3D Velocity of Taiwan: Achievements and Challenges

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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

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 2\textsuperscript{nd} and 3\textsuperscript{rd} Generation Models

\textbf{KC12} Kuo-Chen \textit{et al.} (2012) \hspace{1cm} \textbf{K05} Kim \textit{et al.} (2005) \hspace{1cm} \textbf{W07} Wu \textit{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   Size (kg)  Date (GMT)              CWB Longitude    Latitude    Elev.
Point  dd/mm/yyyy hh:mm:ss.sss ML (GS84)                 (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  ...  1.78  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

<table>
<thead>
<tr>
<th>Model</th>
<th>RMS (s)</th>
<th>Mean (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>K05</td>
<td>0.75</td>
<td>-0.27</td>
</tr>
<tr>
<td>W07</td>
<td>0.66</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model</td>
<td>RMS (s)</td>
<td>Mean (s)</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>----------</td>
</tr>
<tr>
<td>K05</td>
<td>0.37</td>
<td>0.01</td>
</tr>
<tr>
<td>W07</td>
<td>0.49</td>
<td>0.24</td>
</tr>
</tbody>
</table>

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)
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

<table>
<thead>
<tr>
<th>Model</th>
<th>RMS(s)</th>
<th>Perturbation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2D</td>
<td>0.13</td>
<td>-61 ~ 42</td>
</tr>
<tr>
<td>K05</td>
<td>0.37</td>
<td>-10 ~ 10</td>
</tr>
<tr>
<td>W07</td>
<td>0.41</td>
<td>-10 ~ 10</td>
</tr>
<tr>
<td>KC12</td>
<td>0.56</td>
<td>-15 ~ 25</td>
</tr>
</tbody>
</table>
Comparison with Tomography Models
Quantitative Comparison (4 Longer Profiles)

<table>
<thead>
<tr>
<th></th>
<th>Mean (s)</th>
<th>RMS (s)</th>
<th>Variance (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2D</td>
<td>-0.007</td>
<td>0.12</td>
<td>0.02</td>
</tr>
<tr>
<td>K05</td>
<td>-0.25</td>
<td>0.45</td>
<td>0.15</td>
</tr>
<tr>
<td>W07</td>
<td>0.02</td>
<td>0.45</td>
<td>0.20</td>
</tr>
<tr>
<td>KC12</td>
<td>0.34</td>
<td>0.47</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Comparison in Northern Taiwan
Quantitative Comparison (Northern Taiwan)

<table>
<thead>
<tr>
<th>Model</th>
<th>Mean (s)</th>
<th>RMS (s)</th>
<th>Variance (s²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2D</td>
<td>-0.007</td>
<td>0.10</td>
<td>0.01</td>
</tr>
<tr>
<td>K05</td>
<td>-0.15</td>
<td>0.43</td>
<td>0.16</td>
</tr>
<tr>
<td>W07</td>
<td>0.09</td>
<td>0.46</td>
<td>0.20</td>
</tr>
<tr>
<td>KC12</td>
<td>0.28</td>
<td>0.36</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Models slower than real Earth

Models faster than real Earth
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

\[ \text{RMS} = \sqrt{\frac{\sum_{i=1}^{M} (V_i^N - V_i^{N-1})^2}{M}} \]

- \( V_i^N \): 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

RMS of ensemble average models between 2 consecutive realizations
Surface Wave Phase Velocity Tomography
Model from Surface Wave Tomography

Surface Wave Tomography

KC12 (Traveltime)
**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!