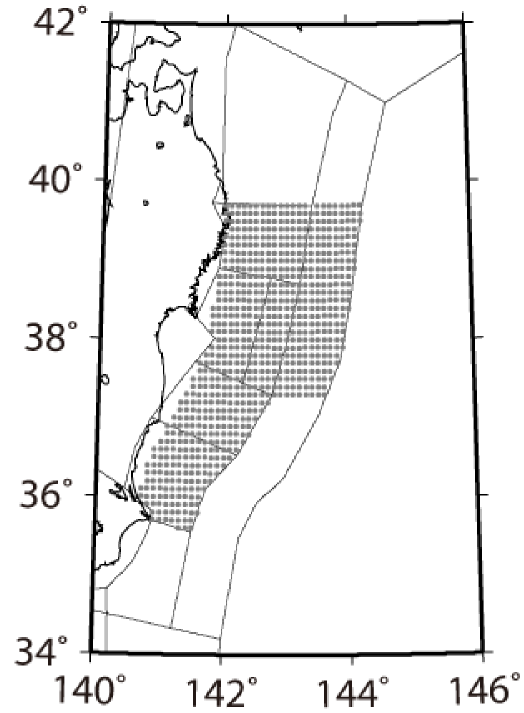
⇩

A new attenuation relation directly applicable up to Mw=9 earthquakes is required for the "Next Generation National Seismic Hazard Maps for Japan".

Strong-Motion Data during the M9 Earthquake vs Existing Japanese Attenuation Relations







Assumed source fault based on HERP (2011)

○ **Observed (on the ground)**

- - - - - **Si & Midorikawa (1999): fop inter-plate earthquakes**

- - - - - **Kataoka et al. (2006): for subduction-zone earthquakes**

- - - - - **Kanno et al. (2006): for shallow (<30km) earthquakes**

- - - - - **Satoh (2010): for inter-plate earthquakes (Pacific plate)**

Strong-Motion Data

- **Update the strong-motion database of Kanno et al. (2006) by adding recent (after the 2003 Tokachi-oki EQ) records.**
  - **Up to end of 2009 and the 2011 Tohoku-oki main shock**
  - **NIED (K-NET and KiK-net), JMA, PARI**

- **Target strong-motion parameters:**
  - **JMA seismic intensity (I)**
  - **Peak ground acceleration (PGA)**
  - **Peak ground velocity (PGV)**
  - **5% damped acceleration response spectra (SA; 0.05-10s)**

- **Data used in the regression analysis**
  - **Earthquake: *Mw*>=5.5 & number of records>=5**
  - **Station: X<=200 km & installed on the ground surface**

    ***X*: closest distance to the source fault**

Modeling

- **The main part follows to that in Kanno et al. (2006)**
- **We use only two parameters, moment magnitude (Mw) and closest distance to source fault (X) in "base model".**
- **We apply "additional correction terms" in order to express other phenomena such site amplification and so on.**

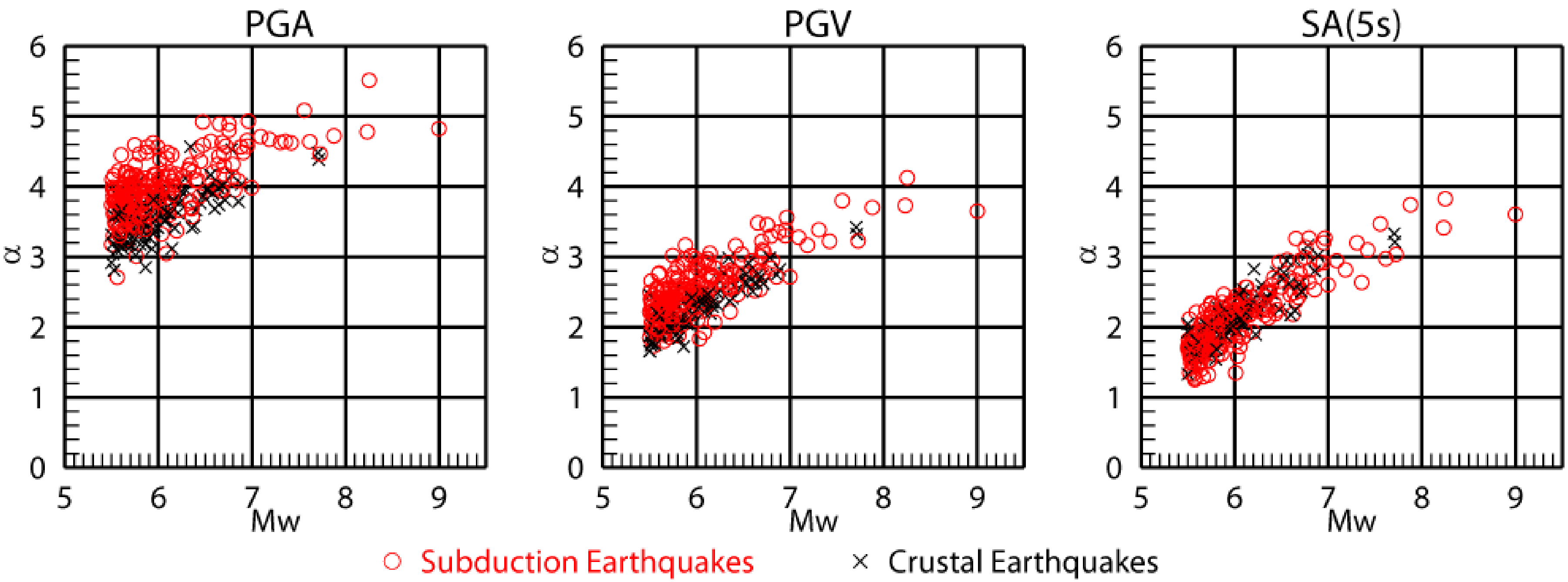
- **We obtain regression coefficients for individual earthquake category (subduction-zone earthquakes and shallow crustal earthquakes).**

- **We exclude the focal-depth dependency from the "base model".**
- **We think that the difference of attenuation term can be expressed by using the earthquake category instead of the focal depth.**

Modeling of Magnitude Term

$$\log A = \sum_i \alpha_i + b \cdot X - \log(X)$$

α_i can be determined for each earthquake



“α_i” saturates at Mw=8 or more

Modeling of Magnitude Term

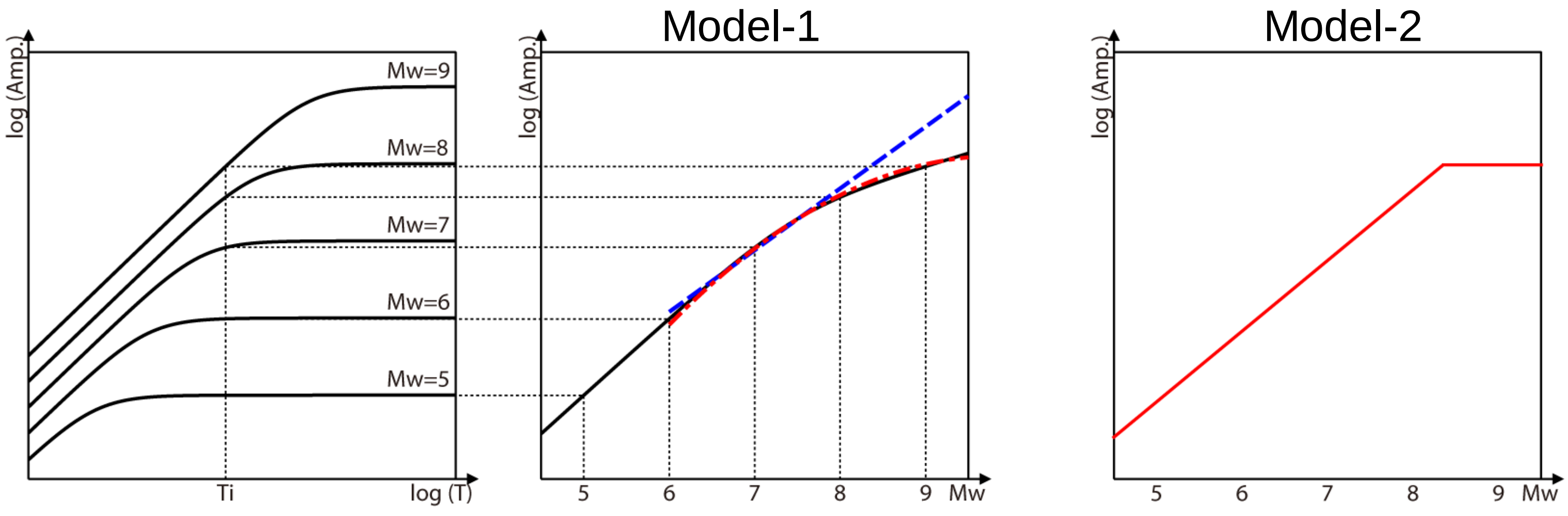
Model-1

Amplitude saturation is approximated by using Mw^2 term

(based on Fukushima, 1996)

Model-2

Amplitudes are completely saturated at $Mw >= Mw_0$



※ This figure is based on Fukushima (1996)

Base Model

Model-1

$$\log A = a_1^{k}(Mw - Mw_{01})^2 + b_1^{k}X - \log(X + d_1 10^{e_1 \cdot Mw}) + c_1^{k}$$

Model-2

$$\log A = a_2^{k}Mw_{02} + b_2^{k}X - \log(X + d_2 \cdot 10^{e_2 Mw_{02}}) + c_2^{k}$$

$$Mw_{02} = \min(Mw, Mw_0)$$

"k" is for subduction-zone or shallow crustal earthquakes

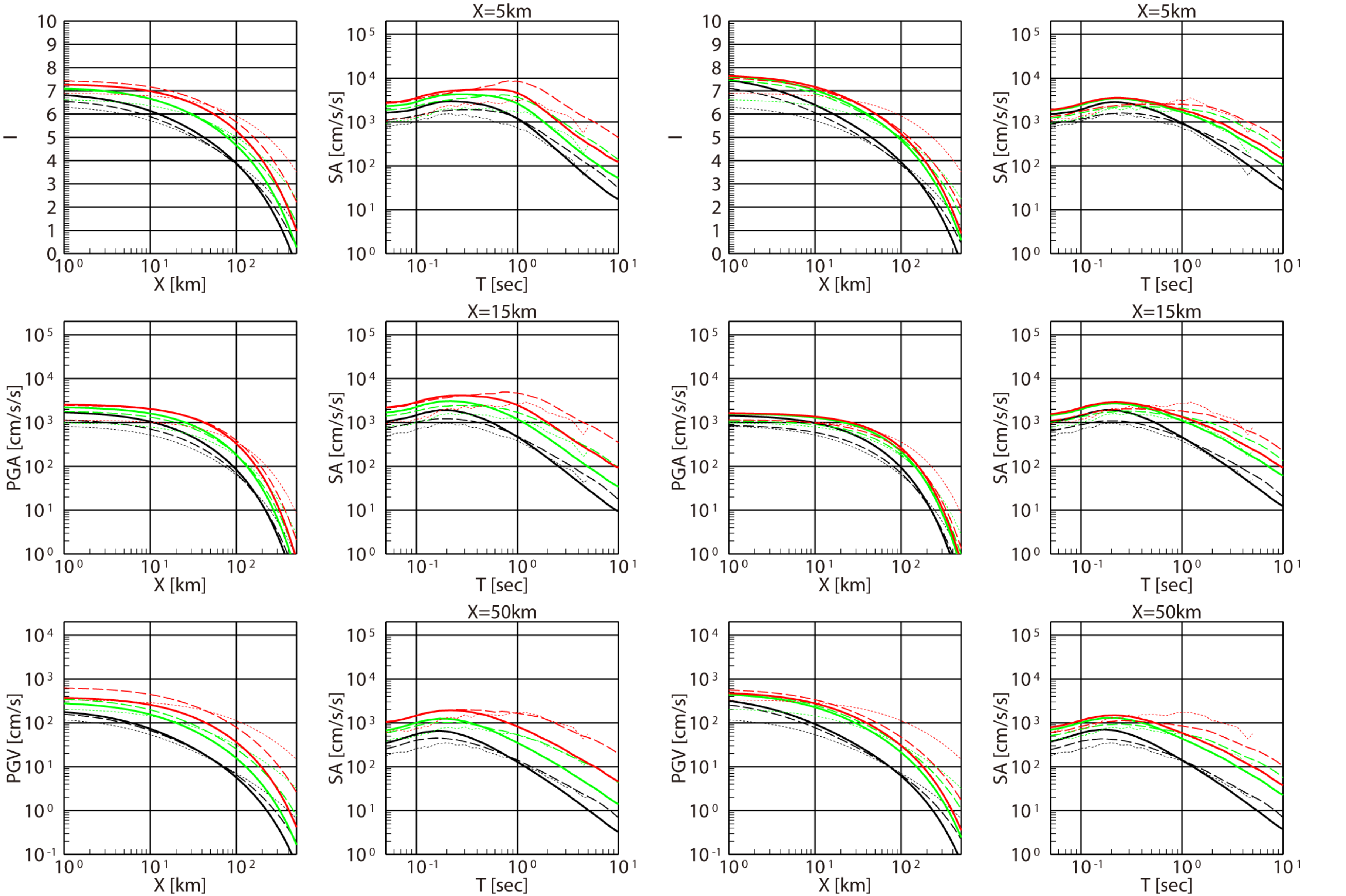
- **Mw_0 & e are assumed to be independent of the period and earthquake category**
- **By trial and error approach, the following parameters fixed as**

$$Mw_{01} = 16.0,\ e_1 = 0.3, \qquad Mw_{02} = 8.3,\ e_2 = 0.5$$

Obtained Base Model

Model-1

Model-2

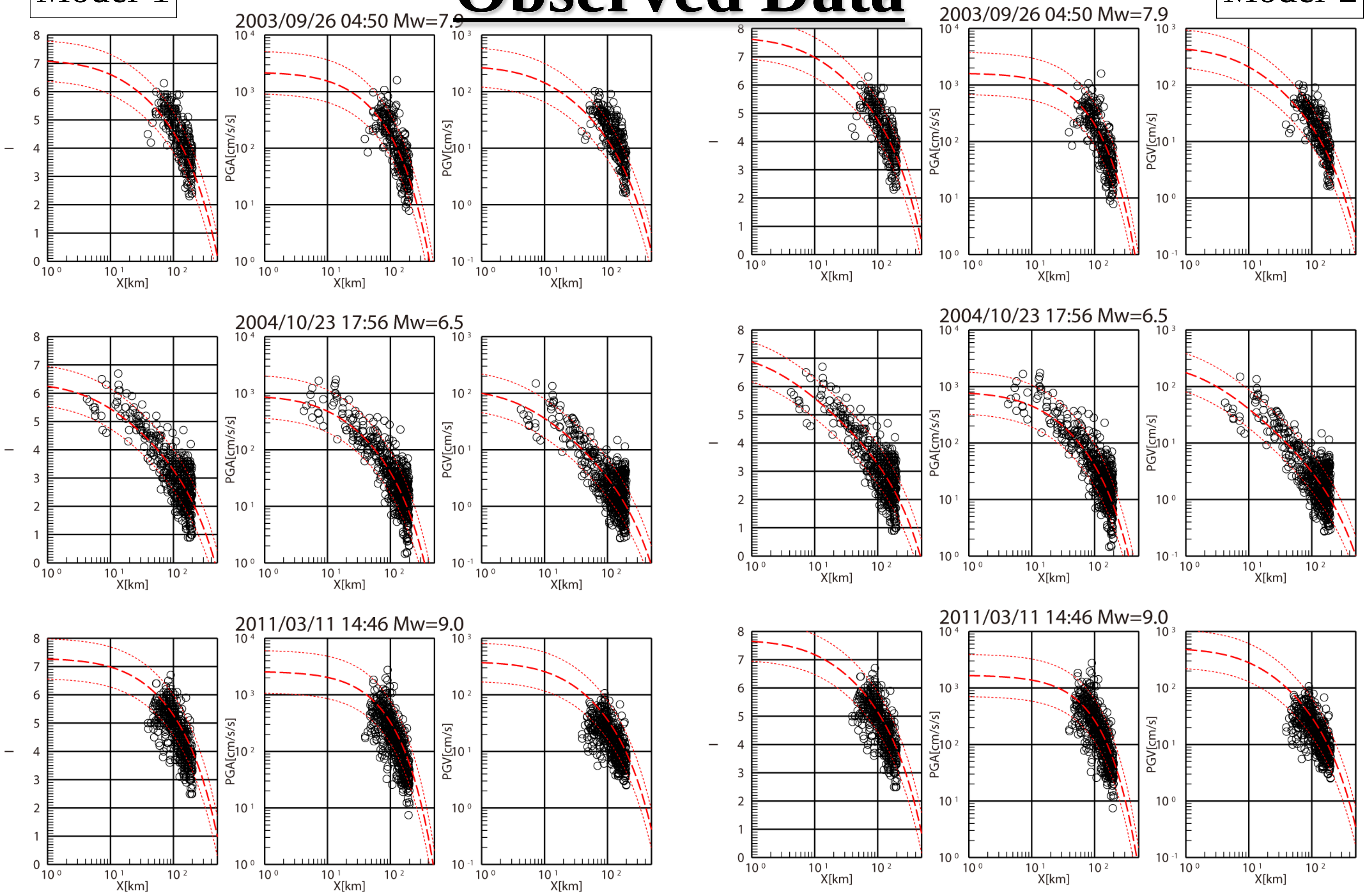


Mw=9.0, Mw=8.0, Mw=7.0 , solid: subduction, dashed: crustal, thin: Kanno et al. (2006)

Comparison of Base Model with Observed Data

Model-1

Model-2



Additional Correction Term-1

-Amplification by deep sedimentary layers-

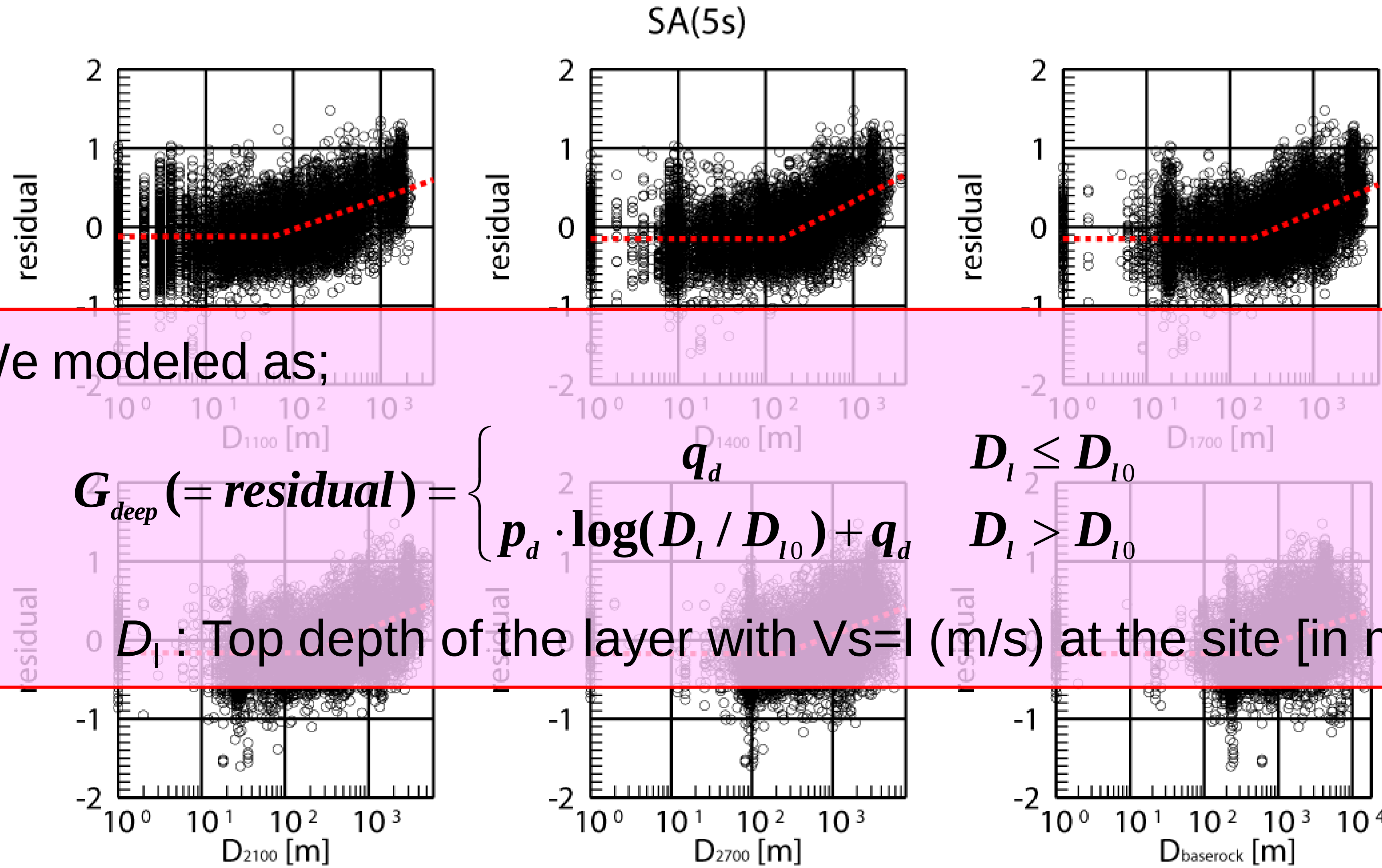
In order to model amplification characteristics by deep sedimentary layers, we examine the relation between *residual* (=log [obs/pre]) and top depth of the layer with Vs=l at observation site (D_l) obtained from the "underground structure model of deep sedimentary layers for whole Japan".

- **"pre" is calculated from "base model".**

- **The structure model consists of 6 major layers on the seismic bedrock whose Vs = 3100 m/s or more.**

  1st layer: Vs = 600 m/s (engineering bedrock)
  2nd layer: Vs = 1100 m/s
  3rd layer: Vs = 1400 m/s
  4th layer: Vs = 1700 m/s
  5th layer: Vs = 2100 m/s
  6th layer: Vs = 2700 m/s

Additional Correction Term-1
-Amplification by deep sedimentary layers-

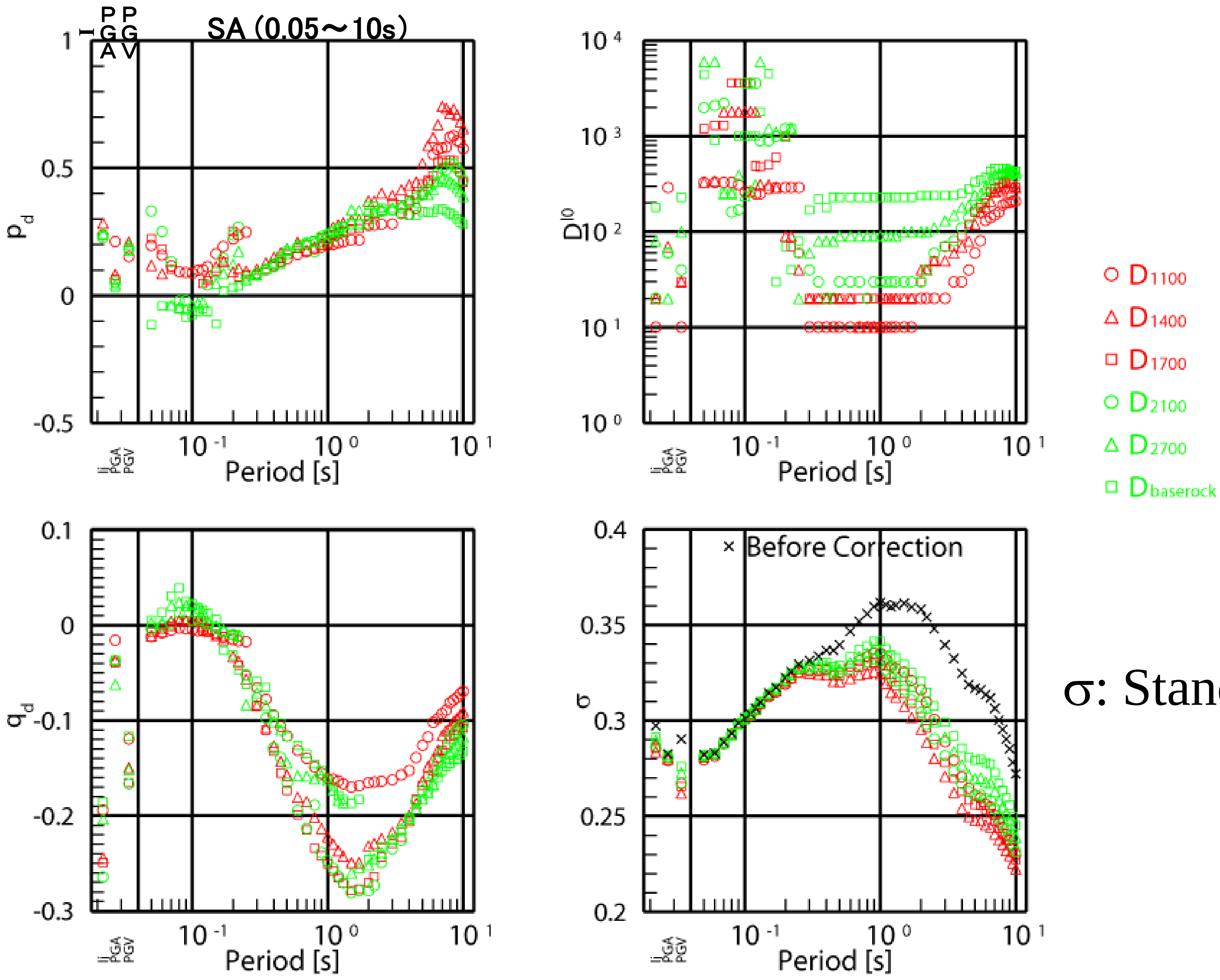


We modeled as;

$$G_{deep}(=residual) = \begin{cases} q_d & D_l \le D_{l0} \\ p_d \cdot \log(D_l / D_{l0}) + q_d & D_l > D_{l0} \end{cases}$$

D_l : Top depth of the layer with Vs=l (m/s) at the site [in m]

Additional Correction Term-1
-Amplification by deep sedimentary layers-

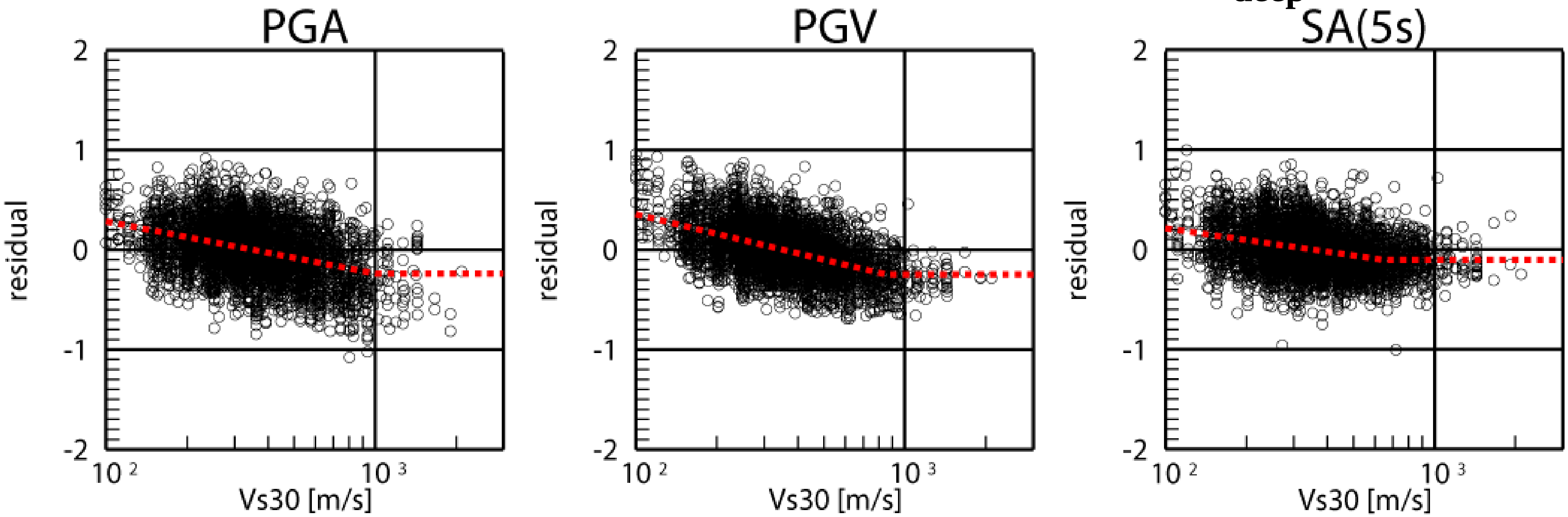


σ: Standard deviation

Additional Correction Term-2
-Amplification by shallow soft soils-

Relation between *residual* (=log [obs/pre]) and average S-wave velocity up to 30m depth at observation site (*Vs*30 in m/s)

•"pre" is calculated from "base model + G_{deep}"

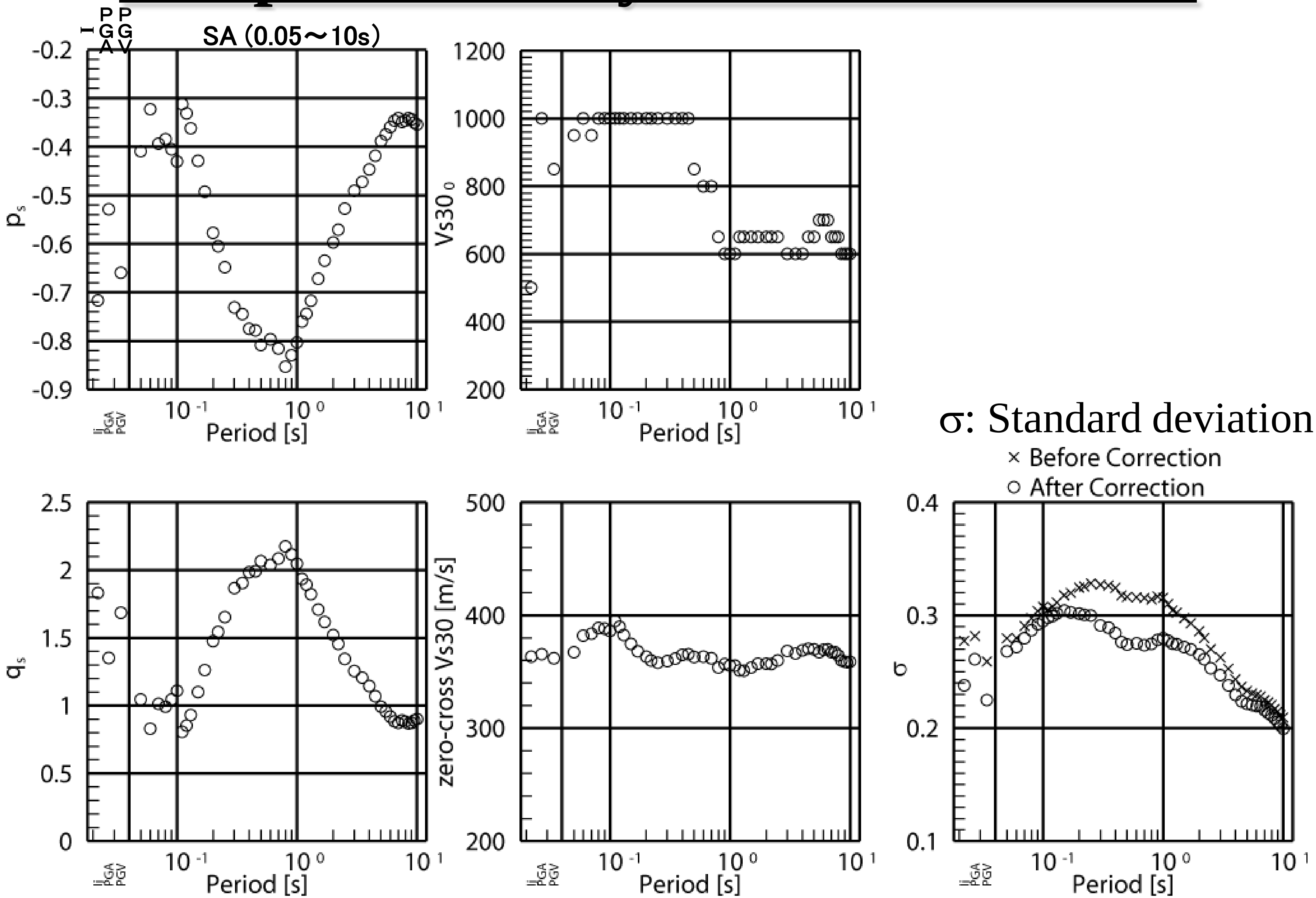


We modeled as;

$$G_{shallow}(= residual) = \begin{cases} p_s \cdot \log Vs30 + q_s & Vs30 \le Vs30_0 \\ p_s \cdot \log Vs30_0 + q_s & Vs30 > Vs30_0 \end{cases}$$

Additional Correction Term-2

-Amplification by shallow soft soils-



Conclusions

- **We suggest a new attenuation relation (ground motion prediction equation) for Japan directly applicable up to Mw=9 by using the strong-motion records of the 2011 Tohoku-oki mega-earthquake.**

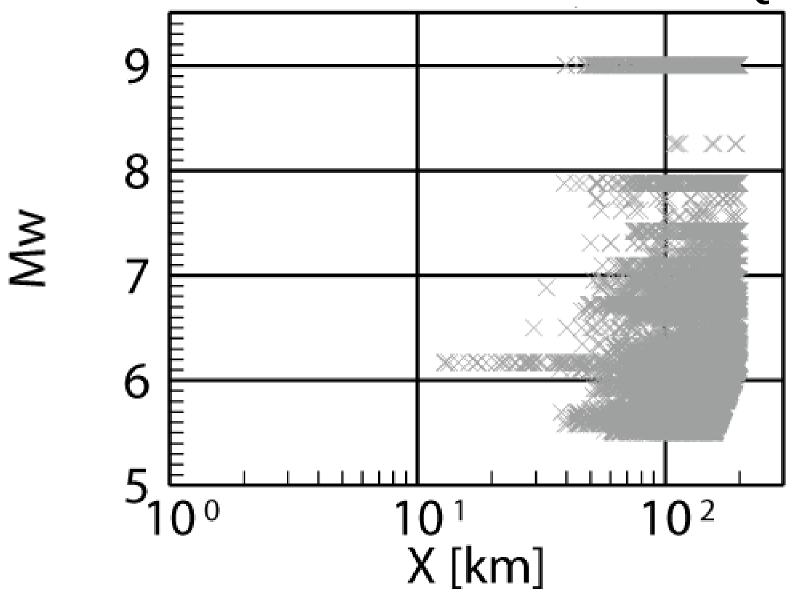
- **We examine two different base models to express amplitude saturation at large magnitude, but we cannot decide which model is better yet.**

- **We also suggest additional terms corresponding to site amplification that can be correct not only shallow soft soils but also deep sedimentary layers.**

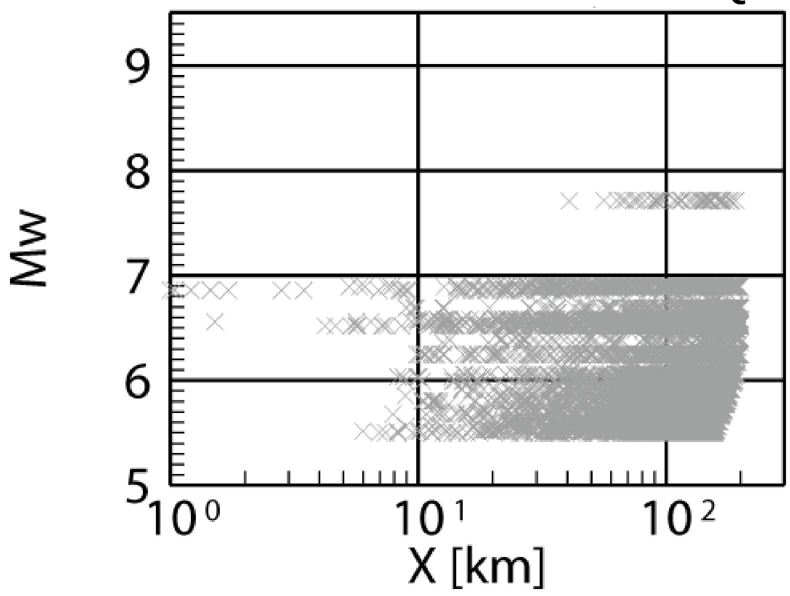
Further Problems

- ✓ **Our new model cannot be constrained at near source region for large earthquakes (X<40km & Mw>7) because there is no strong-motion records in this regression analysis.**

PGA Subduction-zone EQs



PGA Shallow Crustal EQs



- ✓ **We should add many strong-motion records of after-shocks of the Tohoku-oki earthquakes.**

Thank you for your attention !