A 3-D simulation of crustal deformation accompanied by subduction in the Tokai region, central Japan

Hidekuni Kuroki (Meteorological Research Institute), Hidemi Ito and Akio Yoshida (Japan Meteorological Agency)
Contents

1. Motivation
   Why did we study the Tokai region?
   Early studies and technical issues

2. Model
   Rate- and state-dependent friction law
   Geophysical constraints by observations

3. Results
   Crustal deformation derived from this model
   Comparisons between observation and simulation results

4. Summary
Space-time distribution of great earthquakes along the Nankai-Suruga trough

after Ishibashi and Satake (1998)
Purpose of our study

Whether precursory changes for the anticipated Tokai earthquake could be observed or not.
Simulation study

1. Early studies

   Kato and Hirasawa (1999)
   Rate- and state-dependent friction law
   (Dieterich, 1979; Ruina, 1983)

2. Problems

   2-D model

3. What’s new in the present work

   3-D model with a curved plate interface
Model

Dislocation theory

\[ \tau_i(t) = \sum_{j=1}^{N} K_{ij} (V_j^{pl} t - u_j(t)) \frac{G}{2\beta} \frac{du_i(t)}{dt} \]  

where \( \tau \) : shear stress  \( K_{ij} \) : elastic stiffness  \( V_j^{pl} \) : plate velocity  
\( t \) : time  \( u \) : slip amount  \( G \) : rigidity  \( \beta \) : S wave speed

Rate- and state-dependent friction law

\[ \tau_i(t) = \mu_i(t) \sigma_i^{eff} \]

\[ \mu_i(t) = \mu_* + \theta_i(t) + a_i \ln(V_i / V_*) \]  
\[ \frac{d\theta_i(t)}{dt} = - \frac{V_i(t)}{L_i} (\theta_i(t) + b_i \ln(V_i(t) / V_*)) \]  

where \( \tau \) : frictional force  \( \mu \) : friction coefficient  \( \sigma \) : normal stress  
\( \theta \) : state variable  \( V \) : velocity  \( a, b, L \) : friction parameters

after Dieterich (1979), Ruina (1983)
Rate- and state-dependent friction law

Dieterich (1979), Ruina (1983)

\[ a-b < 0 \]

**seismic zone**

\[ a-b > 0 \]

**aseismic zone**

- **unstable slip**
  - rate-weakening \((a-b) < 0\)
  - \(a \ln(V_2/V_1)\)
  - decrease \((b-a) \ln(V_2/V_1)\)

- **stable slip**
  - rate-strengthening \((a-b) > 0\)
  - \(a \ln(V_2/V_1)\)
  - increase \((a-b) \ln(V_2/V_1)\)

- **slip distance**
  - \(L\)
  - \(\mu_1\)
  - \(\mu_2\)

- **velocity**
  - \(V_2\)
  - \(V_1\)
Geophysical constraints by observations

1. Plate configuration
   JMA hypocentral data Harada et al. (1998)

2. Recurrence interval
   90-150 years Ishibashi and Satake (1998)

3. Average seismic coupling coefficient
   0.5 (0-60km depth) Peterson and Seno (1984)

4. Crustal deformation
   Leveling and GPS Observation by GSI

5. Coupling region (Locked zone or seismic zone)
   10-30km depth Matsumura (1997), Sagiya (1999) etc.

6. Plate velocity
   4cm/year Seno et al. (1993)
Modeling of the plate interface

Tokai Region

\[ V_{pl} = 4 \text{cm/year} \quad \text{Seno et al. (1993)} \]

Viewed from Suruga Bay
Friction parameter

\[ a - b < 0 \] Seismic zone

\[ L = 5\text{cm} \]
Time evolution of cumulative displacement

Seismic zone

Aseismic zone

about 150 years
Displacement on the plate interface

100 years before EQ
50 years before EQ
20 years before EQ
10 years before EQ
5 years before EQ
Just before EQ
Shear stress on the plate interface

100 years before EQ

50 years before EQ

20 years before EQ

10 years before EQ

5 years before EQ

Just before EQ

Stress (MPa)
Velocity just before EQ

Coseismic slip distribution

Average slip = 3.9m  Mw=8.0
Level & Strain changes during one day before the earthquake

**Level change**

<table>
<thead>
<tr>
<th>Strain change</th>
<th>Level change</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.7</td>
<td>1.5</td>
</tr>
<tr>
<td>-4.7</td>
<td>8.0</td>
</tr>
</tbody>
</table>

on the ground surface
Temporal change of volumetric strain at Hamaoka station

One Cycle
- One year before EQ
- One day before EQ

Graphs showing strain changes over time (year, hour, day) with magnitudes of $10^{-5}$, $10^{-8}$, and $10^{-7}$.
Subsidence at Hamaoka relative to Kakegawa

Observation by GSI

Simulation result

Kakegawa corrected observed 5mm/year

Hamaoka postseismic 7mm/year

1962 2002
Comparison between GPS observation and simulation result for the vertical displacement

**GPS observation**

April 1997 – April 2000

**Simulation result**

20 to 17 years before EQ
Comparison between GPS observation and simulation result for the horizontal displacement

GPS observation

Simulation result

April 1997 – April 2000

20 to 17 years before EQ
Summary

• A highly shear-stressed ring-shaped zone is formed 50 years before the earthquake around a strongly coupled region.

• Preslip gives rise to level change of the order of 1 mm and volumetric strain change of $10^{-8}$ to $10^{-7}$.

• Subsidence at Hamaoka relative to Kakegawa turns to uplift several years before the earthquake.

• The results of the simulation agree well with crustal deformation observed by leveling and GPS.