Development of a Predictive Simulation System for Crustal Activities in and around Japan - V

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Our research group aims to develop a physics-based predictive simulation system for crustal activities in and around Japan, which consists of a combined simulation model for quasi-static stress accumulation and dynamic rupture propagation and the associated data assimilation software. In the first phase (2003–2005), we constructed a prototype of the combined simulation model on a realistic 3-D structure model. In the second phase (2006–2008), we test the validity and applicability of the combined simulation model, and develop the associated data assimilation software. In 2007, we performed a combined simulation of quasi-static stress accumulation, dynamic rupture, and seismic wave propagation for the 2003 Tokachi-oki earthquake (M8.0). The good agreement between simulation results and observations demonstrates that the physics-based computer simulation is useful for the quantitative evaluation of strong ground motions that will be produced by potential interplate earthquakes. For the data assimilation software, we developed two inversion methods, one of which is to estimate interplate coupling rates from GPS data, and another is to estimate crustal stress fields from CMT data of seismic events. From the inversion analysis of GPS data, we revealed the potential source regions of next interplate earthquakes along the Kuril-Japan trench. From the inversion analysis of CMT data, we obtained the precise 3-D stress pattern in and around Japan.

Keywords: combined simulation, strong motion prediction, geodetic data inversion, interplate coupling, CMT data inversion, crustal stress fields

1. Introduction

The aim of this project is to develop a physics-based predictive simulation system for crustal activities in and around Japan, where the four plates of Pacific, North American, Philippine Sea and Eurasian are interacting with each other in a complicated way. The total system is constructed on a common 3-D structure model called CAMP Standard Model [1]. In the first three years (2003–2005) of the project, we completed a prototype of the combined simulation model for quasi-static stress accumulation and dynamic rupture propagation [2]. In 2006, we tested the validity and applicability of the combined simulation model [3], and began to develop the software to assimilate massive observed data from nation-wide seismic/geodetic networks into computer simulation.

2. Validity tests of the combined simulation for strong ground motions

In 2006, we performed the combined simulation of quasi-static stress accumulation, dynamic rupture propagation and seismic wave propagation for the 2003 Tokachi-oki earthquake (M8.0), which occurred at the the North American-Pacific plate interface [4]. The simulation results are summarized in Fig. 1, where the left panel shows the source region of the 2003 event and the observation stations distributed along coastline. The center panel shows the snapshots of dynamic rupture propagation and seismic wave radiation. The right panel shows the computed and observed ground motions. The good agreement between the simulation results and the observations demonstrates that the physics-based computer simulation is useful for the quantitative evaluation of strong ground motions that will be produced by potential interplate earthquakes.

One of uncertainties in this simulation is the location of rupture initiation point. In 2007, we performed a series of numerical experiments to examine the effects of rupture initiation point on ground motions [5]. We considered the five source models with different rupture initiation points: the real hypocenter (S) and the southernmost (A), northernmost (B), easternmost (C) and westernmost (D) of the source region. The results of numerical experiments are shown in Fig. 2. The normalized velocity response spectrums for Models A-D were less than 4. This means that the amplification due to different rupture initiation points is 4 times at a maximum, which is smaller than 3-D site effects.

3. Interplate coupling along the Kuril-Japan trench, inferred from GPS data inversion

On the basis of elastic-viscoelastic dislocation theory, we can determine the functional form of a stochastic model to extract information about unknown fault slip distribution from observed surface displacement data. In addition to observed data we usually have direct prior information that bounds the values of model parameters within certain ranges and indirect prior information that regulates the structure of stochastic models. Recently, incorporating both direct and indirect prior information into observed data and using Akaike's Bayesian Information Criterion, we derived an inversion formula that unifies the Jackson-Matsu'ura formula with direct prior information and the Yabuki-Matsu'ura formula with indirect prior information, and developed a generalized method of geodetic data inversion [6]. We applied this inversion method to interseismic GPS data (1996–2000) in the Hokkaido-Tohoku region, and obtained the precise slip-deficit rate distribution on the North American-Pacific plate

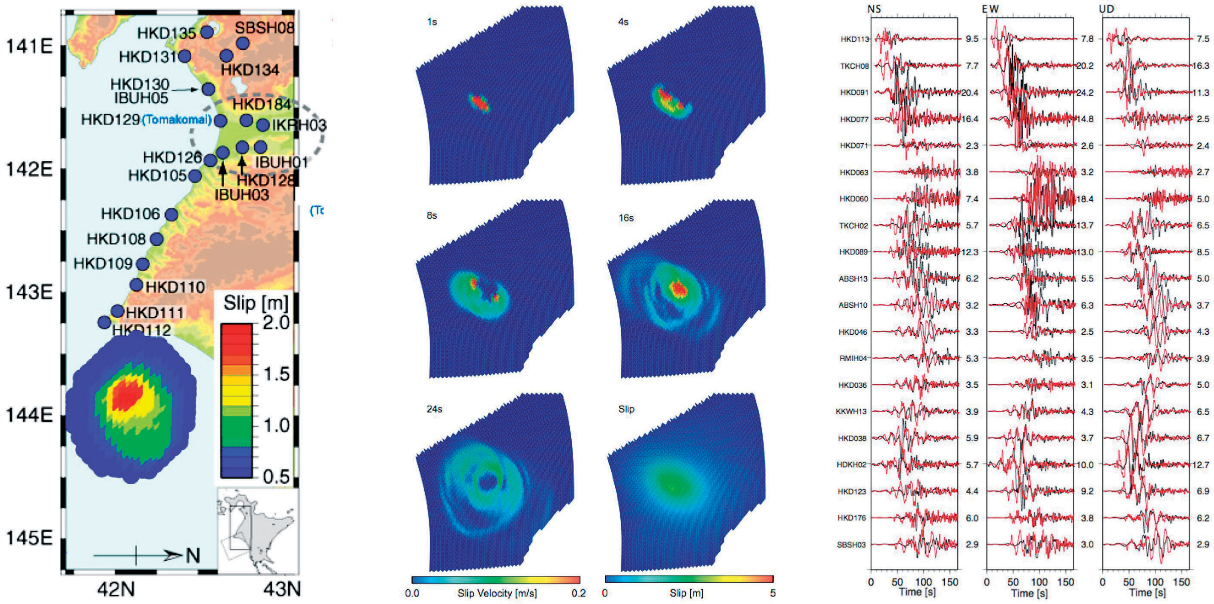

Fig. 1 Combined simulation of quasi-static stress accumulation, dynamic rupture propagation and seismic wave radiation for the 2003 Tokachi-oki earthquake [4]. Left: The location map showing the source region of the 2003 event and the observation stations distributed along coastline. Center: Snapshots of dynamic rupture propagation and seismic wave radiation. Right: Comparison of computed (red) and observed (black) velocity waveforms at the stations.

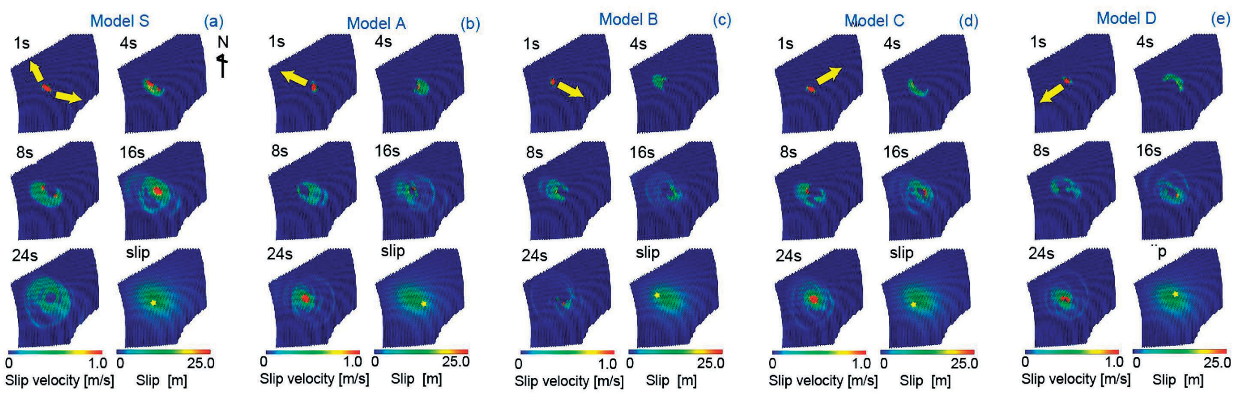

Fig. 2 Snapshots of slip velocity changes for five source models with different rupture initiation points [5]. The yellow arrow at each panel shows a typical rupture propagation direction. At the right bottom of each panel the final slip distribution is shown.

interface. The left panel of Fig. 3 shows the GPS horizontal velocity vectors used for inversion analysis. The right panel is the inversion result showing a trench-parallel slip-deficit zone with five peaks located in the depth range of 10-30 km. These slip-deficit peaks coincide with the source regions of past large interplate earthquakes (M > 7.5) along the Kuril-Japan trench. Given the occurrence time and seismic moment of the last event and the current slip-deficit rate at the potential source region, we can roughly estimate the occurrence time of the next large interplate earthquake along the Kuril-Japan trench.

4. 3-D patterns of tectonic stress fields in and around Japan, inferred from CMT data inversion

We developed an inversion method to estimate tectonic stress fields from CMT data of seismic events by using Akaike's Bayesian information criterion [7]. We applied the method of CMT data inversion to 15,000 moment tensors of seismic events (NIED; Seismic Moment Tensor Catalogue), and estimated the 3-D patterns of tectonic stress fields in and around Japan. The left panel of Fig. 4 shows the horizontal pattern of the inverted stress field at 10 km in depth, which accords with complex tectonic features in and around Japan. The right panel shows three across-arc vertical sections of

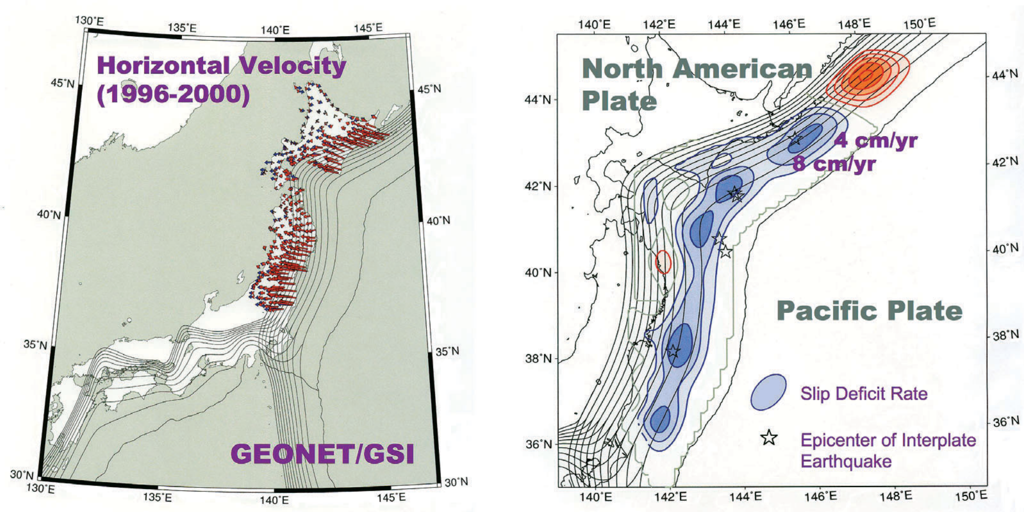

Fig. 3 The distribution of slip-deficit rates on the North American-Pacific plate interface, inferred from GPS data (Hashimoto et al., 2007). Left: GPS horizontal velocity vectors (1996–2000). The plate interface geometry is represented by the iso-depth contours with 10 km-intervals. Right: The distribution of slip-deficit rates. The blue and read contours show the rate of slip-deficit and slip-excess, respectively. The contour intervals are 4 cm/yr. The stars indicate the epicenters of large interplate earthquakes (M > 7.5) in the last 50 years.

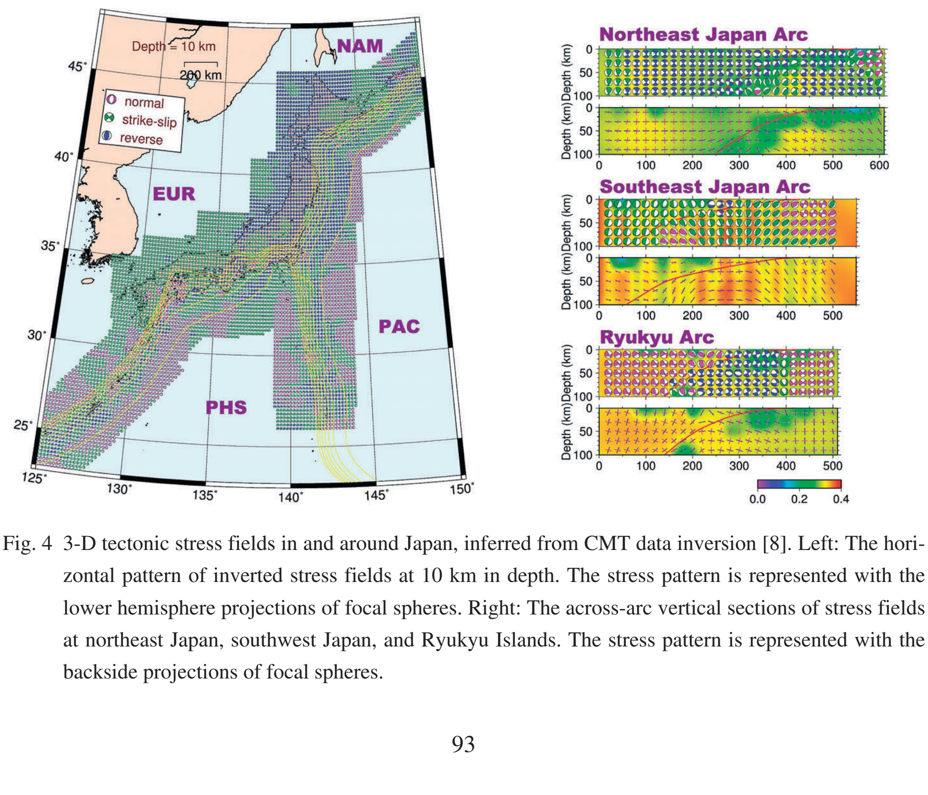

Fig. 4 3-D tectonic stress fields in and around Japan, inferred from CMT data inversion [8]. Left: The horizontal pattern of inverted stress fields at 10 km in depth. The stress pattern is represented with the lower hemisphere projections of focal spheres. Right: The across-arc vertical sections of stress fields at northeast Japan, southwest Japan, and Ryukyu Islands. The stress pattern is represented with the backside projections of focal spheres.

the inverted stress fields at northeast Japan, southwest Japan and Ryukyu Islands, which are remarkably different in back-arc stress patterns from one another: arc-normal compression in northeast Japan, arc-normal extension in Ryukyu Islands, and neutral in southwest Japan.

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日本列島域の地殻活動予測シミュレーション・システムの開発 - V

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本研究プロジェクトは、複雑なテクトニック環境の下にある日本列島及びその周辺域を一つのシステムとしてモデル化し、プレート運動に伴う長期的な地殻変形から大地震の発生まで、時間・空間スケールの著しく異なる地殻活動現象を統一的且つ定量的に予測する並列シミュレーション・システムを開発し、モデル計算と観測データを併合した日本列島域の地殻活動予測シミュレーションを行うことを目的としている。

地殻活動予測シミュレーション・システムは、日本列島域の3次元標準構造モデル(CAMP Standard Model; Hashimoto, Fukui & Matsu'ura, PAGEOPH, 2004)上に構築された、準静的応力蓄積モデル、動的破壊伝播モデル、及び地震／地殻変動データの解析・同化ソフトウェアから成る。平成19年度は、2003年十勝沖地震(M8.0)を例として、準静的応力蓄積モデル、動的破壊伝播モデル、及び地震波動伝播モデルを結合した、プレート境界での準静的応力蓄積–動的破壊伝播–地震波動伝播の連成シミュレーションを行い、理論的な最大地動速度分布と実際に観測された最大地動速度分布の比較を通じて、現実的なプレート境界面形状、摩擦特性、地殻構造等を設定すれば、将来的に発生が予想されるプレート境界地震による地震動を、物理モデルに基づいて予測することが可能であることを示した(Fukuyama, et al., BSSA, 2008)。また、モデル計算と観測データの融合に向けて、直接的先験情報と間接的先験情報を取り込んだ統合逆化公式を導出し(Matsu'ura, Noda & Fukahata, GJI, 2007)、それに基づく地殻変動データ解析手法を国土地理院のGPSデータに適用することで、北海道・東北地域のプレート境界面の固着–すべり状態を明らかにした。同時に、地震のCMTデータから地殻応力を推定するインバージョン解析手法を開発し(Terakawa & Matsu'ura, GJI, 2008)、それを防災科学技術研究所の地震モーメントテンソルデータ(NIED, Seismic Moment Tensor Catalogue)に適用することで、太平洋プレートとフィリピン海プレートが沈み込む日本列島全域の地殻応力の詳細な3次元パターンを明らかにした。

キーワード：連成シミュレーション, 強震動予測, 測地データインバージョン, プレート間カップリング,
CMTデータインバージョン, 地殻応力場