Three Approaches to Interseismic Slip Rates on the Main Marmara Fault and Their Tensorial Correlations with the Kostrov-Based Strain Rates

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Introduction

The interseismic slip distribution in the Marmara fault system represents both observational and modelling challenges. The observational challenge is obvious: the faults are under water and to understand their interseismic behavior (creeping versus locked) requires expensive and logistically difficult underwater geodetic measurements, alongside those on land. Up to now, two such underwater studies have been conducted and they suggest that the segment to the south of Istanbul zone (so-called Central segment) is locked while some creep is probably going on along the neighboring segment to the west. Given these two important findings, the slip distribution problem is still non-trivial due to the fact that our experiments so far demonstrate that the block-based slip inversions and those that only consider a single fault (with the same geometry as one of the boundaries of the blocks) give significantly different results. In this study we approach the problem using three methodologies: block models with spatially non-varying strains within individual blocks, a boundary element approach and a continuum kinematic approach. Although the block model does not give spatially varying strains, the inversion results from the block model can be used as an input to model strain field in the vicinity of the fault. We construct a formulation to correlate the results from these with the strain rates obtained using focal mechanism summations.

Methods and Softwares

Block Model

TDEFNODE is a fortran program that was developped by R. Mccafrey,to model elastic litospheric block rotations and internal strains, locking on block bounding faults etc.

Continumm Model

An approach was developped by J. Beaven and J. Haines, to calculate the "minimum" strain rate field satisfying the geodetic observations.

Boundary Element Method

Poly3D is a software firstly released by A. Thomas that uses boundary element method for modeling faults and fractures discretized into polygonal elements

Other Tools That Used

Velrot is a GAMIT/GLOBK utility script to combine velocity fileds from different analyses

GMT to plot maps, velocities and other parameters that needs to be visualize

Model Inputs

The models in the study were basically produced through two different scenarios.

1[st] Case
Southern Marmara Fault (SMF) is not included in the model.

2[nd] Case
SMF is entered into models and various constraints are imposed on it. (fully locked, freely slip, partial lock)

GPS Velocity Fields
- ayhan_etal_2002
- reilinger_etal_2006
- aktug_etal_2009
- ergintav_etal_2014
- ozdemir&karslioğlu_2019

Geologic Slip Rates
- derived from Zabci_2019

Slip Rates Coming from Different Studies
- Hegert and Heidbach (2010)
- Yamamoto_etal_(2019)
- Lange_etal_(2019)

Model Results

a) Continuum Model

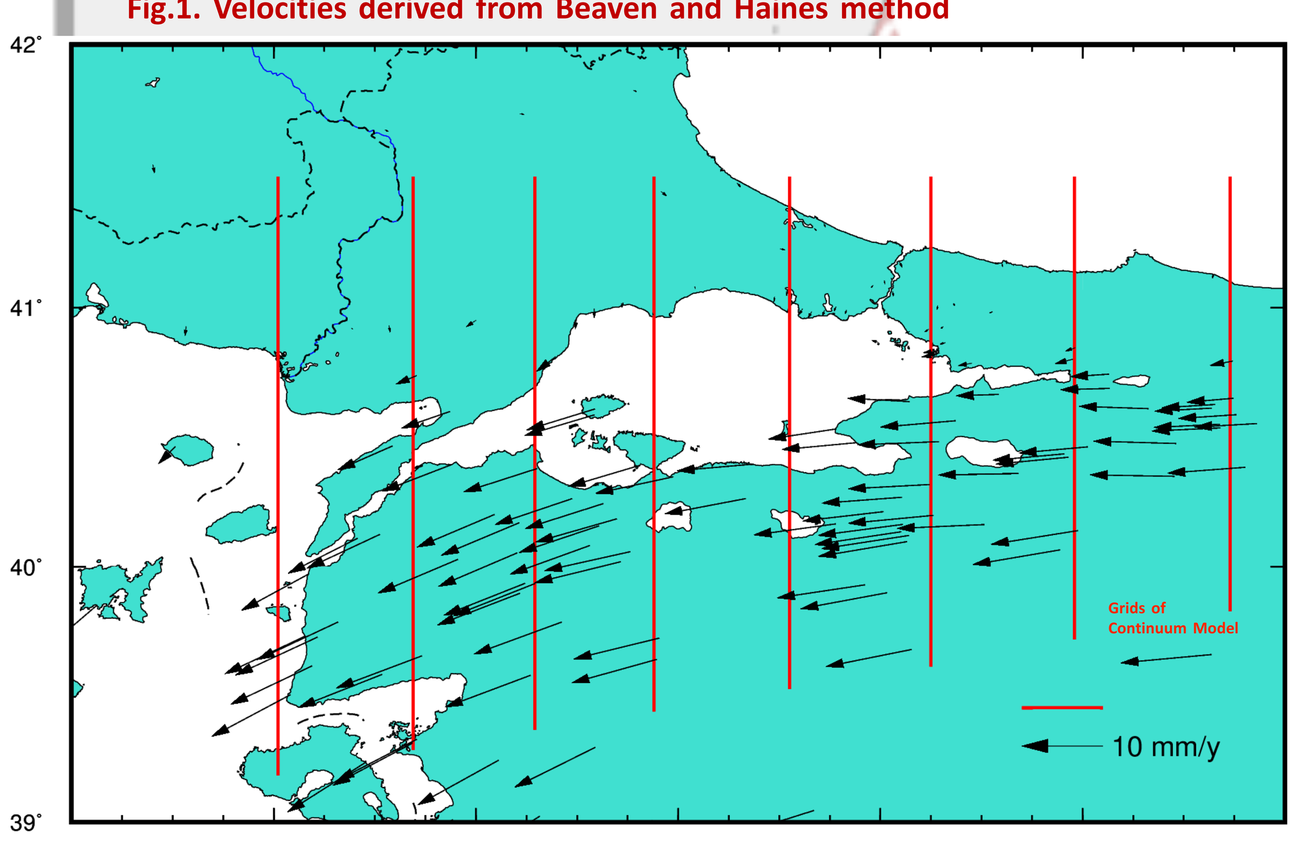
General aim of this method is minimize the following penalty function:

$$\sum_{cells}\sum_{\alpha\beta,\lambda\mu}(\dot{\varepsilon}^{fit}_{\alpha\beta}-\dot{\varepsilon}^{obs}_{\alpha\beta})V^{-1}_{\alpha\beta,\lambda\mu}(\dot{\varepsilon}^{fit}_{\lambda\mu}-\dot{\varepsilon}^{obs}_{\lambda\mu}) + \sum_{points}\sum_{\alpha\beta}(v^{fit}_{x}-v^{obs}_{\alpha})V^{-1}_{\alpha,\beta}(v^{fit}_{\beta}-v^{obs}_{\beta})$$

where $V_{\alpha\beta,\lambda\mu}$ and $V_{\alpha,\beta}$ are the data variance-covariance matrices for the average strain rates and the geodetic velocity measurements respectively, and the subscripts α, β, λ, μ range over longitude ϕ and latitude θ

In this approach we used grid system, at the knotpoints of which, rotation functions $W_{(x)}$ are defined. A suitable spatial distribution of these $W_{(x)}$ will correspond to the best-fitting strain rate field satisfying the GPS observations.

Fig.1. Velocities derived from Beaven and Haines method



b) Boundary Element Method

The approach uses the boundary element model that employs planar triangular elements of constant displacement to model fault surfaces. In this approach, a damped least squares method is used to minimize the functional

$$\sqrt{\|C*b-d\|^2+e*\|D.b\|^2}$$

where b represents the slip distribution on the faults, C the influence coefficient matrix and d the observed deformation data. D is a discrete Laplacian operator for triangulated 2-manifolds.

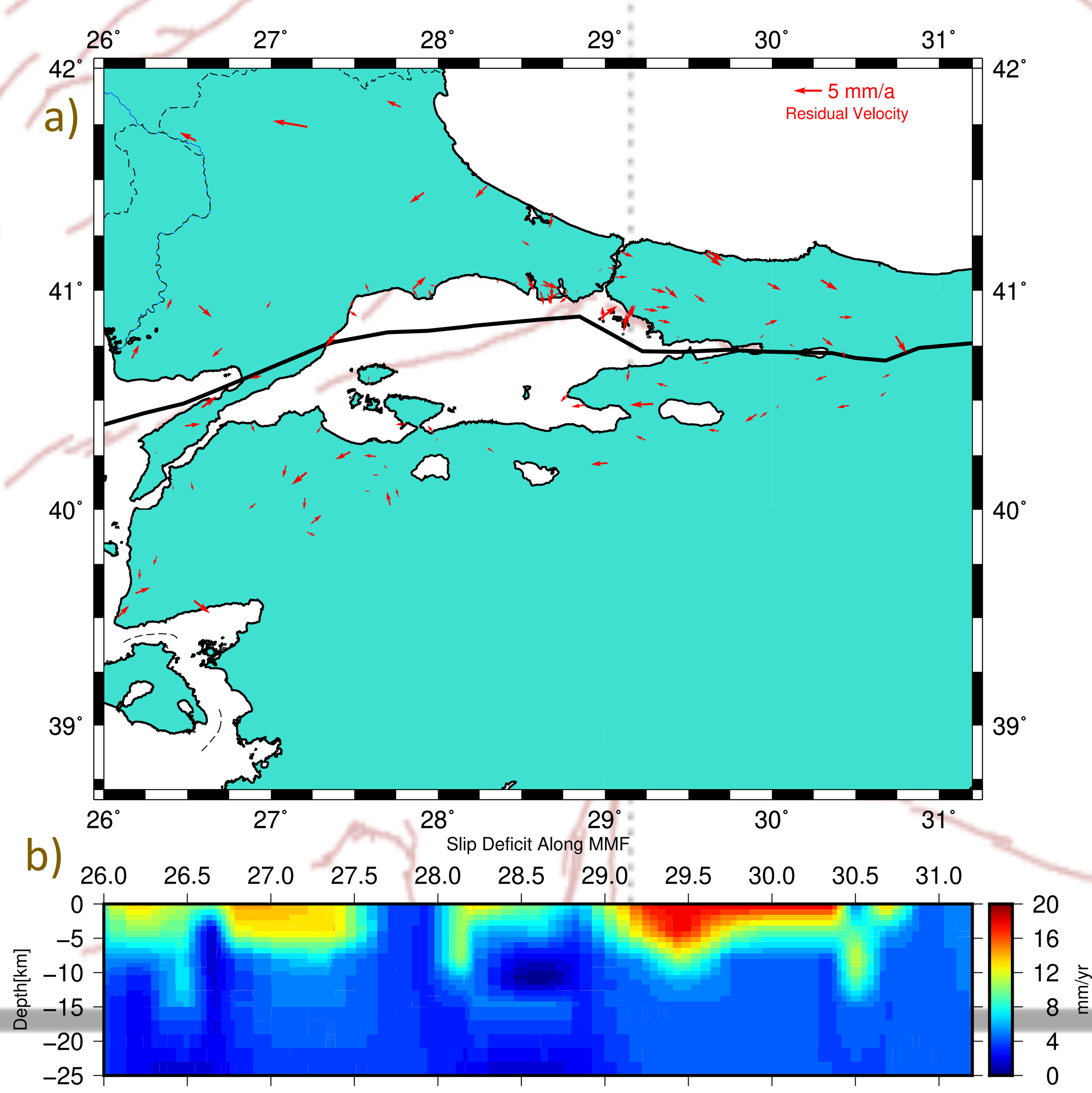


Fig.2. a) Residual velocities for this method b) Slip Rate deficit along MMF

c) Block Model

This approach is tried to ensure that make minimum the penalty function given below.

$$X_n^2 = [\text{ SUM } r^2/(sF)^2] /\text{dof}$$

where r is the residual, s is the standard deviation, F is the scaling factor just described, and dof is the degrees of freedom. The SUM is over all data.

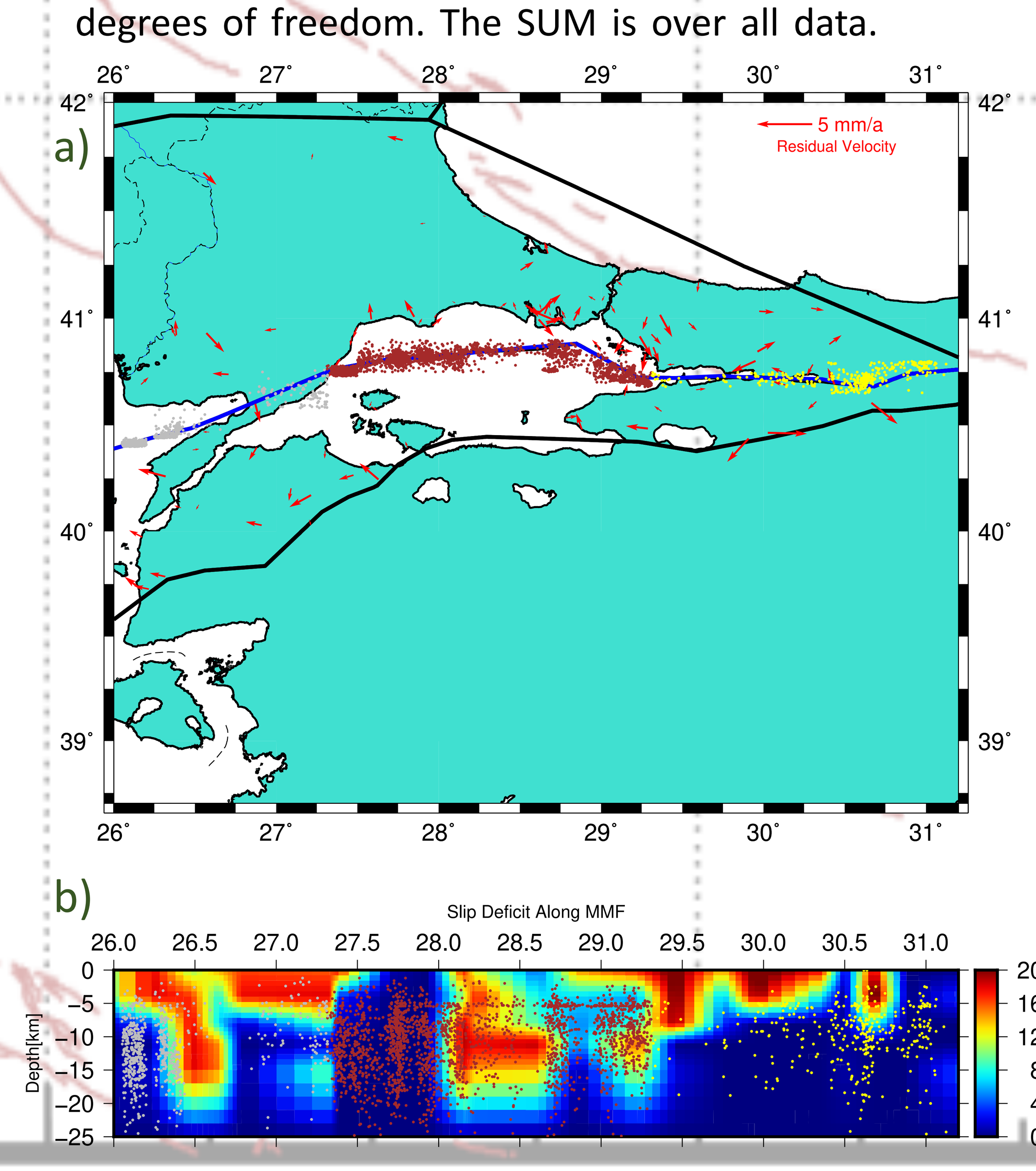
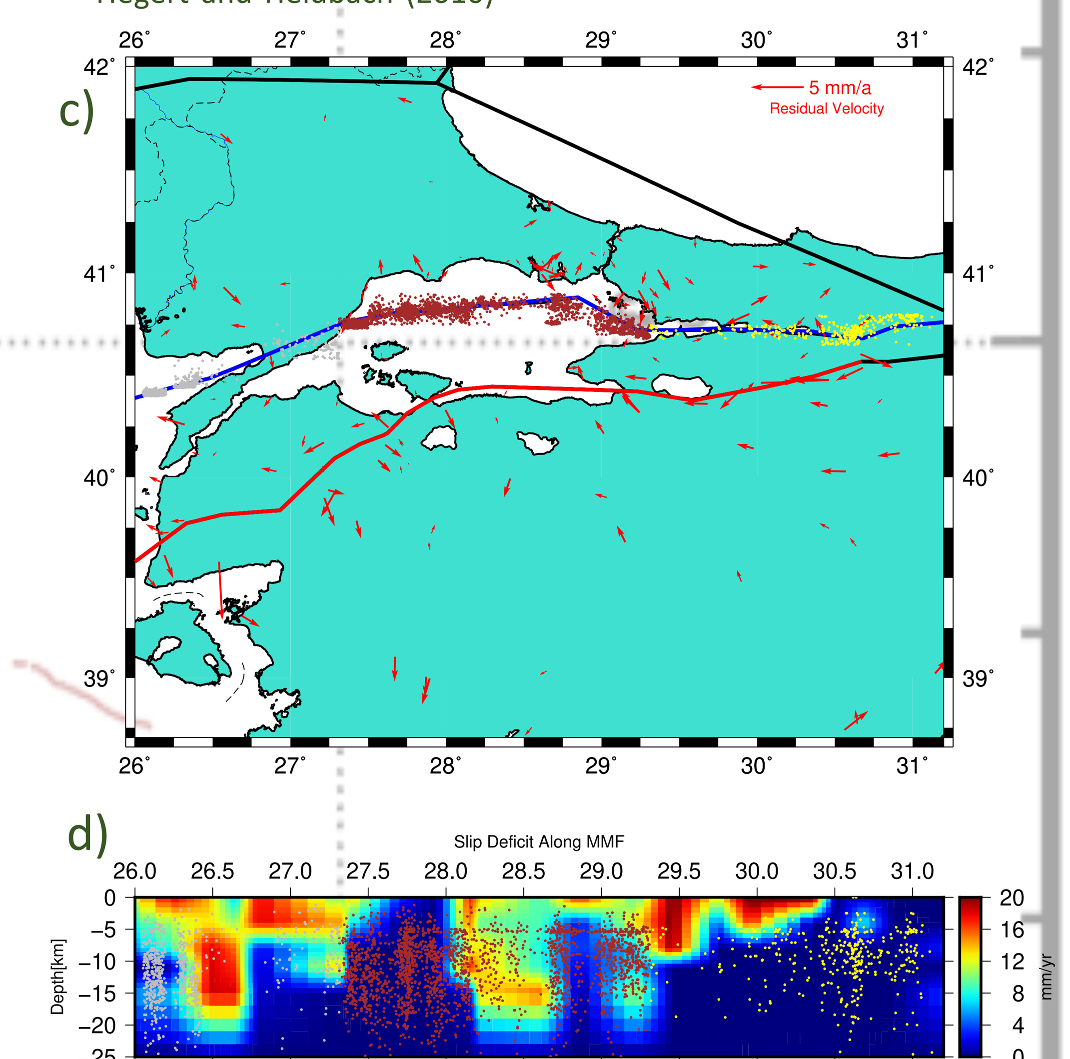


Fig.3. a)residual velocities and seismicity on the Main Marmara Fault yellow circles is represent Izmit segment, browns are show seismicity of segments within the sea and greys are Ganos segment seismicty b) Slip Deficit Along MMF – In this model only MMF is defined as fault (1[st] case)

Fig.4. c) residual velocities and seismicty (Legend is same as Fig 3. d) Locking ratio along fault MMF - In this model SMF also defined as a fault (2[nd] Case) and impose slip rate coming from Hegert and Heidbach (2010)



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