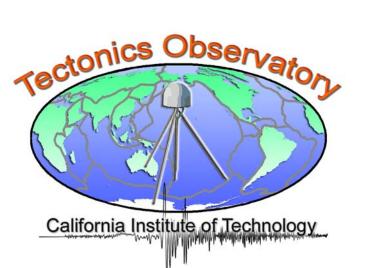# Appropriate Elastic Models for Interpreting Subduction Zone GPS Data

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I. Motivation

Why Study Subduction Zones?

Plate Collision Zones are locations of :

- Primary source of buoyancy driving plate tectonics

- Largest fraction of seismicity on Earth (~ 95%)

- Largest magnitude earthquakes

- Large concentrations of population/infrastructure

Modeling the state of stress and coupling: 10^{-3}-10^4 yrs

Long Term Goal - Dynamic Modeling:

Continuity, Momentum and Energy balance,

Constitutive Relations (Temperature, Mineralogy), and

Boundary & Initial Conditions

Intermediate Goal - Kinematic Modeling:

Fit Surface Geodetic and Geologic Observations by imposing internal velocities on dislocations in an elastic half-space.
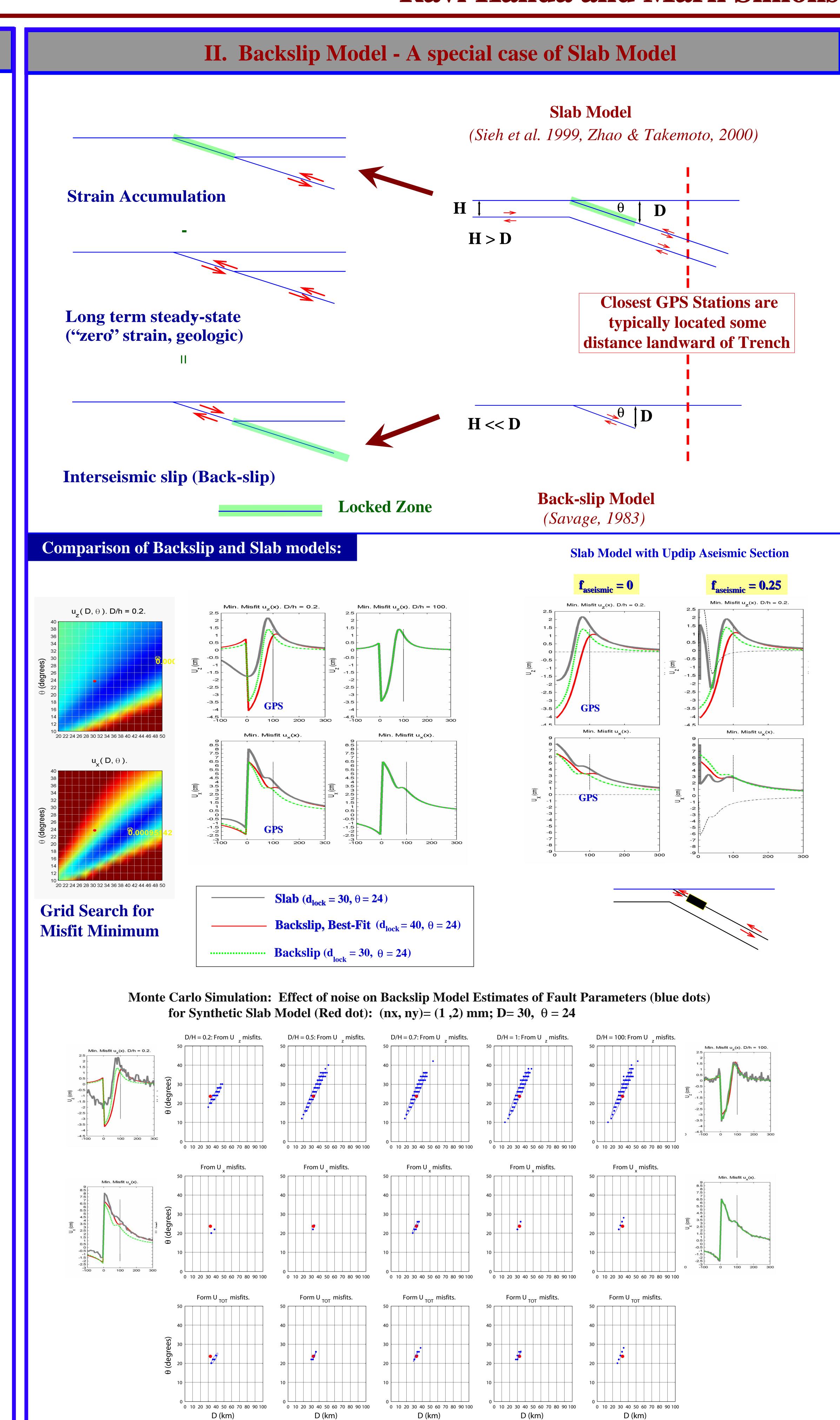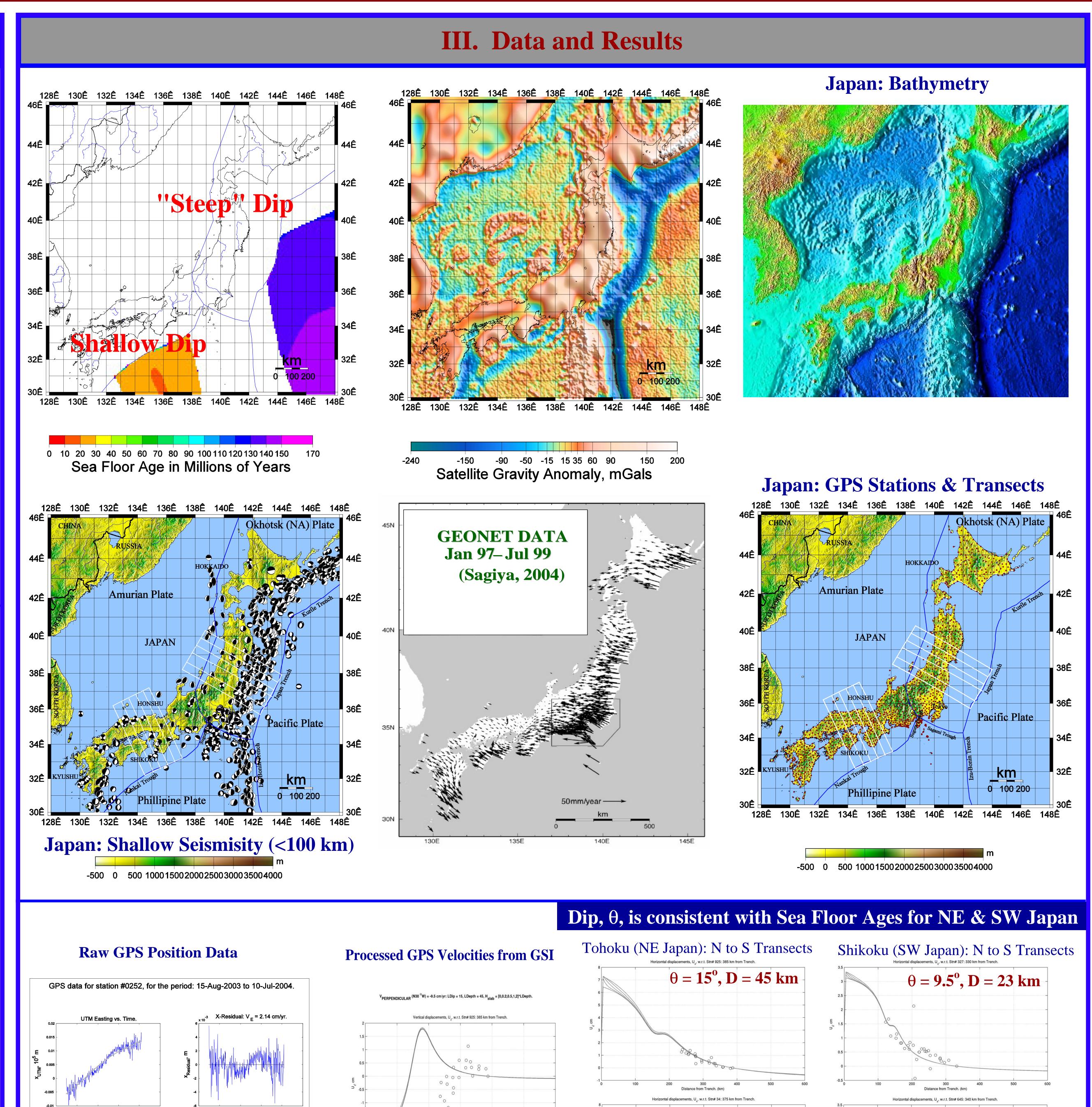
Goals

We want to develop an understanding of why Back-slip model works in modeling subduction zone deformation, in spite of the fact that is it counter-intuitive and is a purely mathematical construct. This is done by developing a more realistic "slab" model that takes the thickness of the subducting slab into account. The backslip model is then explained as a limiting case of the "slab" model, as slab thickness tends to zero, thus giving the backslip model a more intuitive basis.

We also want to determine regions in the world where the backslip model does not work, and see under what conditions the "slab" model explains observed surface deformations better.

Finally, we compare the backslip and slab models to see if the currently available GPS data lets us discriminate between these two models. For this purpose, we use processed (1 year) GPS velocities from GSI, Japan.

The ultimate goal of this endeavor is to be able to relate short-term deformation and its lateral variability to the long-term relationship between seismicity and trench-parallel gravity and topographic anomalies (Song & Simons, 2003).

II. Backslip Model - A special case of Slab Model

Slab Model
(Sieh et al. 1999, Zhao & Takemoto, 2000)

Strain Accumulation

$H > D$

Long term steady-state ("zero" strain, geologic)

Interseismic slip (Back-slip)

Locked Zone

$H << D$

Closest GPS Stations are typically located some distance landward of Trench

Back-slip Model
(Savage, 1983)

Comparison of Backslip and Slab models:

Slab Model with Updip Aseismic Section

$f_{aseismic} = 0$ $f_{aseismic} = 0.25$

Grid Search for Misfit Minimum

— Slab ($d_{lock} = 30$, $\theta = 24$)
— Backslip, Best-Fit ($d_{lock} = 40$, $\theta = 24$)
--- Backslip ($d_{lock} = 30$, $\theta = 24$)

Monte Carlo Simulation: Effect of noise on Backslip Model Estimates of Fault Parameters (blue dots) for Synthetic Slab Model (Red dot): (nx, ny)= (1 ,2) mm; D= 30, θ = 24

III. Data and Results

"Steep" Dip

Shallow Dip

Japan: Bathymetry

Sea Floor Age in Millions of Years
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 170

Satellite Gravity Anomaly, mGals
-240 -150 -90 -60 -15 15 35 60 90 120 150 200

GEONET DATA Jan 97–Jul 99 (Sagiya, 2004)

Japan: GPS Stations & Transects

Japan: Shallow Seismisity (<100 km)

Dip, θ, is consistent with Sea Floor Ages for NE & SW Japan

Raw GPS Position Data

Processed GPS Velocities from GSI

Tohoku (NE Japan): N to S Transects

Shikoku (SW Japan): N to S Transects

GPS data for station #0252, for the period: 15-Aug-2003 to 10-Jul-2004.

$\theta = 15^{\circ}$, D = 45 km

$\theta = 9.5^{\circ}$, D = 23 km

$\theta = 15^{\circ}$, D = 35 km

$\theta = 15^{\circ}$, D = 25 km
Kii Peninsula

$\theta = 15^{\circ}$, D = 52 km

$\theta = 8.5^{\circ}$, D = 26 km

South East NorthWest South East NorthWest

Conclusions

From Panel II at left, the backslip and slab models differ significantly in their predicted surface deformations just above the locked zone, IFF the slab thickness is larger than locking depth. This is true even for noisy data, or when there is an updip aseismic section.

Both the backslip and slab models fit the GPS horizontal velocity data well.   In order to resolve between these two models, we need better vertical GPS velocities (processing in progress). From fitting the horizontal GPS data, however, we possibly see the change in slope associated with the locking depth, in SW Japan (due to shallower dip). In the future, we would like to use leveling or tide-gauge data to complement GPS vertical velocities.