以台灣地體構造數值模型逆推震間期斷層之潛移量

The effects of long-term slip rates to crustal deformation

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研究長期目的：

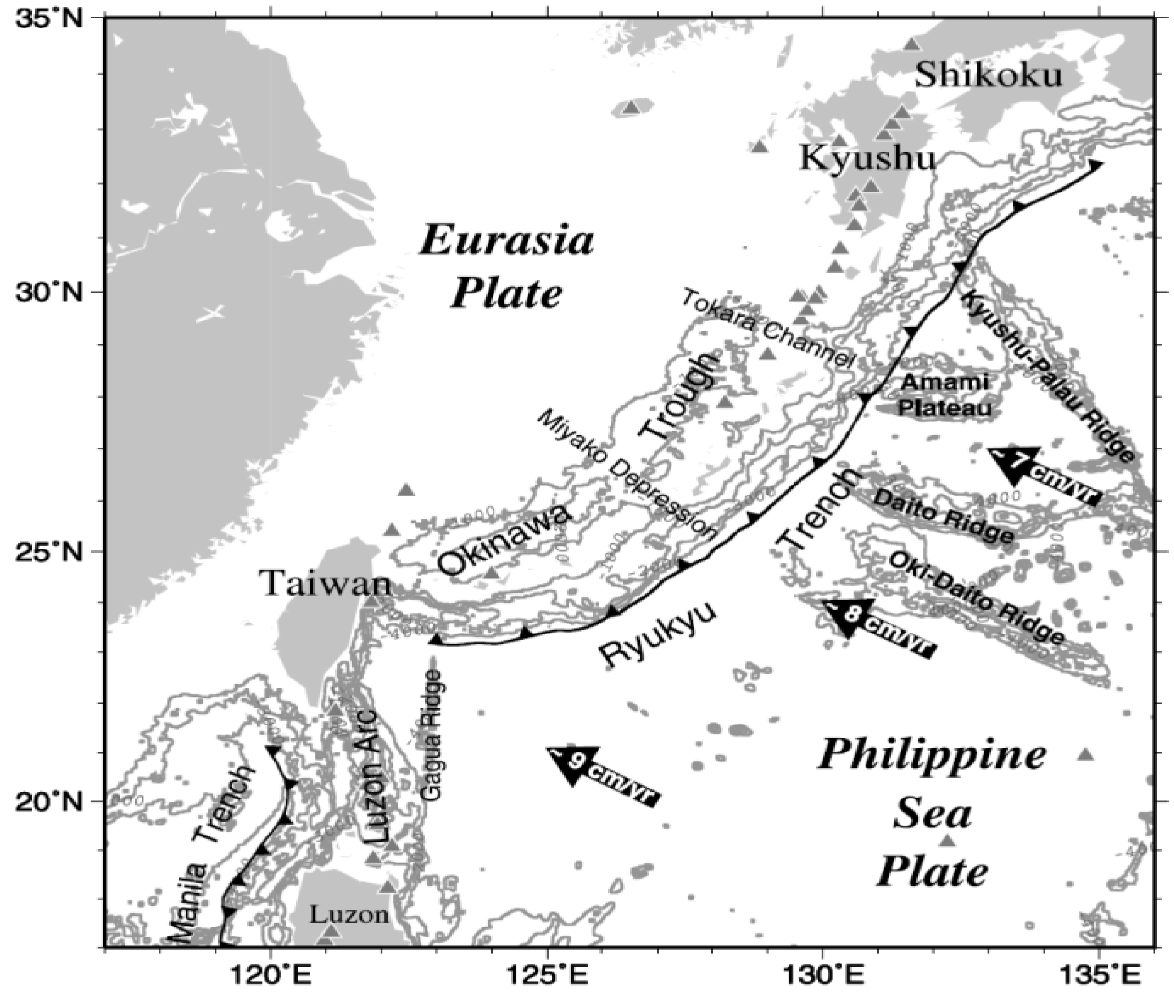
建構一更為接近實際狀況之台灣地體構造三維數值模型。

其特點有二，第一點為將台灣三維速度構造參數引入，以獲得三維地層異向性之彈性參數，並建置於數值模型中，第二點為將台灣各主要斷層建置於數值模型中，反求適當之斷層面潛移率，以增加對地表GPS測站所觀測之地殼變形之吻合程度。

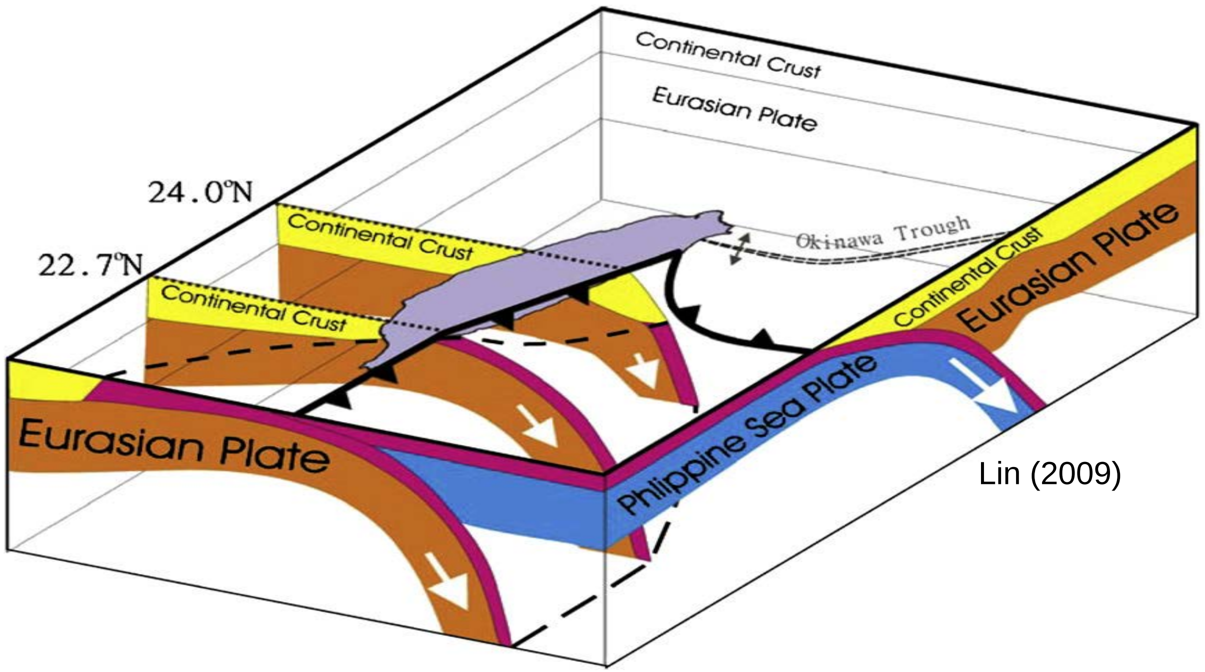
後續應用此更接近實際狀況之數值模型，評估各斷層應力累積之速率，以推估未來相對較有可能發生破壞之斷層及其區位。

台灣地殼活動與模型簡介

Geodynamic framework of the Taiwan region



Wu *et al*. (2010)

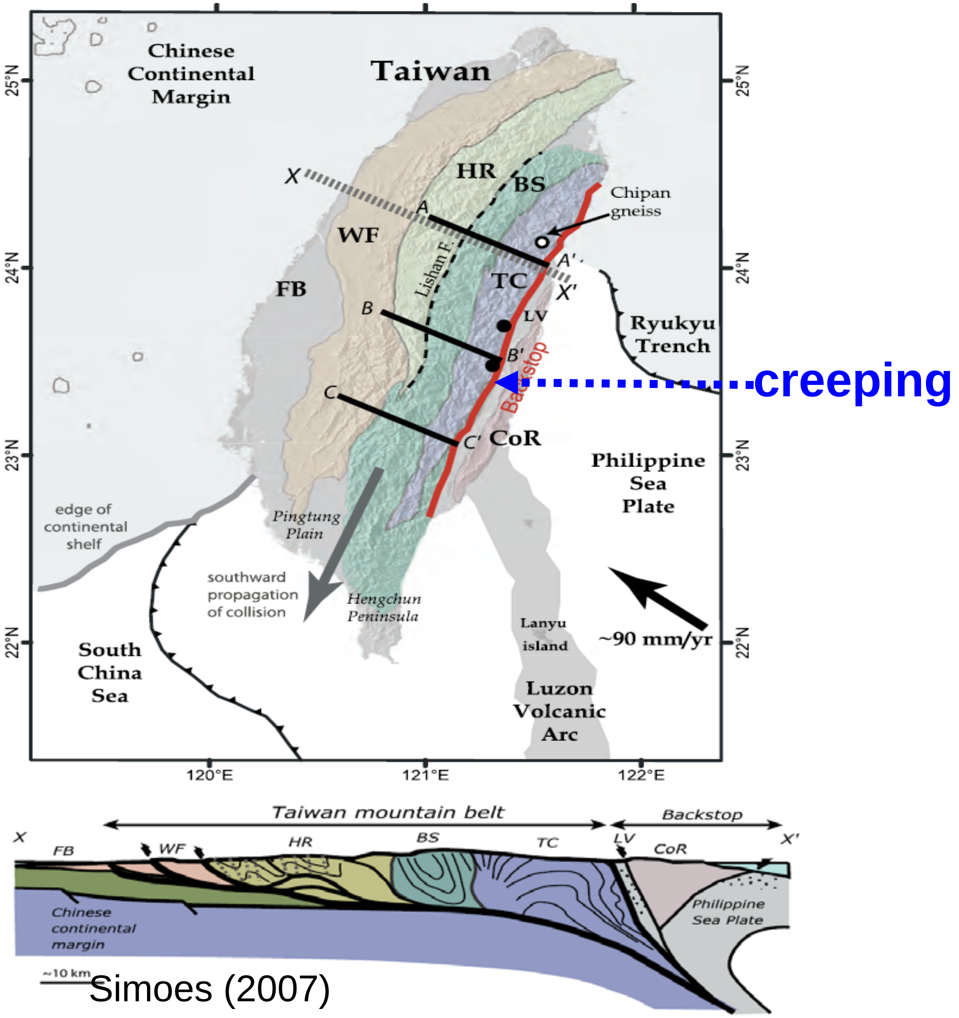


Lin (2009)

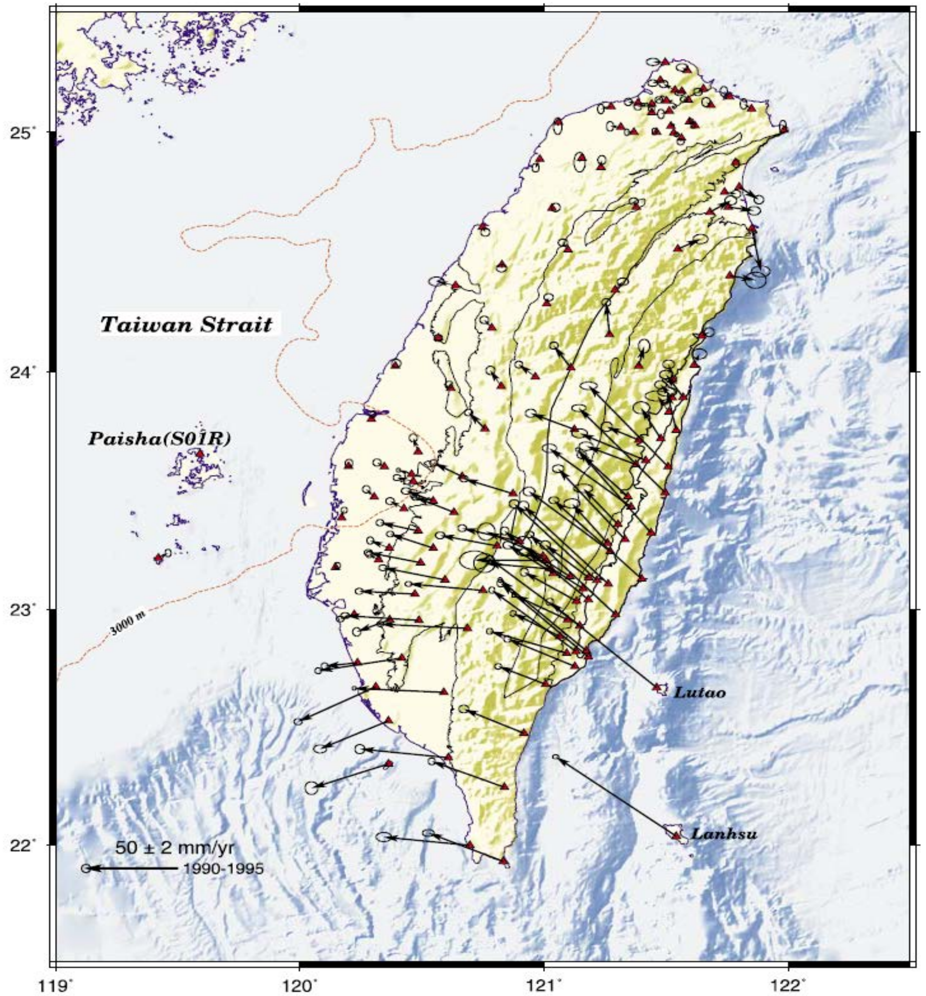
The **Taiwan orogenic belt** is located in the middle of the western margin of the hilippine Sea plate, with the Ryukyu and Luzon subduction systems to the northeast and south, respectively.

Schematic plot of the tectonic model in the Taiwan area. The eastward subduction of the Eurasian plate in southern Taiwan might be extended to central Taiwan, but the subducting slab changes from a typical oceanic plate south of 23°N to the continental margin to the north.

Velocity field of the Taiwan region



Simoes (2007)

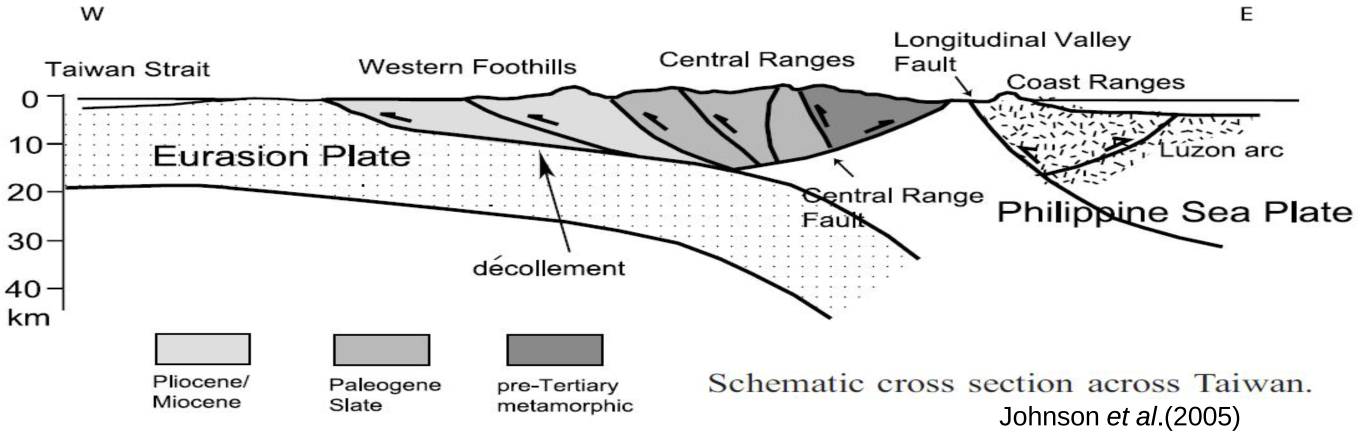


The **7~9 cm/yr** convergence rate across the plate boundary is taken from the GPS data.

Results of the Taiwan GPS Network surveyed four to six times from 1990 to 1995 (Yu *et al*.,1997).

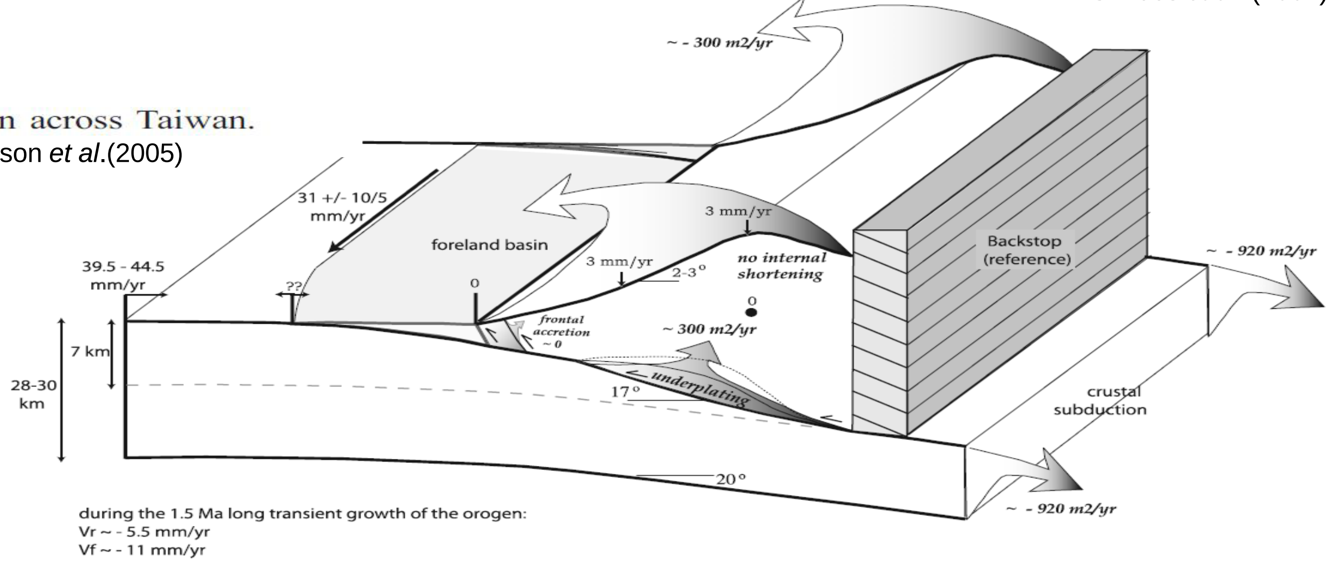
Elastic dislocation model

Earth is approximated as an elastic half-space, and the surface velocity field is attributed to steady creep on buried dislocations. The horizontal data are best explained with a shallow dipping (2º–11º) de´collement underlying the entire Taiwan island.



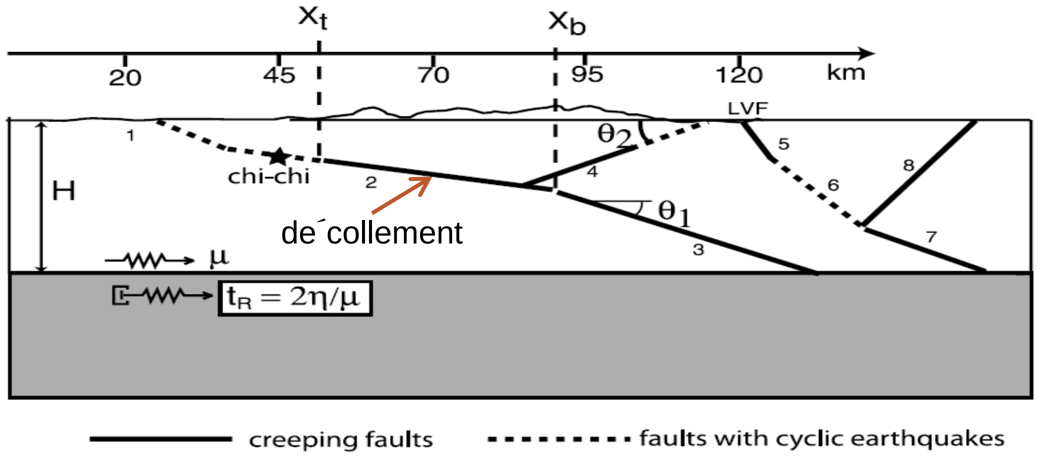
Johnson *et al*.(2005)

Simoes *et al*. (2007)

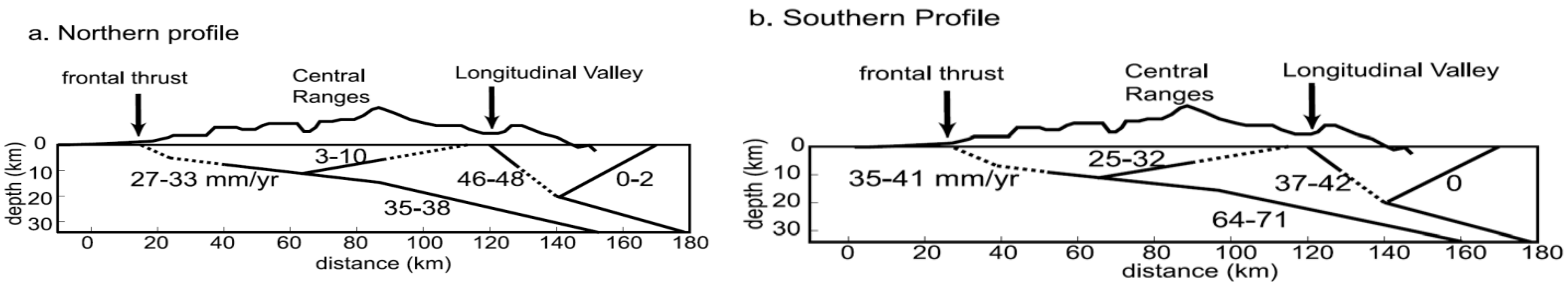


Elastic dislocation model

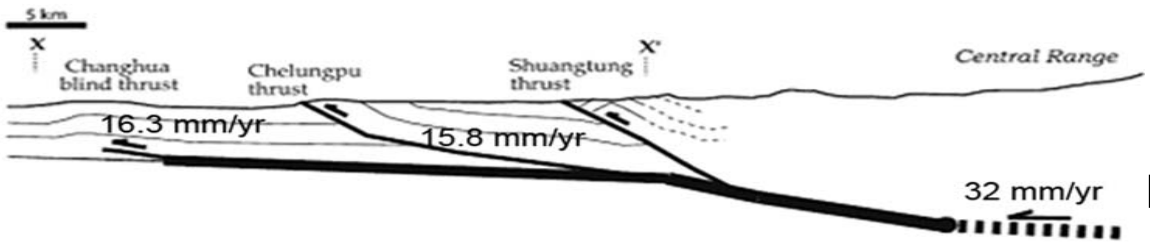
Johnson *et al*.(2005) invert the GPS data for fault geometry and slip rates.



Results of **Kinematic Inversion** :

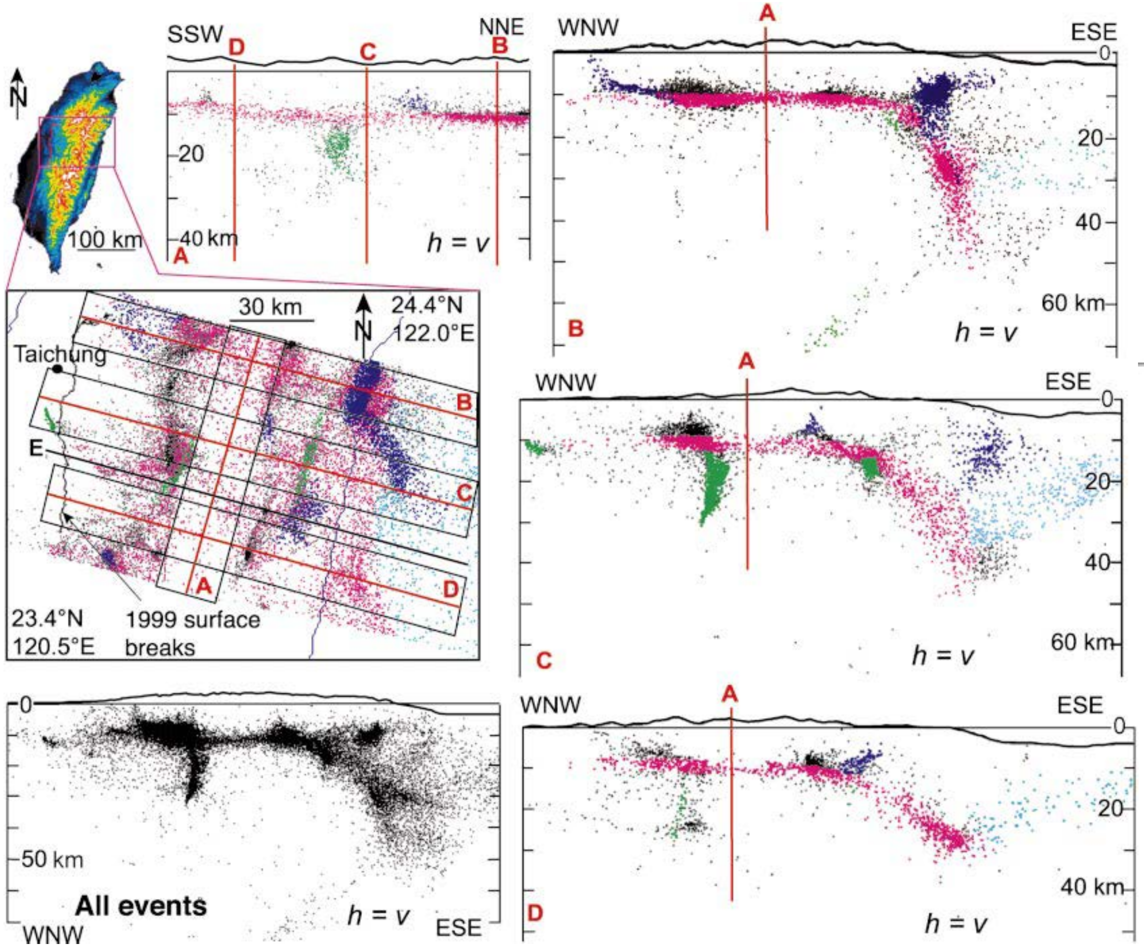


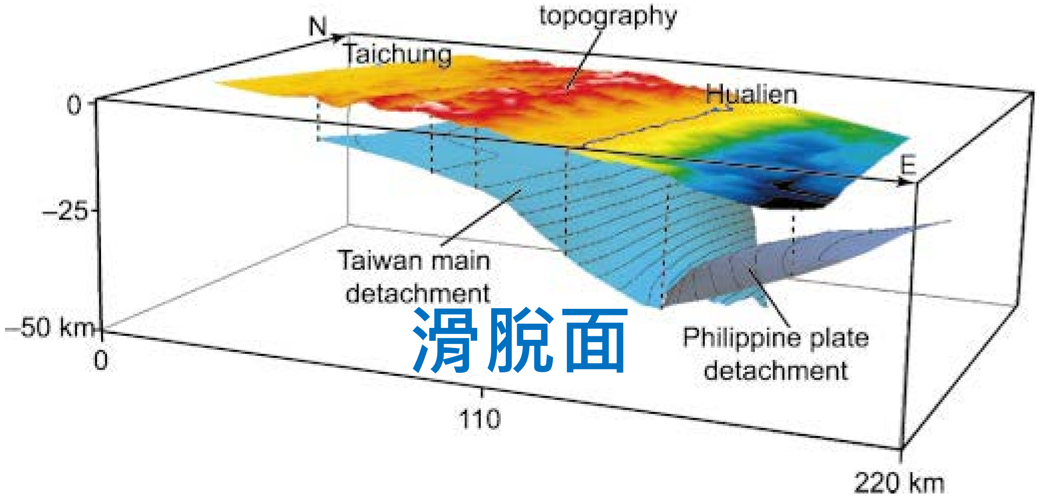
Johnson *et al*.(2005)



Hsu *et al*.(2009)

Location of detachment

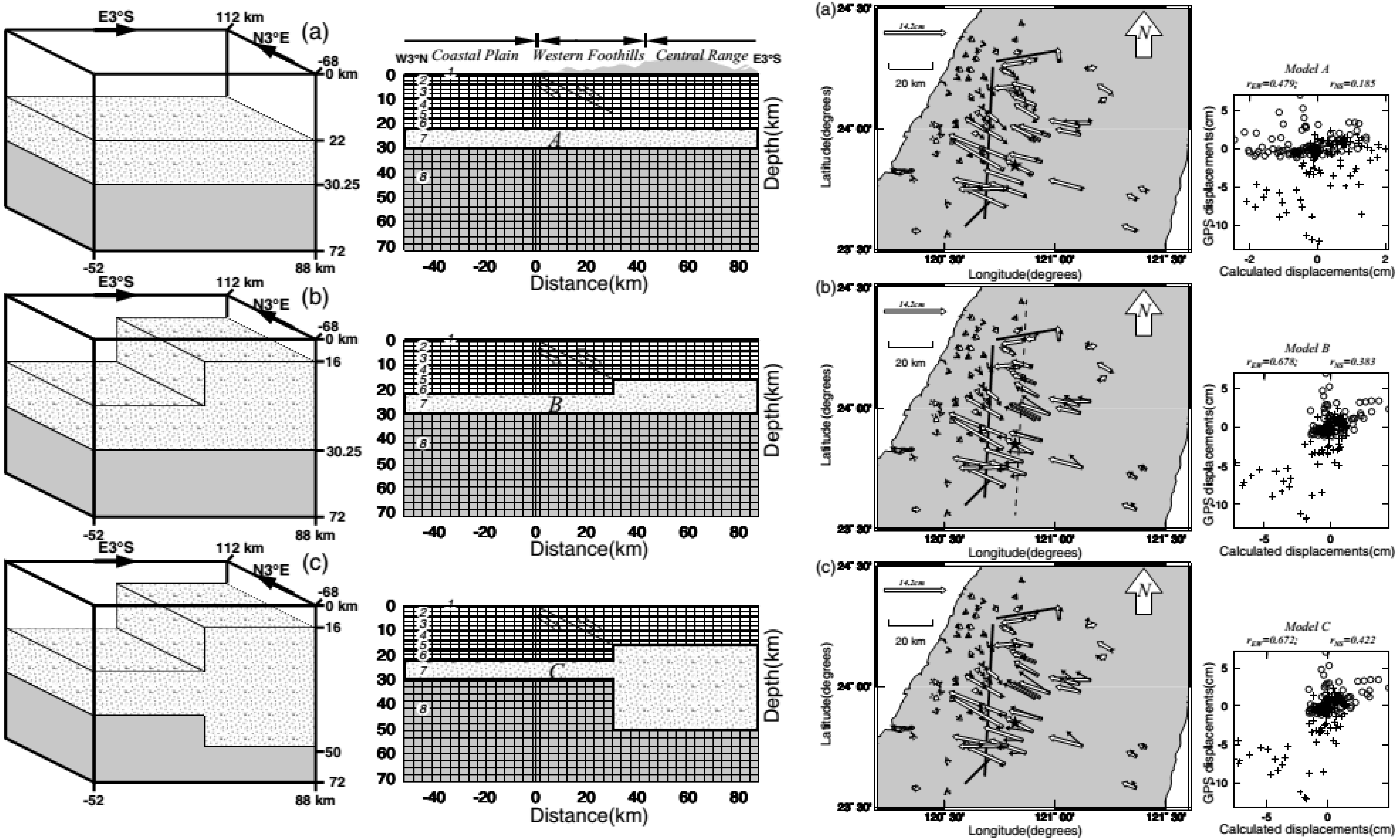




滑脱面

Carena et al.（2002）

Sheu and Shieh (2004)藉由集集地震震後滑移評估塑性區可能位置



2D distinct element model of Taiwan (Hu et al., 2001)

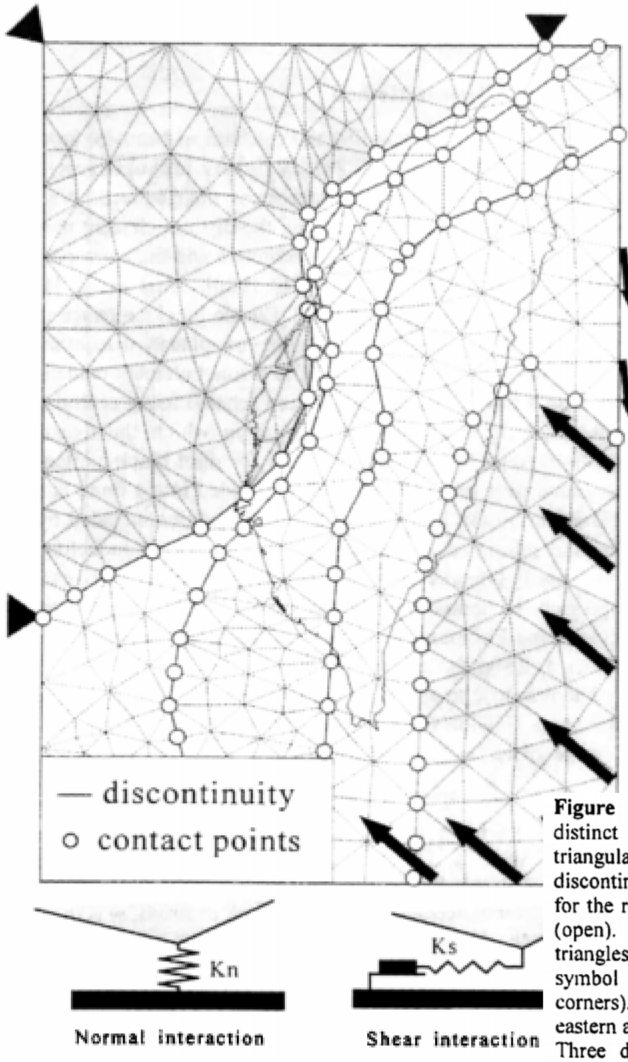
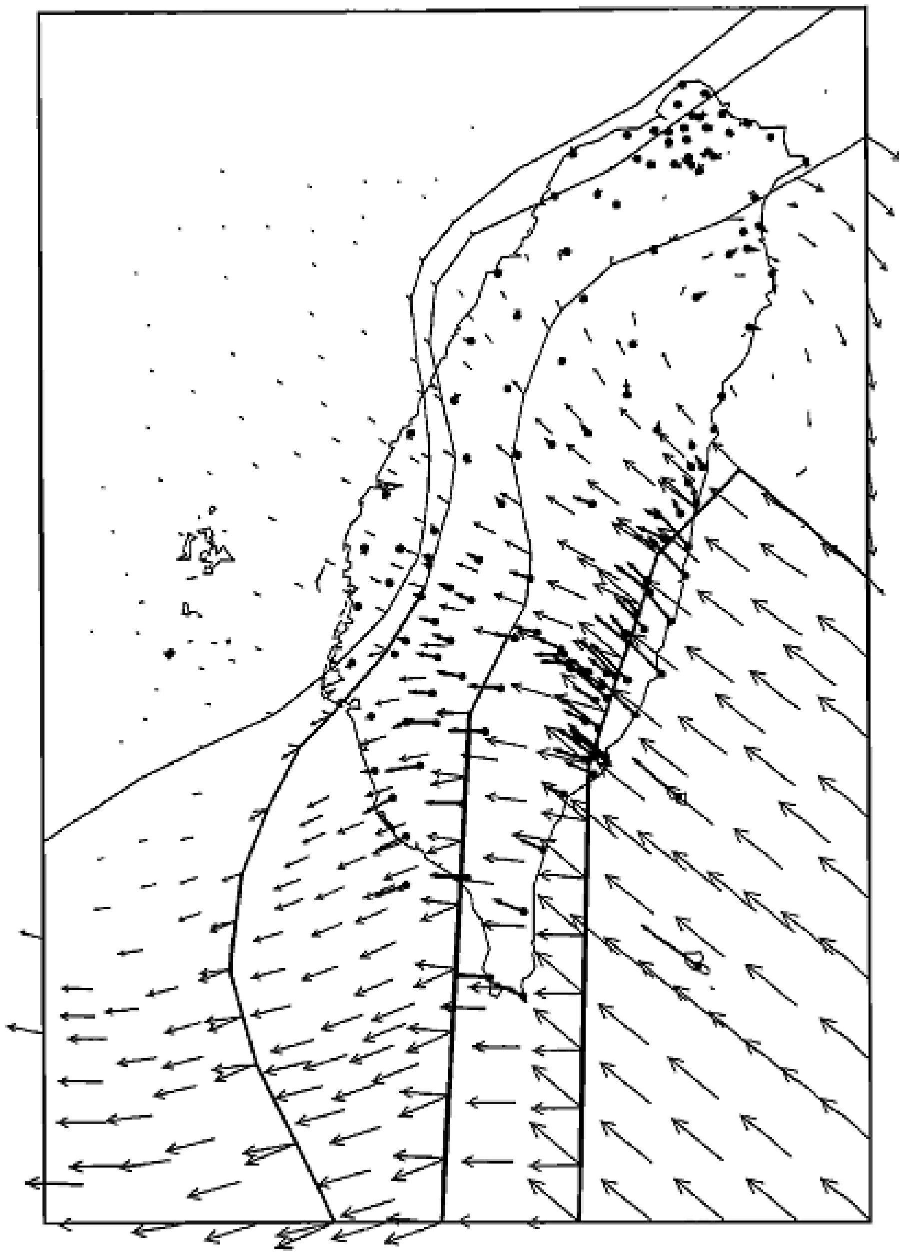
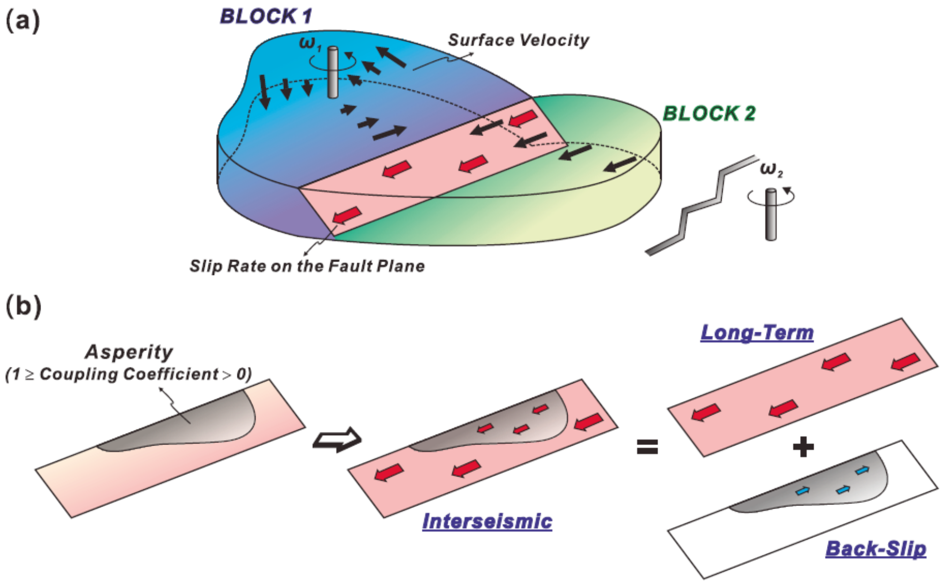


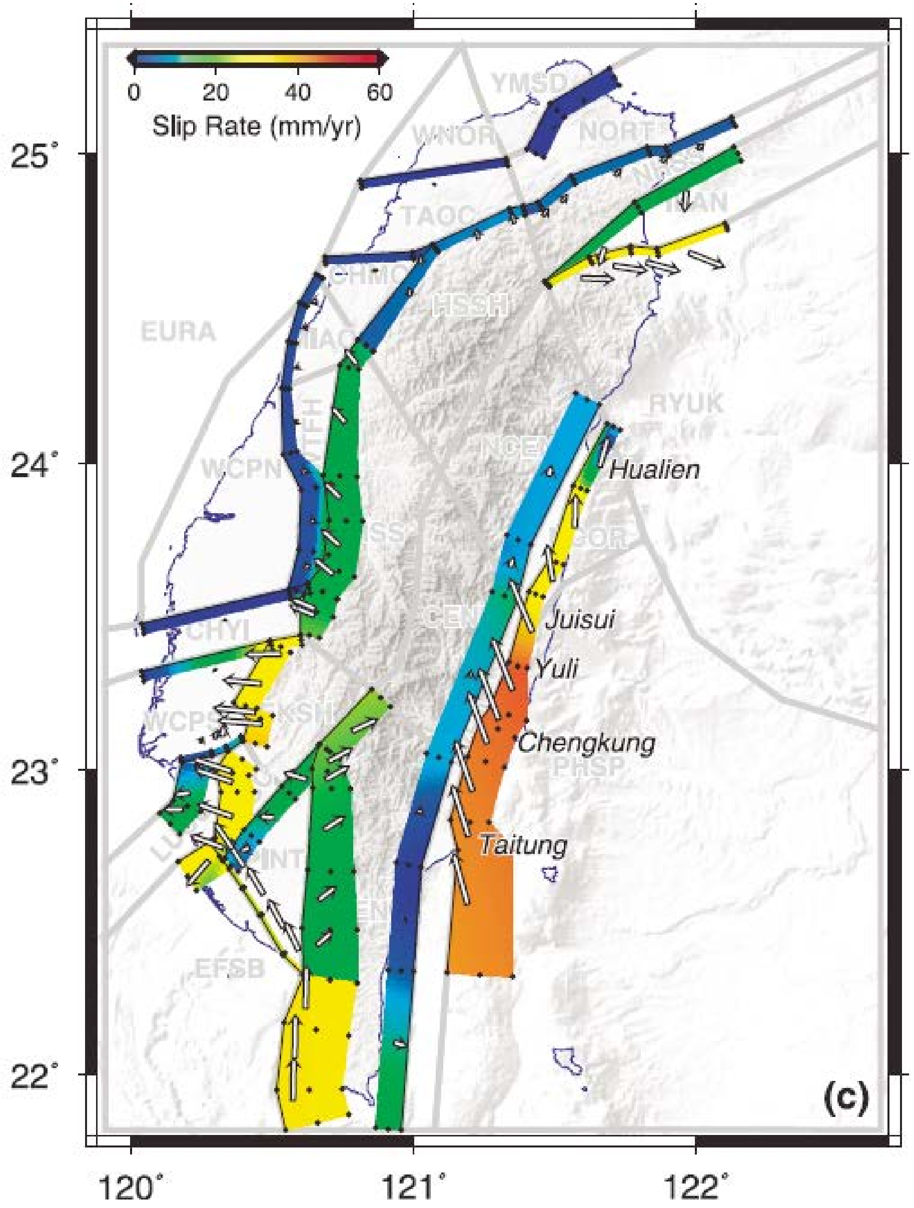
Figure 4. Rheology and boundary conditions for the 2-D distinct element model. Discretization of the medium into triangular zones as dotted lines. Contact points along the discontinuity shown as open dots. Young's modulus is 60 GPa for the rigid subdomain (shaded) and 10 GPa for the weak zone (open). Poisson's ratio is 0.25 for both subdomains. Solid triangles indicate tips of fixed boundaries (northwest corner). No symbol indicates free boundaries (northeast and southwest corners). Solid arrows indicate directions of displacement at eastern and southeastern boundaries (based on GPS, see Figure 3). Three discontinuities are involved: the frontal thrust of the western Taiwan, with its southward transition into the front of the submarine accretionary wedge offshore southwestern Taiwan; the thrust between the Hsuehshan-Central Range and the Western Foothills; and the Longitudinal Valley Fault (see Figure 2). For material properties, see Table 1.



三維塊體模型所評估之台灣斷層潛移量 (Ching et al., 2011)



三維塊體模型示意圖(Ching et al., 2011)



Thomas et al. (2014) 推估之花東縱谷斷層潛移量

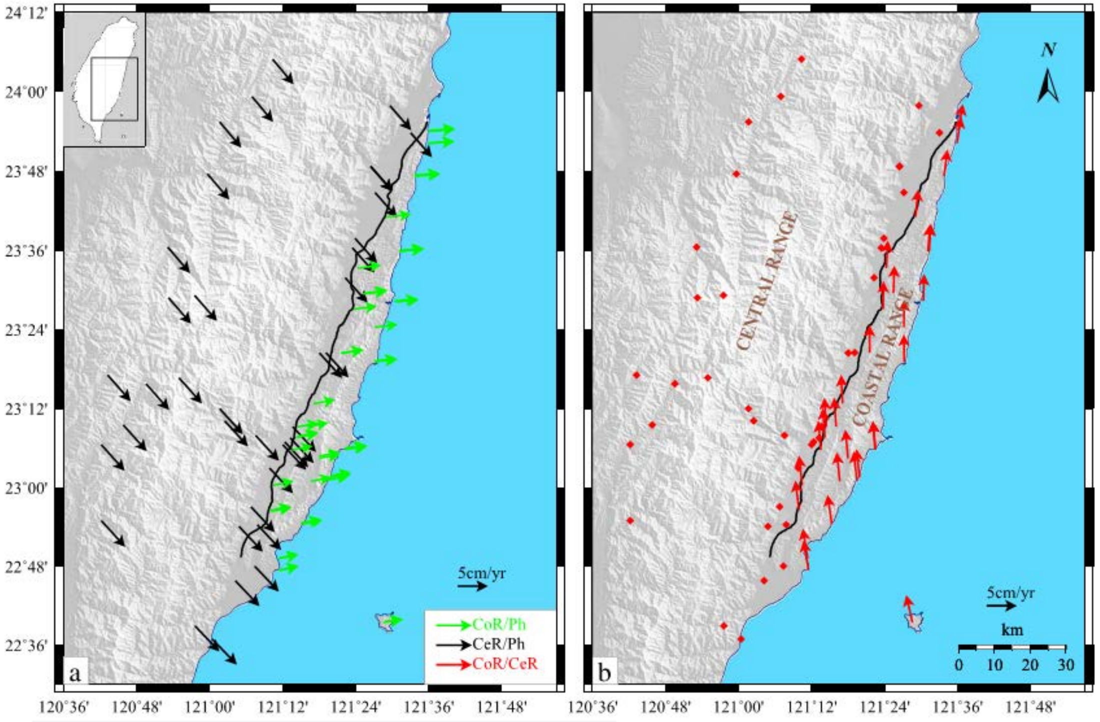
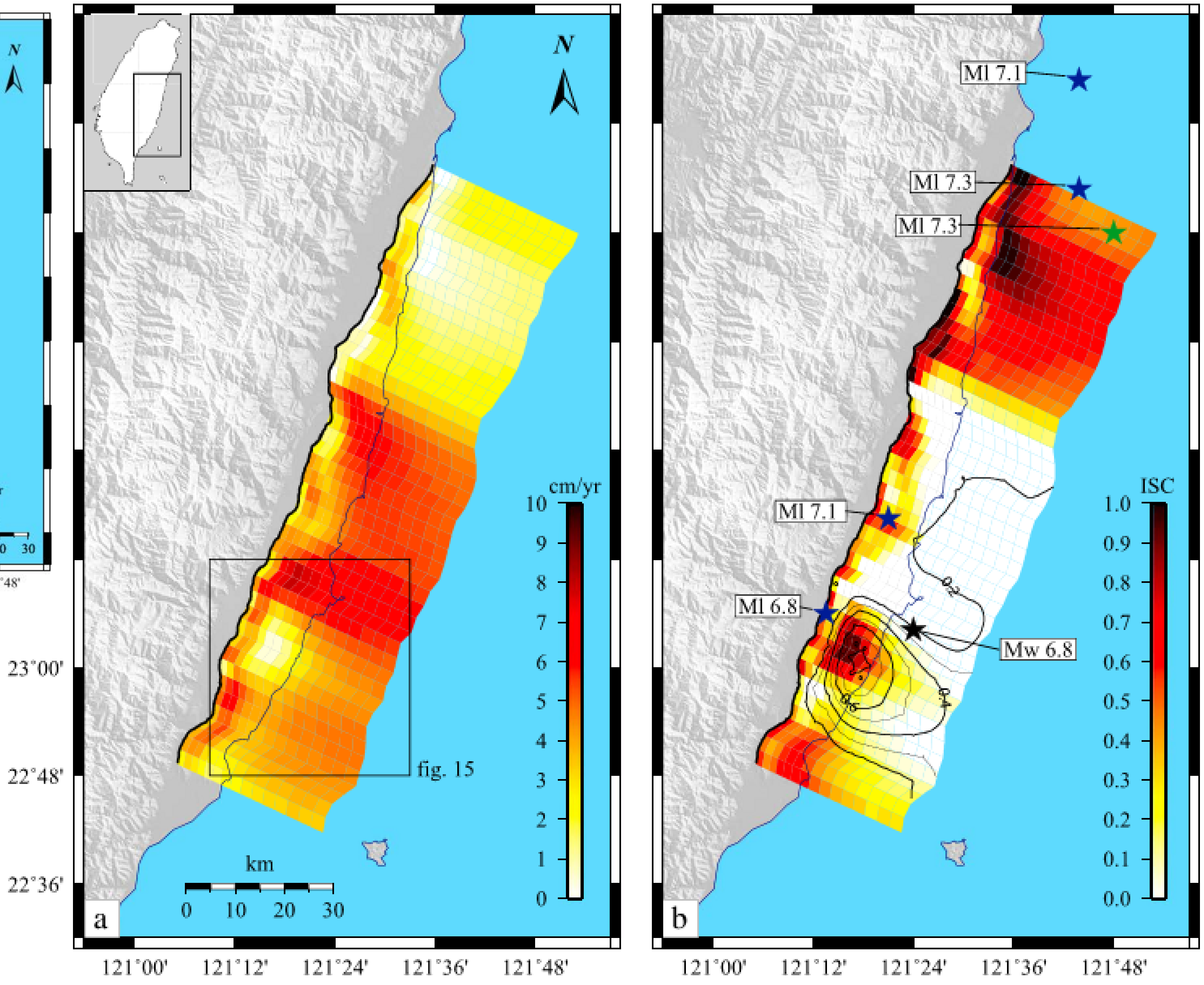


Table 1. Location of Axis and Angular Rotation Rates of Euler Poles Used to Describe the Relative Motions of the Philippine Sea Plate (Ph), Central Range Block (CeR), and Coastal Range Block (CoR)

	Ph/ITRF	CeR/Ph	CeR/CoR	CoR/Ph
Latitude	47.1	32.15	−23.34	−19.42
Longitude	150.4	133.30	−54.93	−58.11
Ω(°/Myr)	−0.9251	−2.1351	7.0154	−4.94



Lithospheric block model
(Huang et al., 2010)

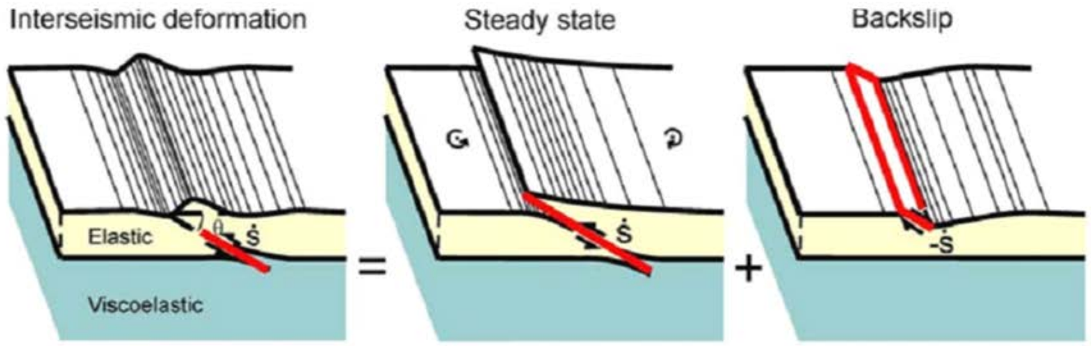
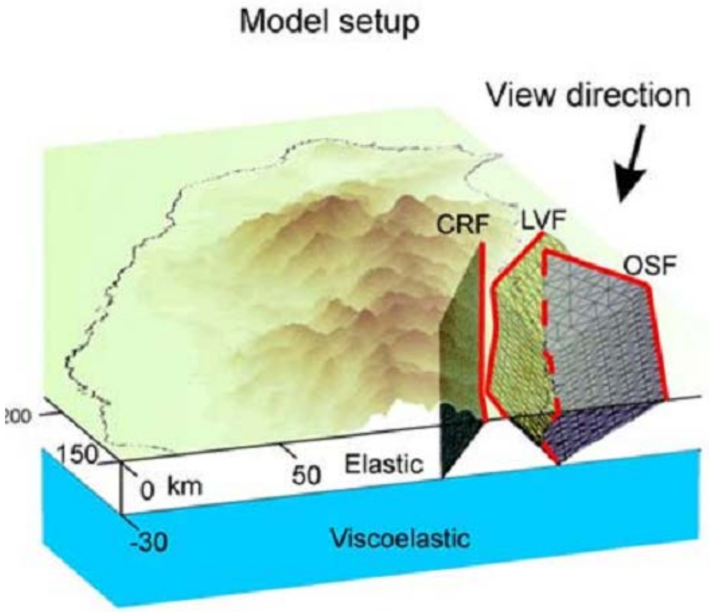
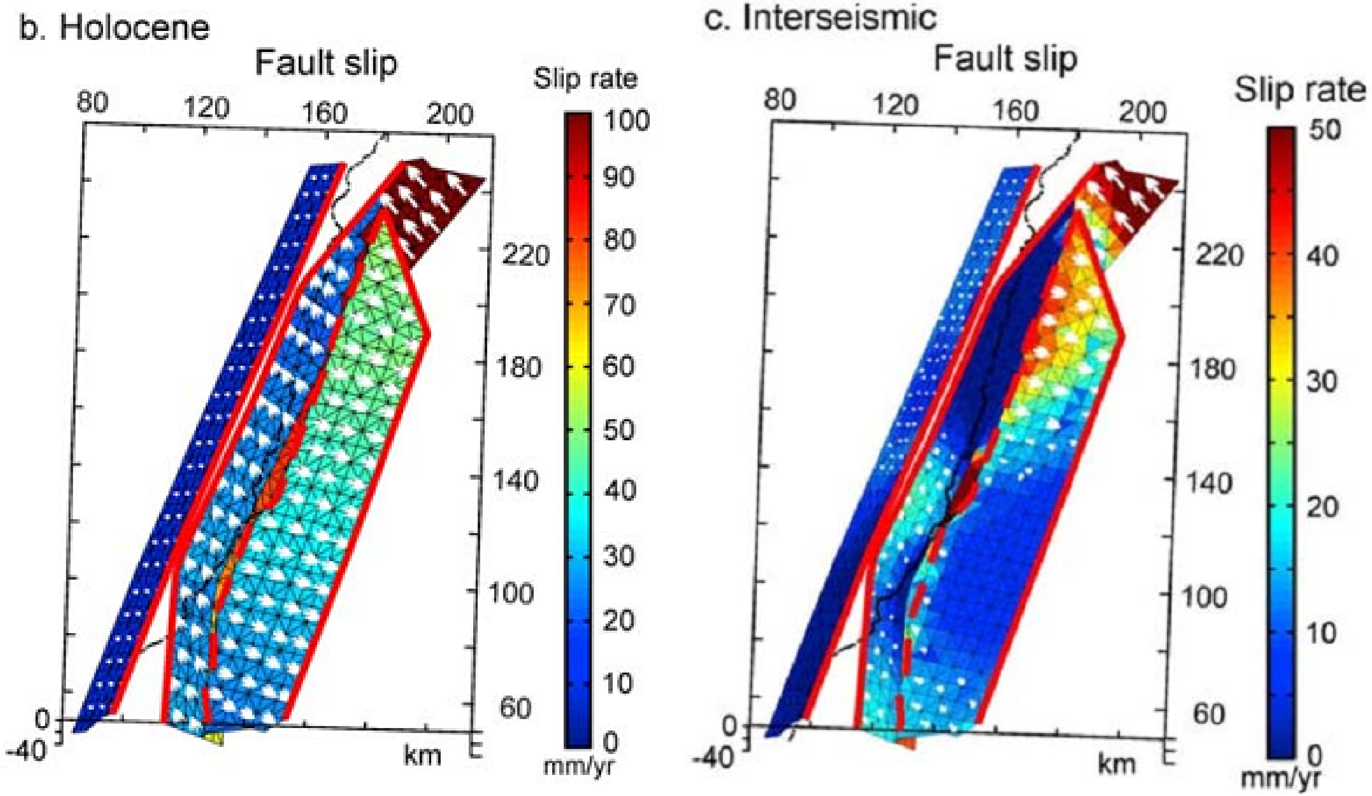


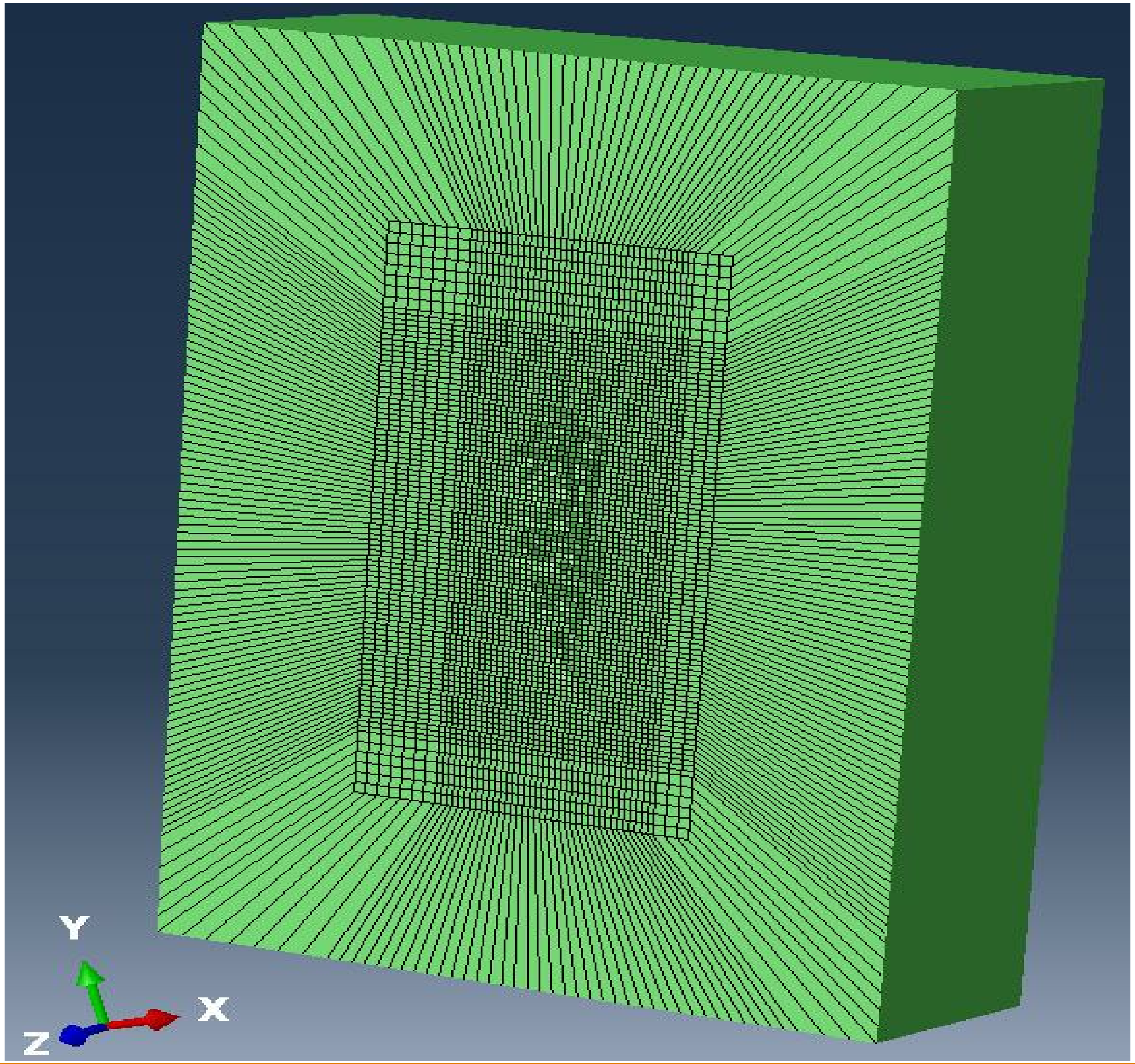
Figure 5. Illustration of lithospheric block model. Interseismic deformation is the sum of deformations for steady state and perturbation by back slip.





模型建置說明

FEM (ABAQUS) Model

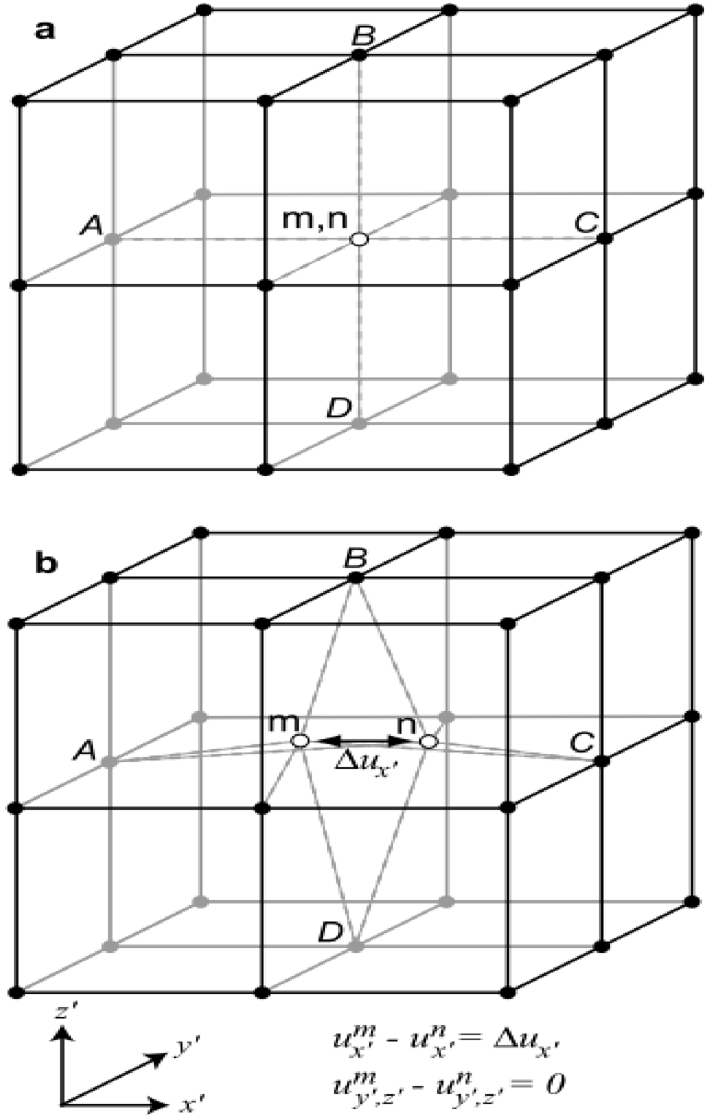


Meshed domain of the numerical model.

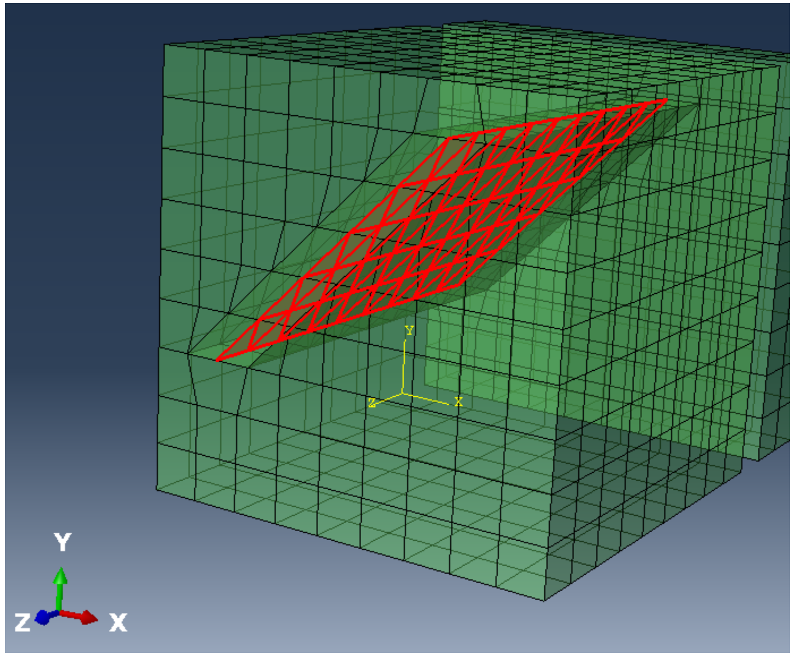
Edge of the model is infinite element.

Surface of model is structured according to DEM of Taiwan.

FEM Model

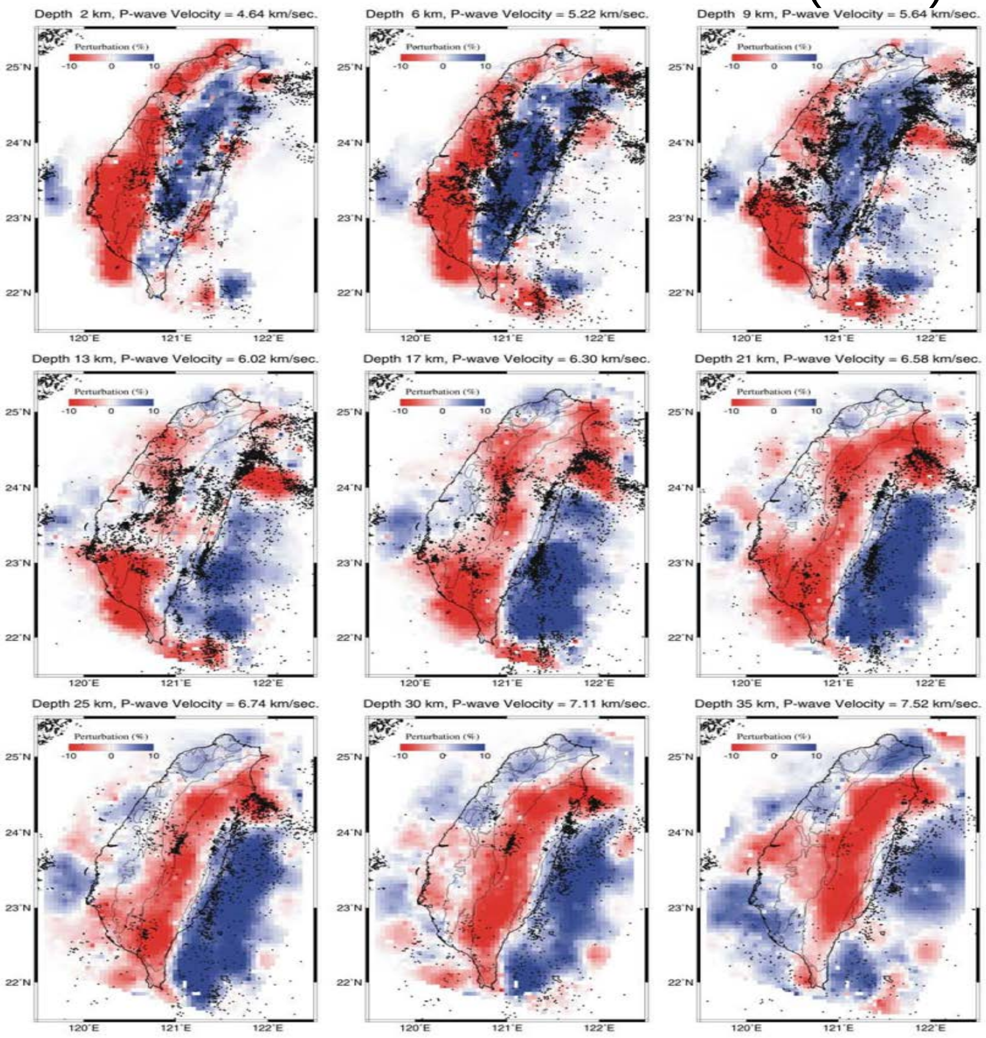


Dislocation of a node-pair. (a) The schematic FEM mesh includes a node-pair consisting of initially collocated nodes m and n on fault patch ABCD. (b) The static dislocation is implemented by imposing the kinematic constraints shown at the bottom, where the dislocation vector, $\Delta \mathbf{u}_{x'}$, is parallel x'.



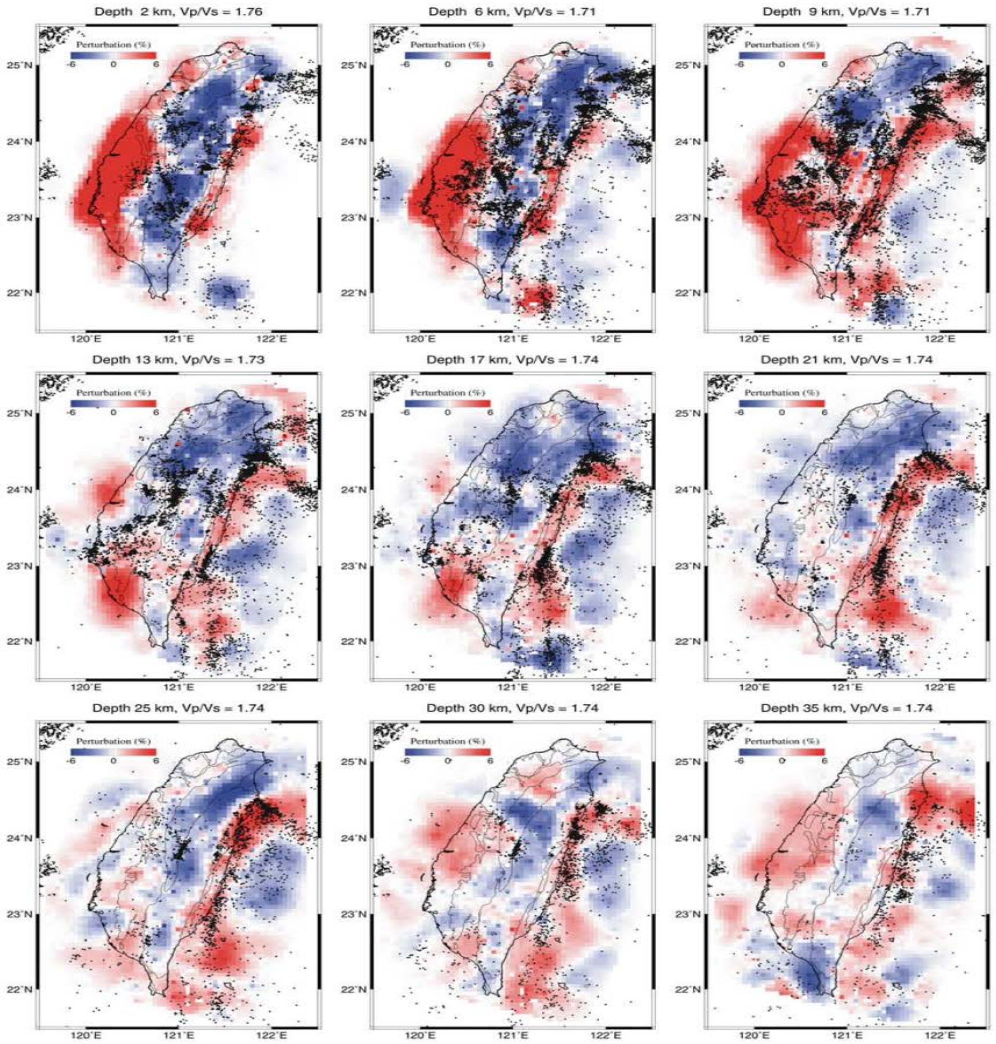
Vp maps at nine different depths. Blue and red show high and low velocity.

Wu *et al*.(2007)



Vp/Vs maps at nine different depths.

Wu *et al*.(2007)



Convert

velocity structure to

Young's modulus (*E*) distribute

V_P

V_S

$\rightarrow$

$$E = \frac{\mu(3\lambda + 2\mu)}{\lambda + \mu}$$

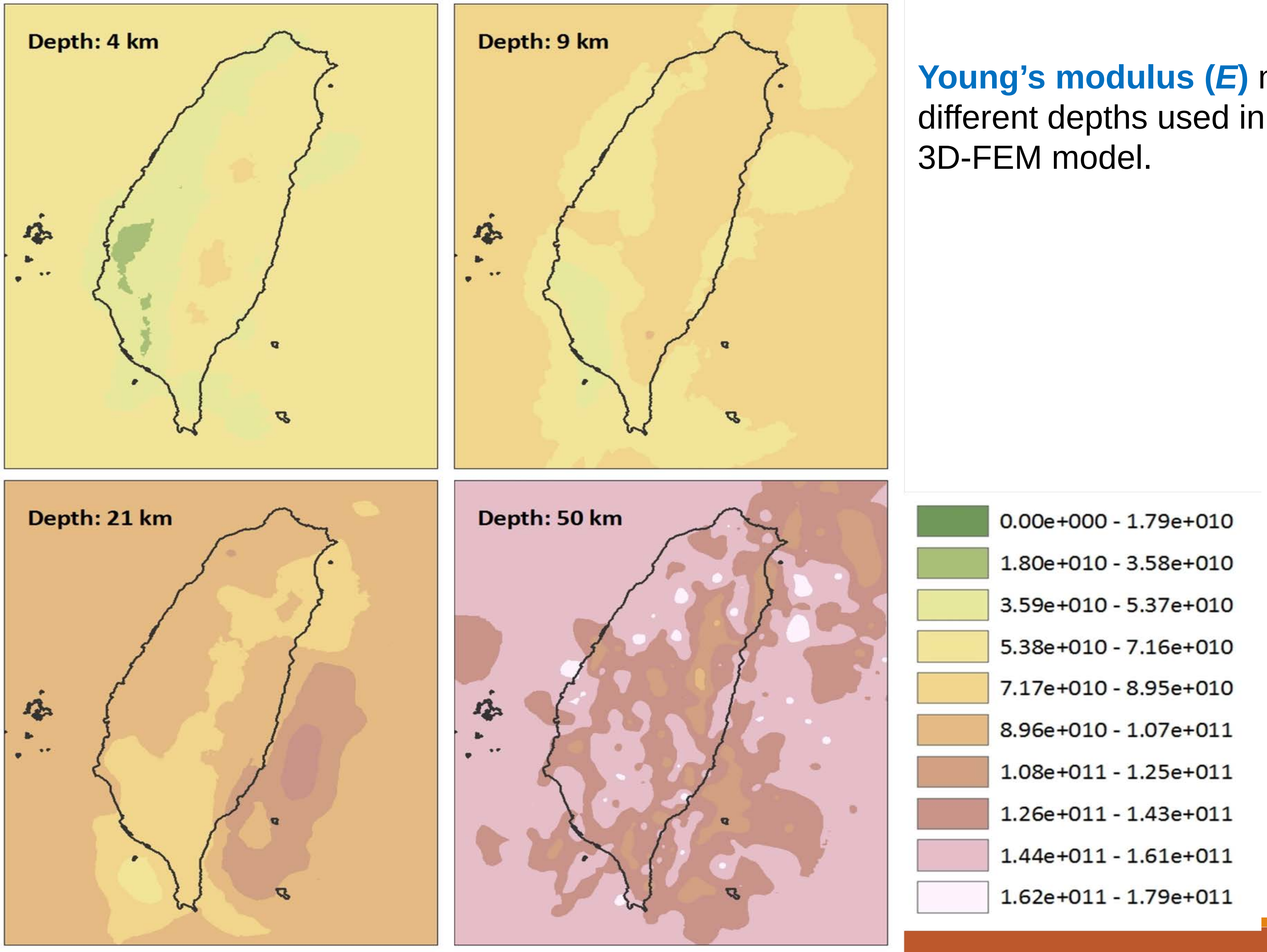
$$\lambda = \rho(V_P^2 - 2V_S^2)$$

$$\mu = \rho V_S^2$$

$\rightarrow$

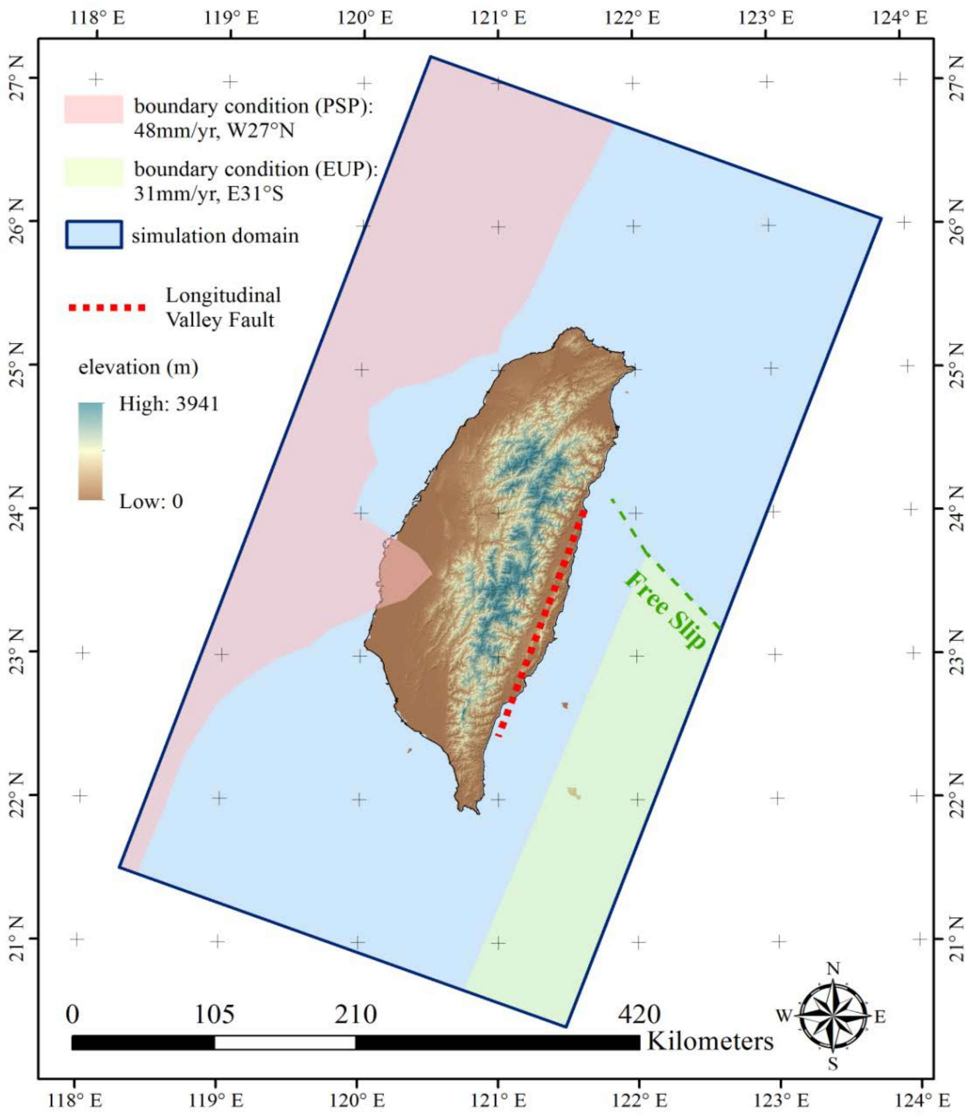
E

Young's modulus (*E*) maps at different depths used in following 3D-FEM model.



(In Pa)

FEM Model



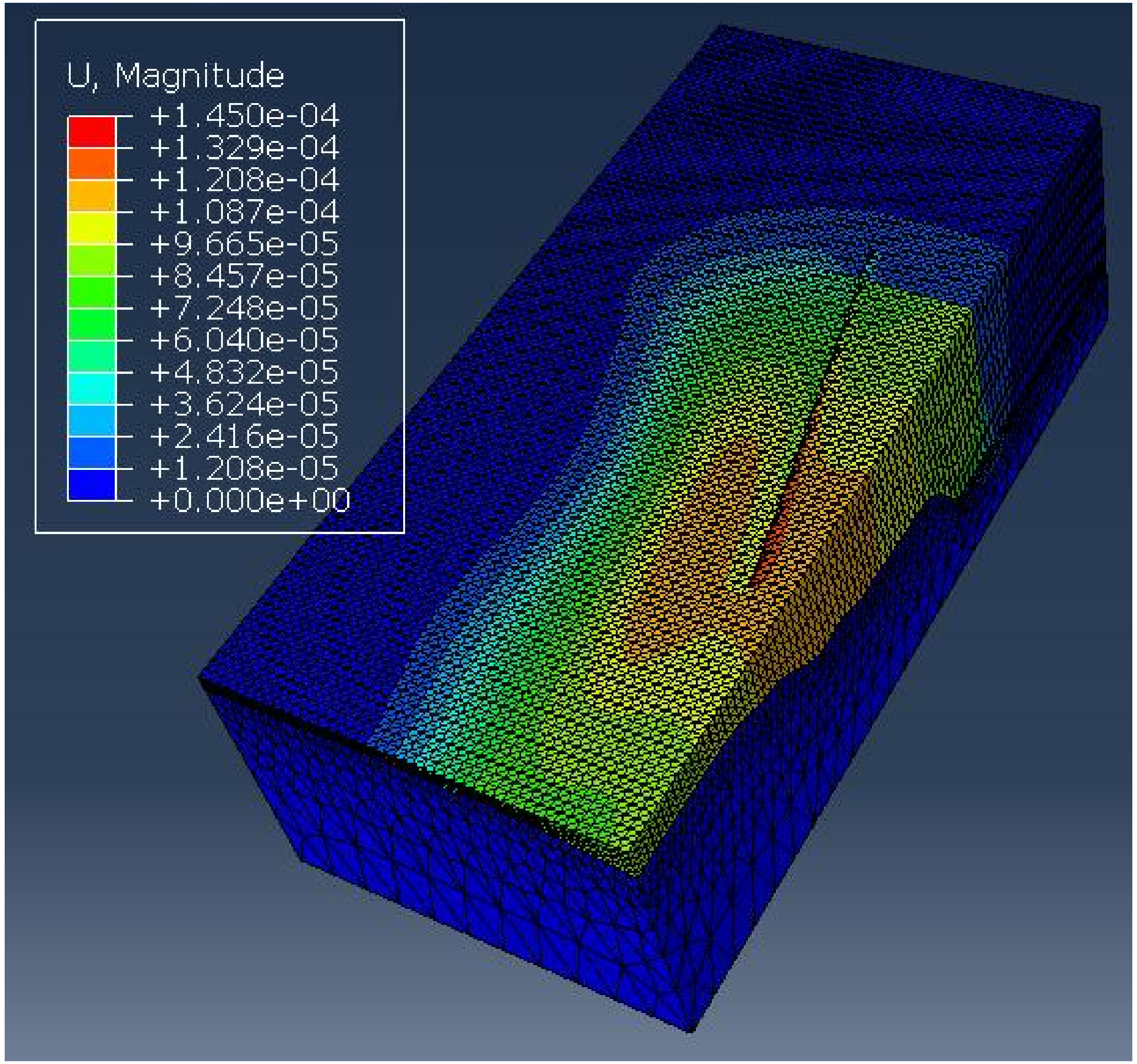
Boundary conditions for the 3-D FEM model.

Blue line indicates simulation domain.

Ryuku trench set as free slip.

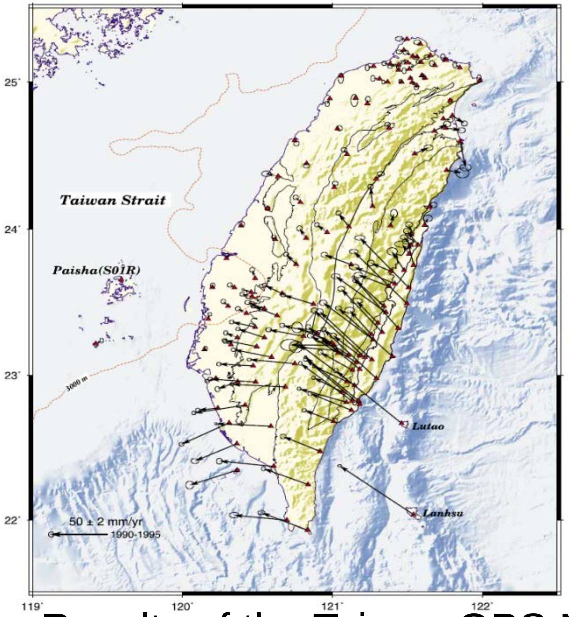
The boundary conditions of Eurasian plate (EUP) and Philippine Sea plate (PSP) are 31mm/yr and 48mm/yr, respectively.

Model test



將邊界條件施加於數值模型後所計算之年移動量(考慮滑脫面的狀態下)。

左圖中移動量之單位為公里。



Results of the Taiwan GPS Network surveyed four to six times from 1990 to 1995 (Yu *et al*.,1997).

Inversion

$$\mathbf{G}\mathbf{m} = \mathbf{d}$$

G is the matrix of synthetic Green's functions for displacement.
m is a vector of dislocations for node-pairs simulating fault slip.
d is the data vector of observed three-component GPS displacements.

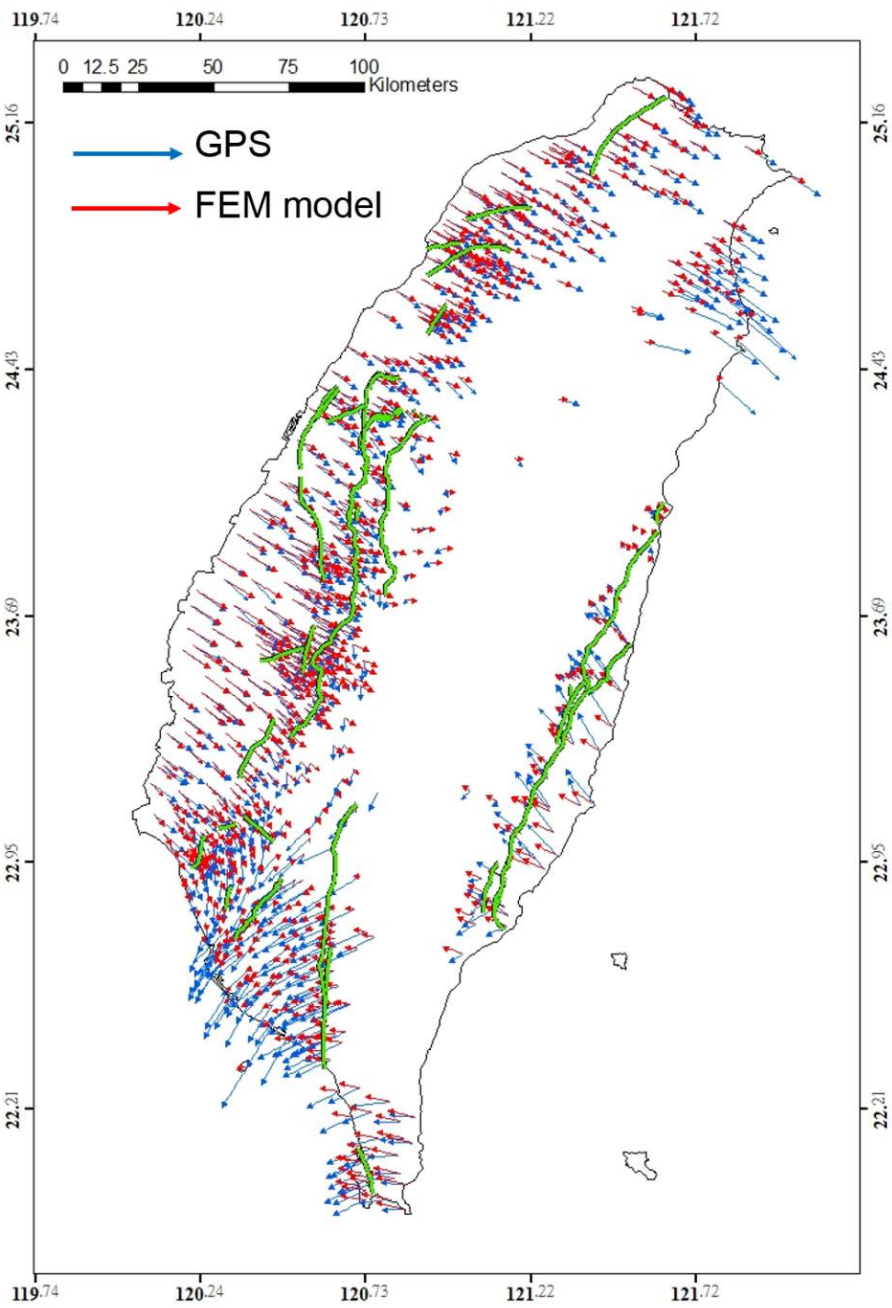
Each coefficient $\mathbf{G}_{ij}$ is a displacement component at location *j* due to a unit dislocation of node-pair *i*. (estimated by FEM model)

$$\min \left\| \begin{bmatrix} \mathbf{G} \\ \lambda \mathbf{L} \end{bmatrix} \mathbf{m} - \begin{bmatrix} \mathbf{d} \\ 0 \end{bmatrix} \right\|$$ (parker, 1977)

L is a Laplacian smoothing matrix that penalizes steep gradients in slip between neighboring dislocations.

λ is a regularization weighting parameter.

目前分析結果

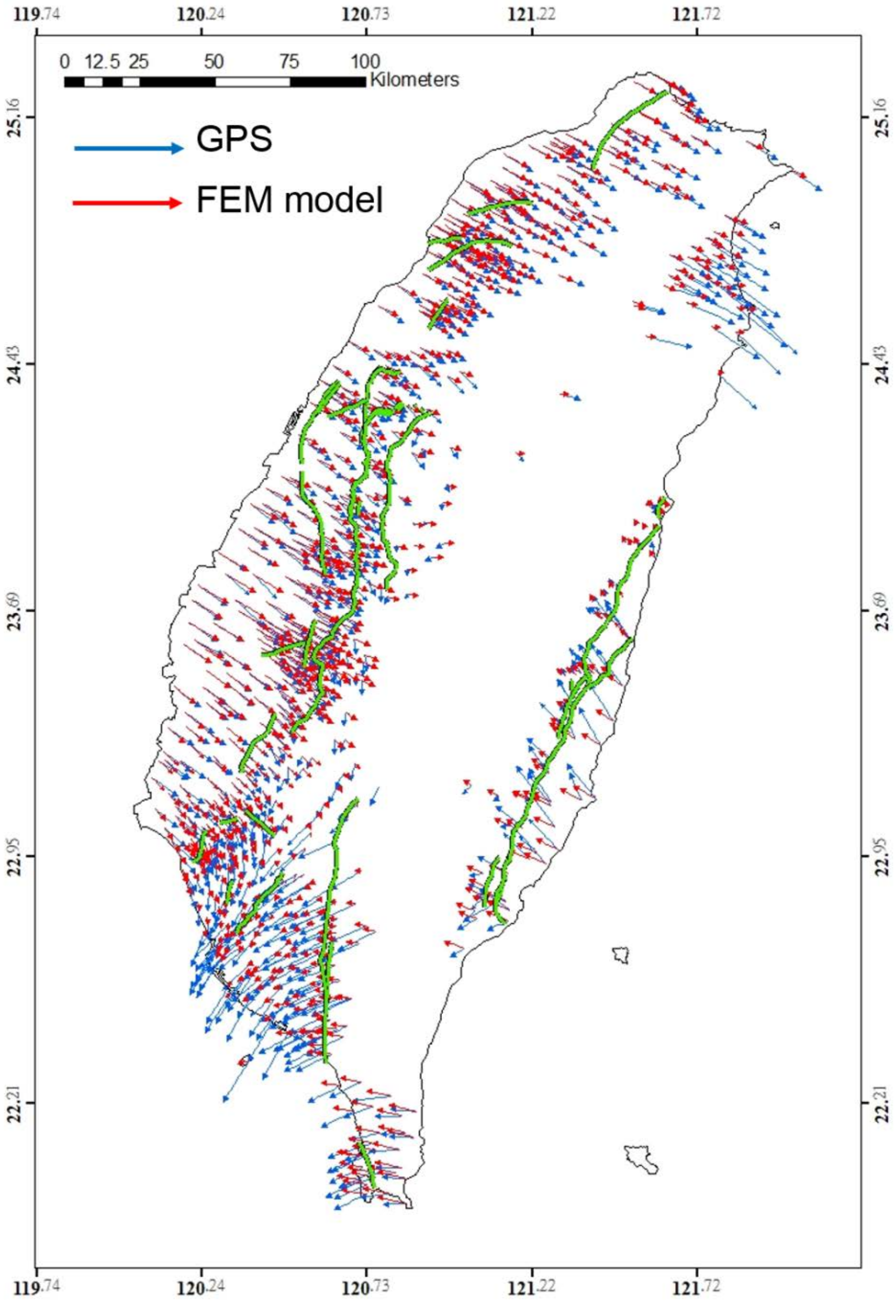


藍色向量為GPS觀測之台灣年地表水平位移場分佈：

本研究模型之束制條件為設置於台灣各地之GPS測站位移資料，為根據經濟部中央地質調查(2010)所之觀測結果，因其位移為相對於澎湖之年相對位移向量，故本計畫將之加上2001至2011年間，澎湖年平均位移向量(中研院地球所郭隆晨博士，2014)，E:2.6cm/yr、S:1.6cm/yr，以獲得台灣各地之年平均絕對位移向量。

紅色向量為以數值模型所計算之位移場，此尚未考慮斷層無震滑移作用：

將琉球海溝以南之模型東部之邊界，施以向北2.2cm、向西4.2cm之年平均位移，模型西部以台灣西部變形前緣(deformation front)為邊界，施以與澎湖年位移量相等之邊界條件，計算地表位移量分布。



GPS與數值模型所獲得之台灣年位移場之主要的差異。

1. 宜蘭地區：GPS位移場明顯大於數值模型所預測之結果，此應為本模型尚未考慮沖繩海槽張裂之作用。

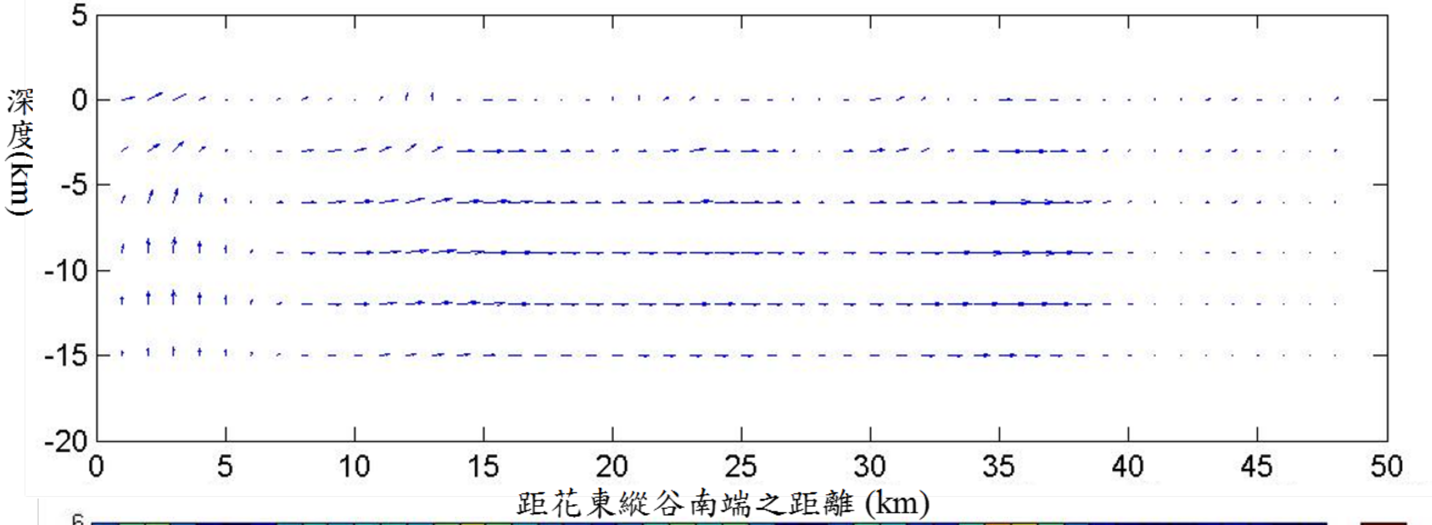
2. 花東縱谷中段：GPS位移場相對於數值模型預測之位移場，位移量較大，且出現向北之分量，此主要成因，應為數值模型尚未考慮花東縱谷潛移作用所導致。

3. 花東縱谷南端與恆春半島：GPS位移場相對於數值模型預測之位移場，出現明顯向南移動之分量。

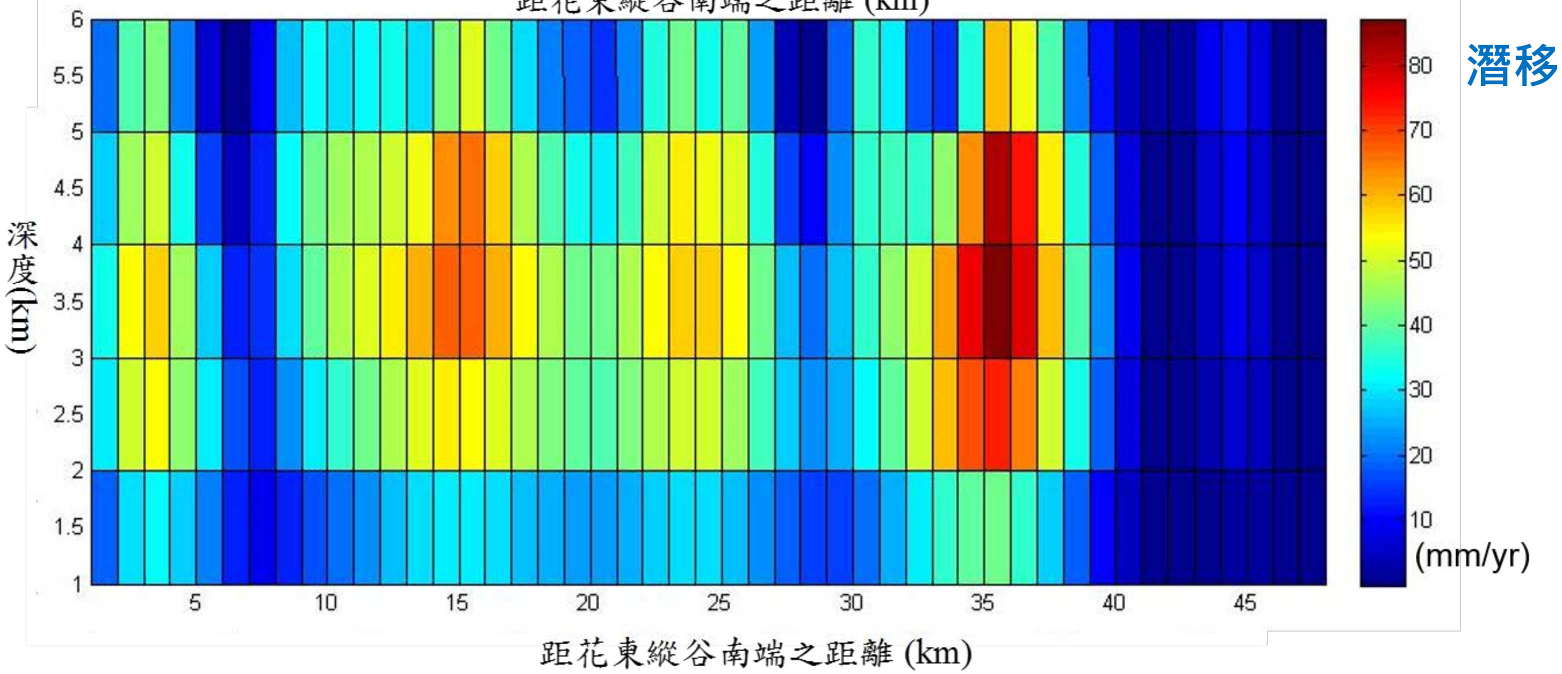
4. 高屏地區：GPS位移場明顯高於數值模型預測之位移場。

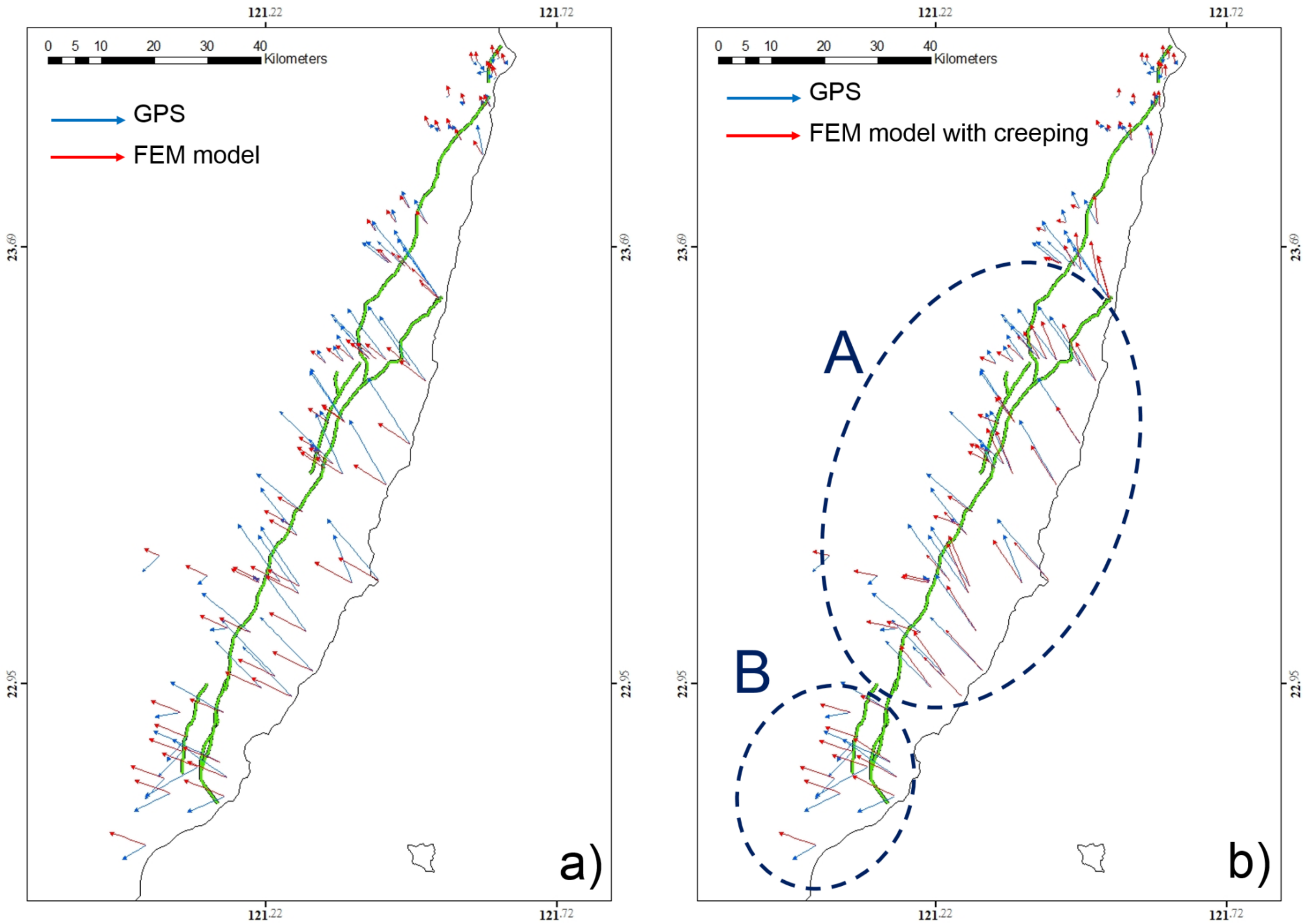
花東縱谷斷層潛移速度逆推結果

潛移方向分布圖



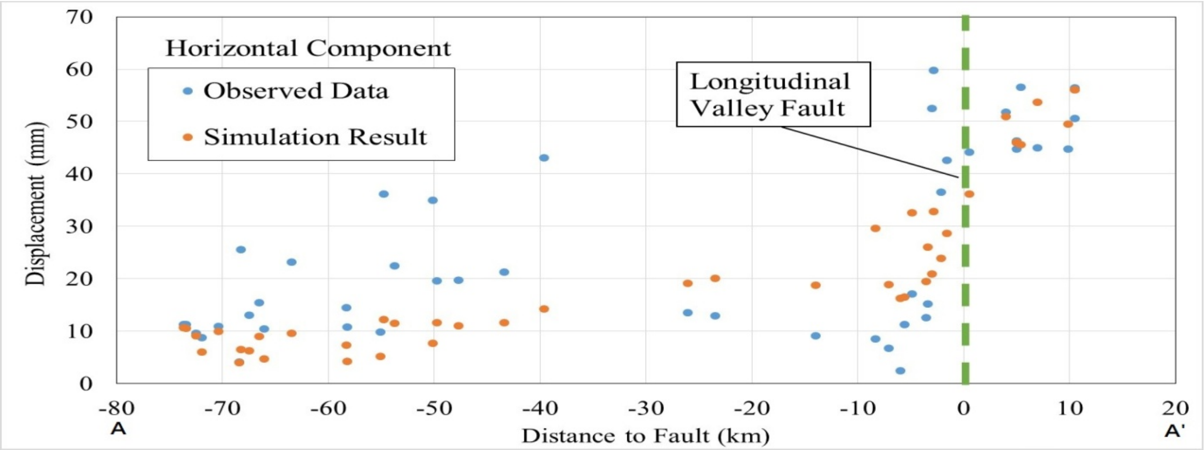
潛移速率分布圖



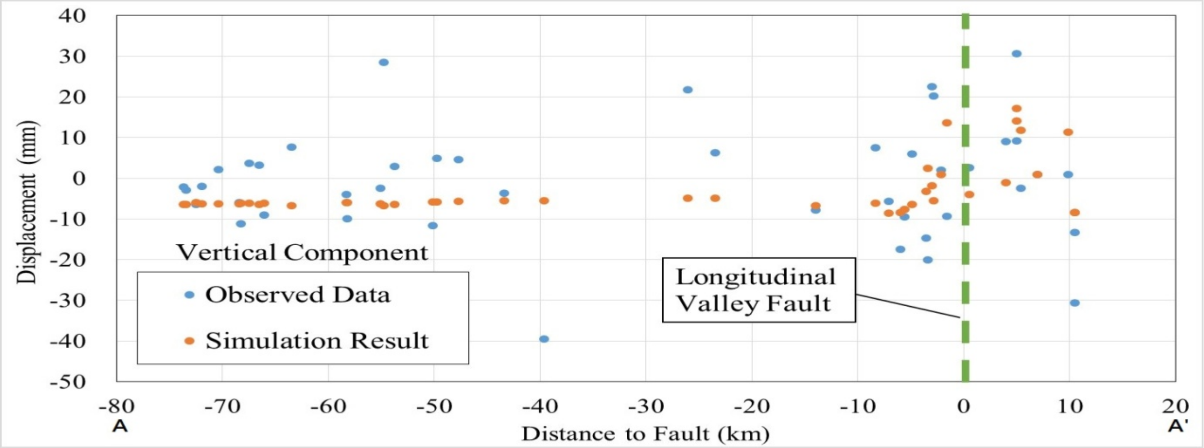


A區之數值模型水平預測量，已與GPS觀測結果接近；

B區之預測結果仍與觀測值有所差異，其原因可能為B區考慮斷層潛移前的數值模型預測量，其向南的分量與GPS觀測值差距太遠，故即使加入潛移作用後，其擬合結果仍然不佳。



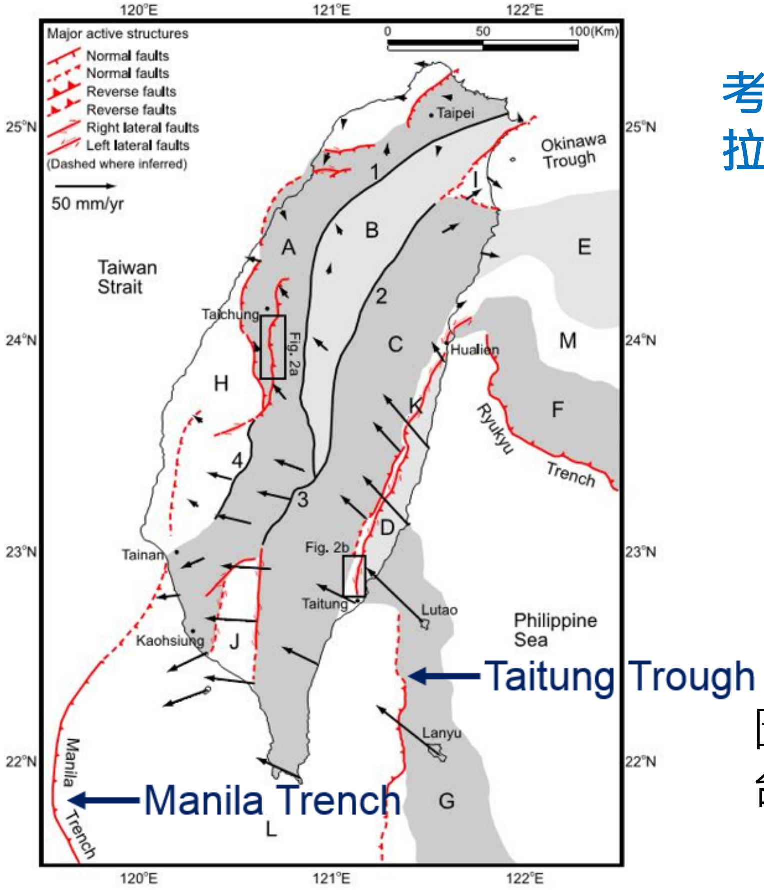
水平方向



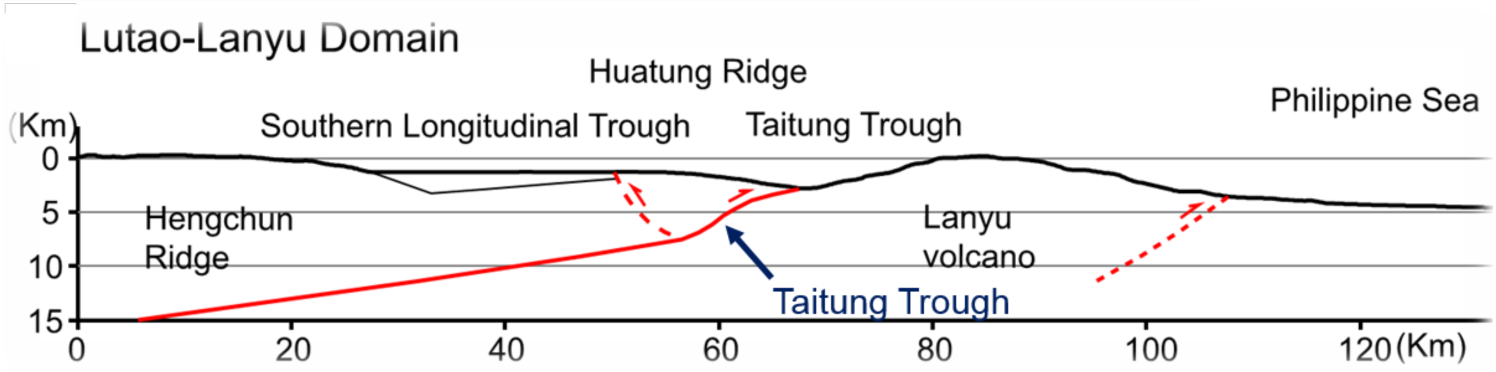
垂直方向

GPS觀測資料由中研院地球所郭隆晨博士提供

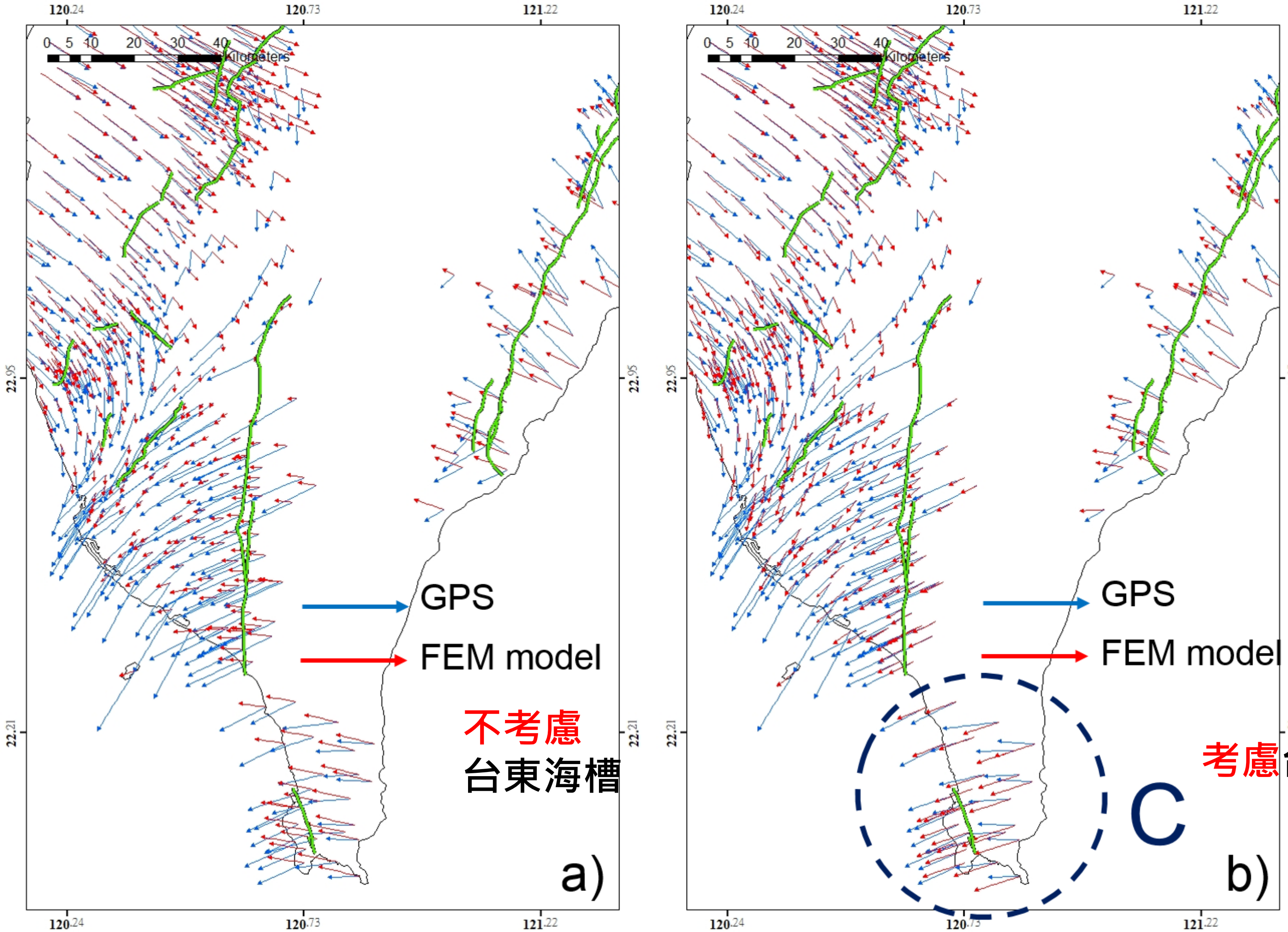
考慮台東海槽(Taitung Trough)與馬尼拉海槽(Manila Trench)之可能影響



圖中為Shyu et al. (2005)所指之
台東海槽(Taitung Trough)與馬尼拉海槽(Manila Trench)位置



將台東海槽(Taitung Trough)之摩擦力設為零a)前與b)後之地表位移速率預測結果

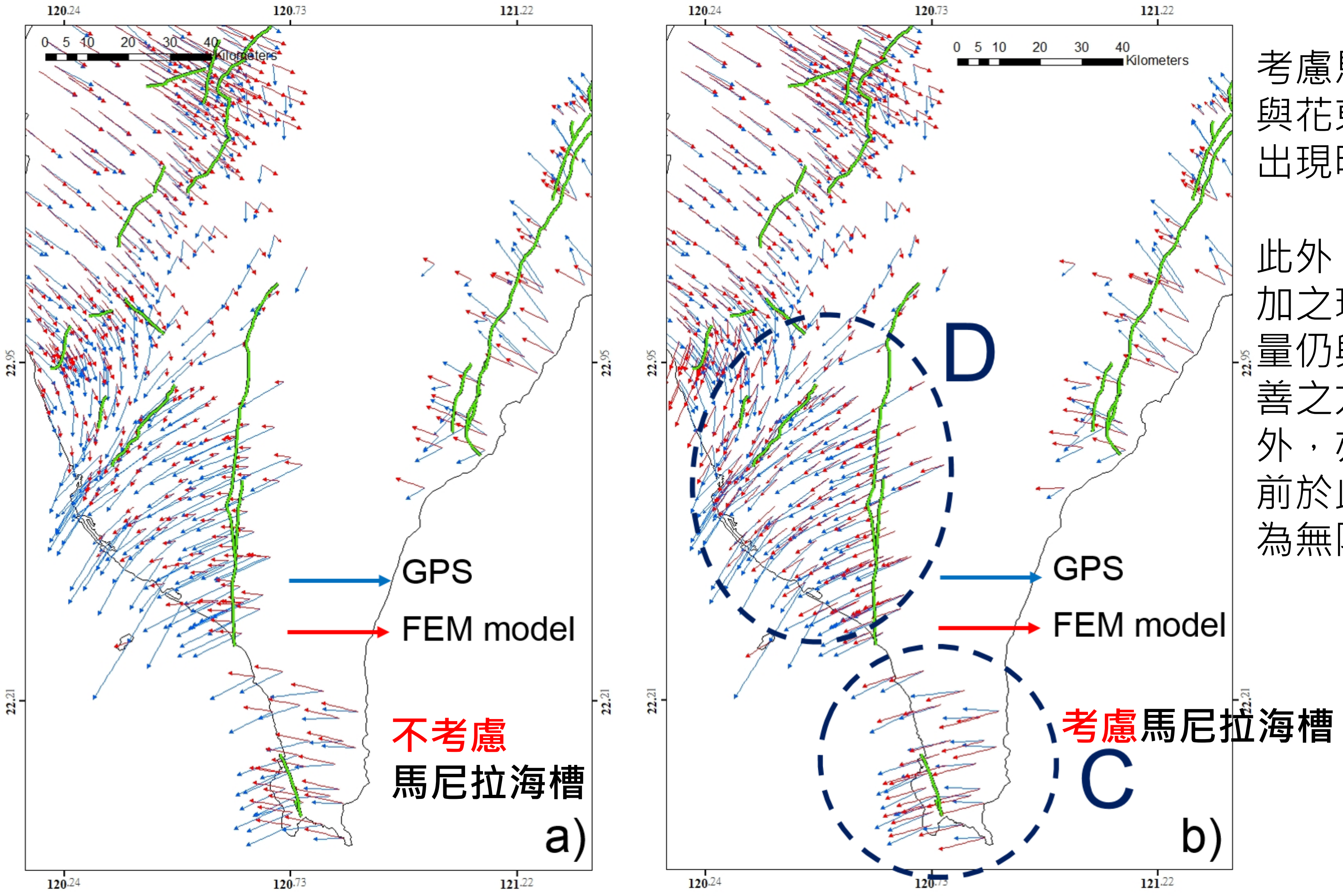


考慮台東海槽

入台東海槽之潛移後，恆春半島(C區)與花東縱谷斷層南端之位移量預測結果出現明顯向南之分量，其向南之分量甚於大於GPS之觀測值所。

此為將摩擦力設為零之結果，實際應不會有如此高之潛移量，但此範例顯示出考慮此斷層之潛移行為後，將有助於預測恆春半島之位移量。

將馬尼拉海槽(Taitung Trough)之摩擦力設為零a)前與b)後之地表位移速率預測結果



考慮馬尼拉海槽之潛移後，恆春半島(C區)與花東縱谷斷層南端之位移量預測結果亦出現明顯向南之分量。

此外，高屏地區(D區)之預測位移量亦有增加之現象，但此加大後之預測值，其位移量仍與GPS觀測值有段差距，其進一步改善之方法除考慮南部其他斷層之潛移行為外，亦建議探討目前邊界條件之合適性(目前於此有限元素模型架構中，邊界元素設為無限邊界)。

簡報完畢

敬請指教