A Probabilistic Assessment of the Causes of Active Deformation in the East Central Mediterranean Using Spherical Finite Element Models

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Abstract

Plate boundary deformation zones represent a challenge in terms of understanding their underlying geodynamic drivers. Active deformation is well constrained by GNSS observations in the SW Balkans, Greece and W Turkey, and is characterized by variable extension and strike slip in an overall context of slow convergence of the Nubia plate relative to stable Eurasia. Diverse, and all potentially viable, forces have been proposed as the cause of the observed surface deformation, e.g., asthenospheric flow, horizontal gravitational stresses (HGSs) from lateral variations in gravitational potential energy, and rollback of the Hellenic slab. We use Bayesian inference to constrain the relative contribution of the proposed driving and resistive regional forces. Our models are spherical 2D finite element models representing vertical lithospheric averages. In addition to regional plate boundaries, the models include well-constrained fault zones like north and south branches of the North Anatolian Fault, Gulf of Corinth and faults bounding the Menderes Massif. Boundary conditions represent geodynamic processes: (1) far-field relative plate motions (2) resistive fault tractions (3) HGSs mainly from lateral variations in topography and Moho topology (4) slab pull and trench suction at subduction zones. The magnitude of each of these is a parameter in a Bayesian analysis of the models in the context of horizontal GNSS velocities. The search yields a probability distribution over all parameters, allowing us to determine mean/median parameter values, robustly estimate parameter uncertainties, and identify tradeoffs. Significant trench suction forces from the Hellenic slab act on the overriding Aegean Sea, including along the Pliny-Strabo STEP Fault. Resistive tractions on most plate boundaries and faults are low. The best-fitting models compare well with paleomagnetic rotations and fault slip rates from previous studies.

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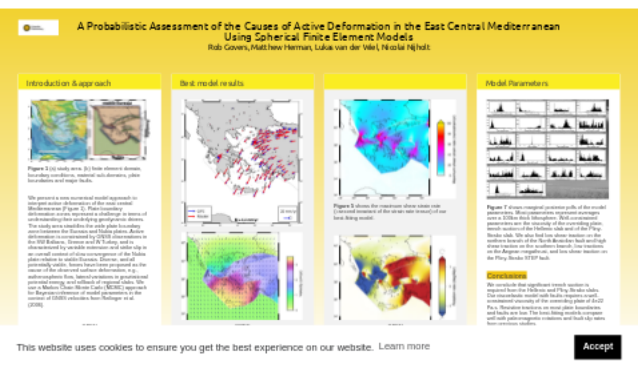

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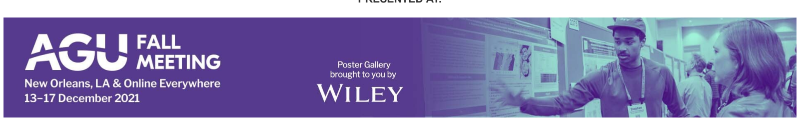

INTRODUCTION & APPROACH

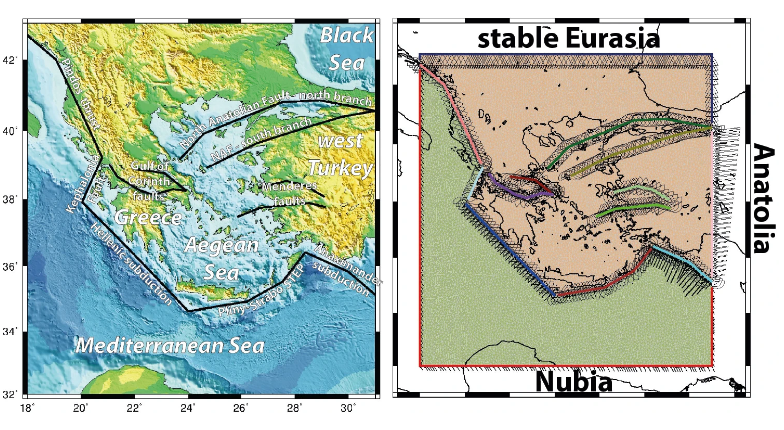

Figure 1 (a) study area. (b) finite element domain, boundary conditions, material sub-domains, plate boundaries and major faults.

We present a new numerical model approach to interpret active deformation of the east central Mediterranean (Figure 1). Plate boundary deformation zones represent a challenge in terms of understanding their underlying geodynamic drivers. The study area straddles the wide plate boundary zone between the Eurasia and Nubia plates. Active deformation is constrained by GNSS observations in the SW Balkans, Greece and W Turkey, and is characterized by variable extension and strike slip in an overall context of slow convergence of the Nubia plate relative to stable Eurasia. Diverse, and all potentially viable, forces have been proposed as the cause of the observed surface deformation, e.g., asthenospheric flow, lateral variations in gravitational potential energy, and rollback of regional slabs. We use a Markov Chain Monte Carlo (MCMC) approach for Bayesian inference of model parameters in the context of GNSS velocities from Reilinger et al. (2006).

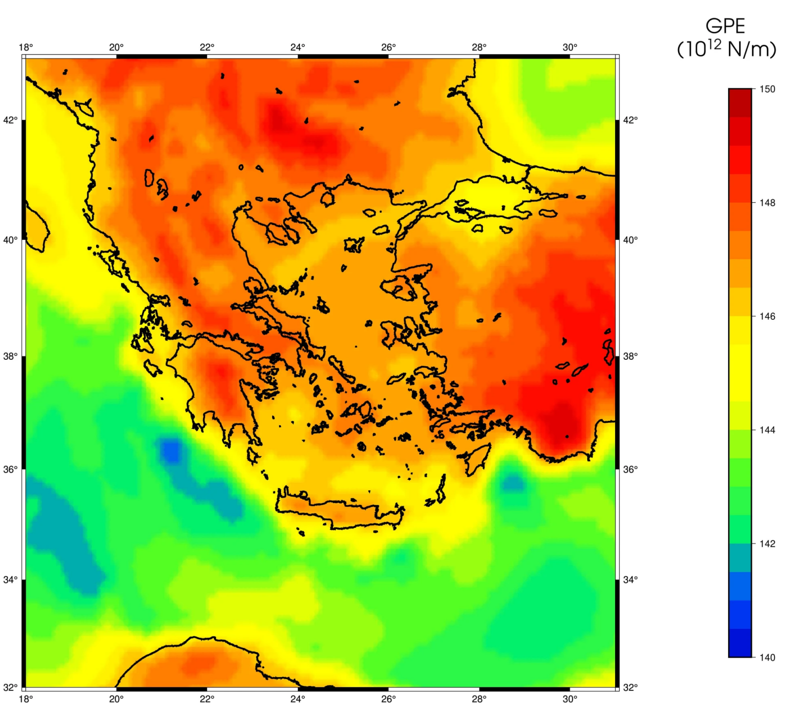

Figure 2 shows that the strongest gradients in Gravitational Potential Energy (GPE) in the model domain occur along active parts of the Africa-Eurasia plate boundary. Horizontal gravitational forces from lateral variations in GPE consequently range up to 12 TN/m. We search for the magnitude of slab pull and trench suction at the Hellenic, Pliny-Strabo, and Anaximander trenches.

The finite element model solves for horizontal velocities and for the sense of slip, and slip rate, on model faults. Mechanical processes beyond the model domain are represented by imposing observed velocities along domain boundaries (D'Agostino et al., 2008; Reilinger et al., 2006). The model is a spherical cap and we adopt the plane stress/thin sheet assumption to compute lithospheric averages of model quantities. We infer the approximate locations and dip of plate boundaries and major faults from seismicity, focal mechanism, and geological observations.

We use a variant of MCMC, the Metropolis Hastings algorithm, to sample the posterior probability density function (pdf) of model parameters (Herman and Govers, 2020). We search for the magnitude of driving and resistive forces, and for the viscoelastic properties of the Aegean-Anatolian domain. After resampling ~100,000 model results, we get ~53,000 samples of the posterior pdfs.

BEST MODEL RESULTS

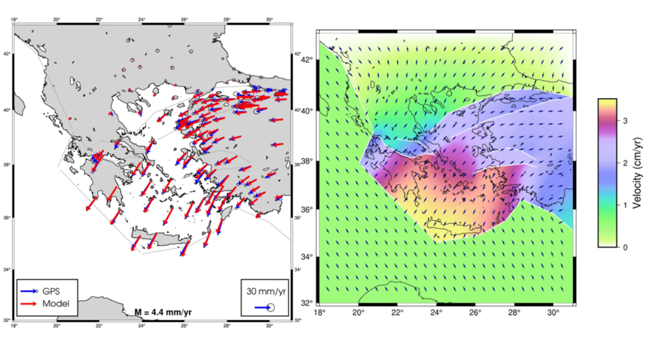

Figure 3 shows velocities of our best-fitting model. The average misfit, weighted by the 1-sigma GNSS velocity uncertainties, is 6.2 mm/yr (unweighted misfit M=4.4 mm/yr).

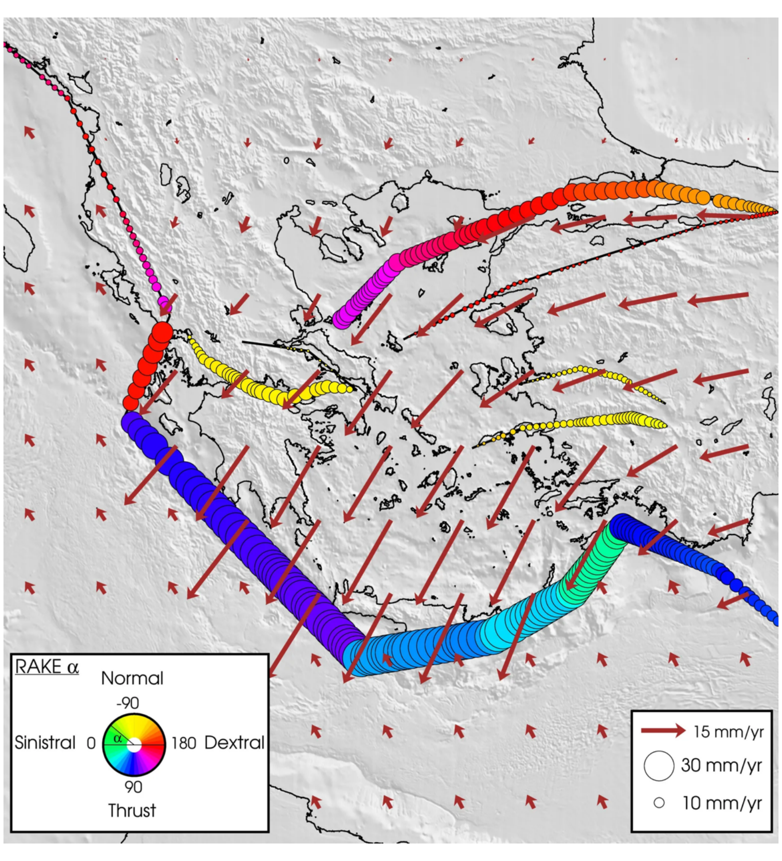

Figure 4 shows fault slip rates and sense of shear of our best-fitting model. The results agree reasonably well with slip rates of the block model of Vernant et al. (2014).

BEST MODEL RESULTS - CONTINUED

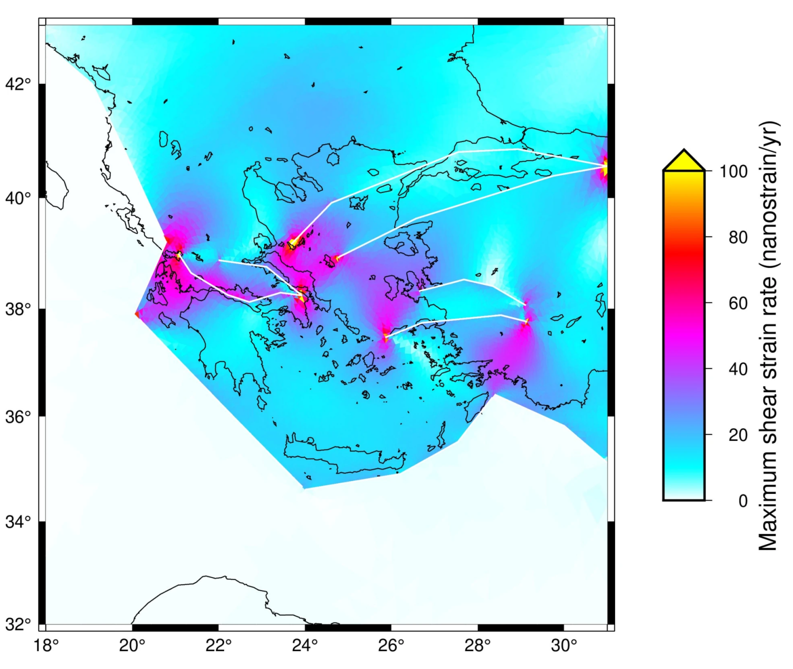

Figure 5 shows the maximum shear strain rate (=second invariant of the strain rate tensor) of our best-fitting model.

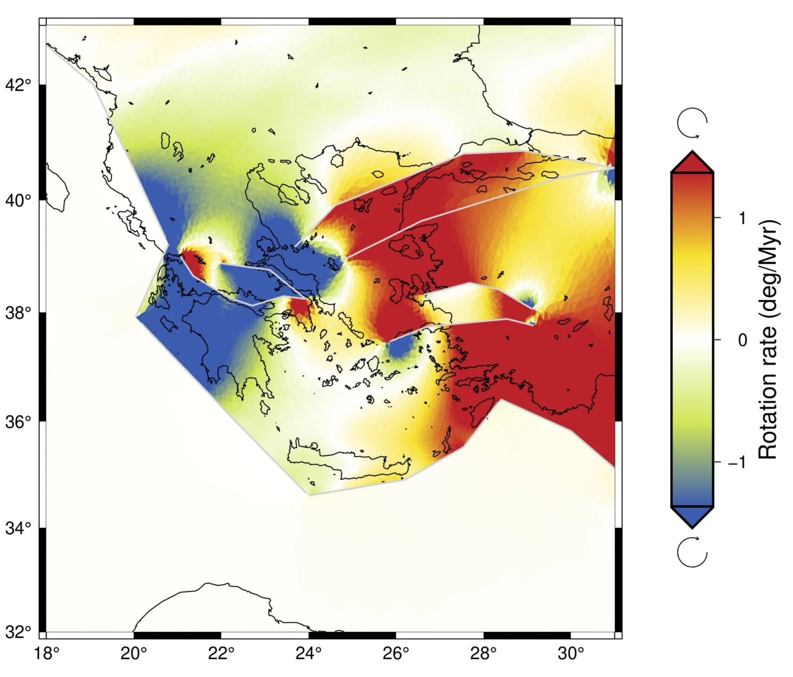

Figure 6 shows vertical axis rotation rates of our best-fitting model. The sense of rotation fits well with paleomagnetic results (e.g., van Hinsbergen and Schmid, 2021).

MODEL PARAMETERS

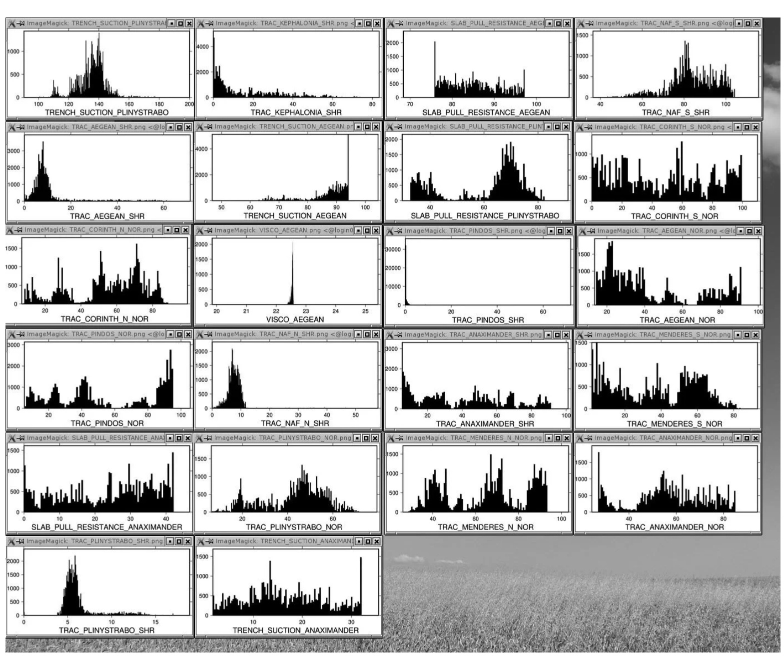

Figure 7 shows marginal posterior pdfs of the model parameters. Most parameters represent averages over a 100km thick lithosphere. Well-constrained parameters are the viscosity of the overriding plate, trench suction of the Hellenic slab and of the Pliny-Strabo slab. We also find low shear traction on the northern branch of the North Anatolian fault and high shear traction on the southern branch, low tractions on the Aegean megathrust, and low shear traction on the Pliny-Strabo STEP fault.

Conclusions

We conclude that significant trench suction is required from the Hellenic and Pliny-Strabo slabs. Our viscoelastic model with faults requires a well-constrained viscosity of the overriding plate of 4e22 Pa.s. Resistive tractions on most plate boundaries and faults are low. The best-fitting models compare well with paleomagnetic rotations and fault slip rates from previous studies.

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DISCLOSURES

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ABSTRACT

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REFERENCES

D'Agostino, N. et al. Active tectonics of the Adriatic region from GPS and earthquake slip vectors. Journal of Geophysical Research 113, B12413 (2008).

Herman, M. W. & Govers, R. Locating Fully Locked Asperities Along the South America Subduction Megathrust: A New Physical Interseismic Inversion Approach in a Bayesian Framework. Geochemistry Geophysics Geosystems 21, 6595–16 (2020).

Nijholt, N., Govers, R. & Wortel, R. On the forces that drive and resist deformation of the south-central Mediterranean: a mechanical model study. Geophys. J. Int. 214, 876–894 (2018).

Reilinger, R. et al. GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions. Journal Of Geophysical Research - Solid Earth 111, B05411 (2006).

van Hinsbergen, D. J. J. & Schmid, S. M. Map view restoration of Aegean-West Anatolian accretion and extension since the Eocene. Tectonics 31, (2012).

Vernant, P., Reilinger, R. & McClusky, S. Geodetic evidence for low coupling on the Hellenic subduction plate interface. Earth And Planetary Science Letters 385, 122–129 (2014).