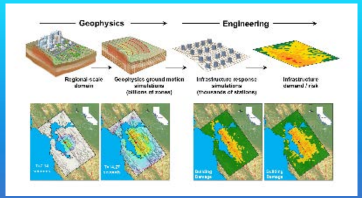

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A New Approach for Broadband Site Amplification Prediction Based on the Mapping Function from Theory to Observation

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Outline of the presentation

- We first derived site amplification factors (SAFs) from the data of the Japanese nationwide networks by using the so-called generalized spectral inversion technique (GIT, Nakano et al., BSSA 2015; JJAEE, 2019).
- We can use these SAFs for strong motion prediction at these observation sites, however, we need at least observed weak motion or microtremor data.
- We tested the capability of the current velocity models in Japan whether they can reproduce or not the observed SAFs by the 1D theoretical transfer functions (TTF).
- We found that the calculated TTFs show more or less acceptable fit to the observed SAFs at ½ sites, however, they tend to underestimate the observed SAFs in general.
- Therefore, we propose a simple, empirical method to fill the gap between the observed SAFs and the calculated TTFs.

How did we perform the Generalized Spectral Inversion (Nakano et al., 2015) to get HSAF?

$$\underbrace{\log S_i}_{\text{Source term}} \quad \underbrace{- n_{l(i)} \log X_{ij} + \sum b_{l(i)k} X_{ijk}}_{\text{Path term}} \quad \underbrace{+ \log G_j}_{\text{Site term=SAF}}$$

$$\log F_{ij} = \log S_i - n_{l(i)} \log X_{ij} + \sum b_{l(i)k} X_{ijk} + \log G_j$$

F_{ij} Fourier spectra for earthquake *i* at site *j*

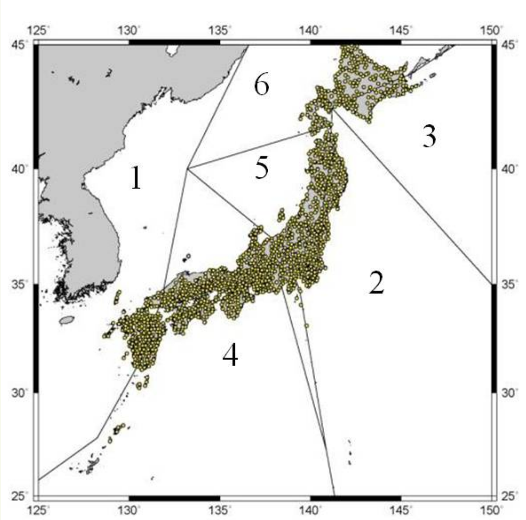
S_i source factor

G_j site amplification factor

X_{ij} hypocenter distance; X_{ijk} hypocenter distance in the region *k*

n geometrical spreading factor for earthquake of type *l*, *l*=1 to 3

b intrinsic and scattering attenuation in the region *k*, *k*=1 to 6



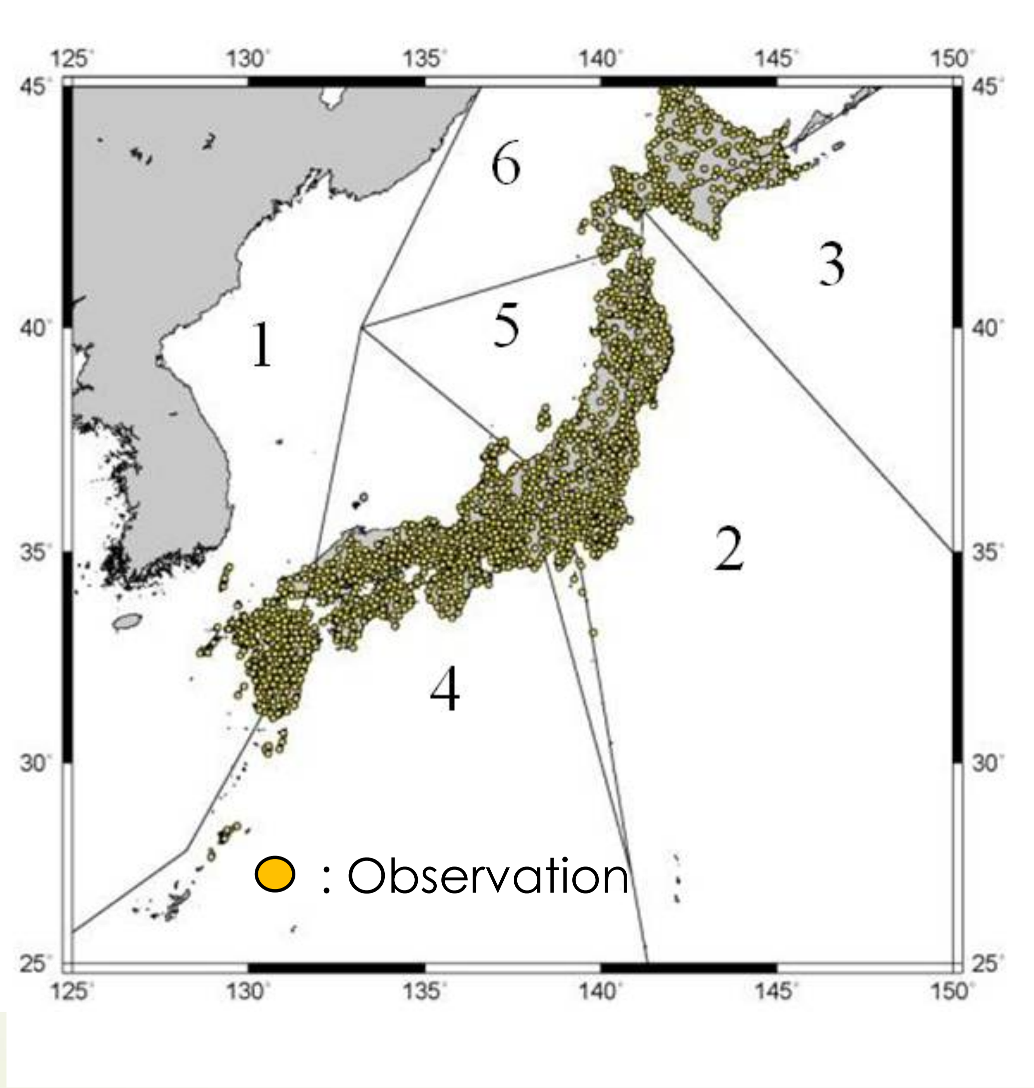
Reference YMGH01 after extraction of site effect

Fourier spectrum 0.12Hz～20Hz, RMS values of NS and EW comp and UD comp.

Duration 5 s (M<6) to 15 s (M>7) from the onset of S-wave.

See Nakano et al. (BSSA 2015) for details.

Strong motion dataset for GIT is expanded. We use 6 regions for different attenuations.



Period: 1987～2016

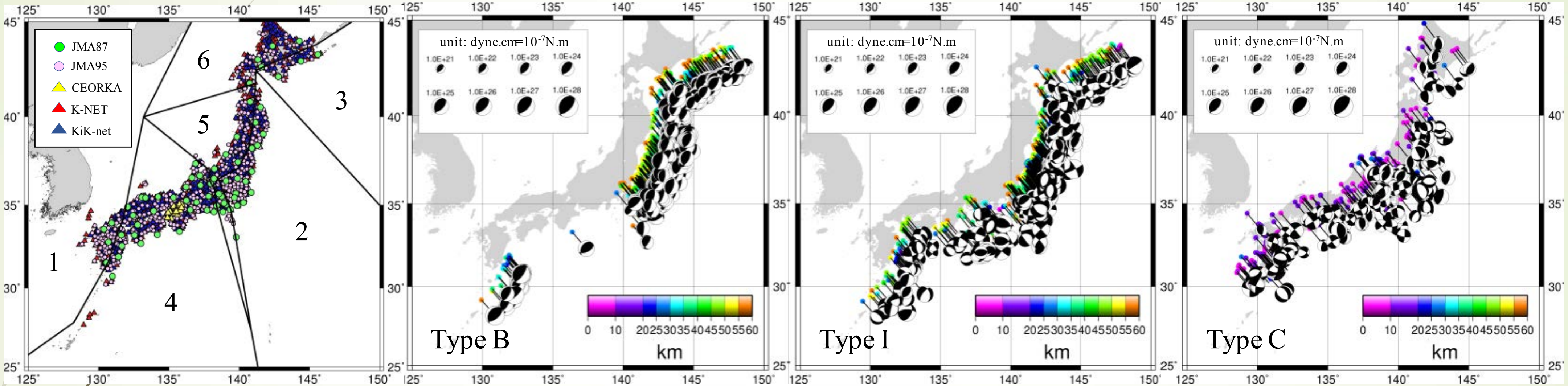
Condition:

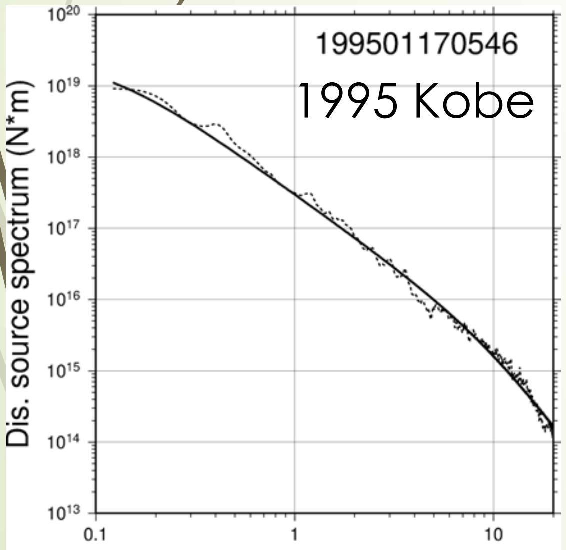
- $M_{jma} \geqq 4.5$
- Source distance ≦ 200km
- Focal depth ≦ 60km
- Observation point ≧ 3

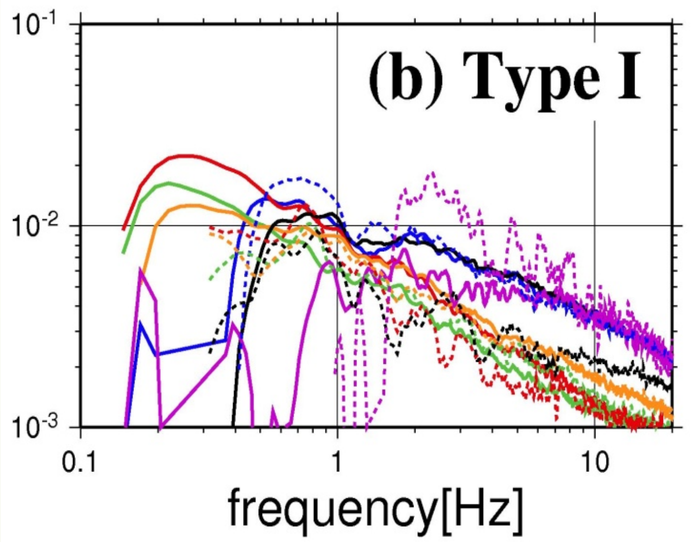
Recording organization:

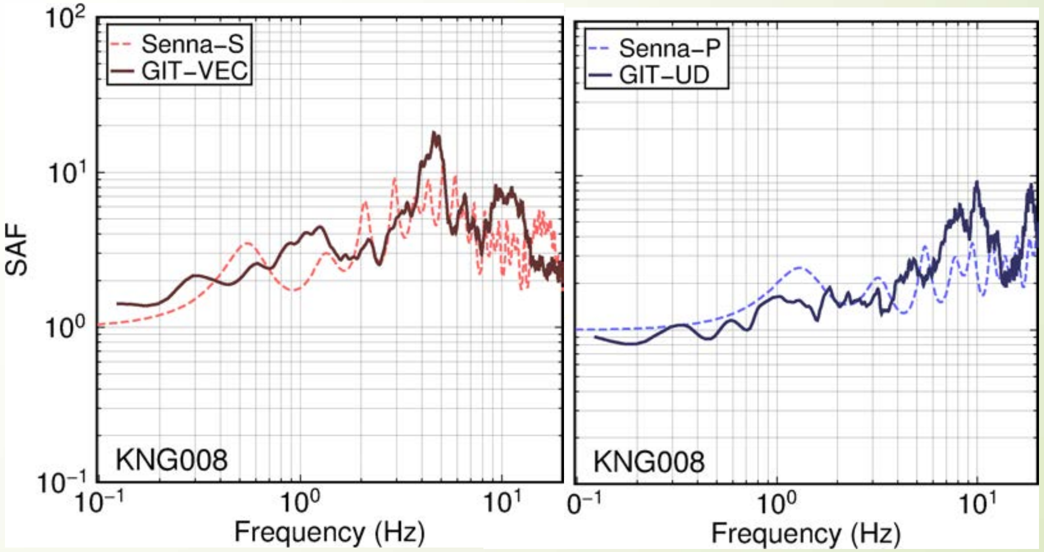
K-NET(1,135), KiK-net(696), JMA95(648), JMA87(78), CEORKA(36)
Total No. of sites: 2,593
No. of EQs: 1,734 events
EQ-Site pairs: 150,468
(No. of waveforms: x3)

The results of source, path, and site look nice. ➔We have a good separation of 3 factors.

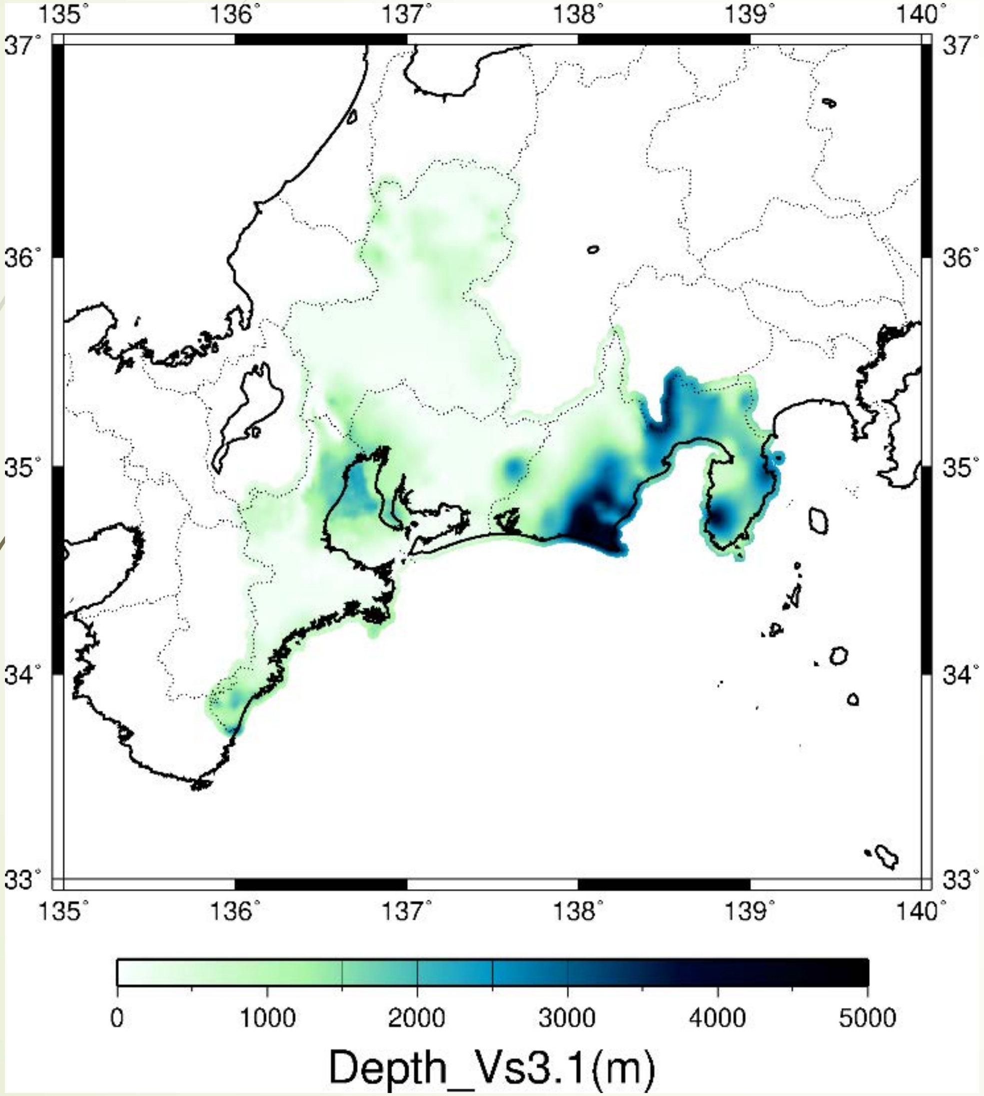


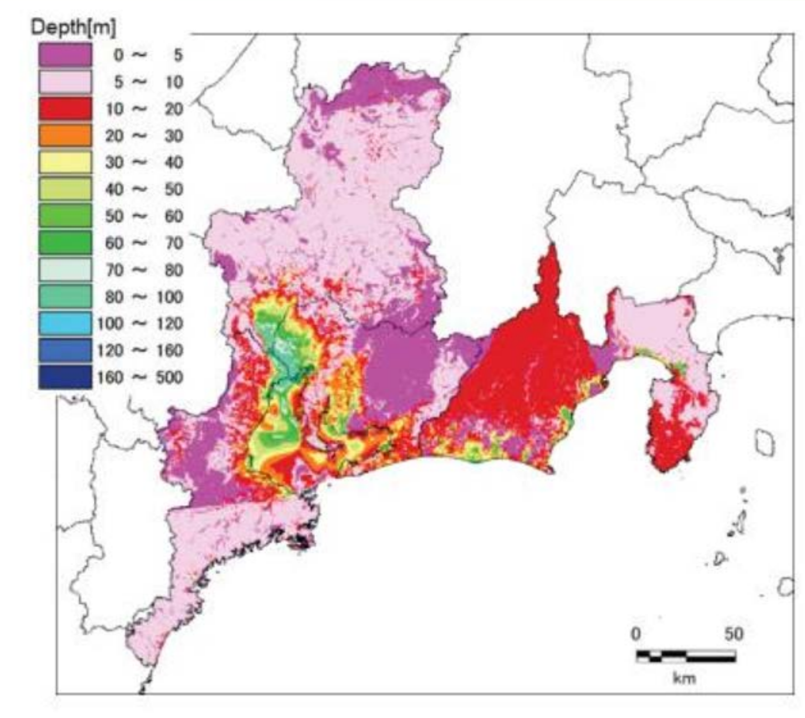






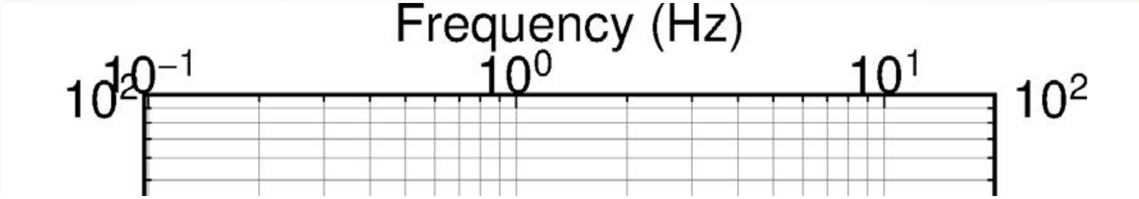
Unified deep and shallow velocity structure (Senna et al., JDR 2014; Wakana et al. JDR, 2019)



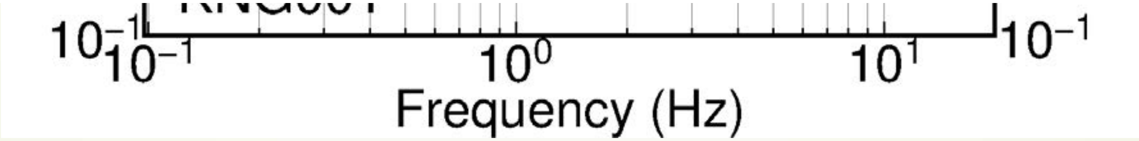


Depth_Vs350 (m)

Horizontal Site Amplification Factors by GIT and 1D S-wave Theory (Senna et al., 2014, 2019)



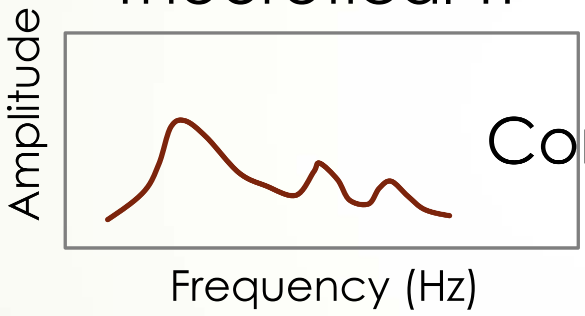
1) About 1/3 of the sites show very good matching.
2) The rest of sites show smaller theoretical prediction than the observed HSAF.
3) The observed HSAF is much smoother than the theoretical HSAF after the fundamental peak frequency.



Step1: At 546 stations in Kanto and Tokai, we obtain Frequency and Amplitude Modification Ratio (FMR & AMR)

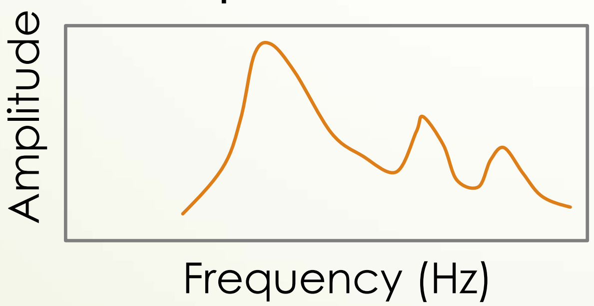
Unified structure (Senna et al., 2019)

Theoretical TF



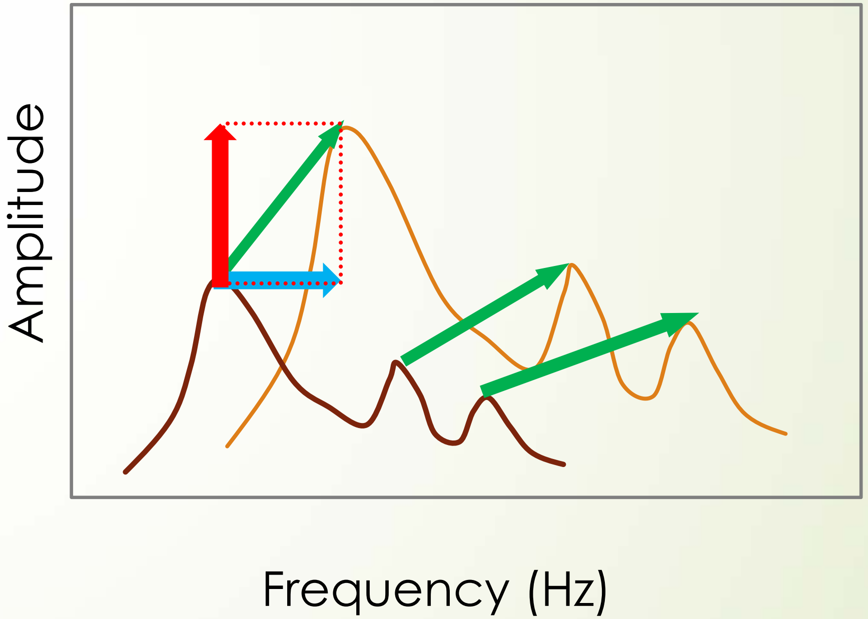
GIT site factor (Nakano et al. 2019)

Empirical SAF



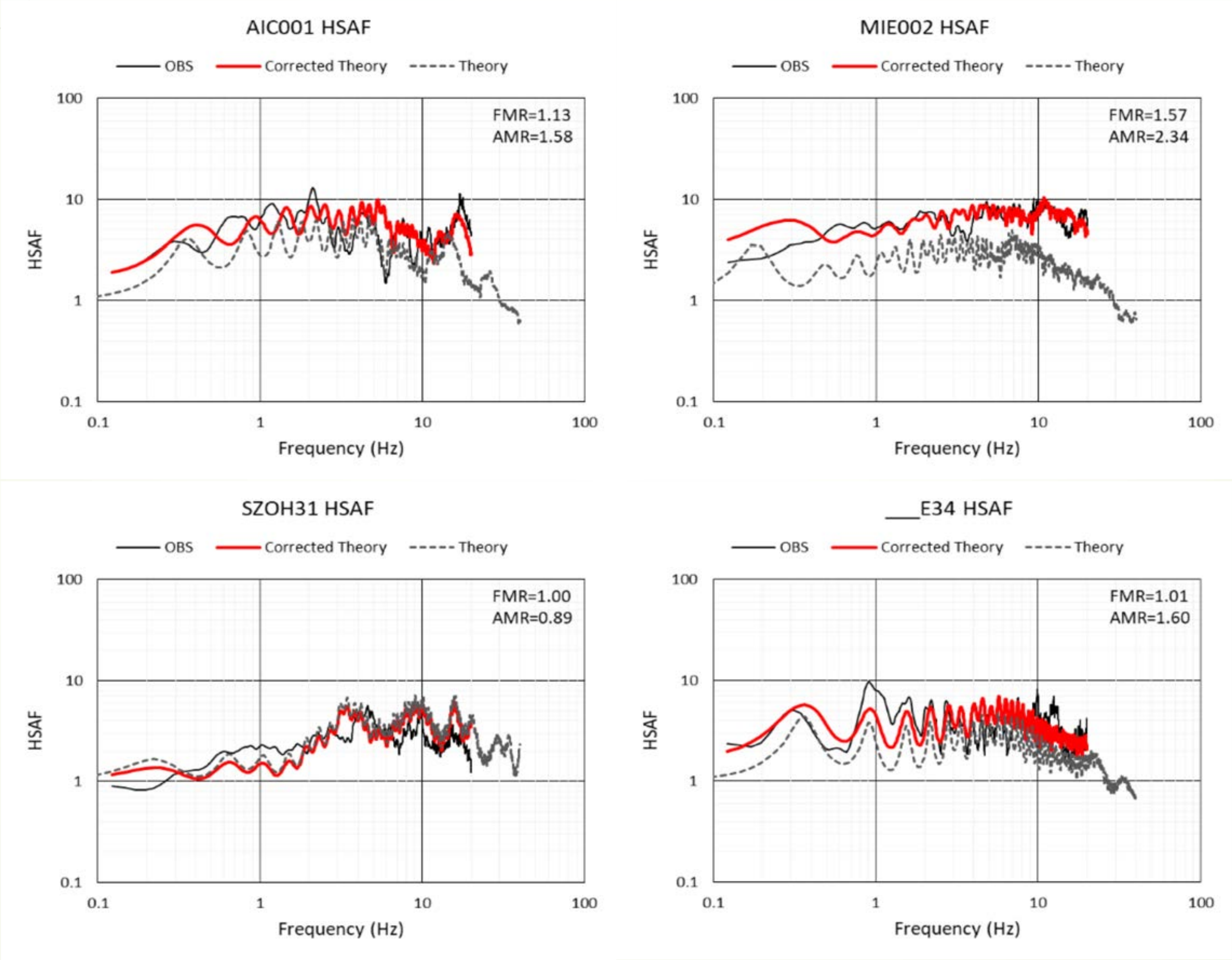
Compare

Amplitude Modification Ratio (AMR) : Match amplitude



Frequency Modification Ratio (FMR) : Shift frequency

Theoretical TF with **modification by FMR & AMR** in comparison to **observed SAF**.

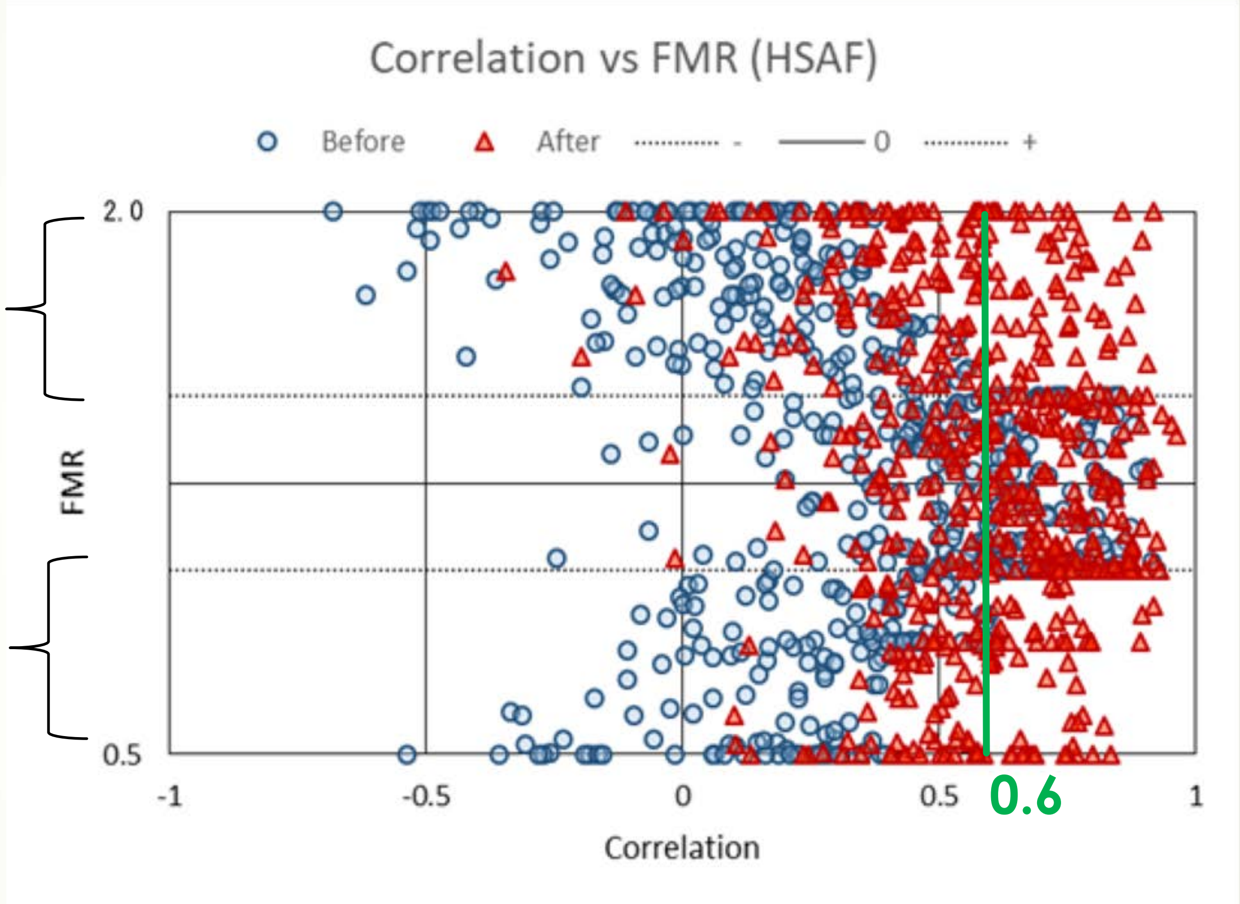


Correlation before and after the correction w.r.t. FMR

TTF is shifted to lower freq.
➔Large FMR

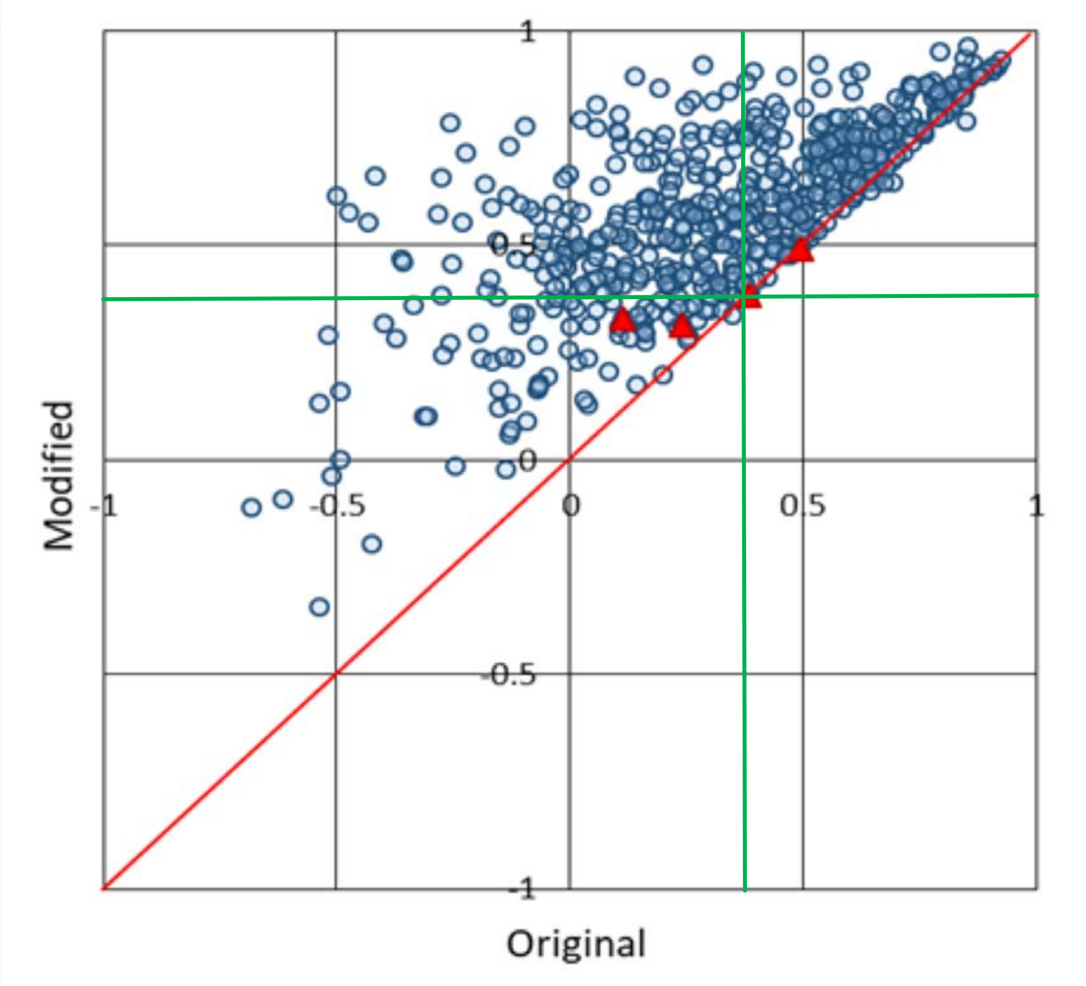
TTF is close to SAF
➔ FMR~1

TTF is shifted to higher freq.
➔Small FMR



For sites with higher correlation (>0.6) before modification, we restrict the searching range of FMR within 0.8<FMR<1.25 to avoid unnecessary strong modification (i.e., shift to the next peak frequency).

Improvement of the correlations between observed SAF and TTF at 546 sites (before vs. after).



Red triangle: sites for real interpolation test for validation.

All the sites are located above the 1:1 line. Negative correlation sites becomes only 7 from 84.

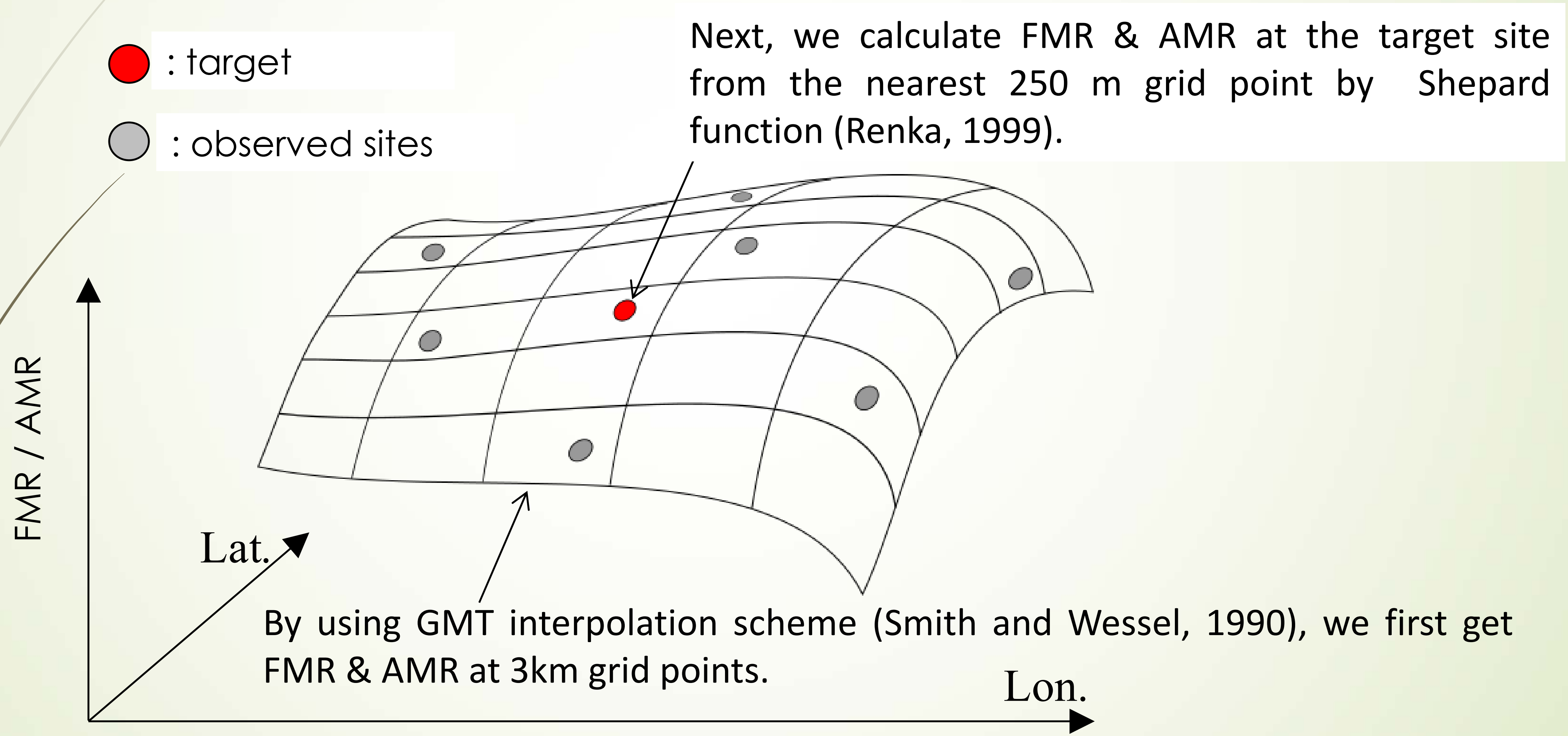
Negative correlation sites were decreased from 84 to 7, while sites with correlation higher than 0.4 were increased from 235 to 453.

Improvement in both the residuals and correlations between observed SAF and calculated TTF (before vs. after).

	Residual	Original	Modified	Correlation	Original	Modified	
Good	<1.25	5	43	<0.0	84	7	Poor
	1.25-1.50	175	389	0.0-0.4	227	86	
Poor	1.50-2.00	286	108	0.4-0.6	116	186	Good
	2.00-3.00	77	6	0.6-0.8	85	193	
	3.00<	3	0	0.8-1.0	34	74	
	Total	546	546	Total	546	546	

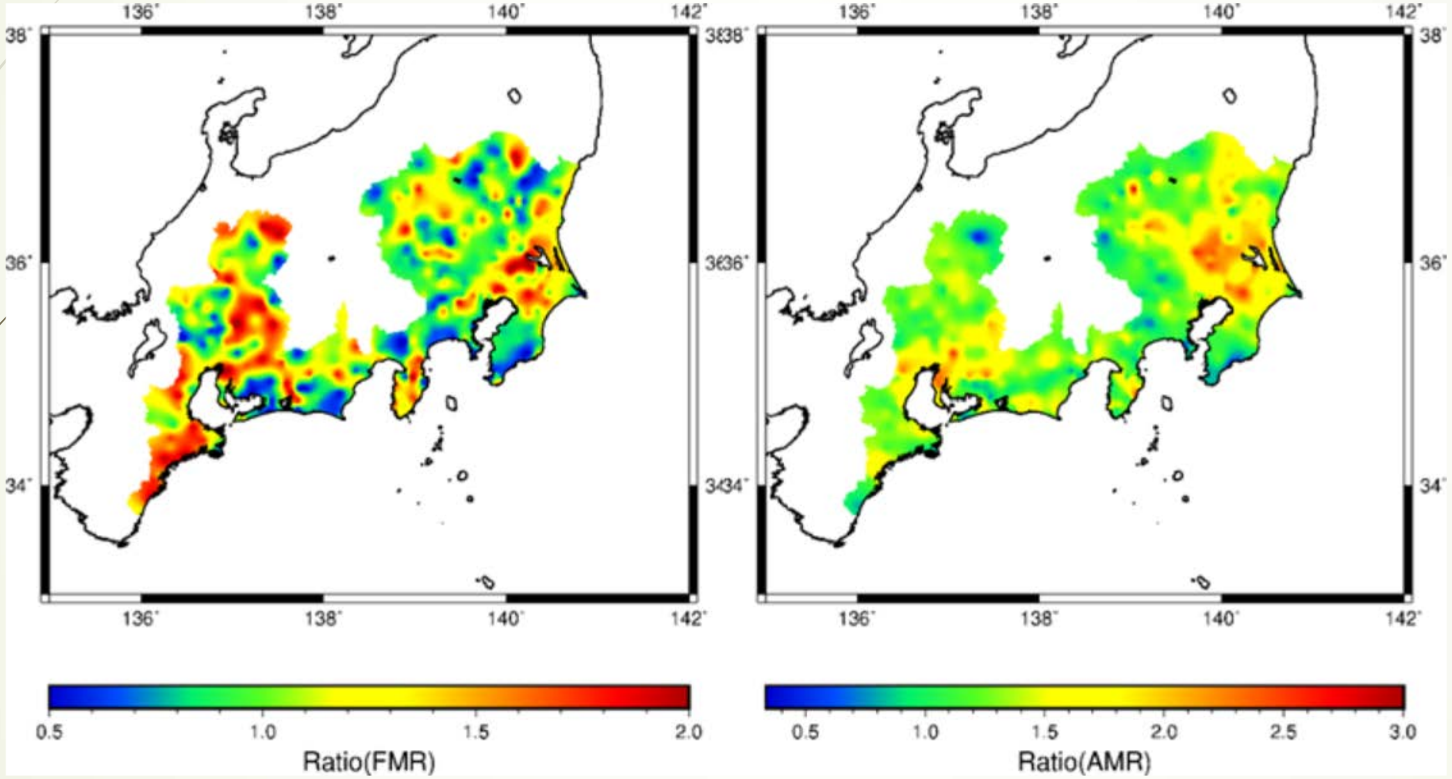
In both residuals and correlations, numbers of good sites are increased, while numbers of poor sites are decreased.

Step2: Based on FMR & AMR at 546 sites, we use two-step interpolation to get FMR & AMR at every 250m grid point.



Spatial Interpolation in FMR & AMR

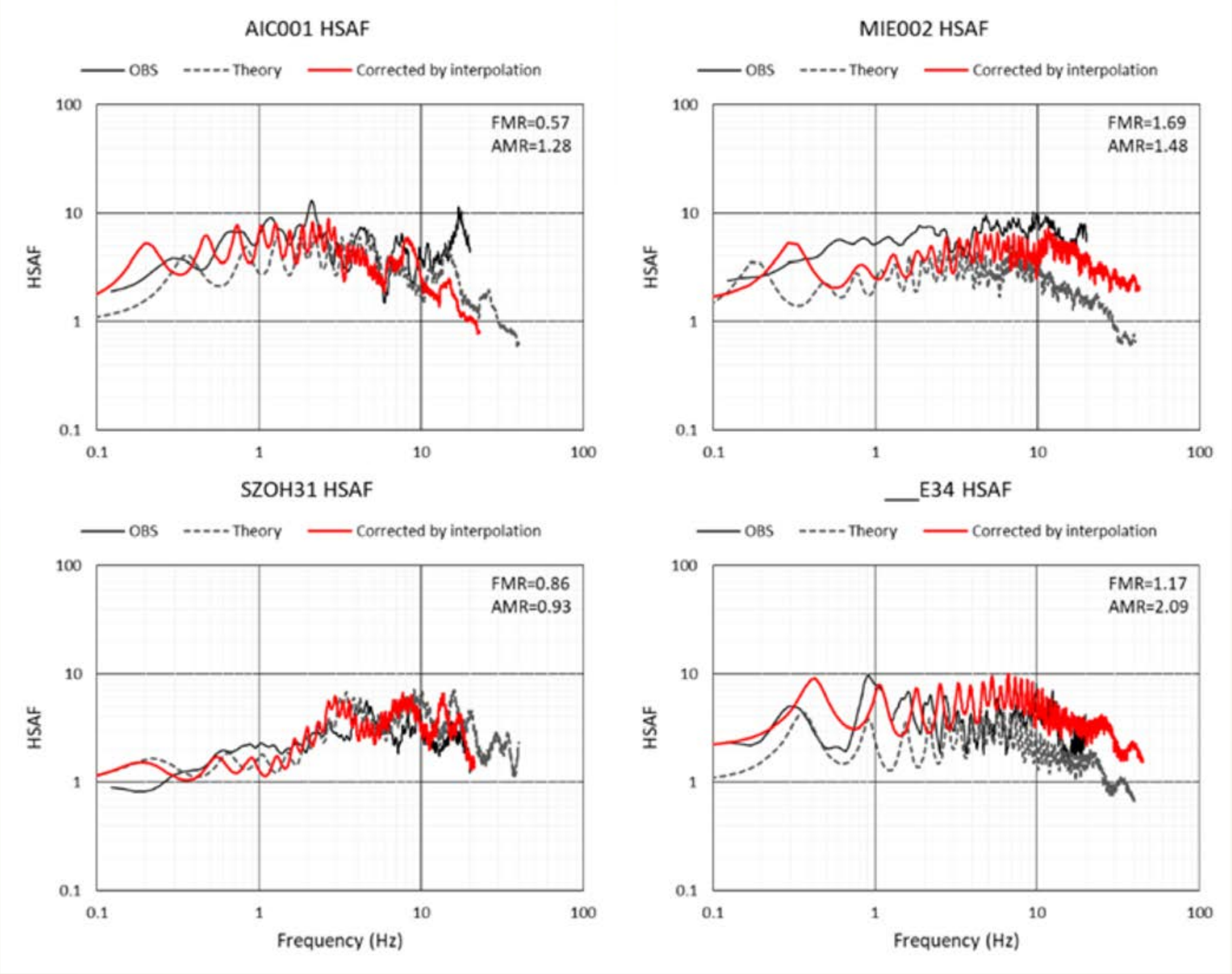
In step2, we spatially interpolate FMR & AMR from 546 sites based on the Surface function of GMT (Smith and Wessel, 1990) and the Shepard function by Renka (1999)



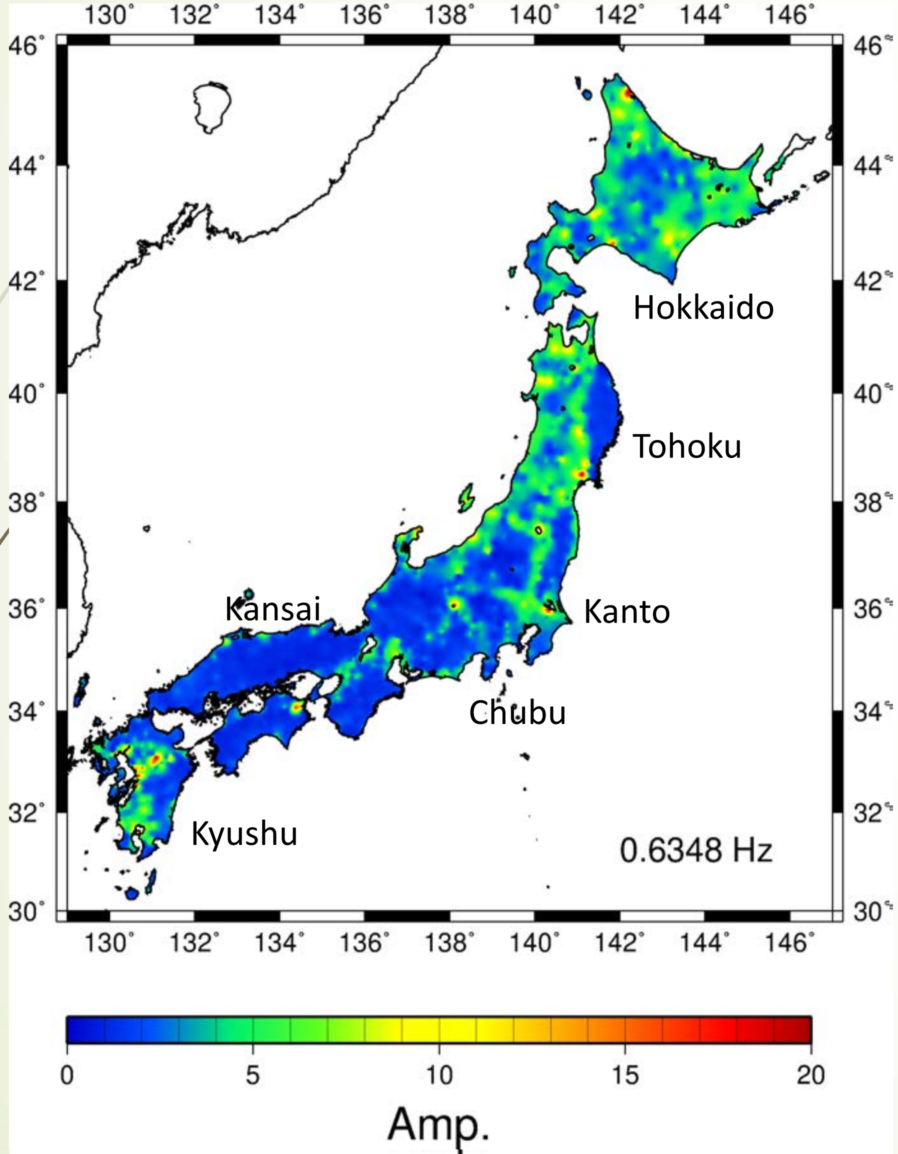
We need stronger correction of FMR in the Tokai region, while we need stronger correction of AMR in the Kanto region. We should note that we cannot find good correlation with Vs30 or Z3.1 because they are reflected already in TTF.

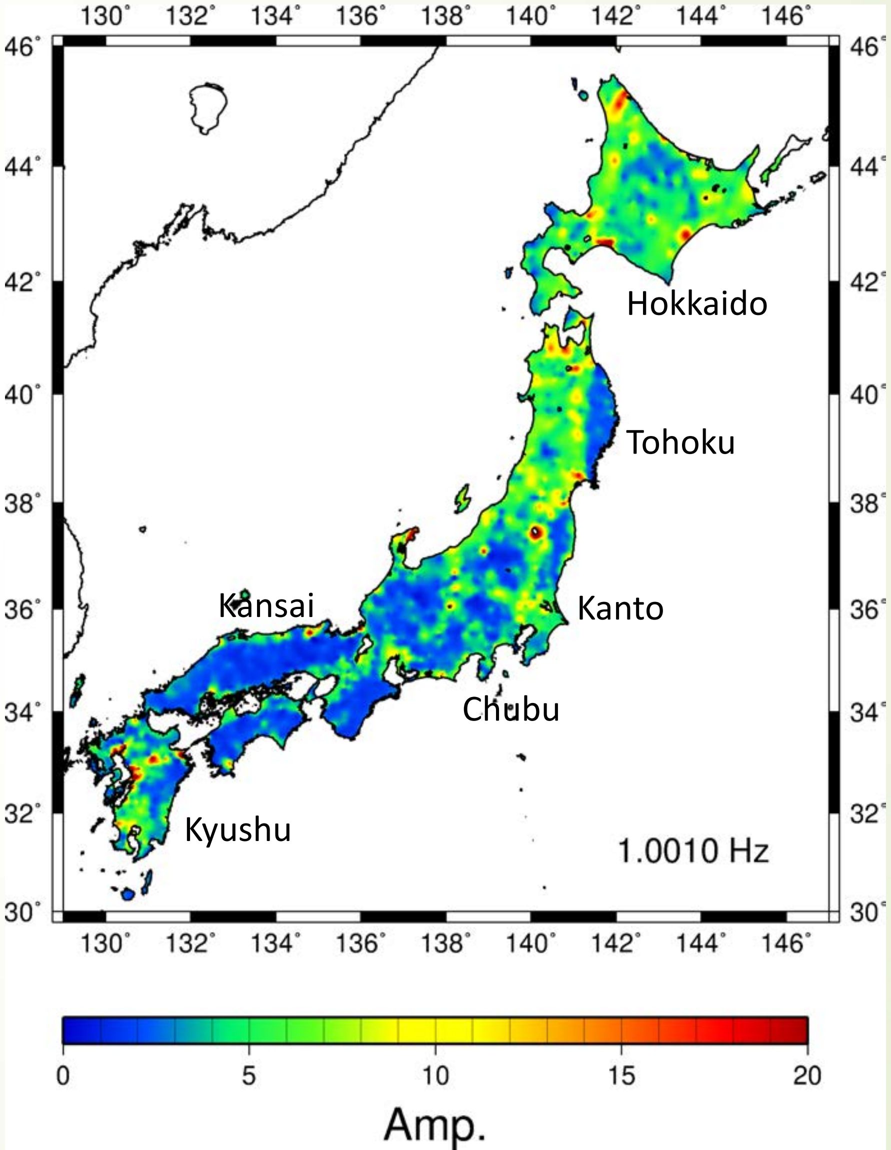
Validation exercise of the interpolation scheme

Compare the predicted TTFs with interpolated FMR and AMR with SAF.

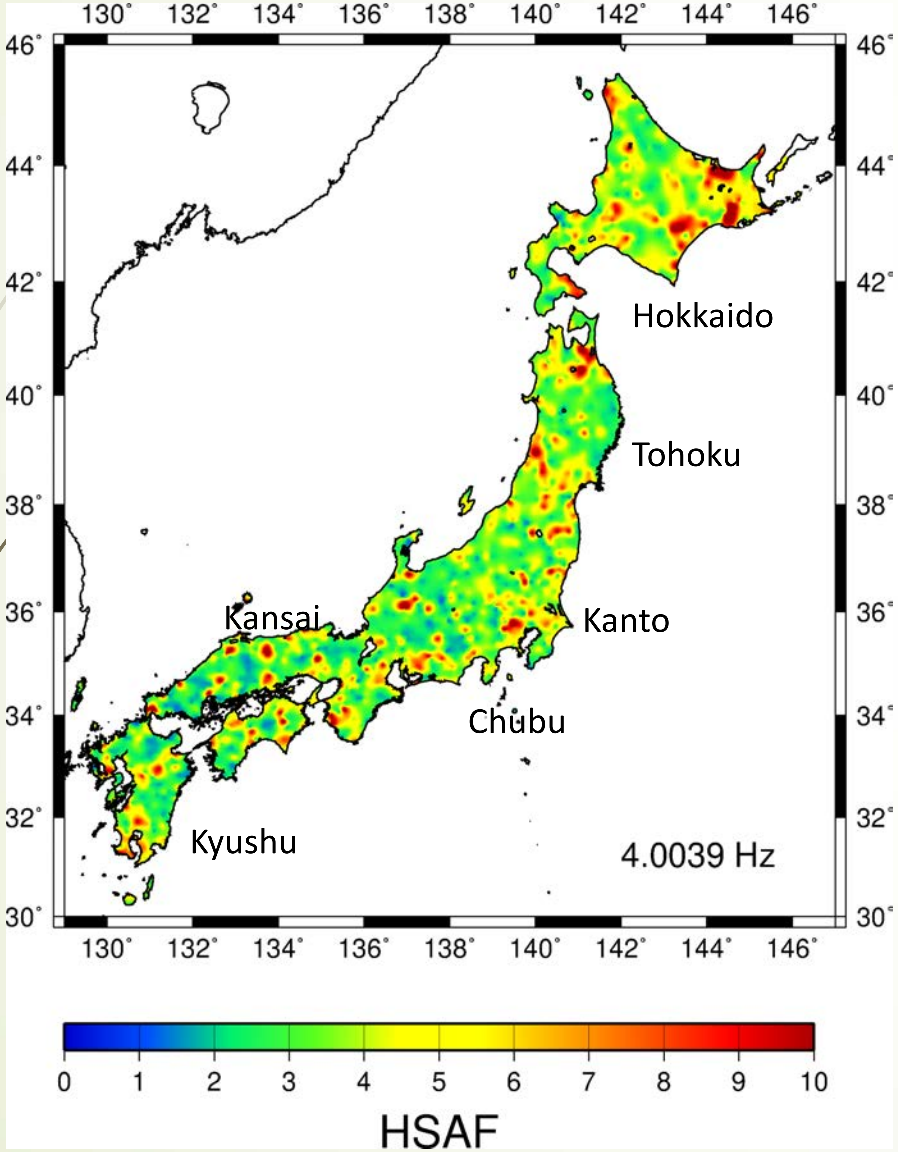


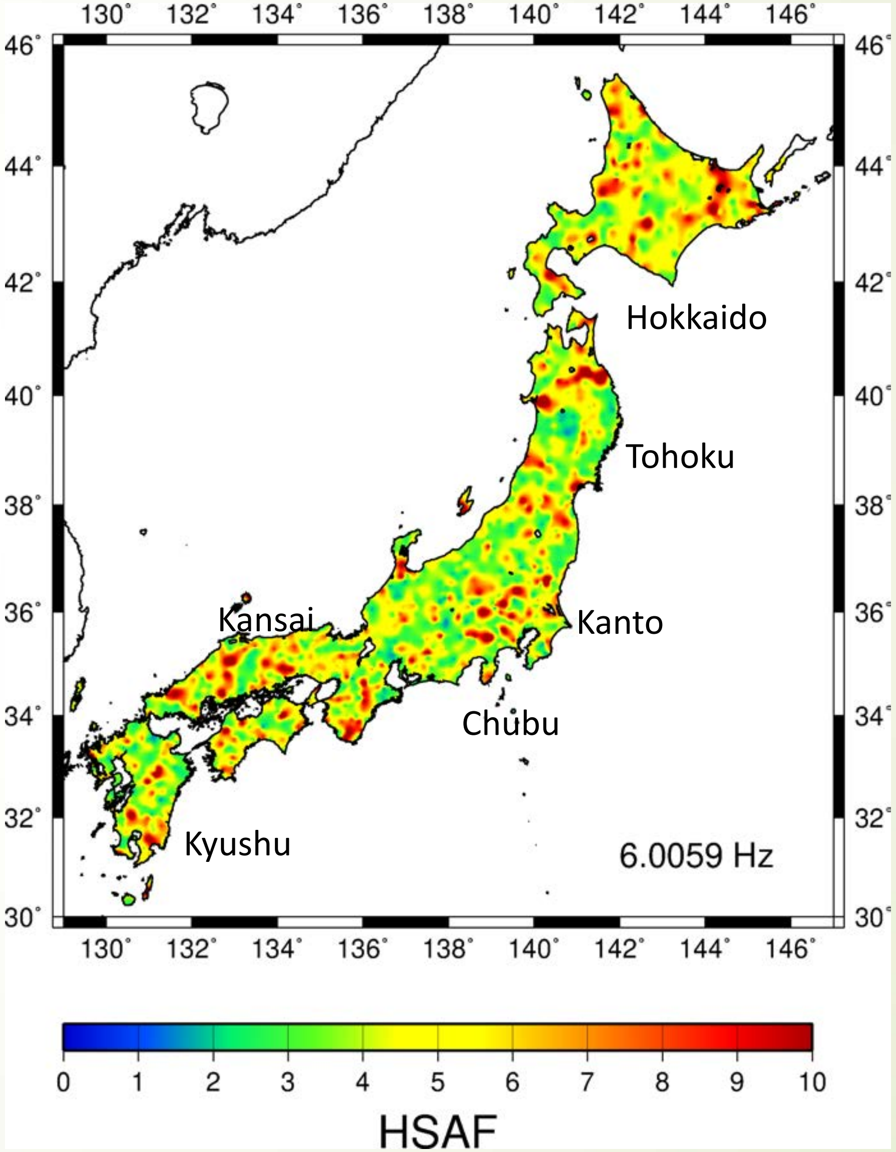
How can we see the gross picture of HSAF?



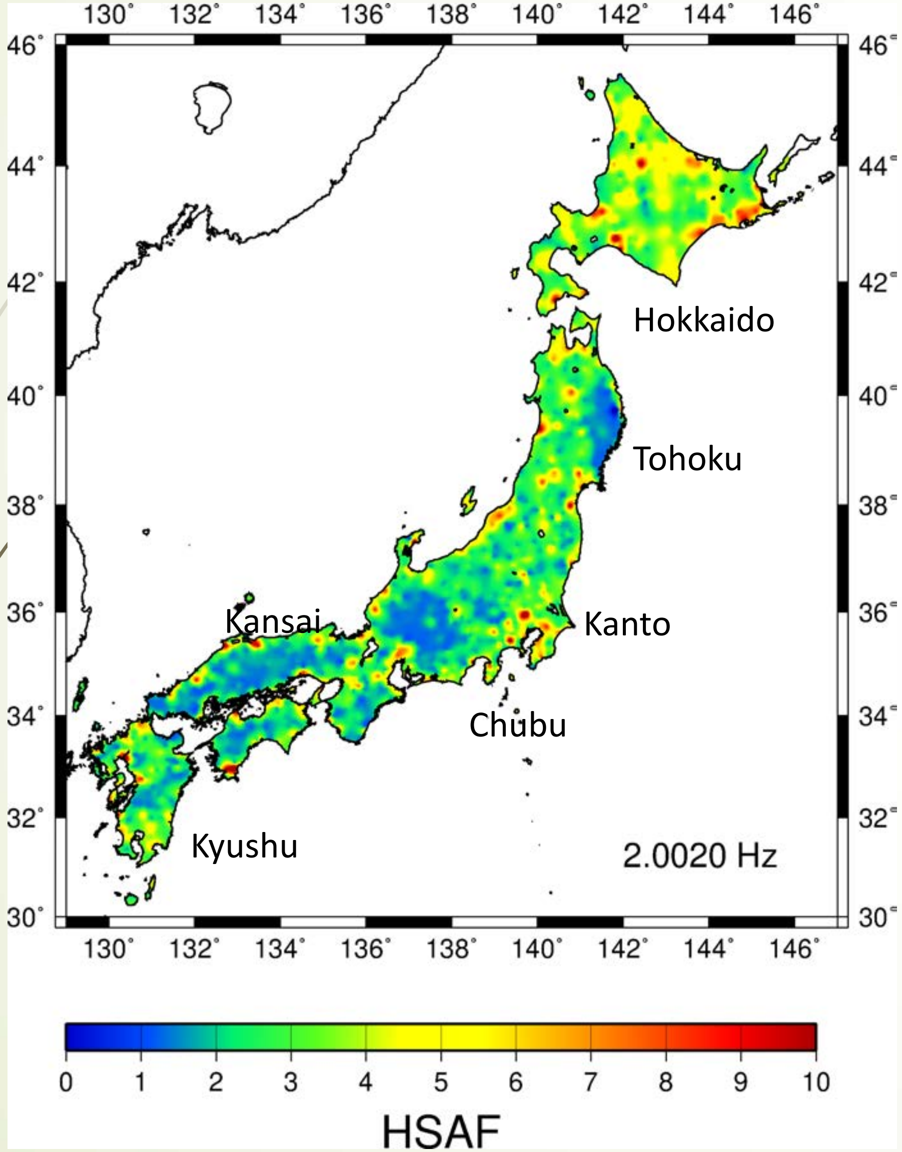


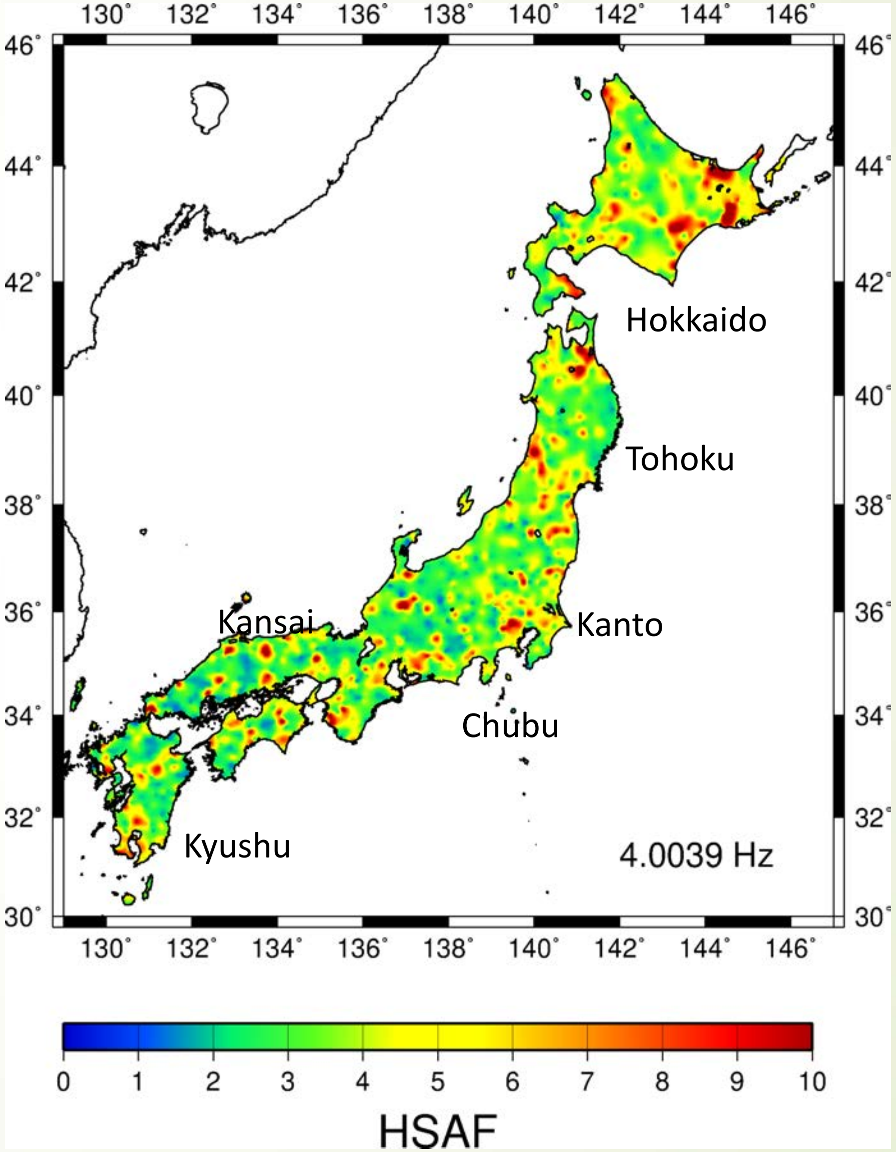
What is the spatial variations in high frequency?





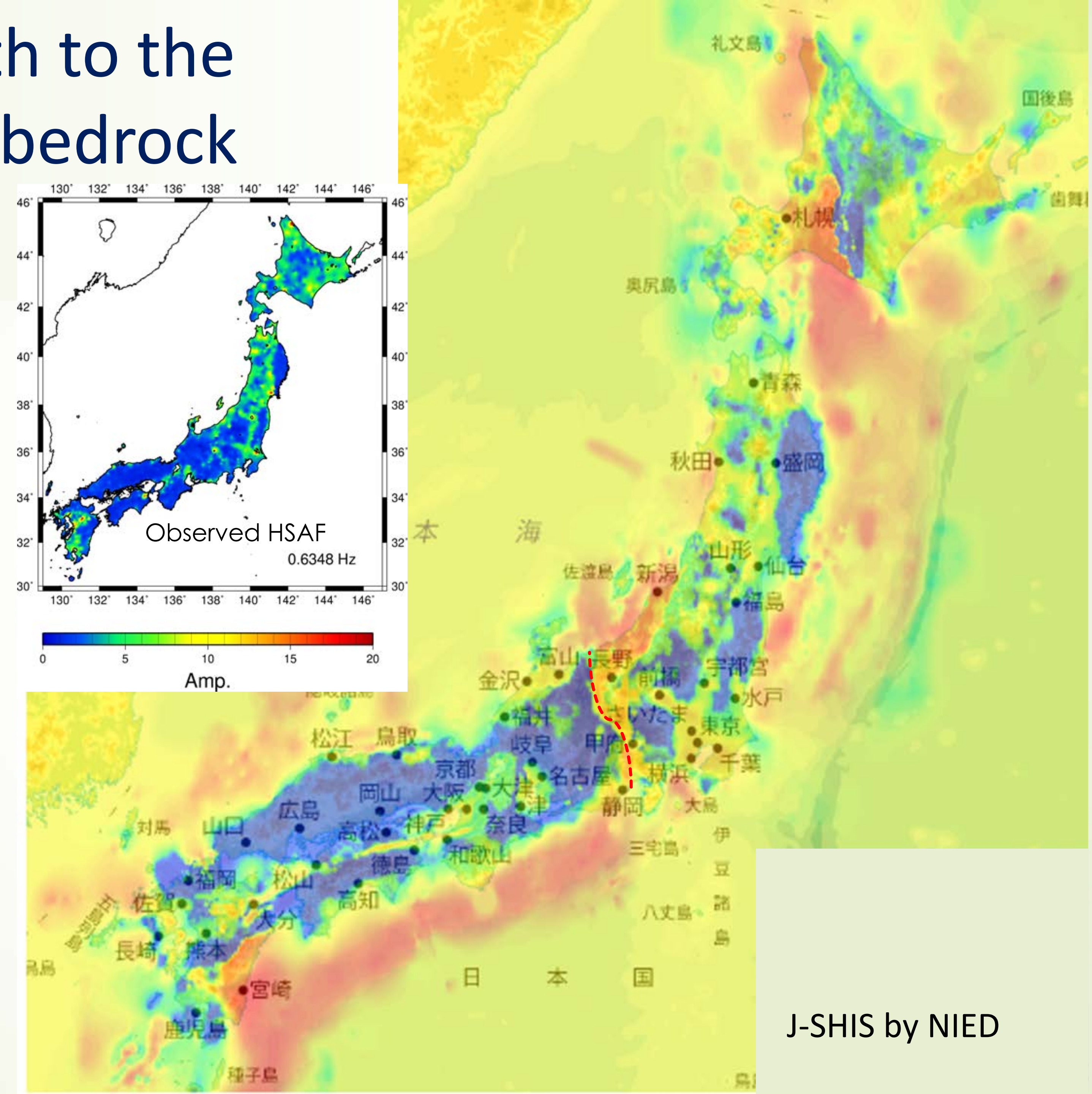
How about the spatial variation of TTF (w/o correction)?





Does the depth to the seismological bedrock correlate?

- We found good correlation of the low frequency HSAF with the depth to the seismological bedrock.
- Eastern side of Japan shows systematically deeper basin depths.



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What is important to learn on site effects?

The obtained spatial stability of HSAF comes from

1) the use of the seismological bedrock as a reference, and
2) the use of a relatively short duration for the S-wave part.

The broadband HSAF is a consequence of the up- and down-going S-wave propagations within the whole basin and so the separation of the influential frequency and corresponding depth is simply not possible. That is to say, “the seismic wave does not see the engineering bedrock.”

Issue: Do we really need high frequency ?

- We have been investing a lot to expand our knowledge on the strong ground motions, especially to reproduce the high-frequency component in the synthetics, because the engineers want to have synthetics with reliable high frequency component up to 10 Hz.
- The engineers believe that the resonance is taking place when building will collapse. Therefore, it would be useless if the synthetics do not have a precise amount of high-frequency component.
- However, the history of devastating structural damage shows, the cause of heavy damage is not the resonance in the elastic regime, but the input energy that makes nonlinear deformation beyond the limit. If we are concerned about the devastating damage, we need not to take care too much about the high-frequency component.

Thank you for your attention.

References:

Ito, Eri, Kenichi Nakano, Shigeki Senna and Hiroshi Kawase: S-Wave Site Amplification Factors from Observed Ground Motions in Japan: Validation of Delineated Velocity Structures and Proposal for Empirical Correction, Earthquake (Ed. Walter Salazar), doi: 10.5772/intechopen.95478 (Open access).

Nakano, K., S. Matsushima, and H. Kawase: Statistical properties of strong ground motions from the generalized spectral inversion of data observed by K-NET, KiK-net, and the JMA Shindokei Network in Japan, Bulletin of the Seismological Society of America, Vol.105, 2662-2680.