3D Velocity of Taiwan: Achievements and Challenges

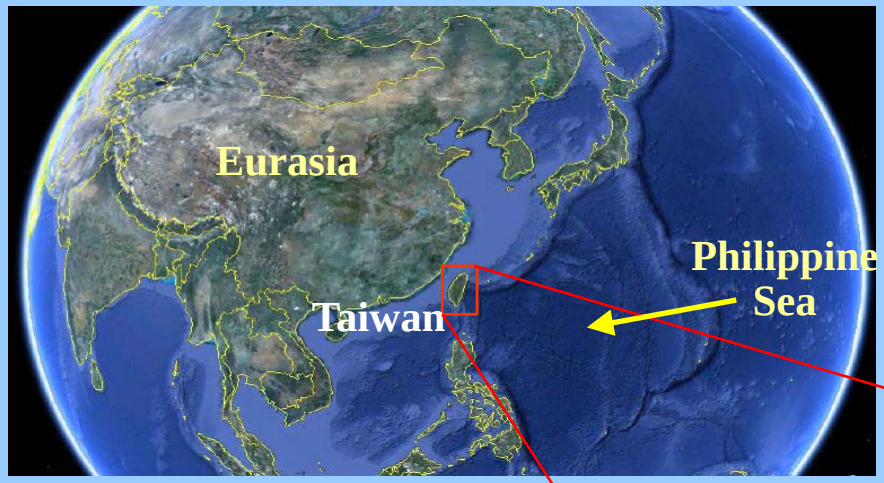
Li Zhao

Institute of Earth Sciences, Academia Sinica.

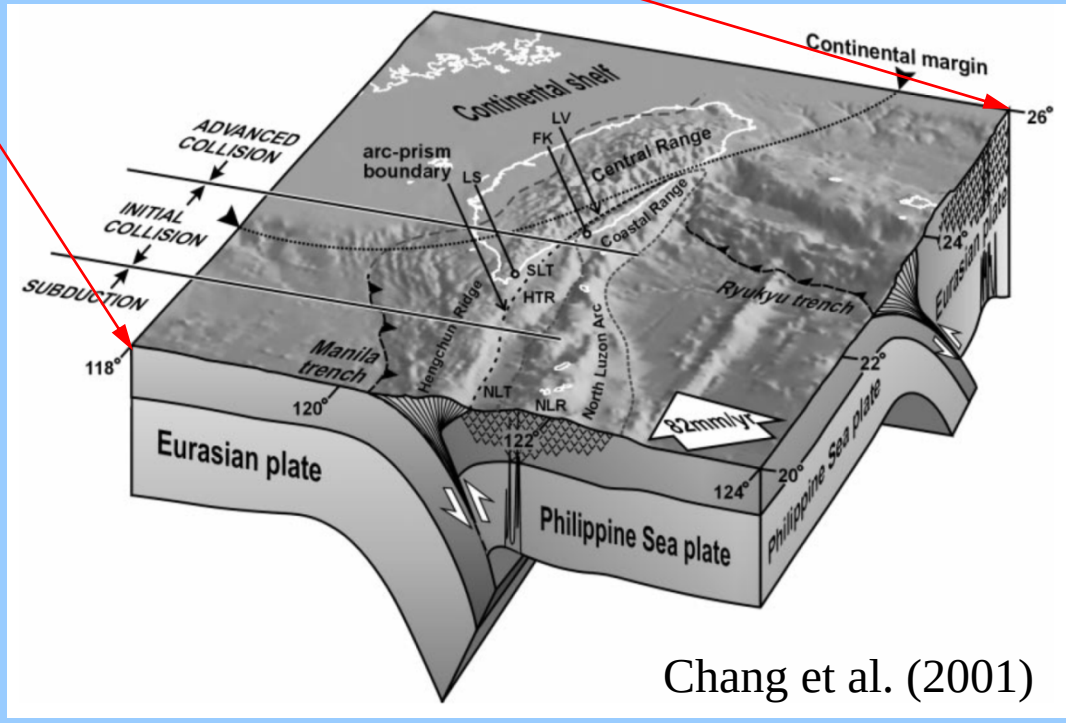
Outline

- A brief review of the development of 3D models for the Taiwan region
- Recent advancement with improved datasets
- Applications of ground-truth first-arrival times from TAIGER project
- Contribution from surface wave data
- Future direction

Tectonic Setting of Taiwan

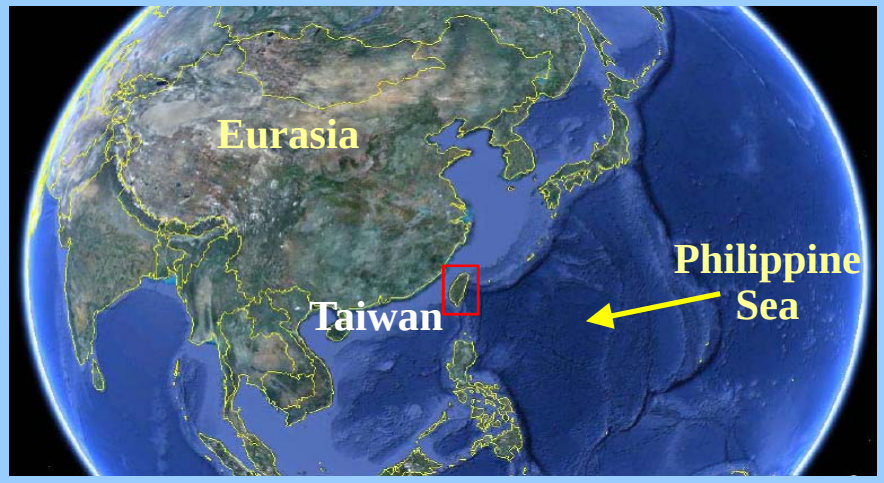


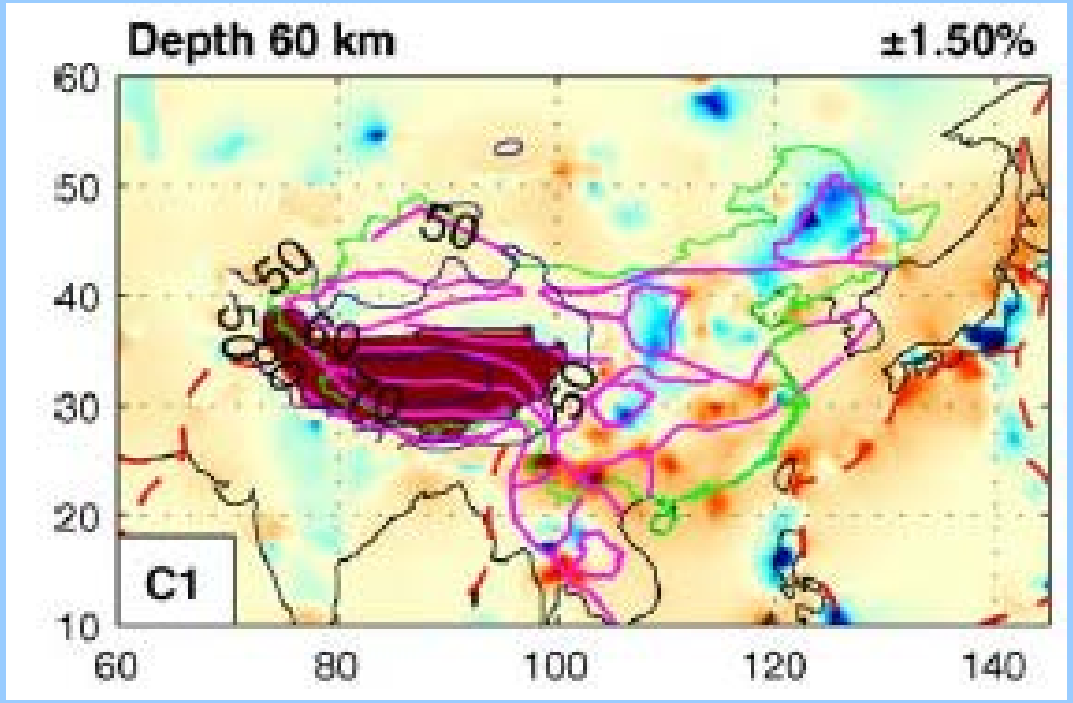
- Oblique convergent boundary between Eurasia and the Philippine Sea plates
- Active subductions: northward in the northeast and eastward in the south
- Arc-continent collision between two subductions
- Continental margin in the west and accretion in the east



Chang et al. (2001)

Taiwan in Regional Studies





Li et al. (2006)

Development of 3D Models of Taiwan

First generation: limited travel time data at a small number of stations (< 100) from numerous local earthquakes

Roecker et al. (1987); Shin & Chen (1988); Rau & Wu (1995); Ma et al. (1996).

Second generation: more extensive travel time data at more stations from numerous local (and teleseismic) events

Kim et al. (2005); Wang et al. (2006); Wu et al. (2007).

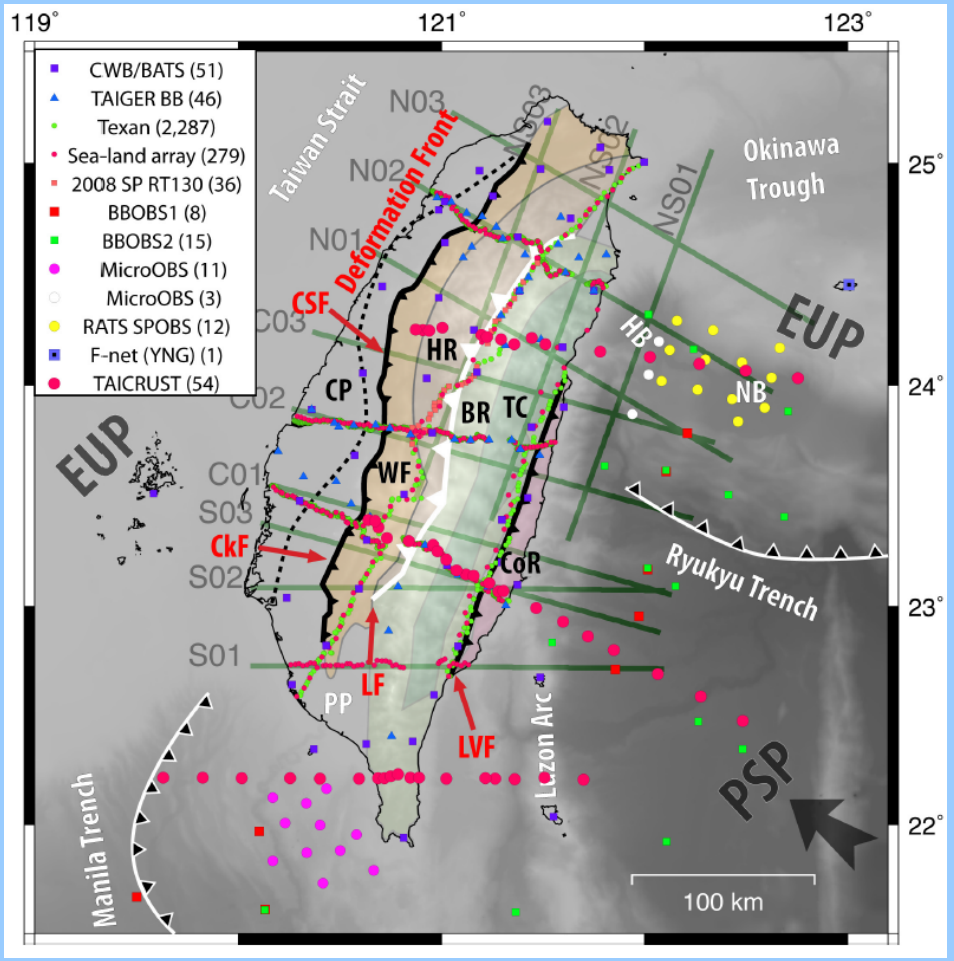
Third generation: travel time data at numerous stations (TAIGER project) from local, teleseismic and active sources

Kuo-Chen et al. (2012).

Third Generation: the TAIGER Project

TAiwan Integrated GEodynamics Research Project

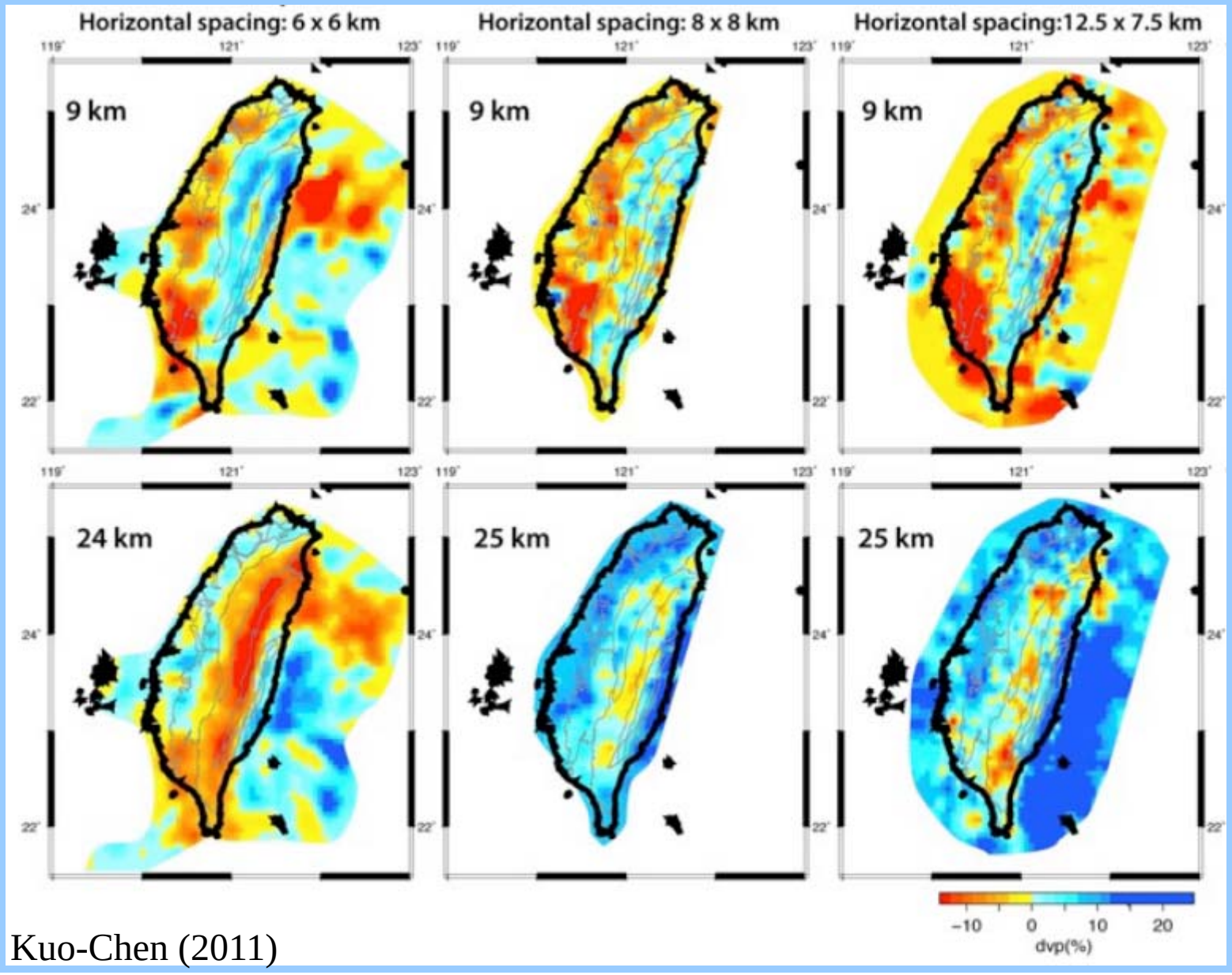
1. Passive: land and marine broadband deployments.
2. Active:
   - ➢ Land explosions
     - 10 explosions (two transects)
     - 1400 recording sites
   - ➢ Marine seismic surveys
     - Six transects
3. Other geophysical means.



Kuo-Chen (2011)

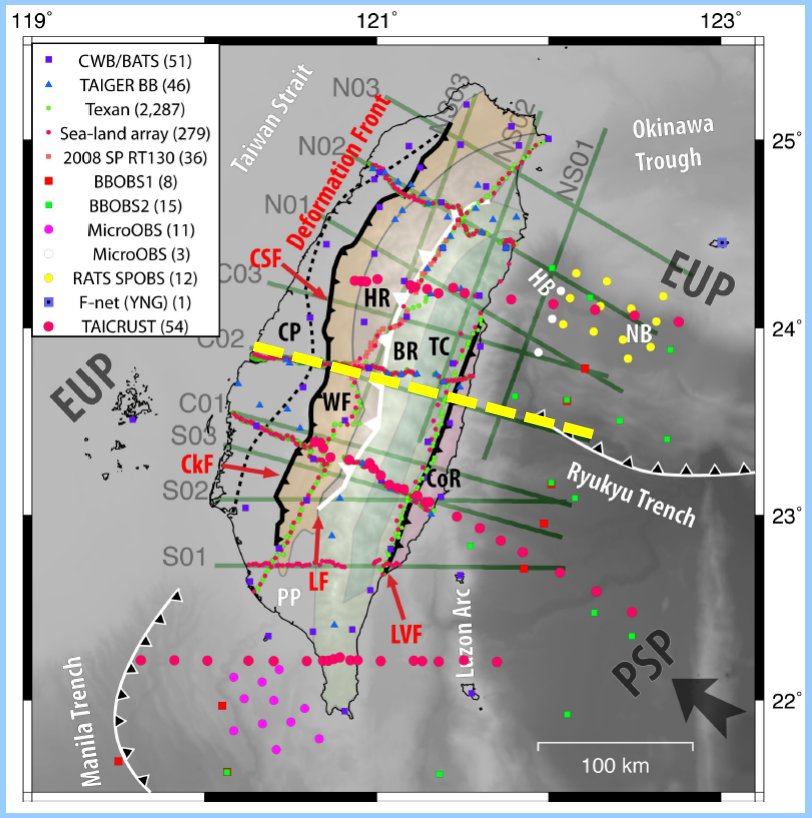
Comparison of 2nd and 3rd Generation Models

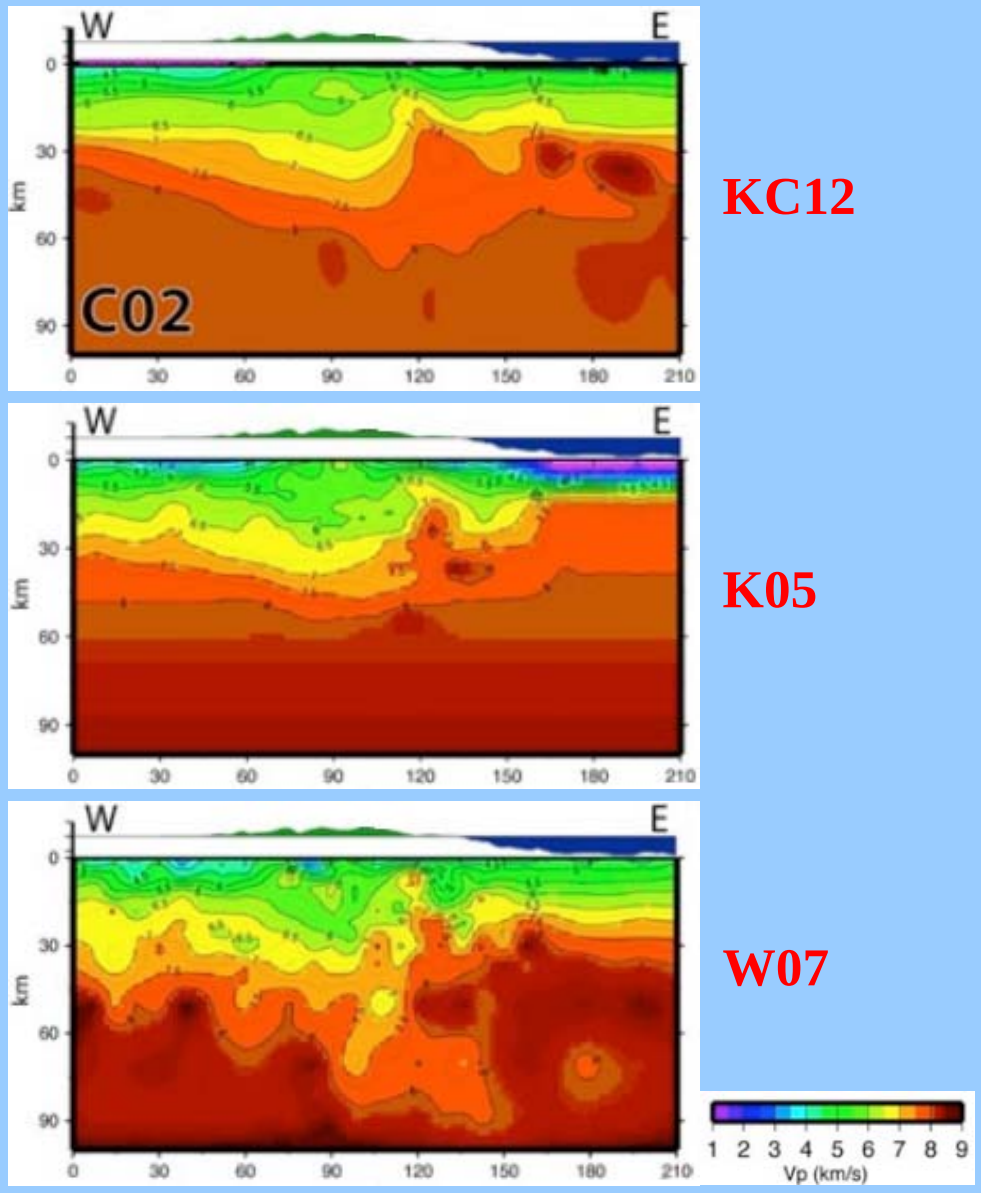
KC12 Kuo-Chen *et al.* (2012) **K05** Kim et al. (2005) **W07** Wu et al. (2007)



Kuo-Chen (2011)

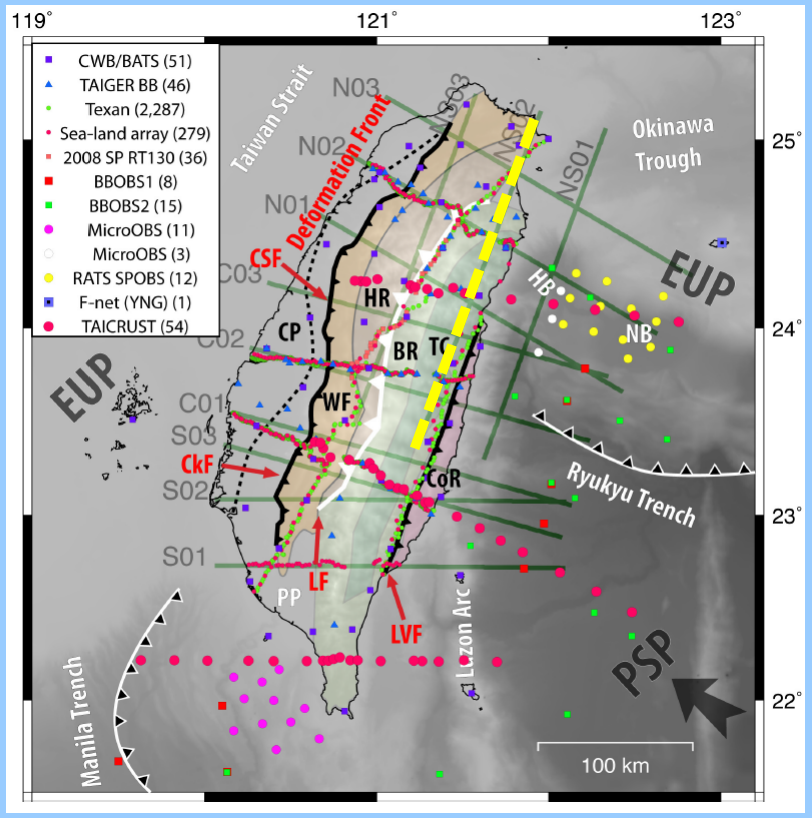
Comparison along a Central E-W Transect

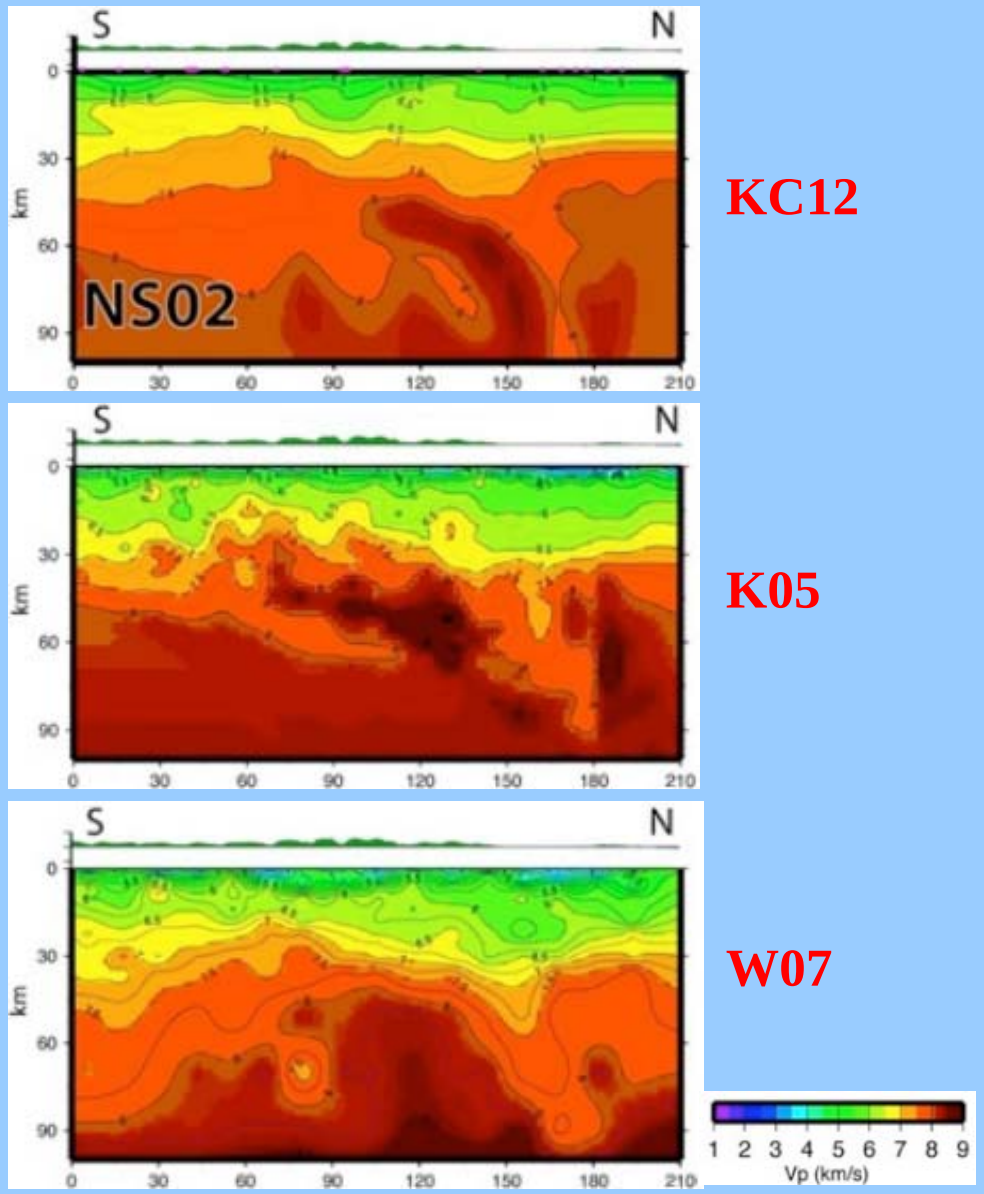




Kuo-Chen (2011)

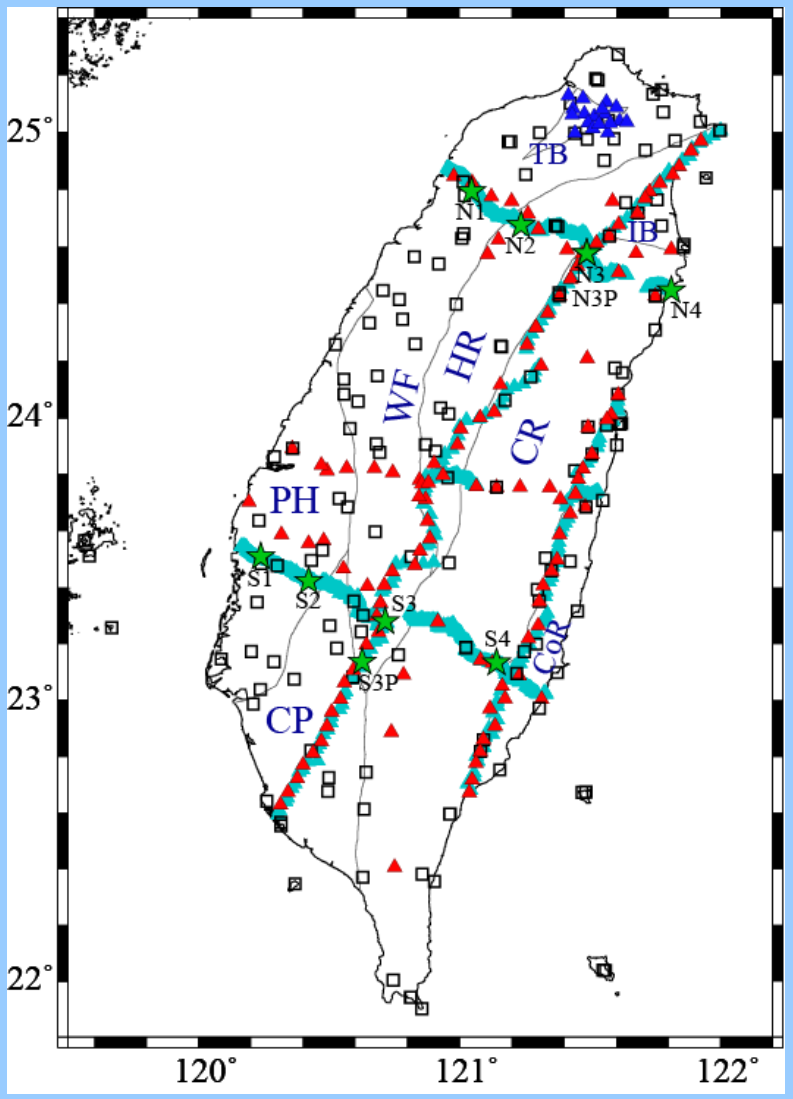
Comparison along a Central N-S Transect





Kuo-Chen (2011)

Model Evaluation Using Ground-Truth Data

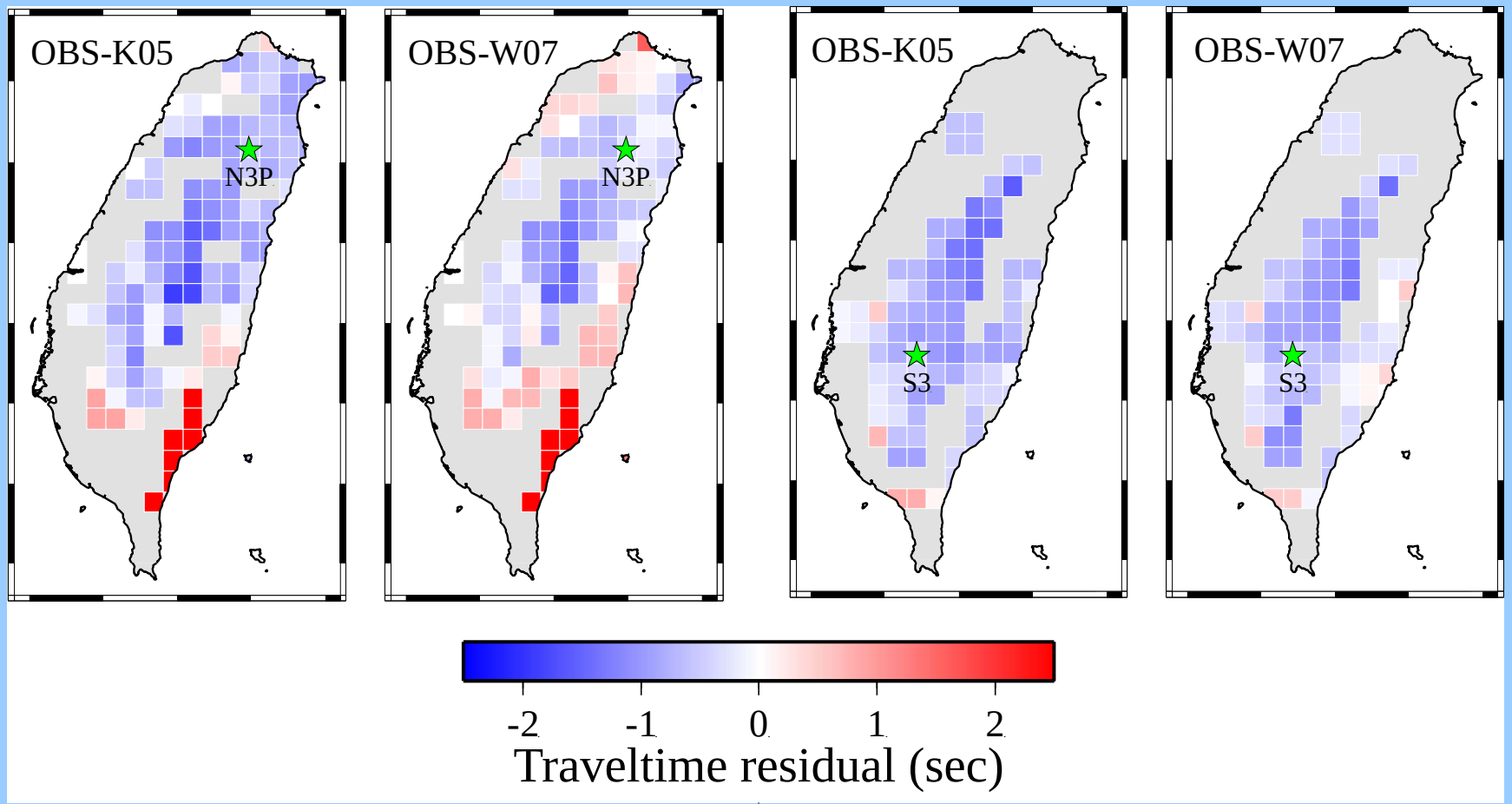


Ground-truth data comes from:

- 10 Explosions by the TAIGER project
- Total number of land receiver sites: ~1000
- Hand-picked first-arrival times (error < 0.1s)
- Total number of reliable picks: ~ 6000

Shot Point	Size (kg)	Date (GMT) dd/mm/yyyy	hh:mm:ss.sss	CWB ML	Longitude (GS84)	Latitude	Elev. (m)
S1	1000	02/27/2008	17:01:49.486	3.02	120.238026	23.508864	6
S2	750	02/27/2008	17:30:57.350	2.62	120.421259	23.423385	20
S3	500	02/26/2008	18:02:45.860	1.89	120.714736	23.280129	650
S3P	1500	02/26/2008	17:32:43.290	1.78	120.626749	23.136994	335
S4	750	02/28/2008	17:02:08.560	2.30	121.141722	23.132877	390
N1	750	03/06/2008	17:03:23.068	2.56	121.045868	24.793562	55
N2	750	03/06/2008	17:34:56.364	1.55	121.235817	24.675632	590
N3	750	03/04/2008	18:01:17.988	2.10	121.487867	24.576938	405
N3P	3000	03/04/2008	17:01:17.824	2.67	121.487867	24.576938	405
N4	1000	03/05/2008	17:03:40.008	2.43	121.811684	24.446901	6

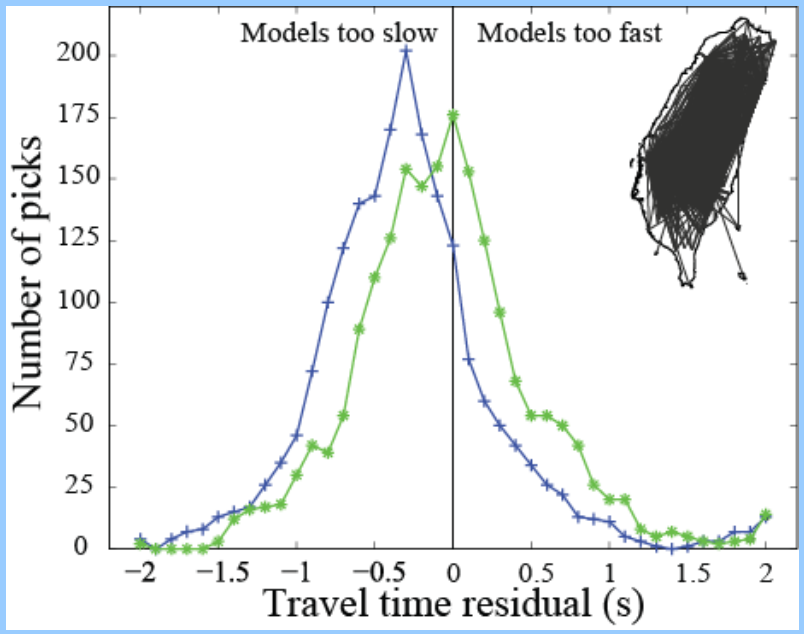
Travel Time Residuals of Models K05 and W07



Lin et al. (2011)

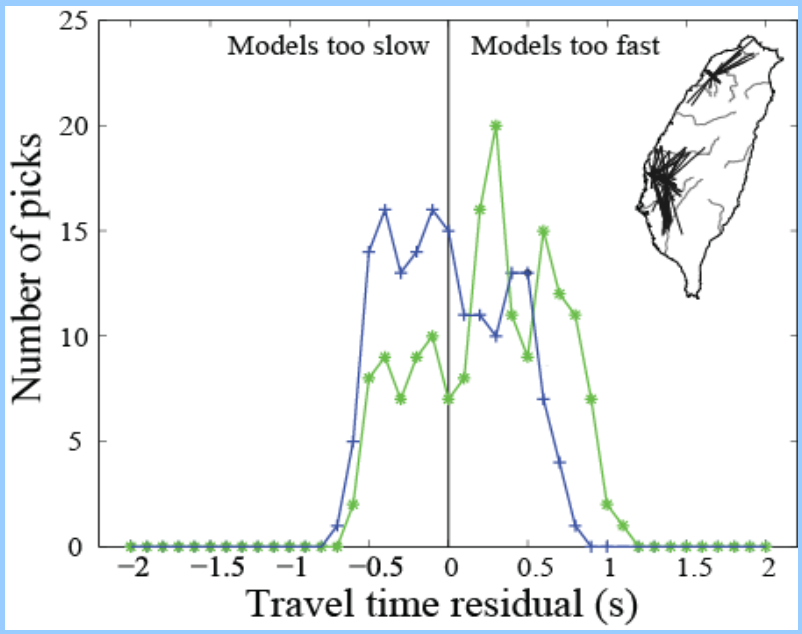
Statistics of Travel Time Residuals

All picks



Model	RMS (s)	Mean (s)
K05	0.75	-0.27
W07	0.66	-0.03

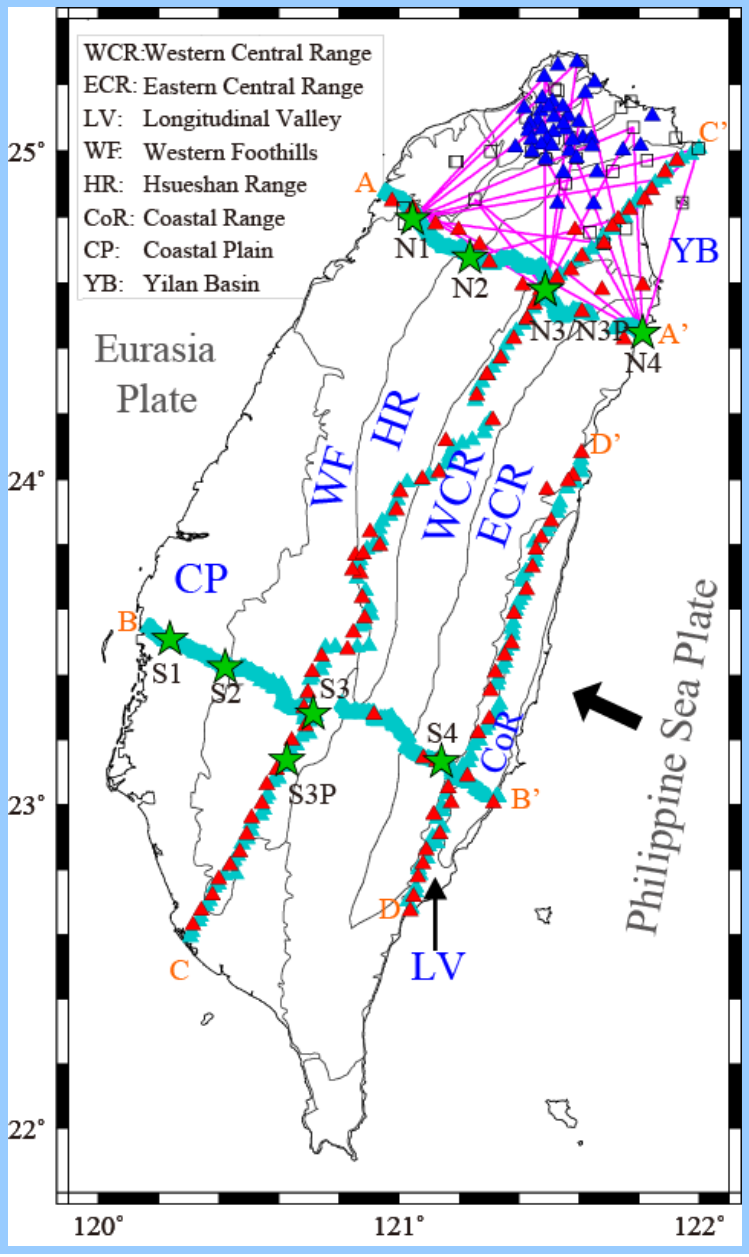
Picks from Coastal Plain



Model	RMS (s)	Mean (s)
K05	0.37	0.01
W07	0.49	0.24

Lin et al. (2011)

Constraining Structure by Ground-Truth Data



First-arrival times from four long profiles and dense receivers in northern Taiwan

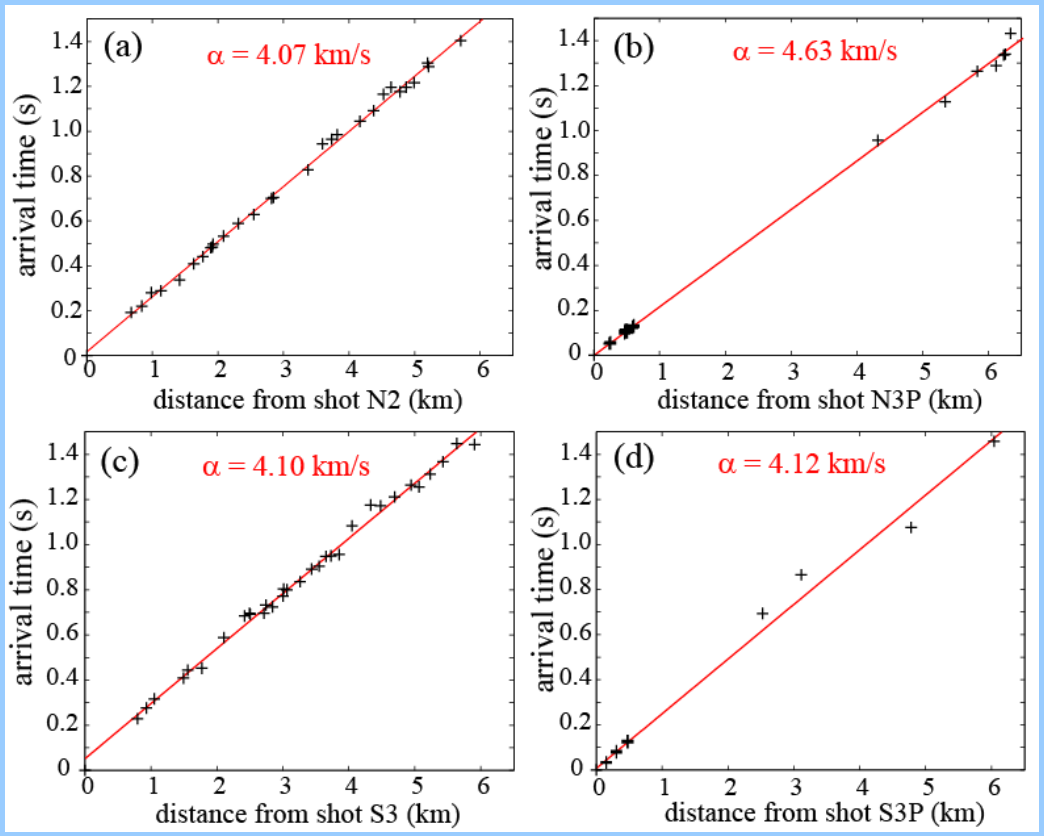
10 Explosions

First-arrival picks: ~ 3400 (out of ~ 6000)

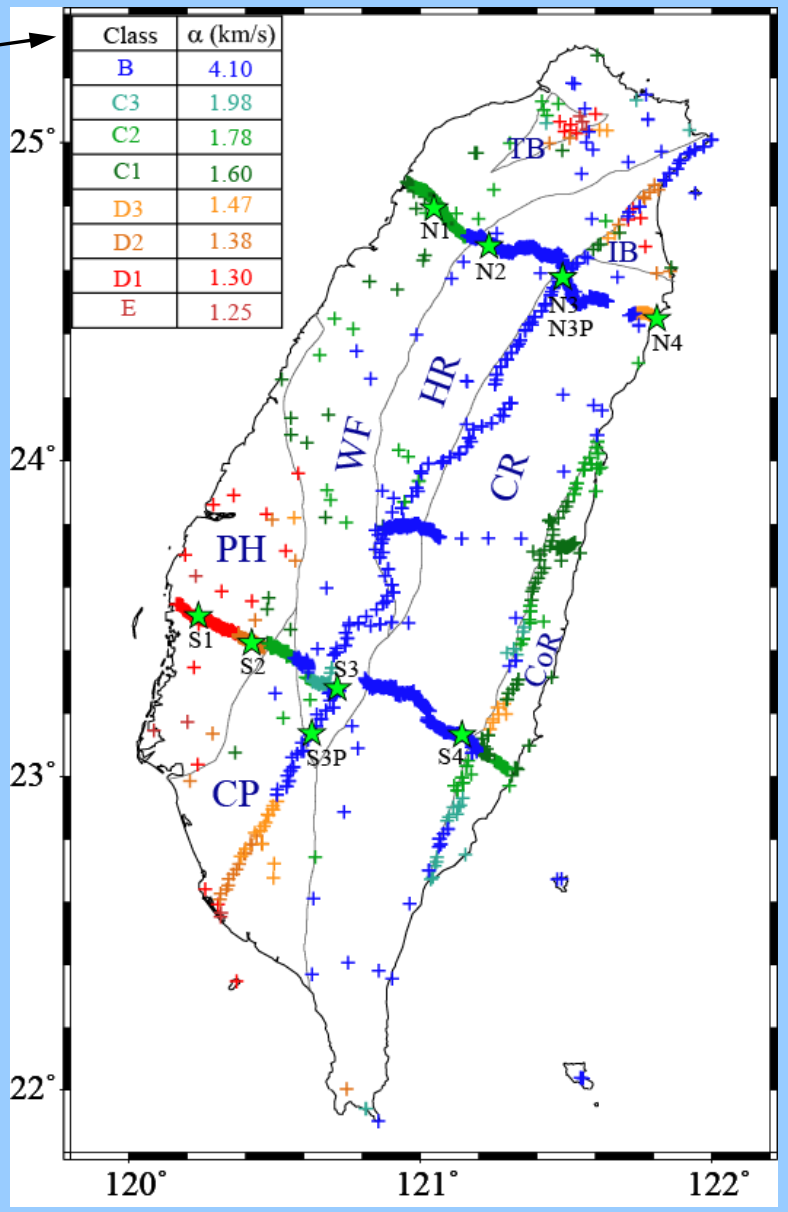
Shot Point	Size (kg)	Date (GMT) dd/mm/yyyy	hh:mm:ss.sss	CWB ML	Longitude (GS84)	Latitude	Elev. (m)
S1	1000	02/27/2008	17:01:49.486	3.02	120.238026	23.508864	6
S2	750	02/27/2008	17:30:57.350	2.62	120.421259	23.423385	20
S3	500	02/26/2008	18:02:45.860	1.89	120.714736	23.280129	650
S3P	1500	02/26/2008	17:32:43.290	1.78	120.626749	23.136994	335
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N1	750	03/06/2008	17:03:23.068	2.56	121.045868	24.793562	55
N2	750	03/06/2008	17:34:56.364	1.55	121.235817	24.675632	590
N3	750	03/04/2008	18:01:17.988	2.10	121.487867	24.576938	405
N3P	3000	03/04/2008	17:01:17.824	2.67	121.487867	24.576938	405
N4	1000	03/05/2008	17:03:40.008	2.43	121.811684	24.446901	6

Near-Surface Wave Speed Estimation

Surface site classification from Lee & Tsai (2008)

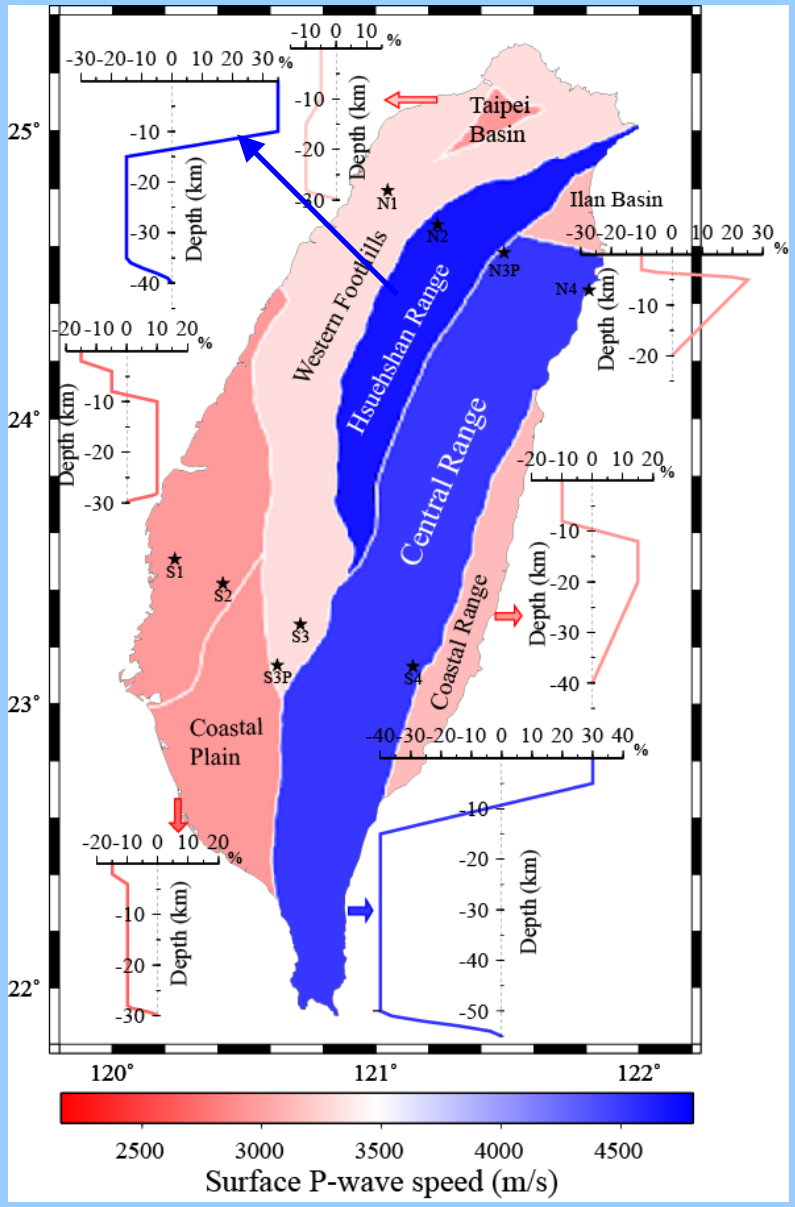


Lin et al. (2011)

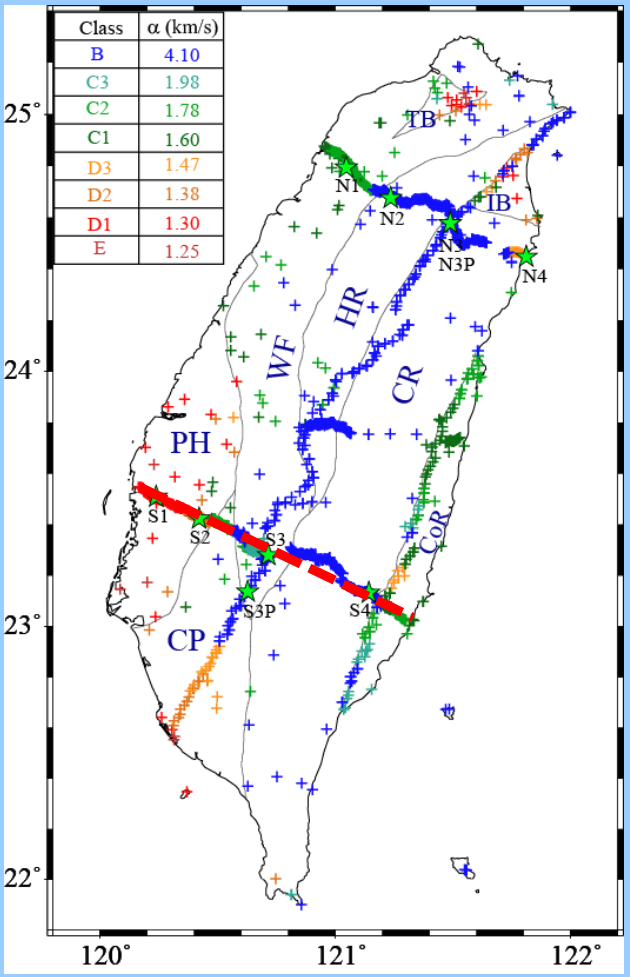


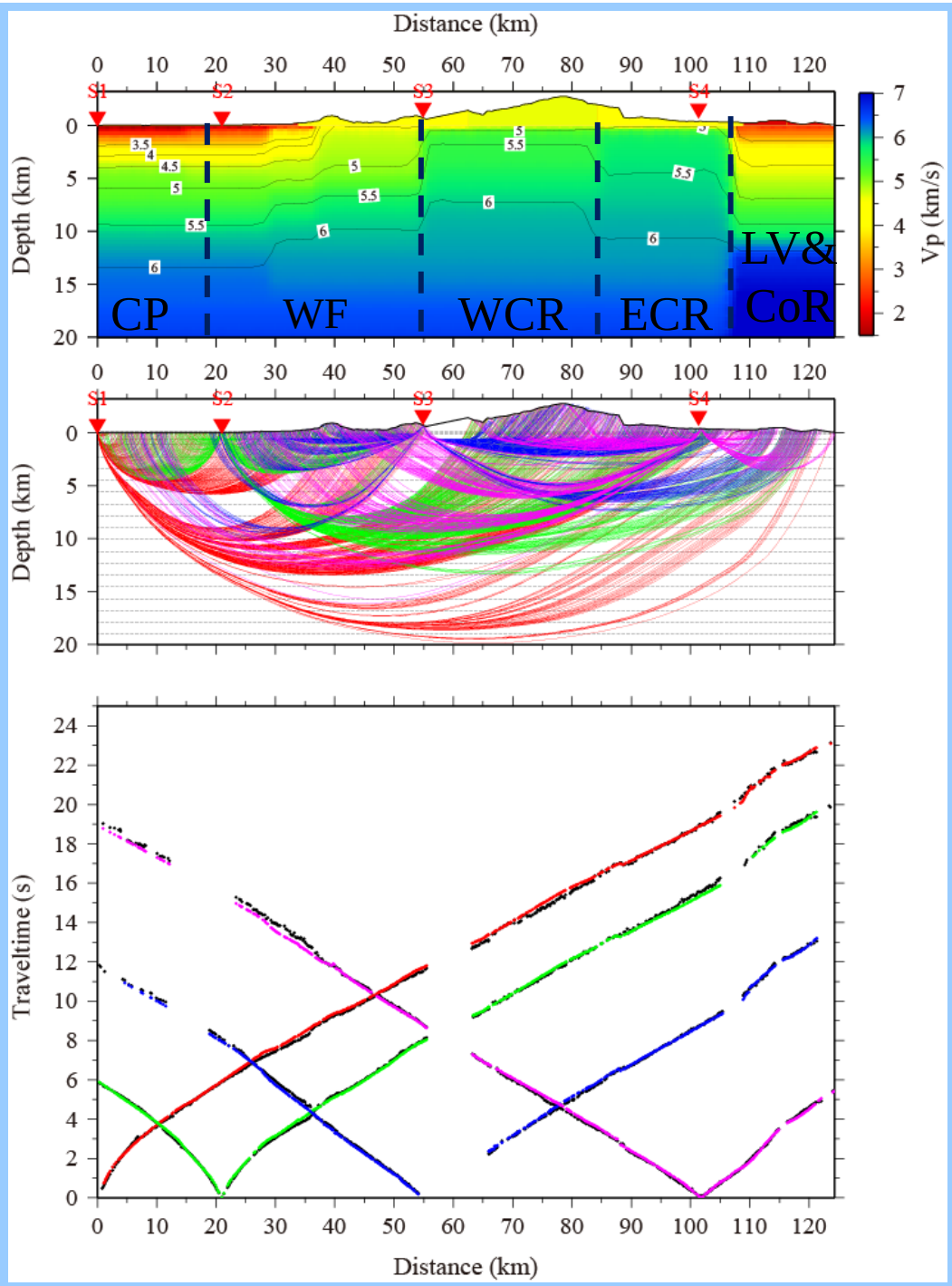
Geological Zonation of Taiwan



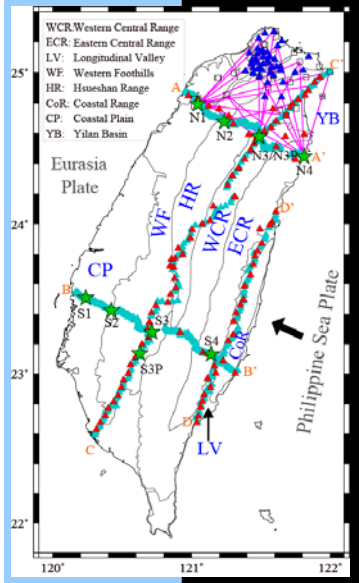


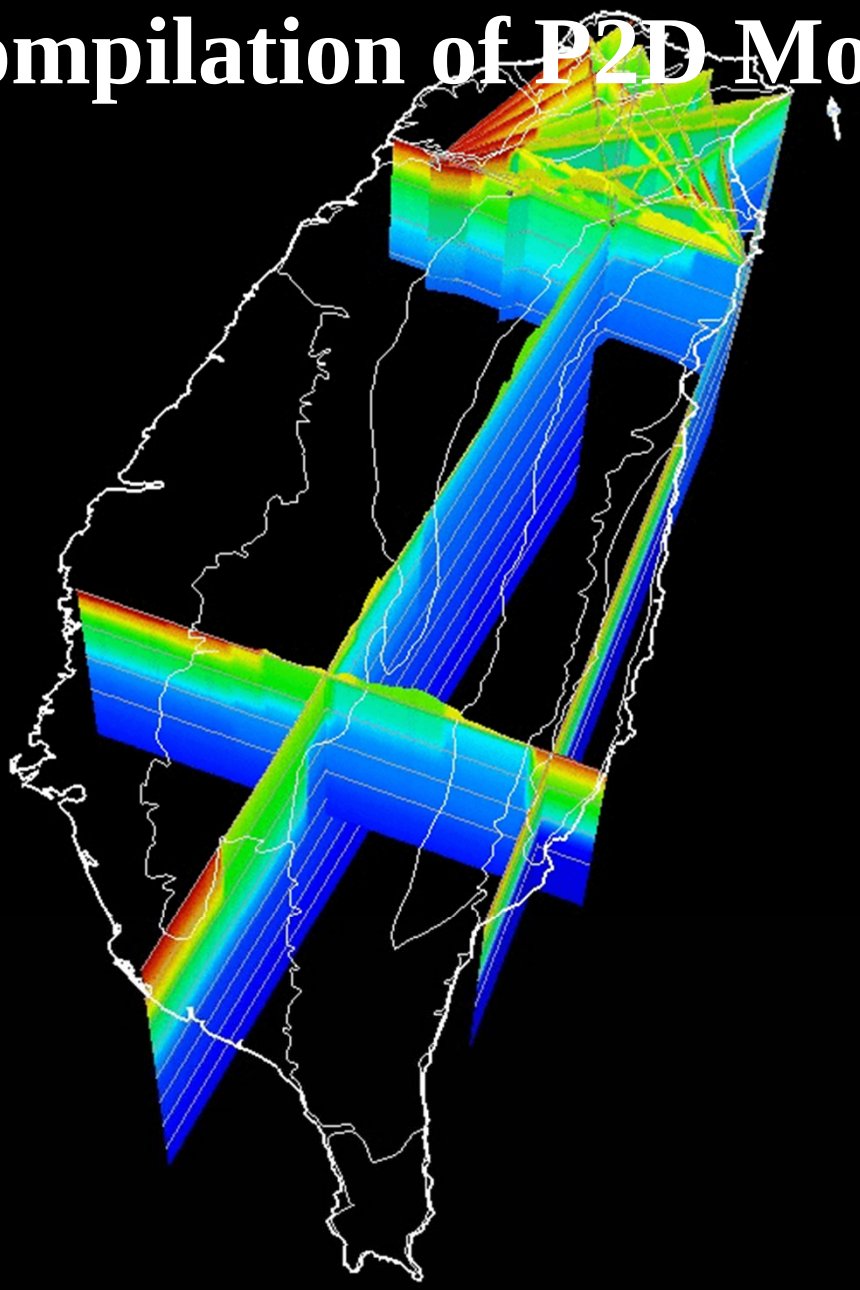
Pseudo-2D (P2D) Model

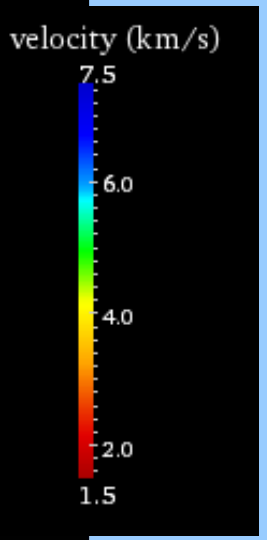




Compilation of P2D Models

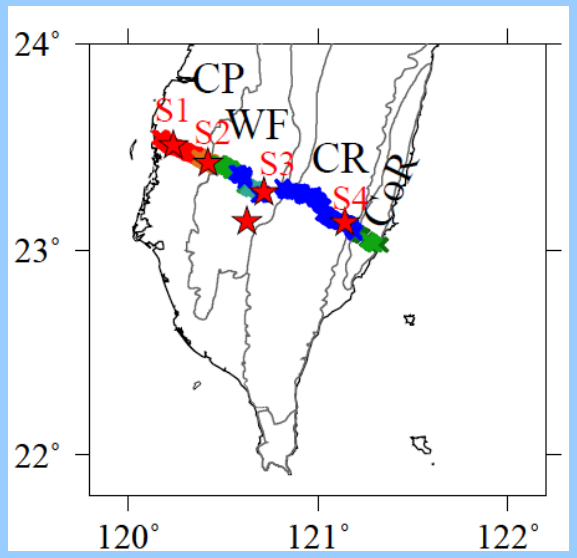


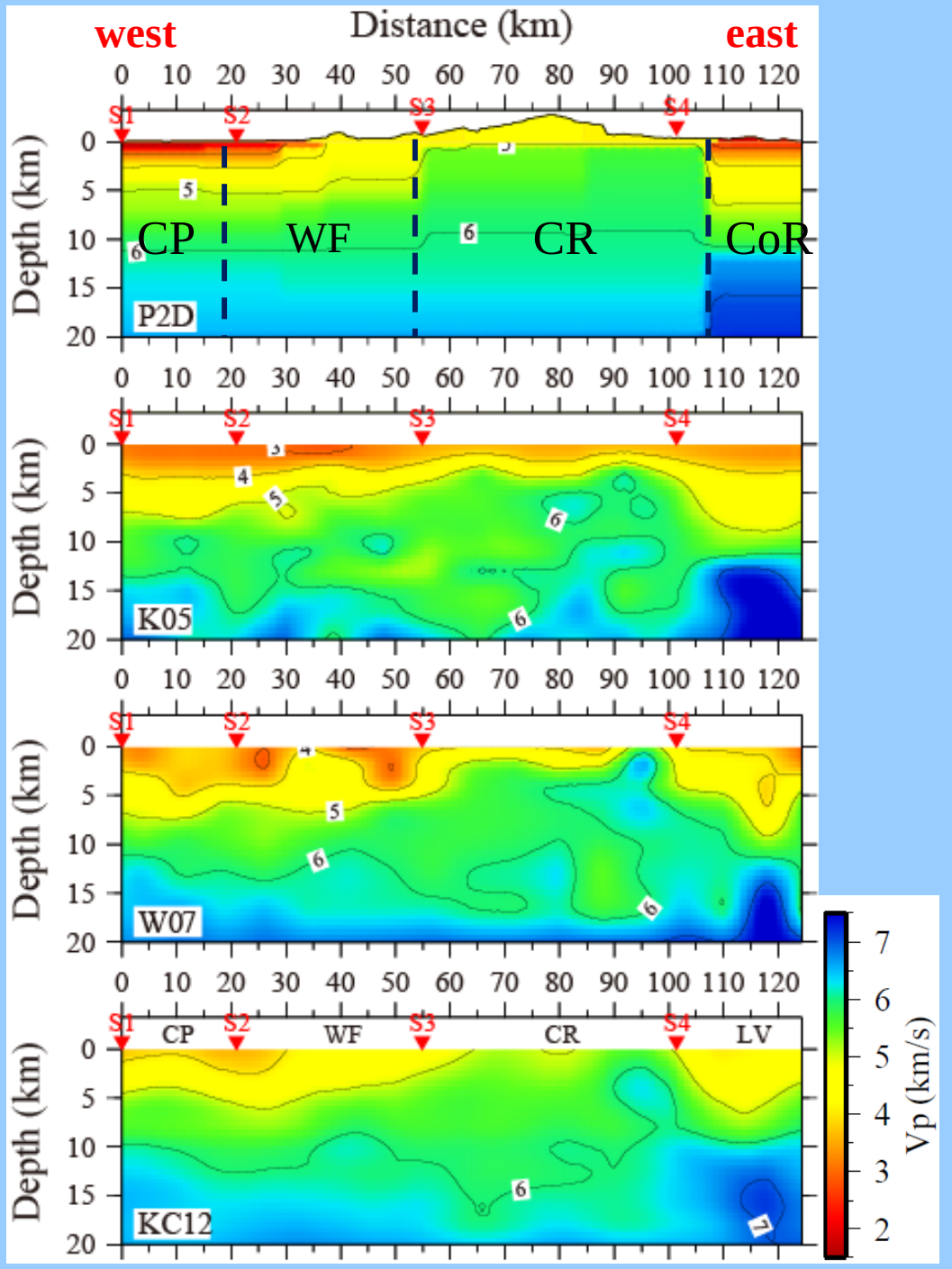




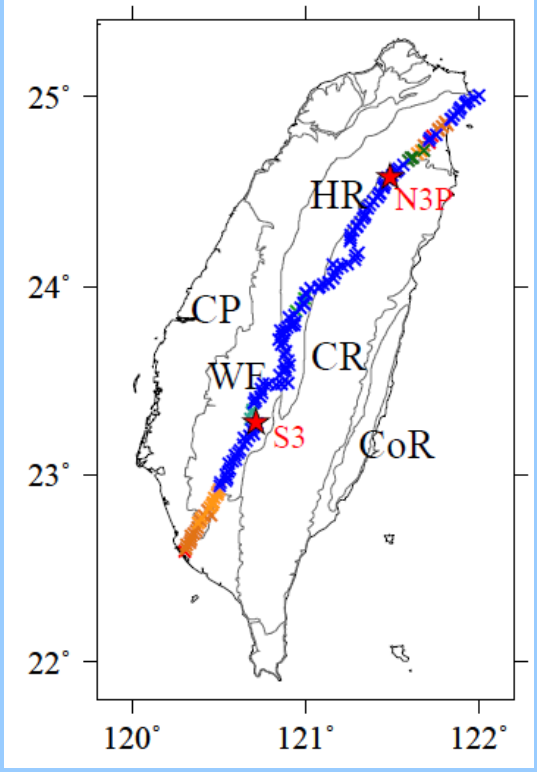
Comparison with Tomography Models

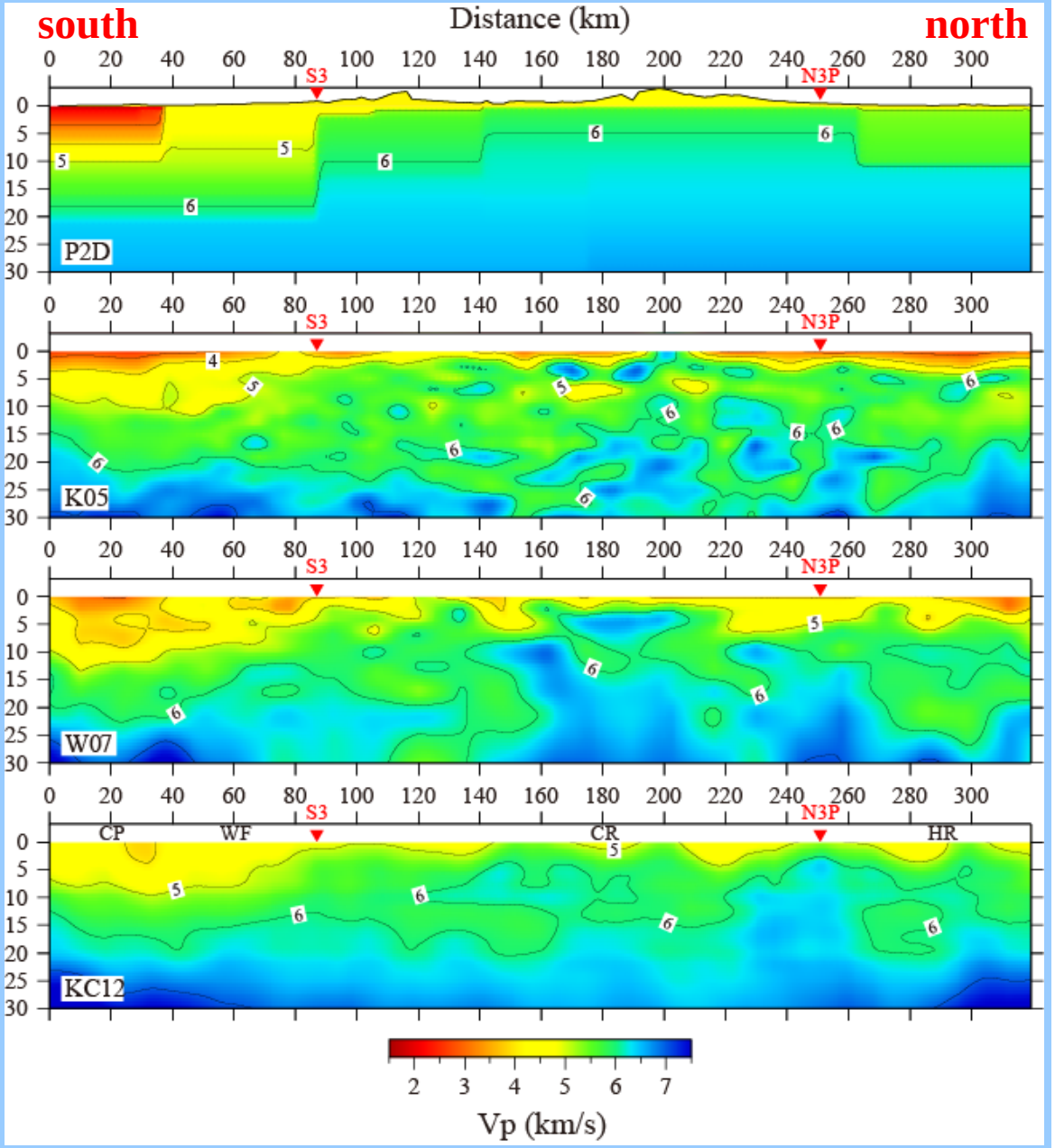
Model	RMS(s)	Perturbation (%)
P2D	0.13	-61 ~ 42
K05	0.37	-10 ~ 10
W07	0.41	-10 ~ 10
KC12	0.56	-15 ~ 25



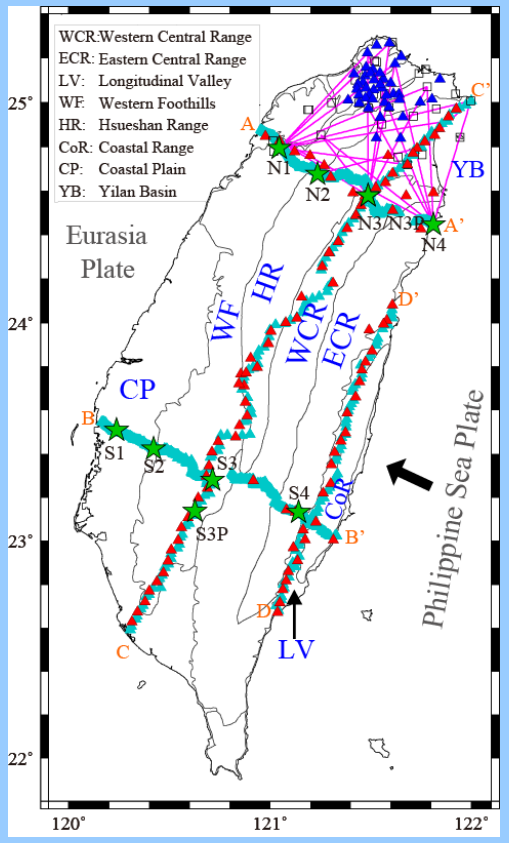


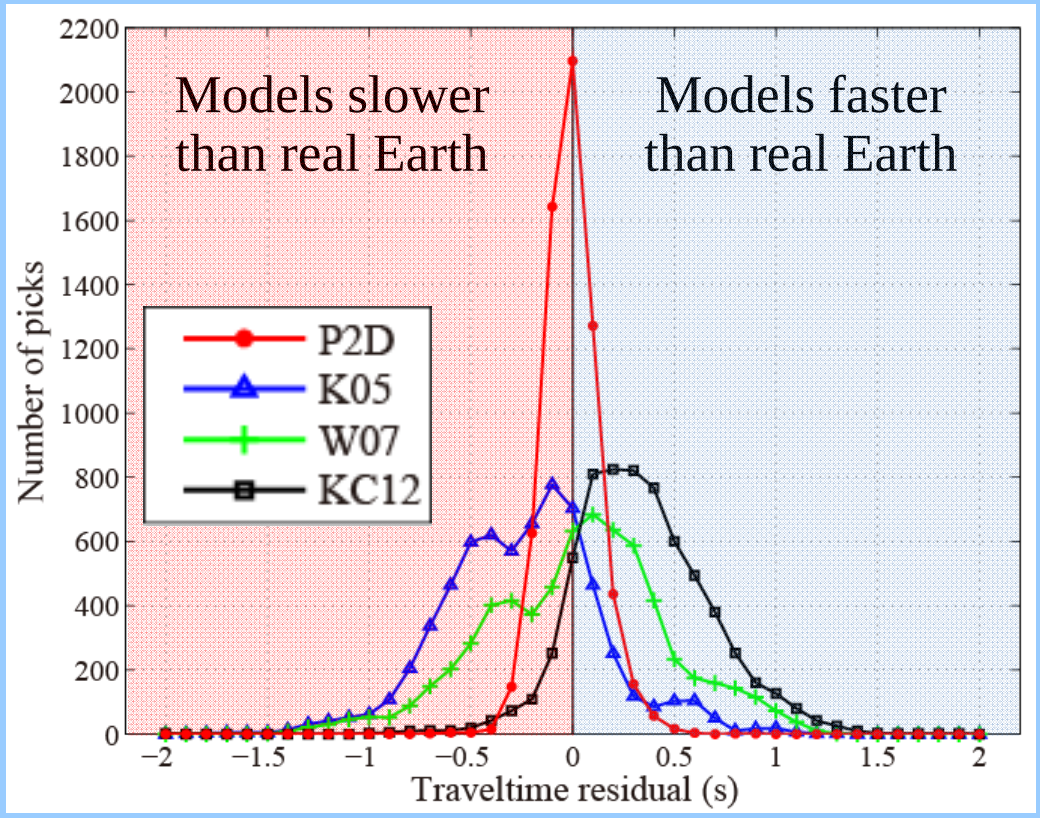
Comparison with Tomography Models





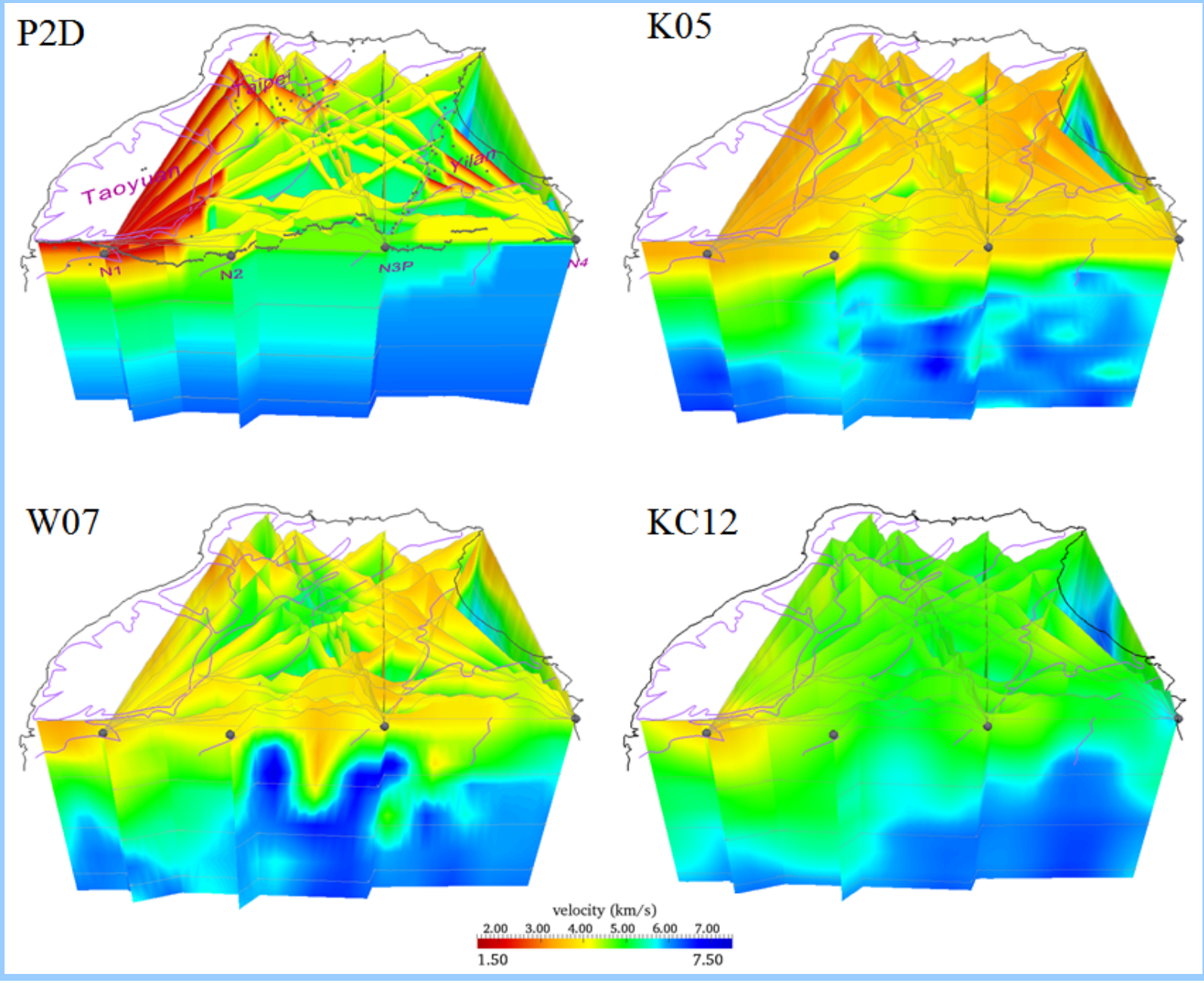
Quantitative Comparison (4 Longer Profiles)



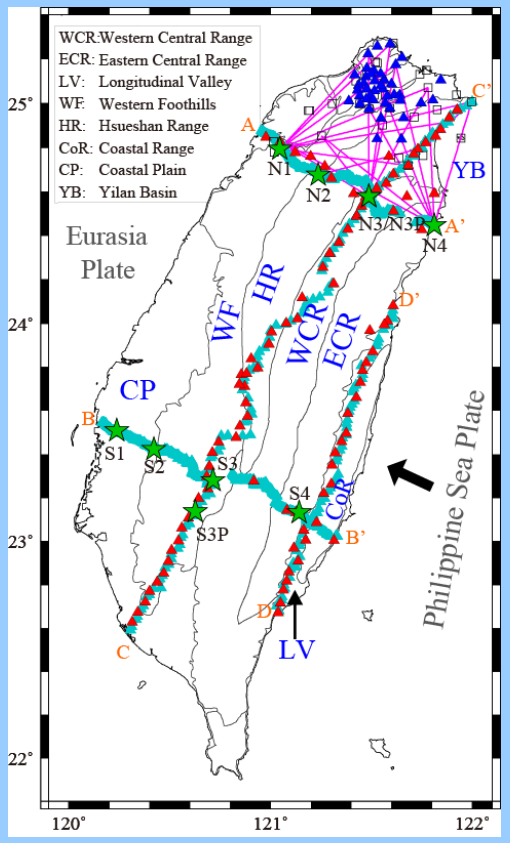


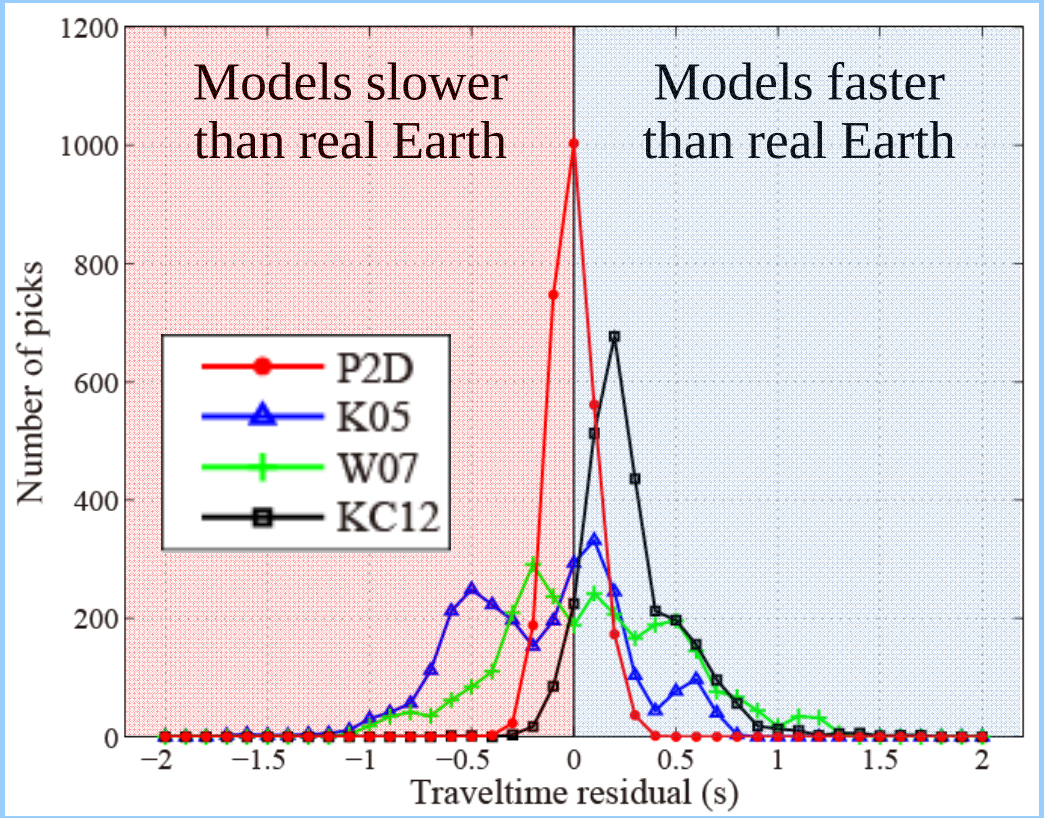
	Mean (s)	RMS (s)	Variance (s^2)
P2D	-0.007	0.12	0.02
K05	-0.25	0.45	0.15
W07	0.02	0.45	0.20
KC12	0.34	0.47	0.11

Comparison in Northern Taiwan



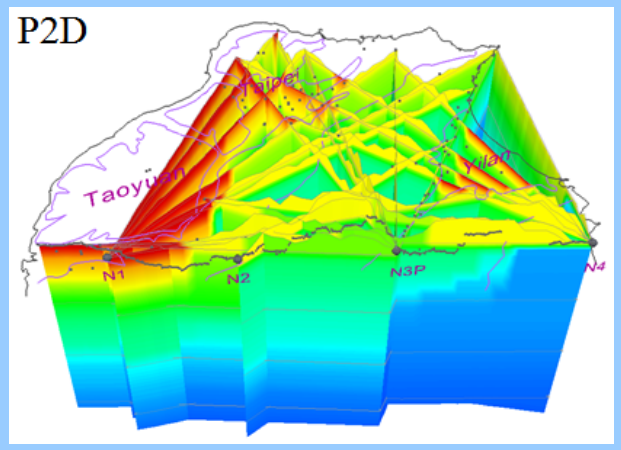
Quantitative Comparison (Northern Taiwan)

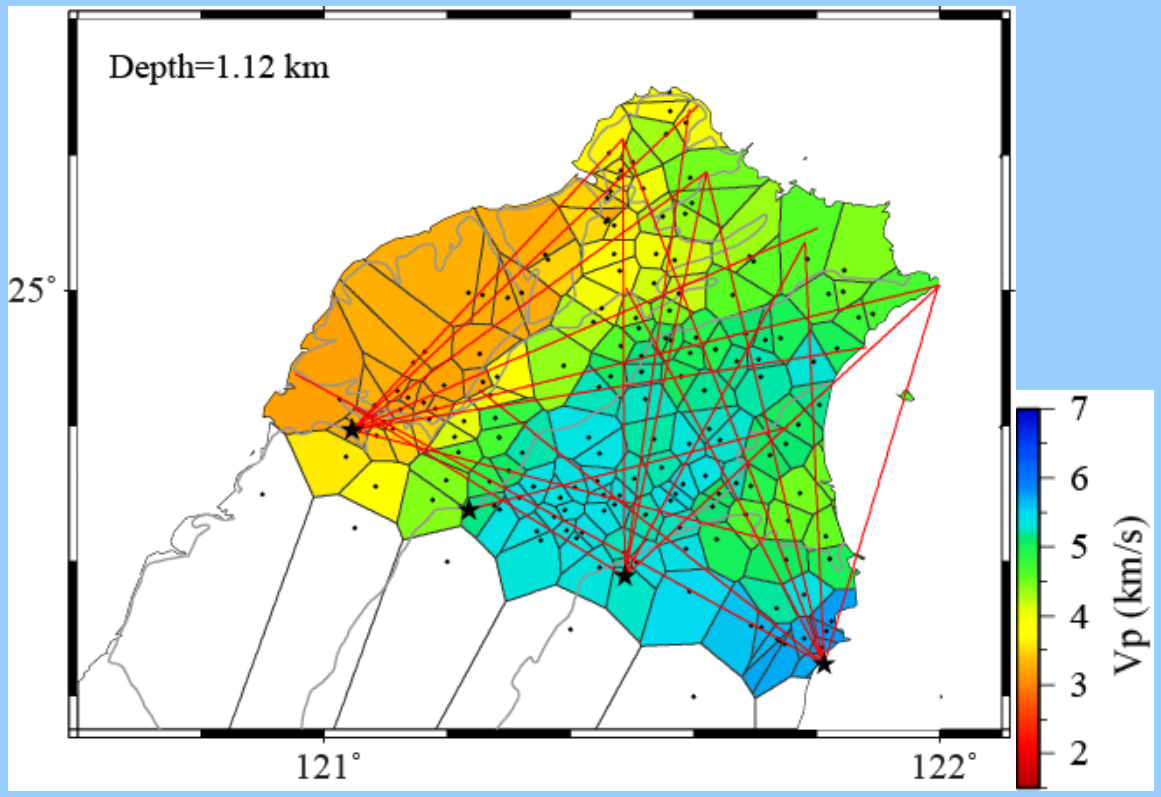




	Mean (s)	RMS (s)	Variance (s^2)
P2D	-0.007	0.10	0.01
K05	-0.15	0.43	0.16
W07	0.09	0.46	0.20
KC12	0.28	0.36	0.06

Partition Modelling Tomography in Northern Taiwan





1. The study region is partitioned by horizontal Voronoi cells.
2. The Voronoi cells are determined by randomly-generated control points (black dots) with density based on distribution of P2D profiles.
3. The velocity in each cell is assumed homogeneous, with value determined by the average of all the P2D profiles passing through the cell (red lines).

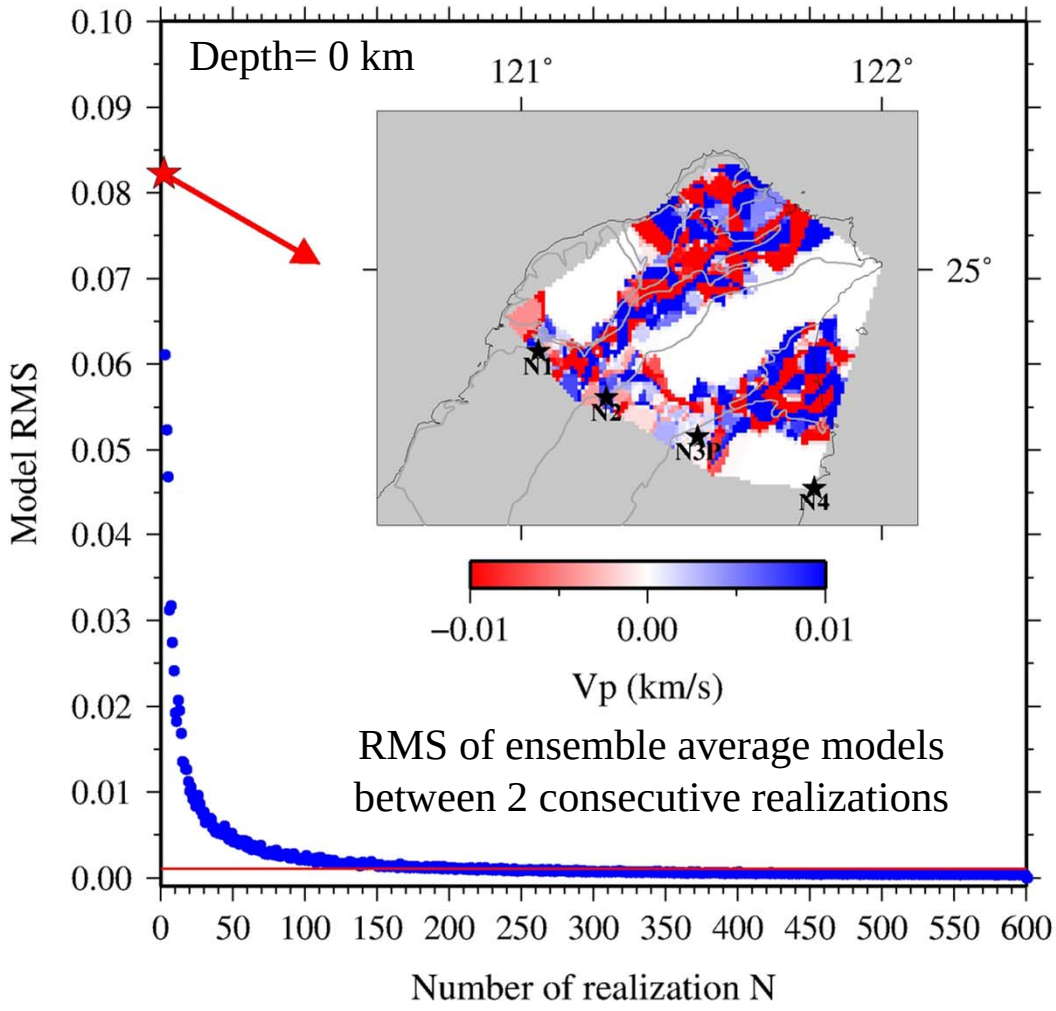
Stability Test

$$\mathrm{RMS} = \sqrt{\frac{\sum_{i=1}^{M}(V_i^N - V_i^{N-1})^2}{M}}$$

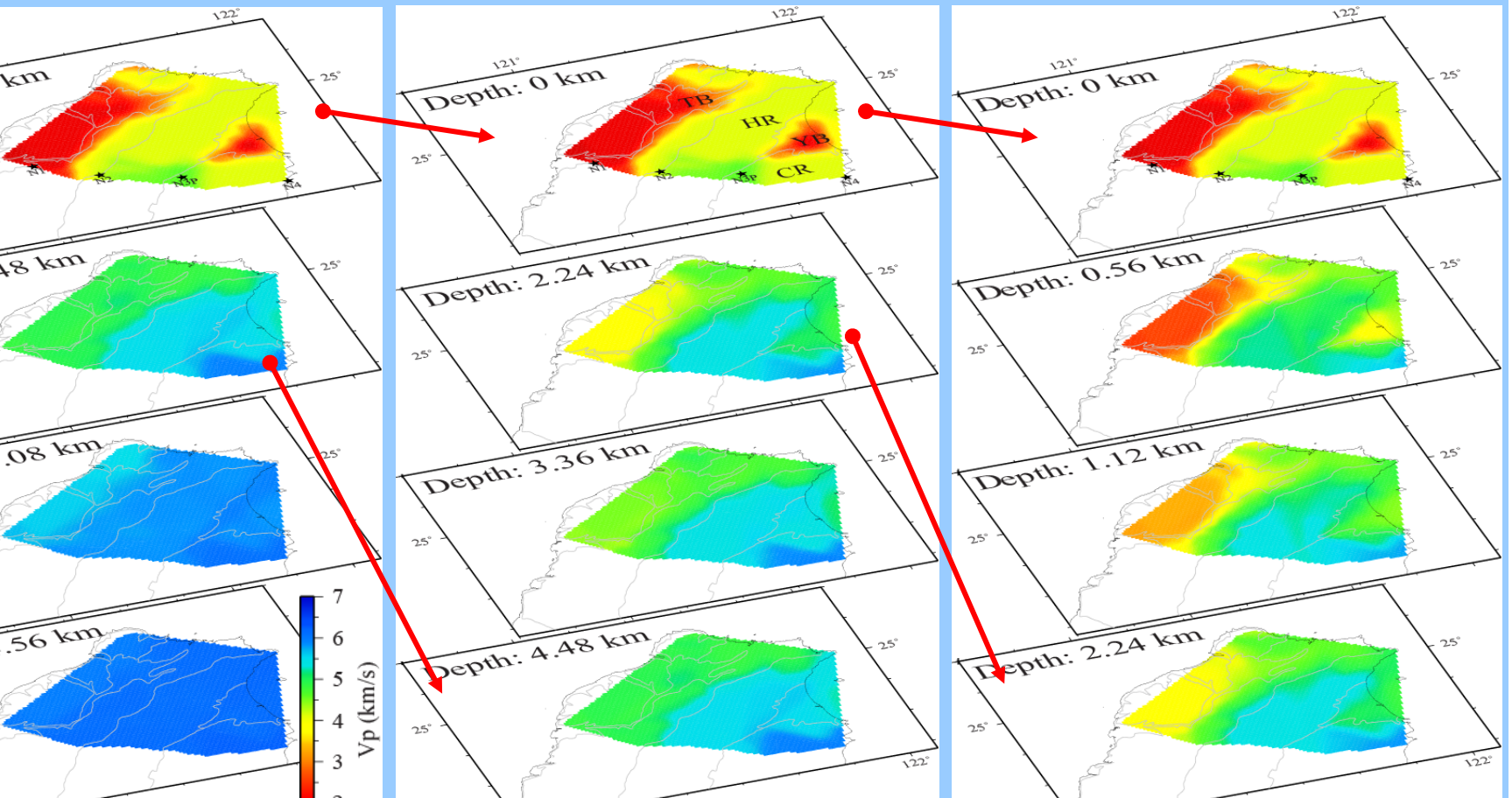
V_i^N : Ensemble average velocity at point i after N realizations

V_i^{N-1} : Ensemble average velocity at point i after N-1 realizations

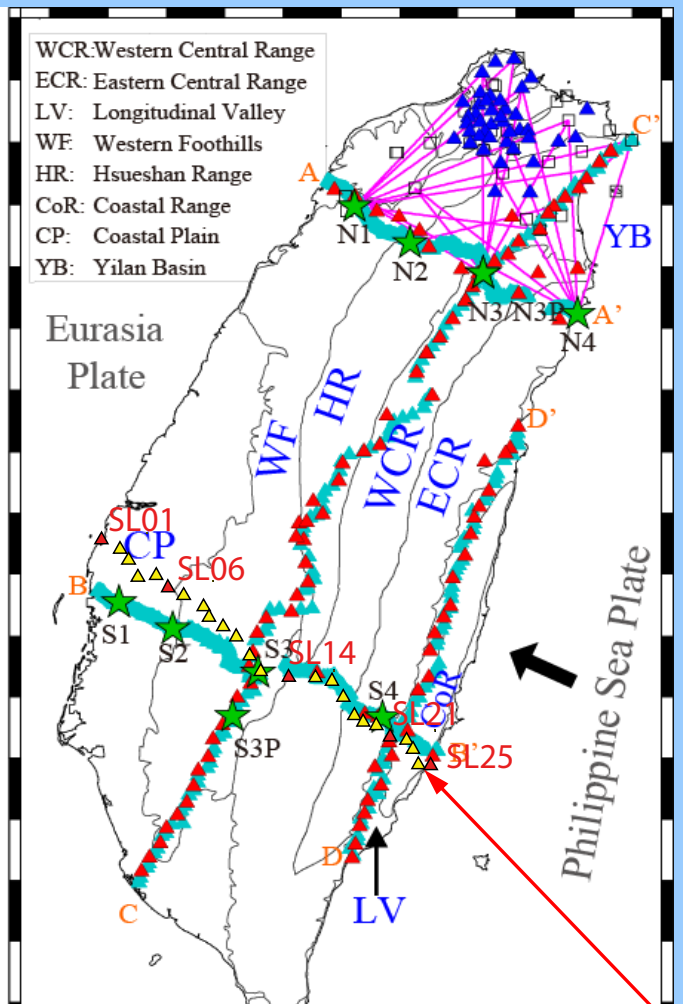
M : number of sampling points

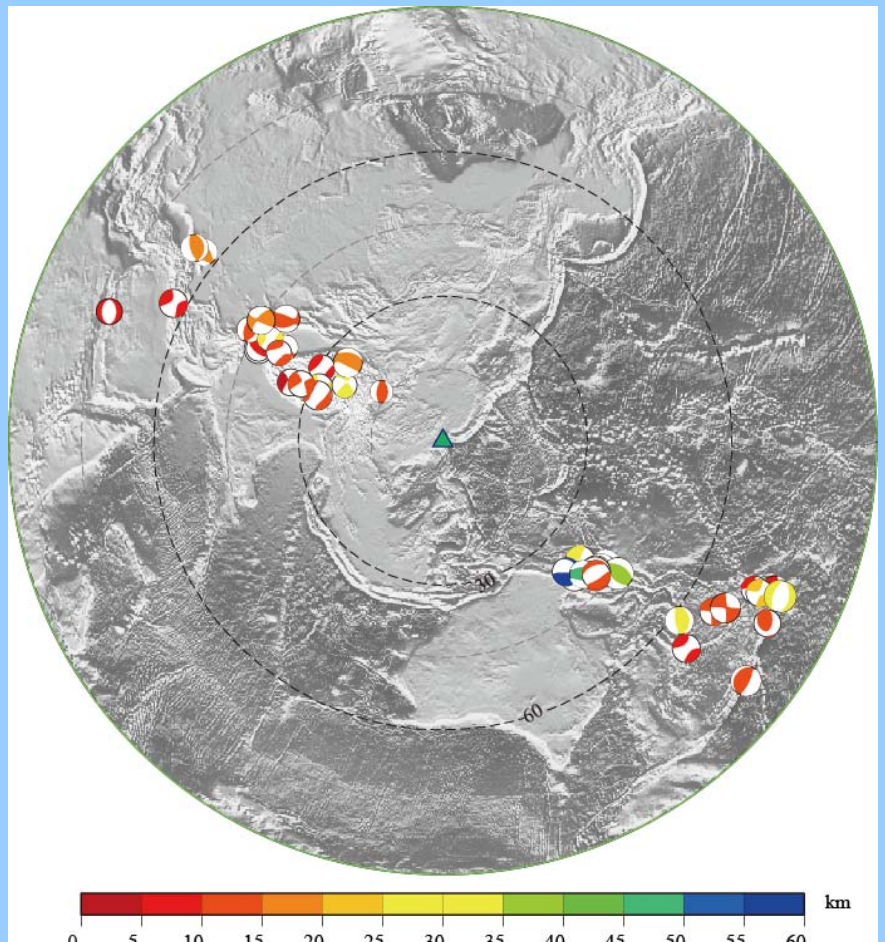


emble Average Model of Northern Taiwan

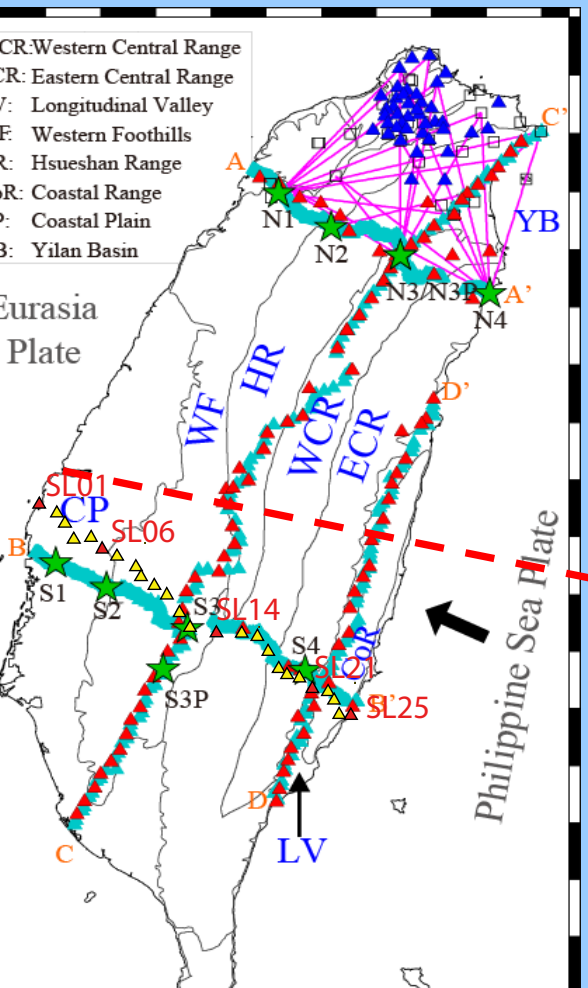


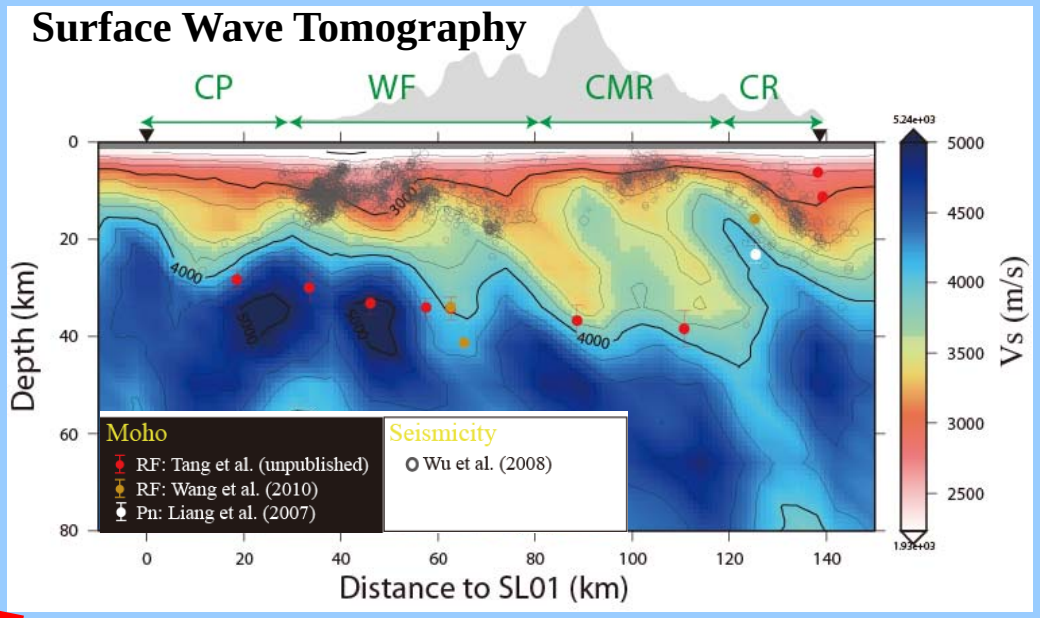
rface Wave Phase Velocity Tomography



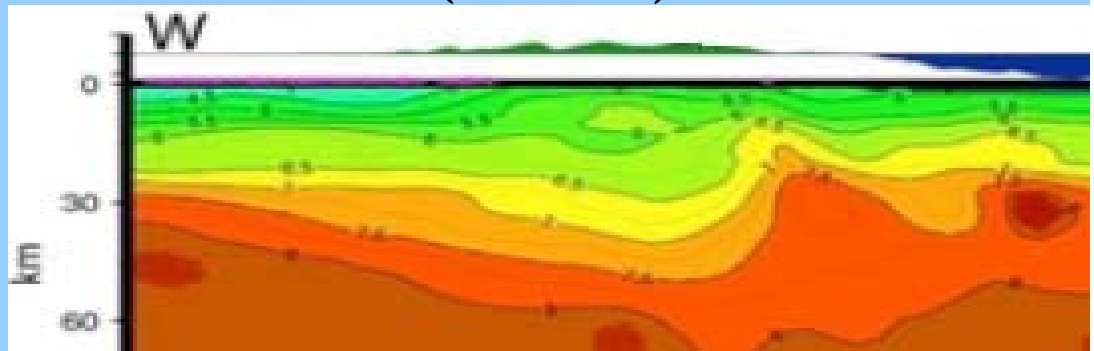


Model from Surface Wave Tomography

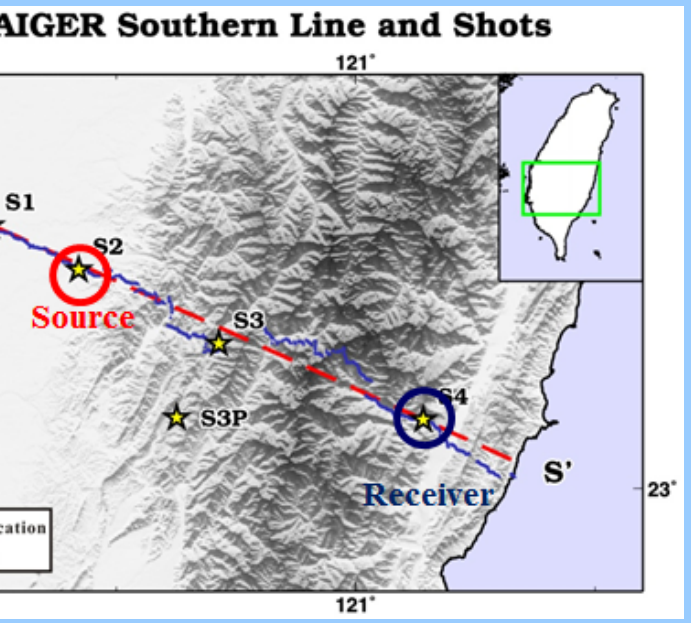




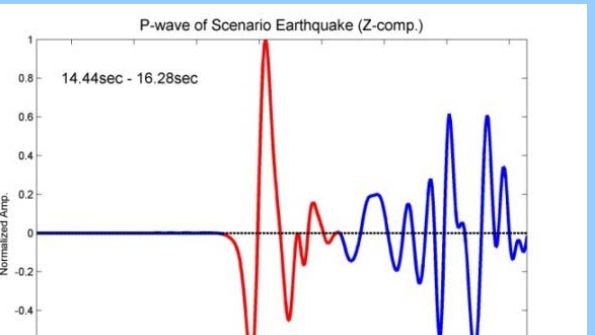
KC12 (Traveltime)

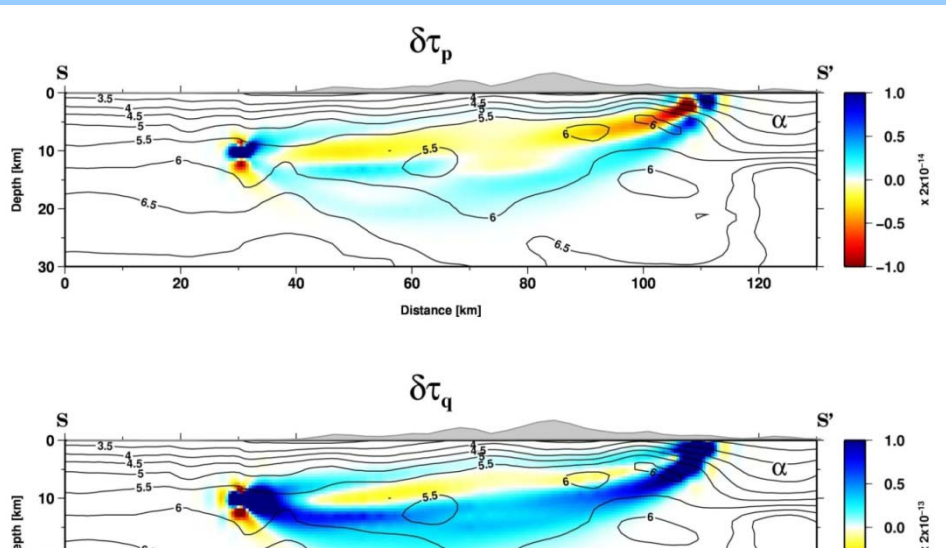


ure Direction: Finite-Frequency Approach



- Numerical modeling of wavefield in 3D structure with irregular geometry
- Full-wave sensitivity kernels
- Multi-scale, iterative inversions
- Account for anelasticity effects





Thank you!