台灣強地動模型的現況與未來
下一代模型的研究方向

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丘士正

All Models Are Wrong But Some Are Useful – George Box, 1976

- The only question of interest is “Is the model good enough for this particular application?”

- … cunningly chosen parsimonious models often do provide remarkably useful approximations

現況

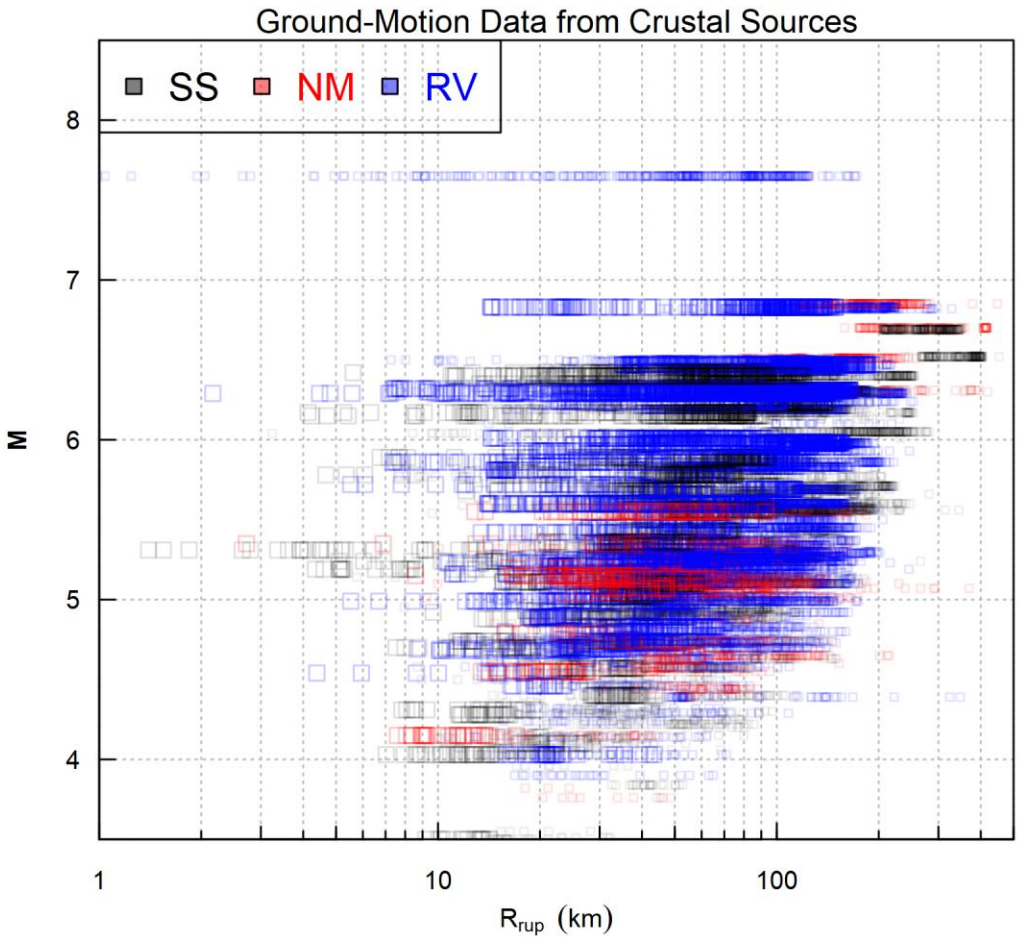
- Multiple GMPEs, <u>usable</u> for hazard assessment in Taiwan
  - Significant progress in the last 3 years (2016 – 2018)
    - Sponsored by TaiPower

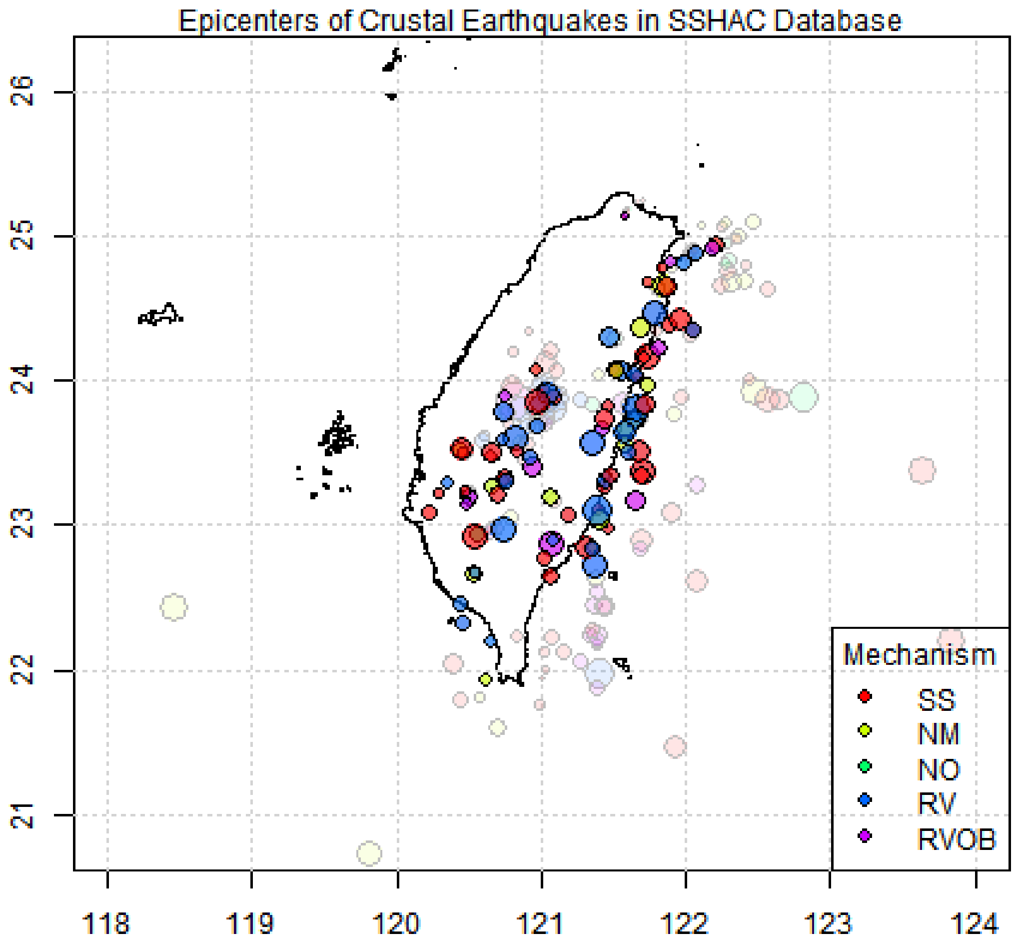
  - Each GMPE includes models for the two parameters of the predictive distribution of PSA
    - Median
    - Standard deviation

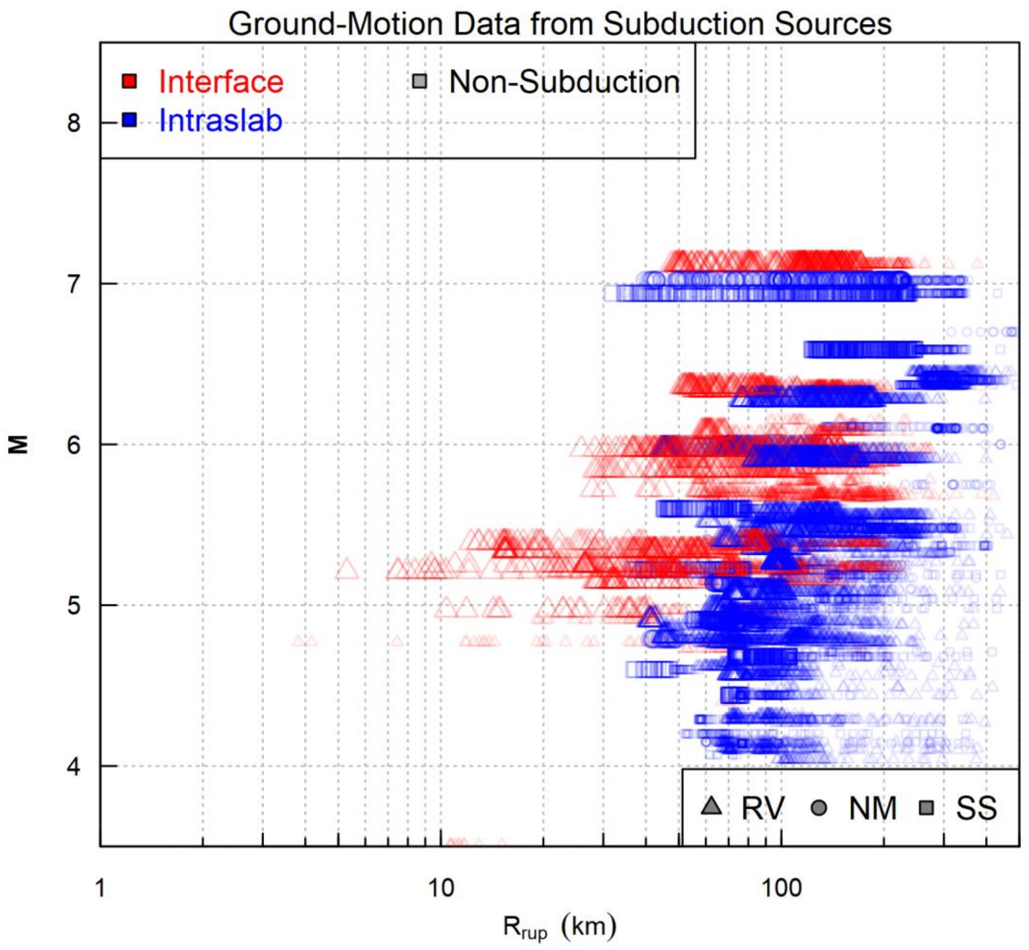
  - A high-quality database makes a huge difference
    - TNGA, v9, 2018.06.20
      - Database Team lead by Dr. Po-Shen Lin
      - Comprehensive and good for GMPE development

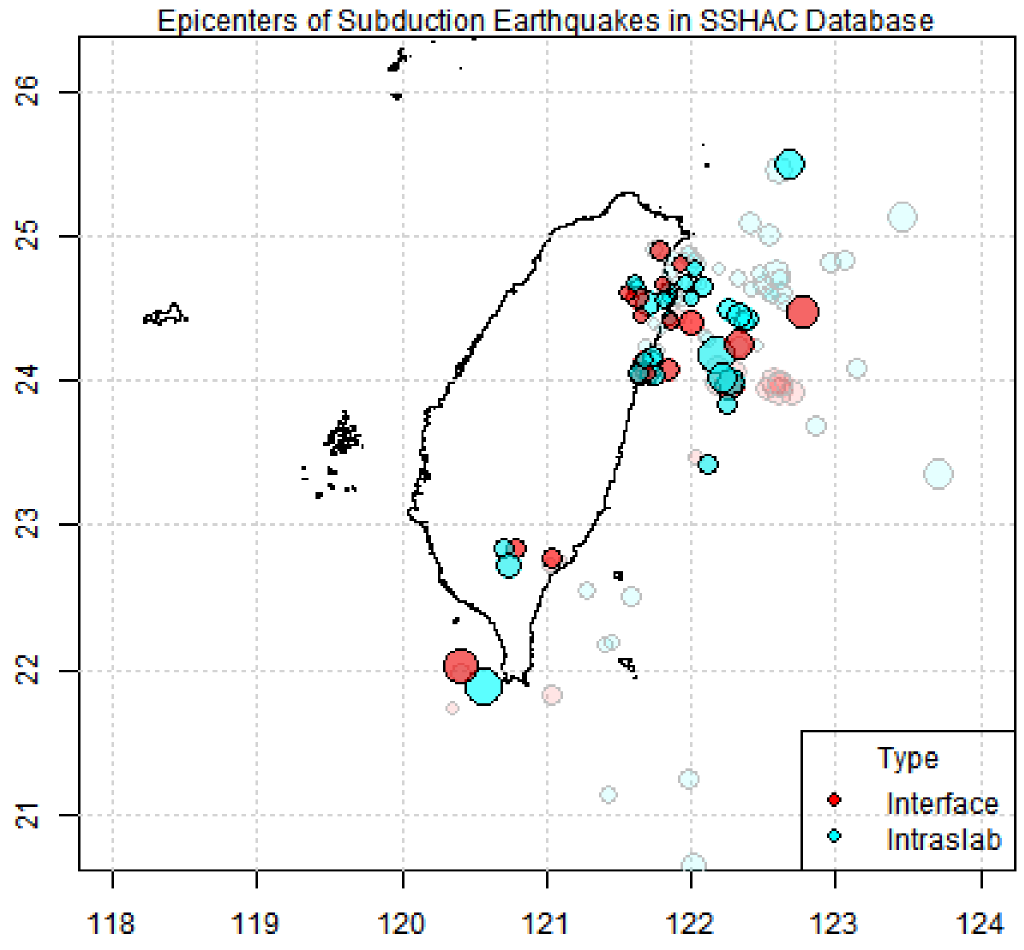
    - It’s important to continue data collection to support next generation of GMPE

Available Taiwan Data






Ground-Motion Data from Subduction Sources
Interface
Intraslab
Non-Subduction
RV
NM
SS
M
R_{rup} (km)


Epicenters of Subduction Earthquakes in SSHAC Database
Type
Interface
Intraslab

Minimum Criteria for a GMPE Useful to PSHA

1. GMPE should fit reasonable well Taiwan ground-motion data
2. GMPE should extrapolate reasonably well outside the magnitude and distance range of Taiwan data
3. GMPE should include terms to account for site amplification
4. GMPE should be developed using a mixed effect regression model or equivalent, and regression should account for PGA truncation at 4 gal
5. GMPE should be for the RotD50 or geometric mean of the two horizontal components

Nine GMPEs for Crustal Earthquakes

- Seven models are obtained by adjusting existing GMPEs to match Taiwan data
  - Borrow their scaling relations in the nearfield of a large magnitude event
  - ASK14, BSSA14, CB14, CY14, I14, AB14, and Bi14

- Two models are developed specifically for Taiwan
  - Chao et al., 2018:
    - Taiwan data only, but extrapolation is guided by another published GMPE
  - Phung et al., 2018:
    - Combined Taiwan and Japan data, but account for known differences between the two regions

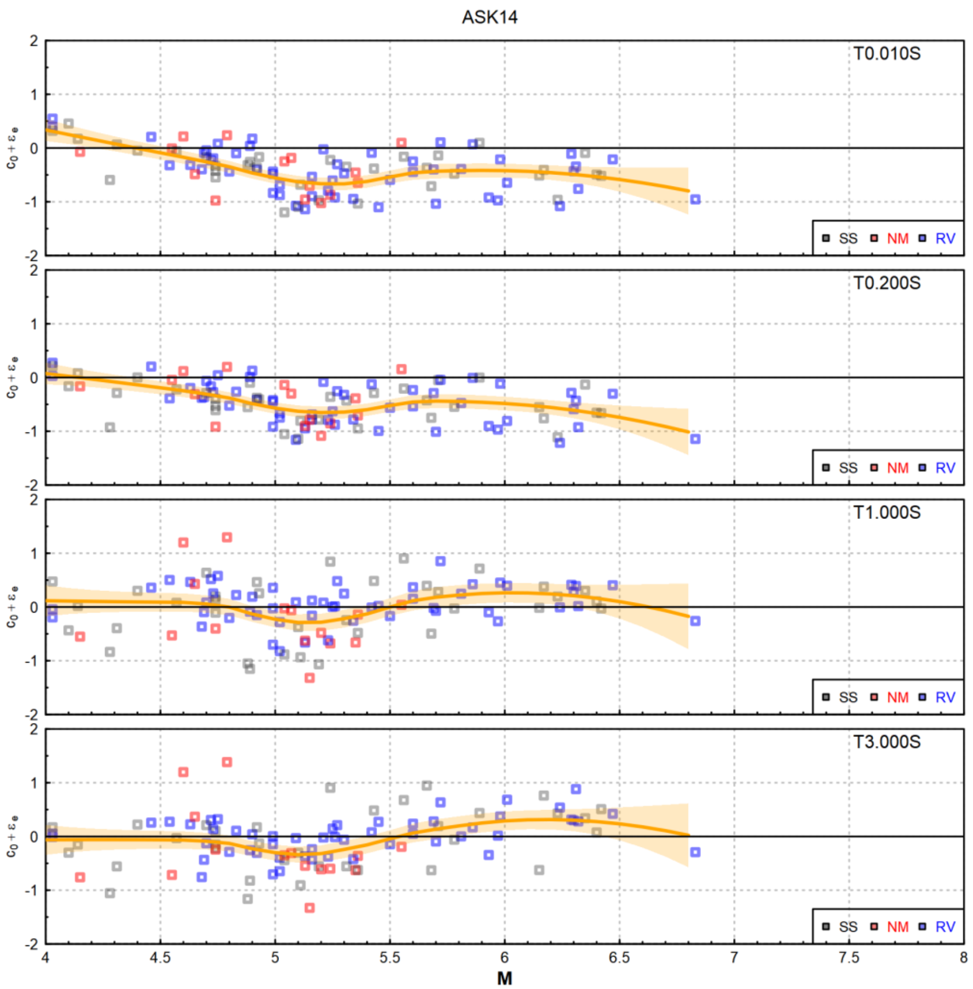
Four GMPEs for Subduction Earthquakes

- Two models are obtained by adjusting existing GMPEs to match Taiwan data
  - LL08, AGA16

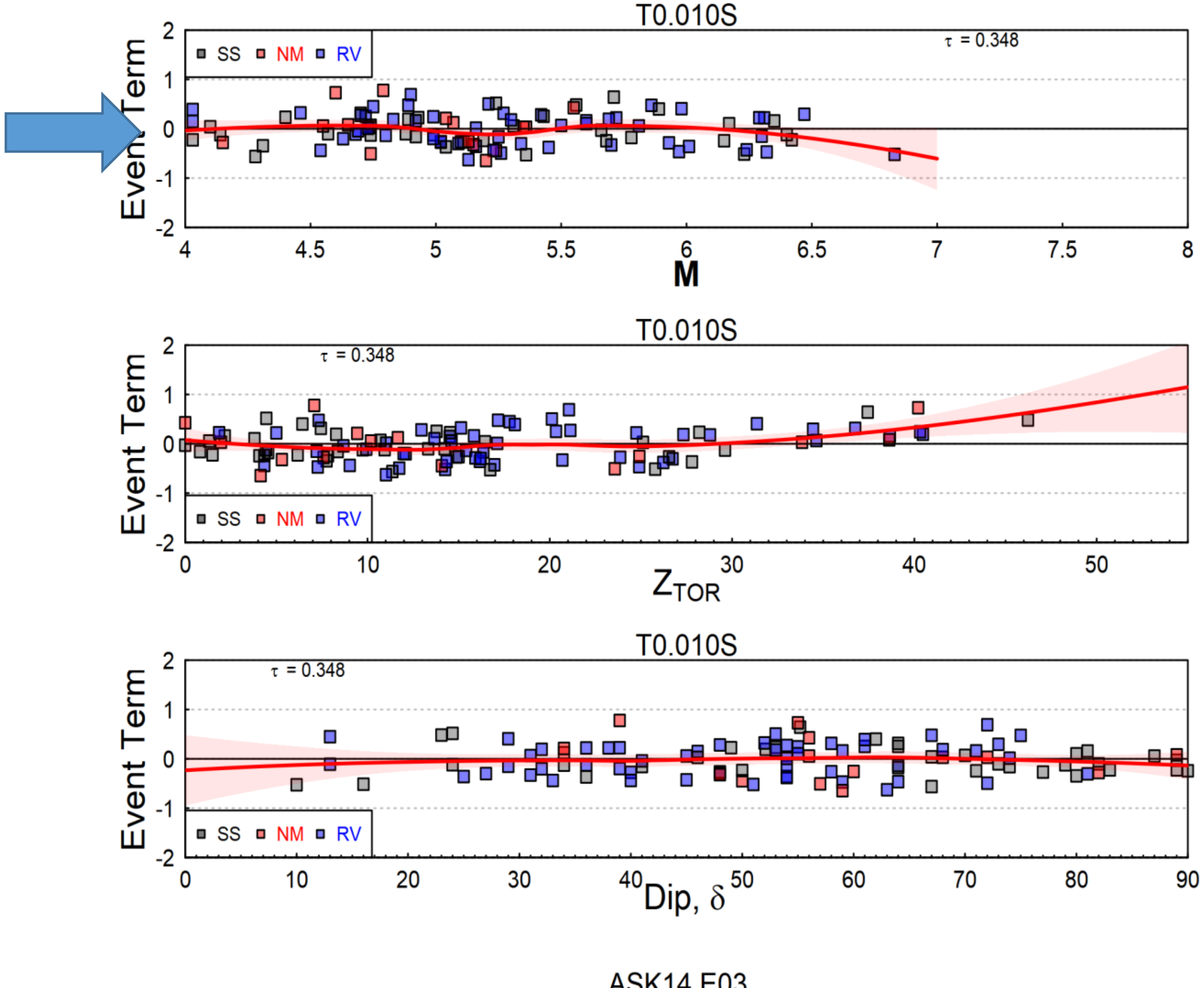
- Two models are developed specifically for Taiwan
  - Chao et al., 2018:
    - Taiwan data only, but extrapolation is guided by another published GMPE
  - Phung et al., 2018:
    - Combined Taiwan and Japan data, but account for known differences between the two regions

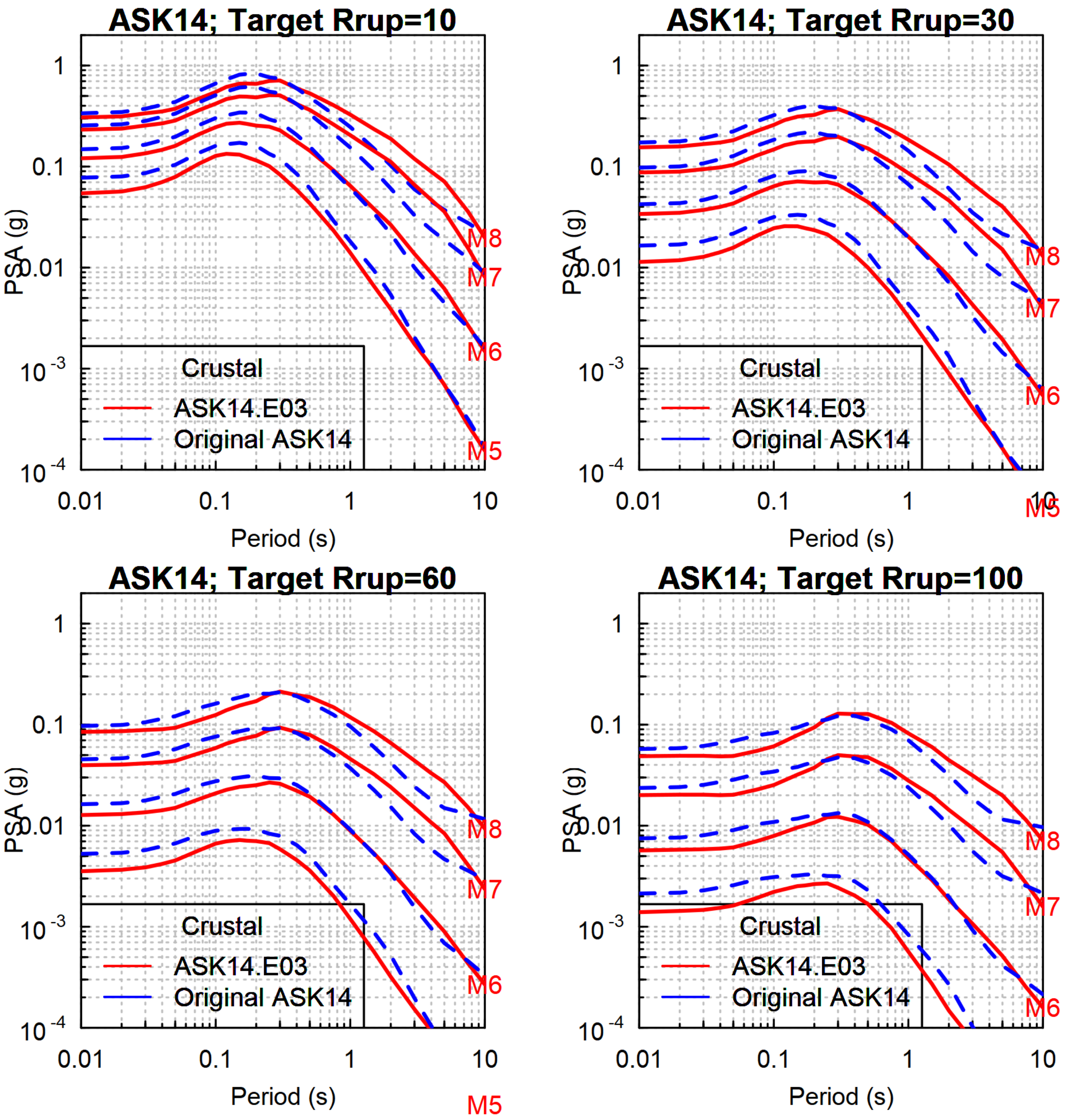
Example of Model Adjustment

Before

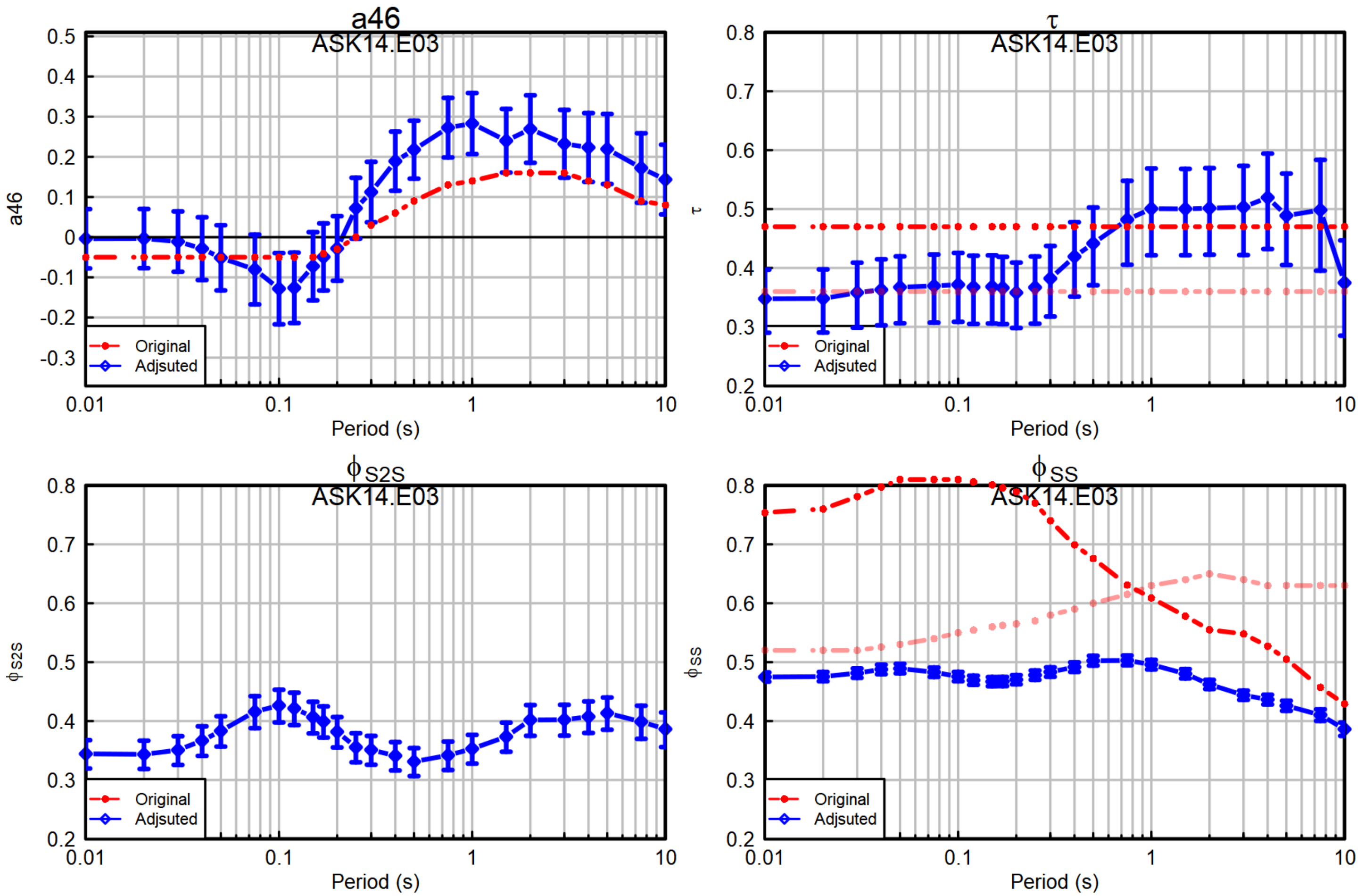


After




ASK14; Target Rrup=10
ASK14; Target Rrup=30
ASK14; Target Rrup=60
ASK14; Target Rrup=100
PSA (g)
Period (s)
Crustal
ASK14.E03
Original ASK14
M8
M7
M6
M5

- A model for the standard deviation of ground-motion prediction
  - Single site
    - Remove contribution from the site-to-site variation of repeatable site effect



下一代模型

- Again, database is crucial
- Nearfield environment
  - Constrain on M- and R-scaling
    - Recent large earthquakes, Taiwan and other regions
    - Simulations of ground motion by calibrated and validated methods
  - Nearfield physical processes
    - Polarization
    - Directivity
    - Fling
- Regionalization within Taiwan
- Others
  - Basin response
  - Nonlinear soil response
  - Regional difference between Taiwan and other regions

Database for Next-Generation GMPE

- Ground-Motion Data
  - Older SMA1 data
    - Large magnitude subduction zone events
  - BATS data
    - Add data of crustal earthquake
  - Mountain array data
  - Data from earthquakes after 2016
- Site characterization (V_{S30} and $Z_{1.0}$) for all recording stations
  - Mountain array stations
- 3D Qs/Qp models (useful for regionalization within Taiwan)
- $Z_{2.5}$
- Predictors for directivity effect and polarization effect
- Four amplitude
- ……….

Near-Field Seismic Environment (1/5)

- Taiwan-specific constraints on ground motion scaling in nearfield of large events
  - More data (older earthquakes)
  - Other regions (after correction for regional differnces)
  - Simulations of ground motion
  - Other constraints

Near-Field Seismic Environment (2/5)

- Design time series and design PSA spectra should account for
    - S-wave Polarization
        - Amplitudes on the two orthogonal horizontal components are unequal
            - The most well known example: strike-normal PSA > strike-parallel PSA, for long periods
    - Directivity
        - Velocity pulse generated by the near simultaneous arrival of large amount of energy in a short time window, when rupture propagates toward the site of interest
            - More prominent when it is rotated to the strike-normal direction (the direction of stronger shaking due to S-wave polarization)
    - Fling
        - Velocity pulse associated with the rebound of overly strained rock during an earthquake rupture
            - Appear mostly in the strike parallel direction

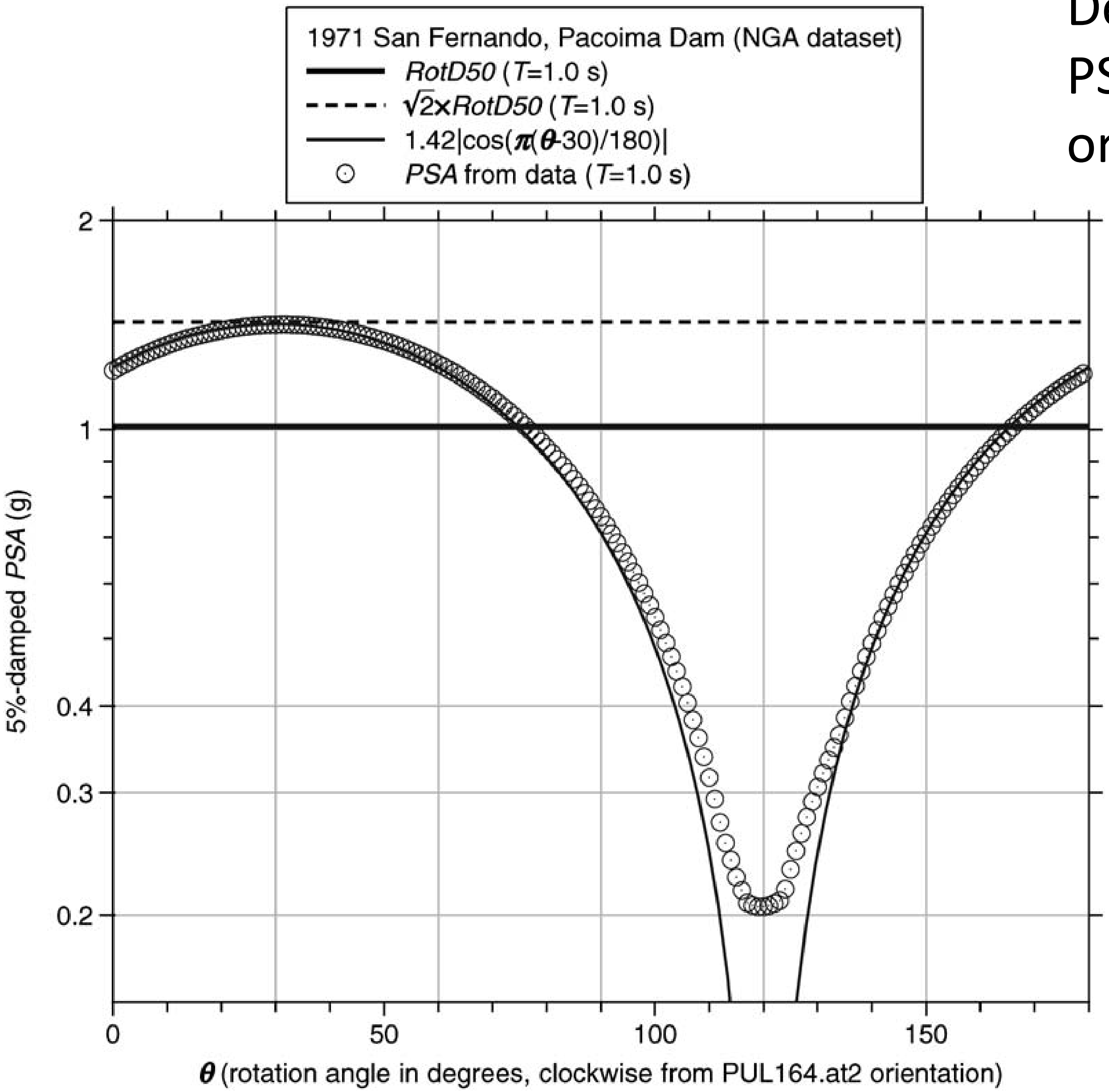
Near-Field Seismic Environment (3/5)

- Model for polarization effect
  - Choose and then populate predictor data

Polarization

- PSA depends on sensor orientation
- RotD50 (Boore, 2010) is the average of PSA over the non-redundant set of orientation (0 to 180 degrees)
  - Orientation independent

- Polarization of Pacoima Dam record
  - 30 degrees is the maximum, 120 degrees is the minimum
  - 70 degrees is about the same as 160 degrees



Dependence of PSA[T=1s] on sensor orientation

From Boore, 2010

Polarization

- Expect to see strong polarization effect for long periods
  - Effect for short period is less (less predictable due to wave scattering)

- Examples of engineering application
  - Strike-Normal, Strike-Parallel
    - Smoerville et al., 1997, FN/Ave, FP/Ave
  - Maximum PSA (RotD100)
    - Shahi and Baker (2014): RotD100/RotD50
  - Arbitrary orientation
    - Transverse and longitudinal directions of a bridge or a dam

- Need a model to predict PSA at any orientation
  - Predict the rotational pattern, given the fault geometry and site location

Polarization

- Proposed predictor:
  - Physics behind the rotational pattern is the S-wave radiation pattern for a finite source
  - Predictive model uses radiation pattern as predictor

- Approximate S-wave radiation pattern
  - A single point (hypocenter)
    - Aki and Richards, 1980
  - Average of two points
    - Spudich and Chiou, 2008
  - Average over a line
    - Chiou and Spudich, 2014
  - Can we do better?

Near-Field Seismic Environment (4/5)

- Directivity Effects

- Several models for directivity effects are available
  - Four directivity models by the NGA-W2 directivity working group (2014)
- But, not yet widely used in PSHA

Directivity

- Need to be aware of the current challenges when we develop the directivity model for Taiwan

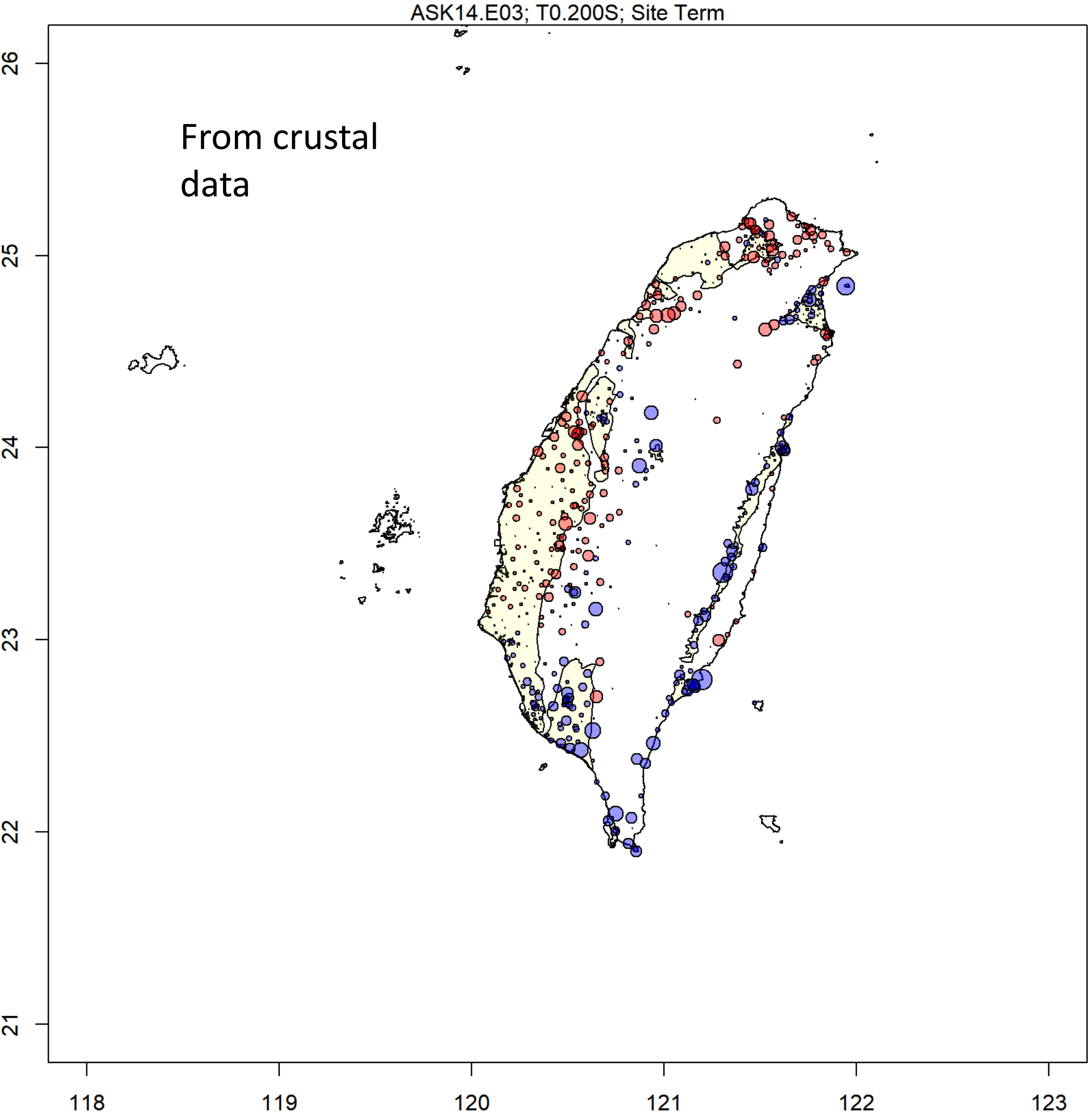
- Why they have not been widely used in PSHA
  - Reliability of directivity model
    - Still hampered by relatively lack of data
    - Large model to model variation
  - Implementation in PSHA
    - Very long computation time
      - Centering requires calculation for extra sites near the target site
      - Hypoenter of future rupture is randomized because its location is unknown
    - Complex rupture
      - Rupture segments with large gap between them
      - Rupture segments have discordant dip direction
        - Dipping toward each other

Near-Field Seismic Environment (4/5)

- Both fling and directivity create velocity pulse
  - Fling pulse is one-sided and directivity pulse is two-sided
  - Fling pulse is on strike-parallel direction and directivity is on strike-normal
- A few models available for fling
- Model development is hindered by
  - Insufficient near-field data
    - The more data we are able to add to the current database, the better we will be
  - Require special processing to extract fling from the recording
    - Processing result is sensitive to selection of input parameter
  - Separation of fling from directivity pulse

Regionalization

- GMPE development focuses on capturing the average behavior for the entire Taiwan region
  - There are evidences suggesting spatial inhomogeneity within TW
    - Examples: Site residual
      - It’s possible that regional path effect is mapped into site residual


ASK14.E03; T0.200S; Site Term
From crustal
data
26
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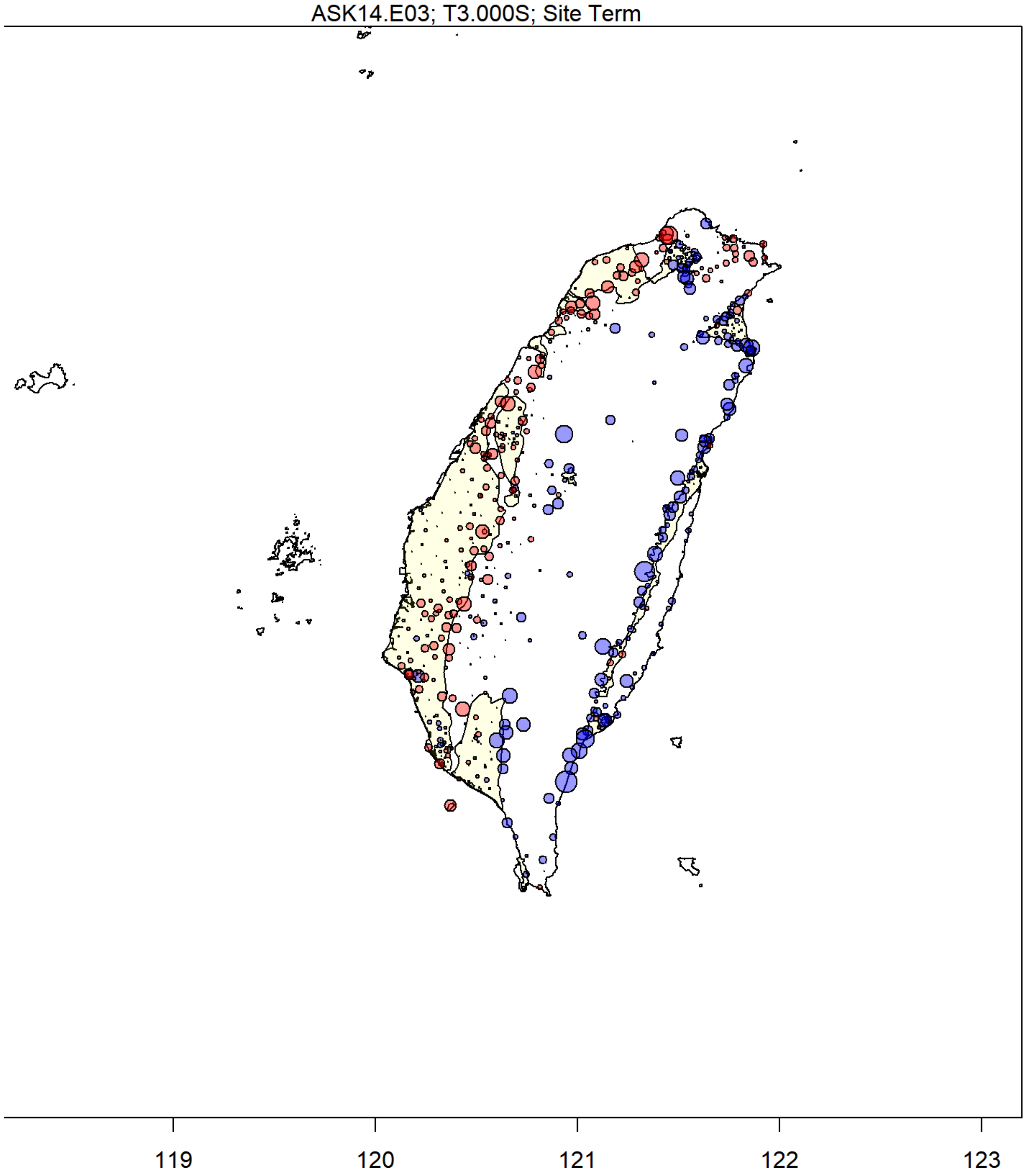
ASK14.E03; T3.000S; Site Term
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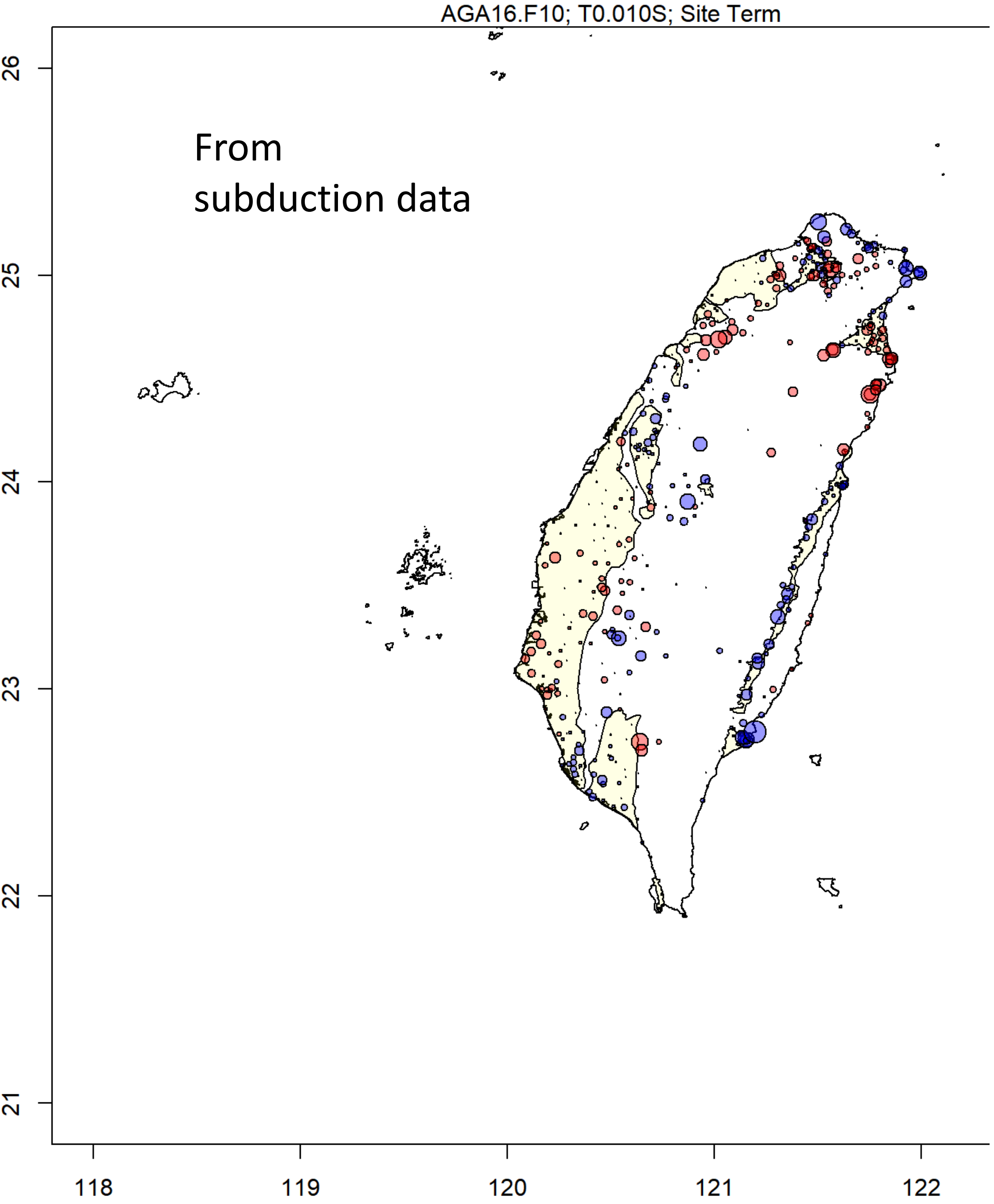

AGA16.F10; T0.010S; Site Term
From
subduction data
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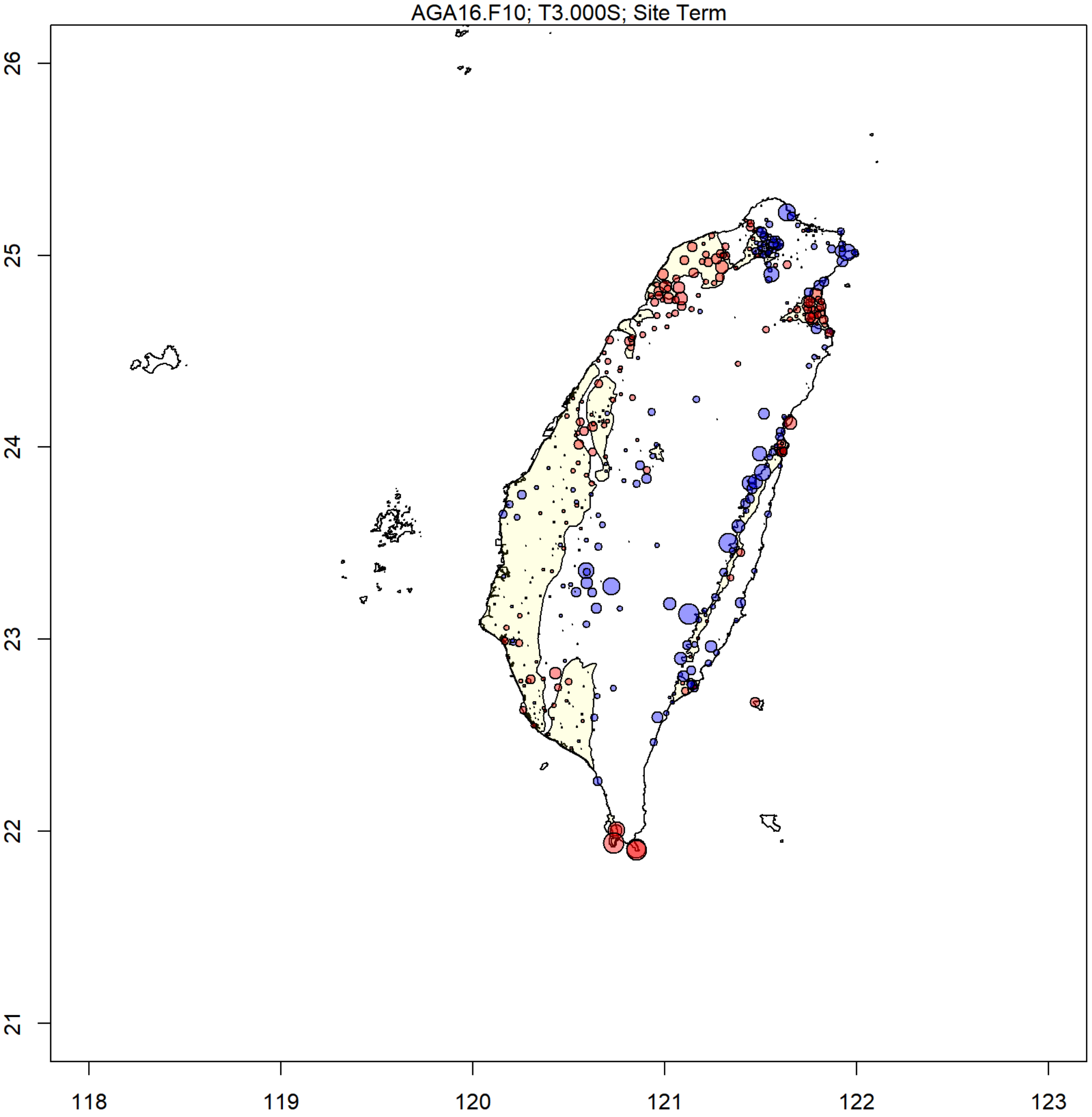

AGA16.F10; T3.000S; Site Term
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Regionalization

- Benefits of regionalization within TW
  1. More accurate median
  2. Smaller residual standard deviation

- Regionalization can be made on different scale
  - Large subdivision within TW
  - Gaussian Process (non-ergodic GMPE)
    - Gaussian process has other extra benefits
    - Steep learning curve
      - Non-Ergodic Working Group, lead by Dr. Norm Abrahamson

Beyond Vs30

- Effect of S-wave velocity gradient

Basin Response (Period > 0.5s)

- Important to high-rise buildings and bridges

- $Z_{2.5}$ is preferred by some researchers because it is more effective in modeling the long period data
  - Is this also true for Taiwan?

- Currently we are forced to use $Z_{1.0}$ because $Z_{2.5}$ is unavailable
- Is there a way to collect $Z_{2.5}$?

- 3D simulation of basin effect can help guide our model
  - Directional response (source-to-basin direction)

- Duration and basin generated waves

Nonlinear site response

- Taiwan-specific GMPE (Chao18) has a larger de-amplification from soil nonlinear response, compared to the adjusted GMPE (which is based on California data)
  - We need to verify and understand the difference
  - California’s nonlinear response is suitable for Japan’s subduction data

- Theoretical site response analysis
  - Help extrapolate outside the range of current data (level of loading)
    - Based on Vs profile and soil dynamic properties suitable for Taiwan

Understand Observed Differences Between Taiwan and Other Regions

- Crustal GMPE
  - Taiwan’s short period ground motion is weaker than that in California
- Subduction GMPE
  - Taiwan’s short period motion is lower than the other subduction zones (Japan, South America, New Zealand)

- Develop input models to stochastic simulation
- GMPE for Fourier amplitude spectra

Complete Cycle of GMPE Development

- Useful GMPEs
  - Current generation of GMPEs
  - Next generation
- Usable in PSHA and design practice
  - Implementable in PSHA
  - Tools and resources for implementation
- Used in PSHA and design practice
- Each of us could and should find and play his/her role