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Unique Insight into the February 6 2023 Türkiye Earthquake Doublet from GNSS Geodesy

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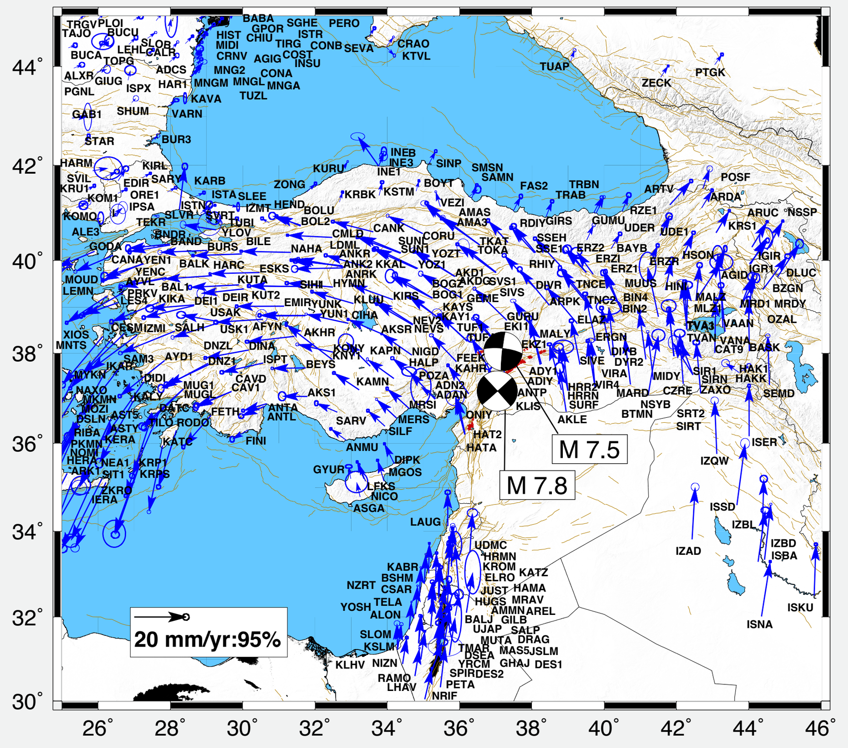
Abstract

The February 6 2023 earthquake sequence in the East Anatolian Fault Zone (EAFZ) was dominated by events of magnitudes (Mw) 7.8, 6.7, 7.5, and 6.0 within an 11-hour time window. The EAFZ falls within the CORS-Tr, the Turkish national network of 167 GNSS stations with a spacing of 80-100 km, delivering carrier phase data every 1 s. This dense network allows us to estimate the displacement field during this devastating earthquake sequence with unique spatio-temporal resolution and precision. This presents the opportunity to understand this sequence in ways that are enabled by GNSS: (1) CORS-Tr data started in 2008 which, together with global data, provides a long-term context on plate and crustal block rotations, interseismic strain accumulation, co-seismic strain release, and post-seismic relaxation. (2) GNSS effectively extends the temporal sensitivity of seismology from seconds to decades, enabling detection of aseismic deformation that is not associated with the seismic radiation field. (3) In contrast to InSAR, GNSS provides temporal resolution between the events, and unambiguously samples displacements in 3 dimensions. Given these unique capabilities, scientific interpretation can be enhanced by considering the GNSS data together with complementary data from seismology, geodetic imaging techniques such as InSAR, pixel tracking, optical methods, and geological data on surface rupture.

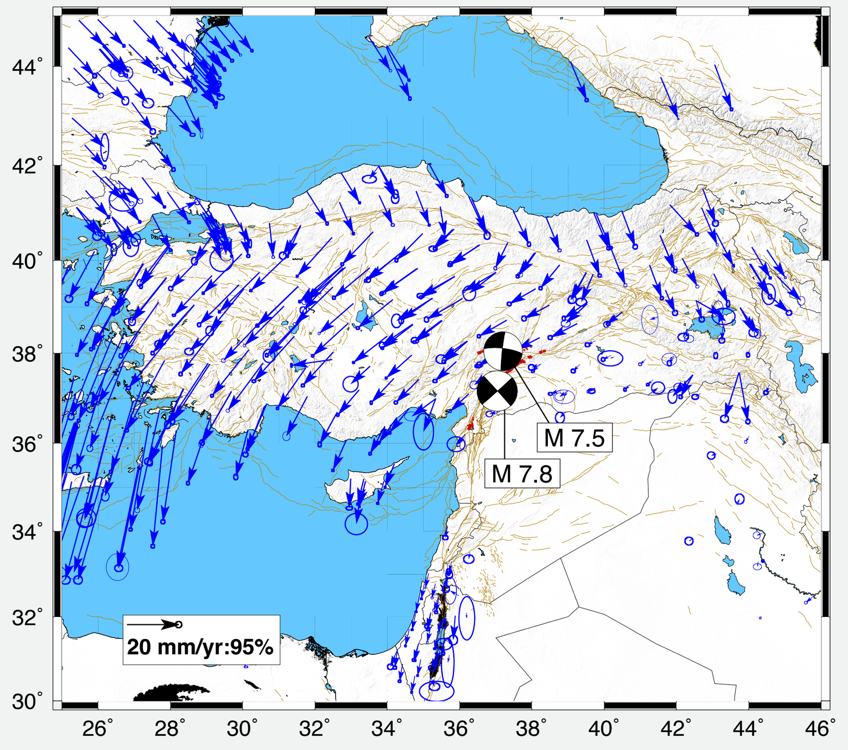
Here we present results that highlight the strengths of the CORS-Tr GNSS data for constraining all aspects of the seismic cycle, including pre-seismic strain accumulation, the permanent coseismic displacement including far-field motions that are sensitive to the deepest part of slip, and postseismic deformation. Our analysis considers 5-minute time series which enable distinguishing separate coseismic displacements from the individual events that occurred on the same day, and 24-hour time series that resolve significant coseismic displacements over 1000 km from the epicenters. Comparison of the coseismic displacement azimuths with the pre-seismic tensor strain rate field suggests close alignment between strain accumulation and release for each event in the doublet. We resolve the clear signal of postseismic deformation with a relaxation time constant of ~0.1 years following the doublet.

MIDAS GPS Velocities
Eurasia Reference Frame



http://geodesy.unr.edu/velocities/midas.EU.txt

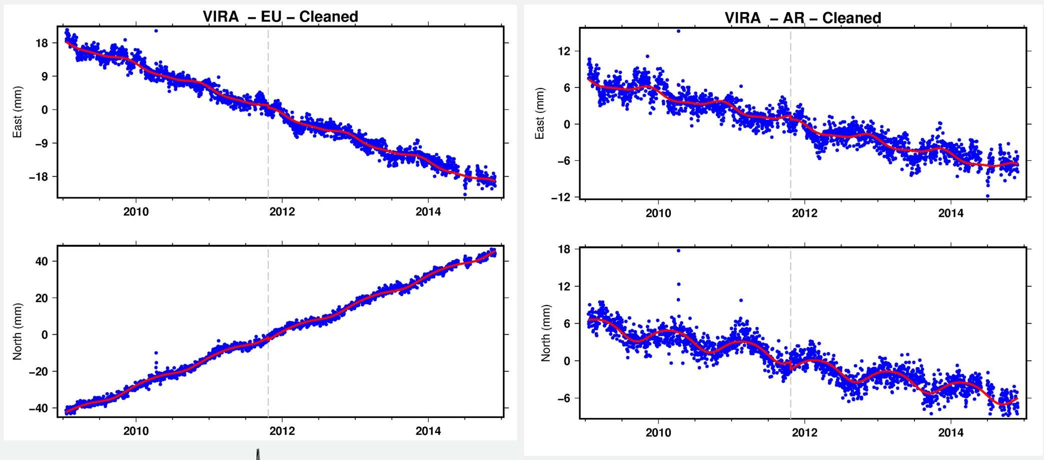
Arabia Reference Frame

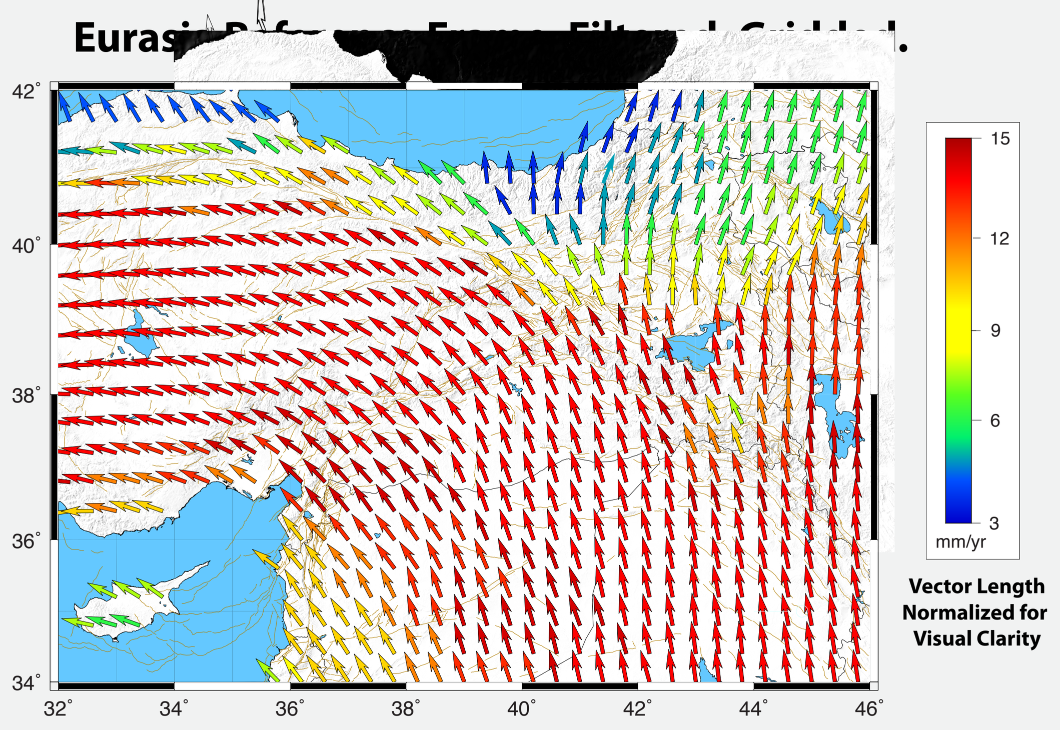


http://geodesy.unr.edu/velocities/midas.AR.txt

Interseismic Velocity and Strain Rates

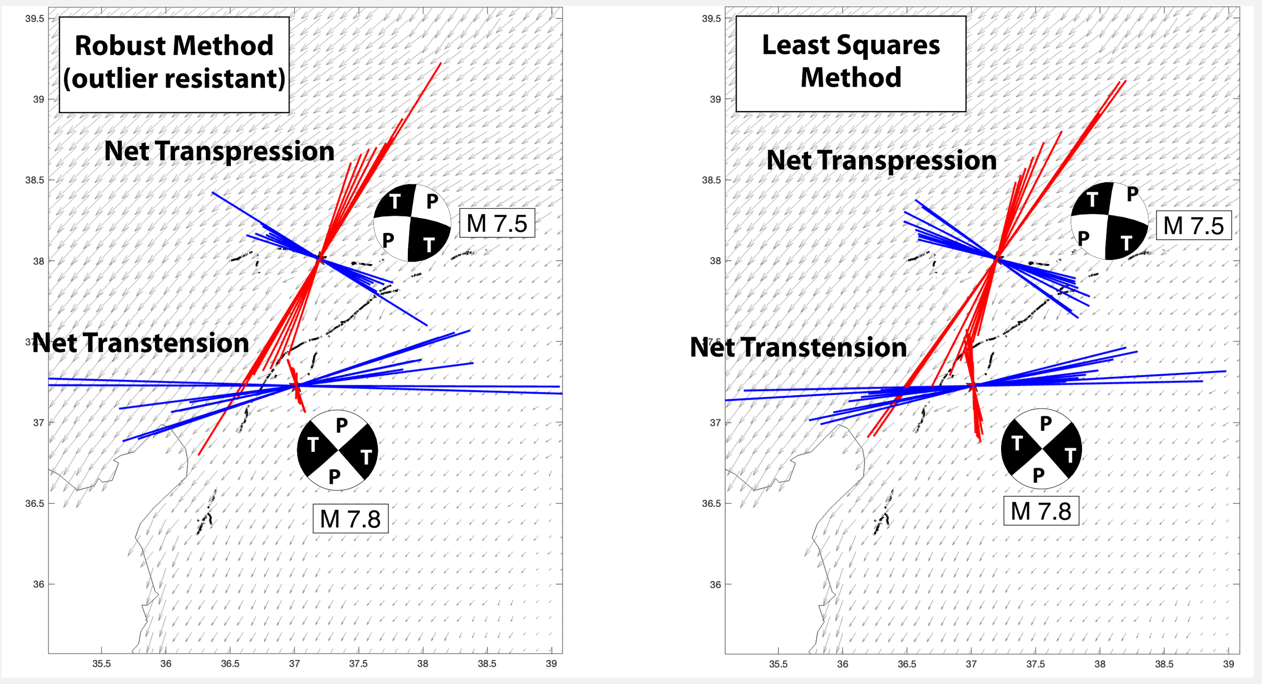
Example Daily Position Time Series





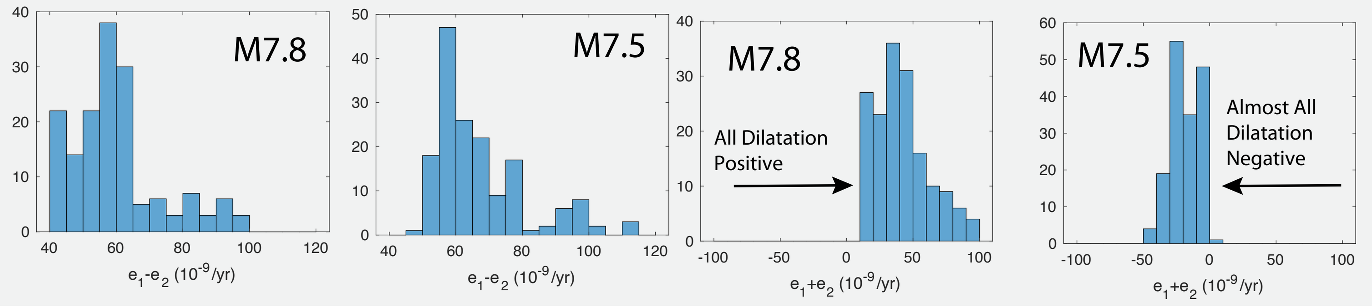
Velocities: Arabian Reference Frame. Filtered. Gridded.

Strain Rates: Red = Principal Axis of Contraction,
Blue = Principal Axis of Extension



Shear Component of Interseismic Strain Rate

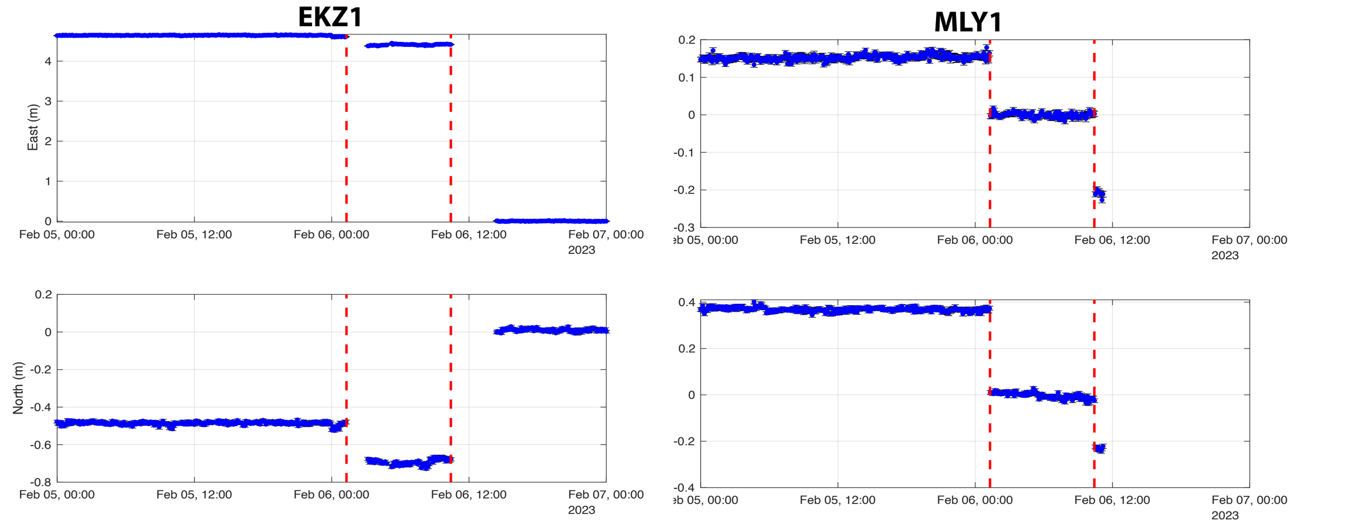
Dilatational Component of Interseismic Strain Rate



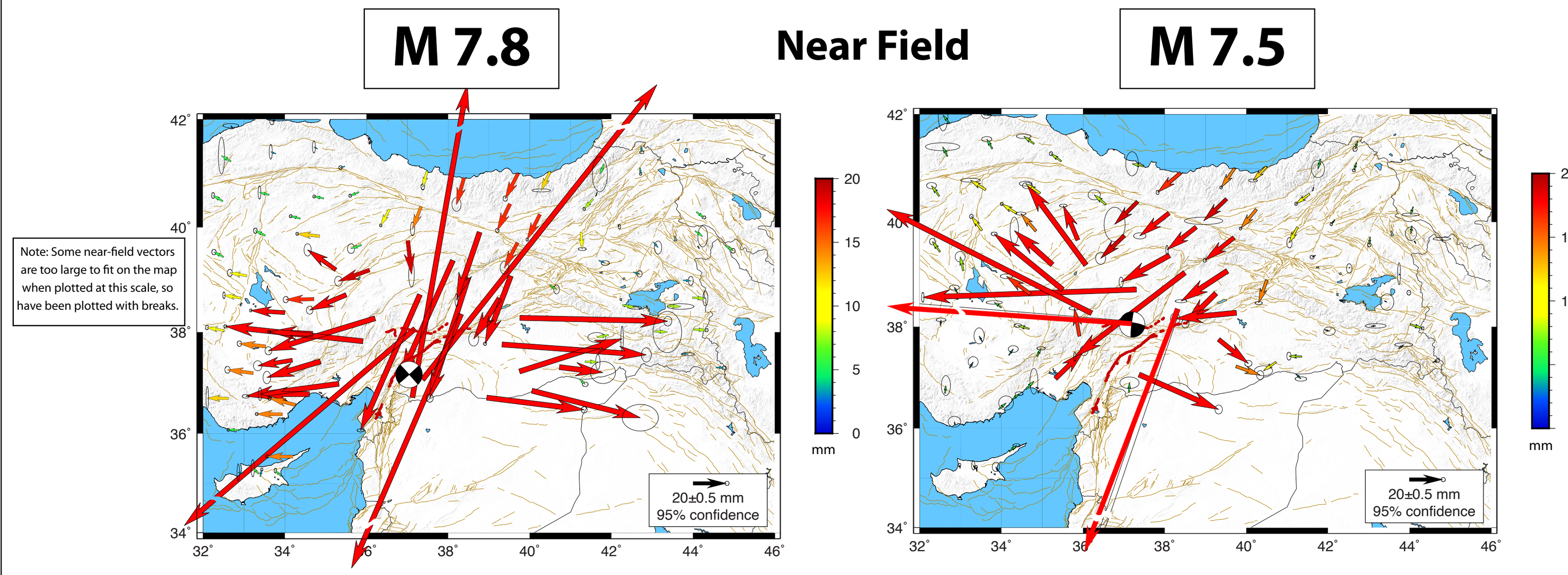
Take Away Point: The EAFZ and the Savrun-Çardak faults experienced similar rates but different styles of strain accumulation prior to the Kahramanmaraş earthquake sequence. **The EAFZ experienced transtension, while the Savrun-Çardak fault experienced transpression. This would tend to reduce net fault locking prior to the M7.8 mainshock, but increase net locking on the fault prior to the M7.5.**

Coseismic Displacements

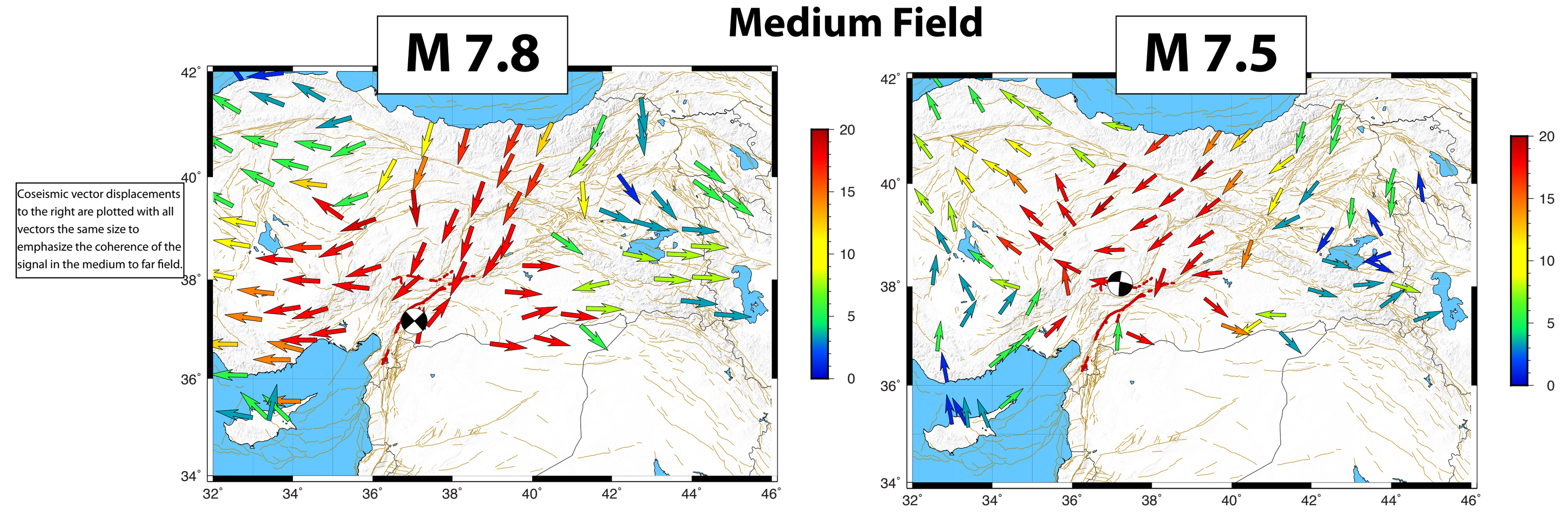
Example 5 Minute Time Series



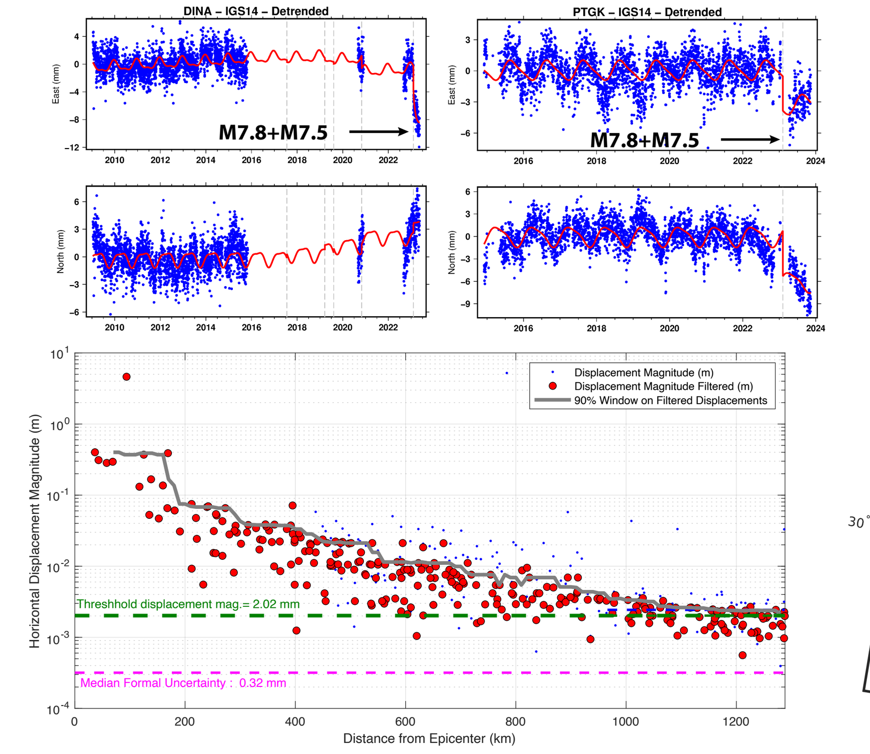
Near Field

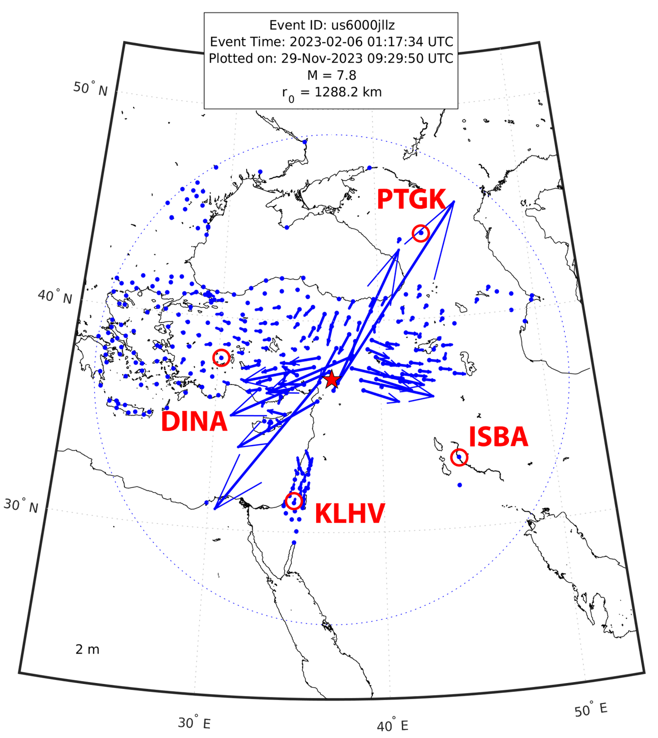


Medium Field



Far Field

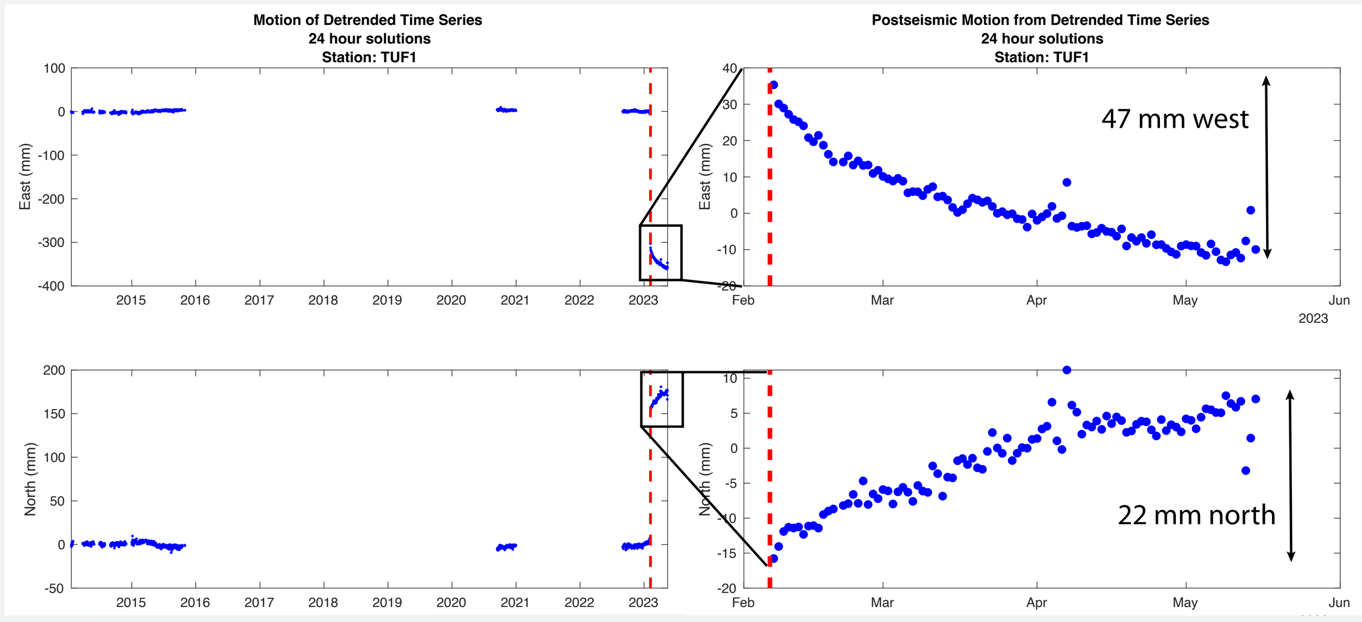


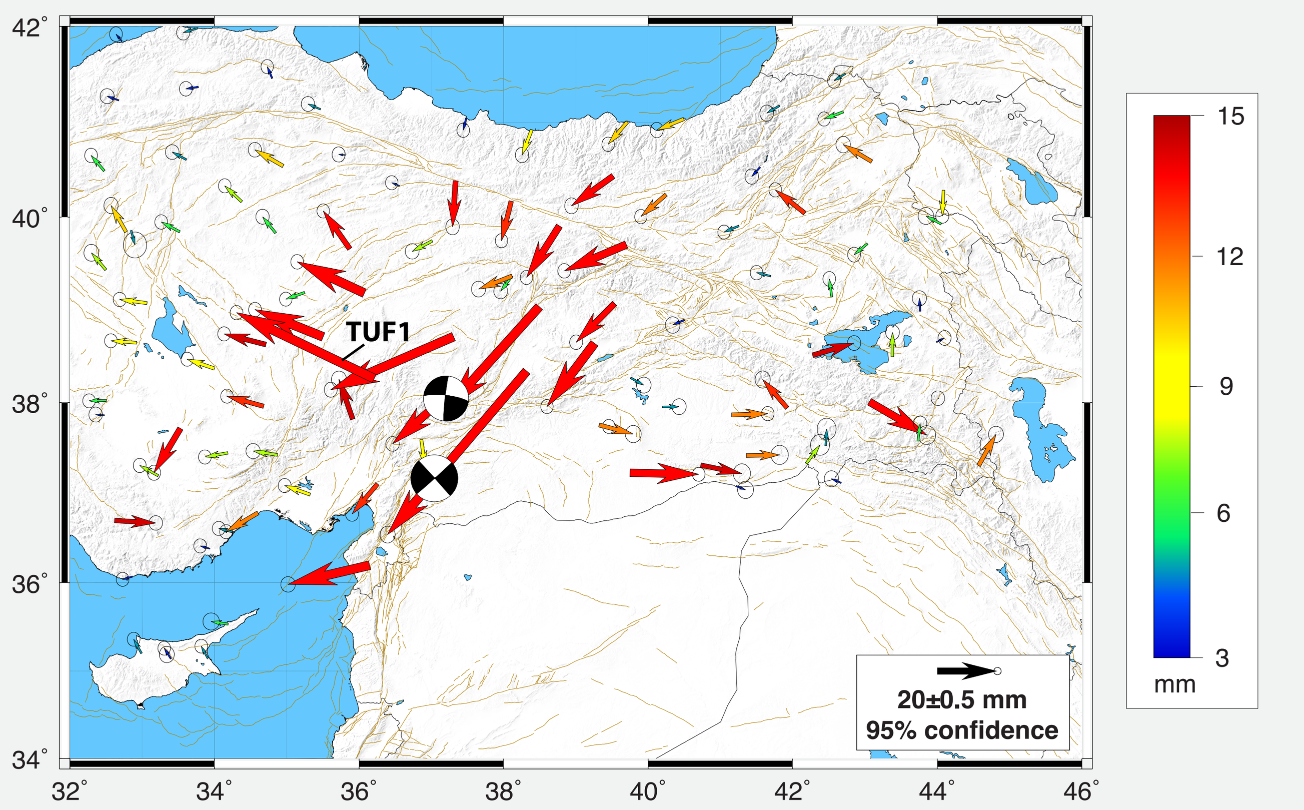


Take Away Points: Between the M7.8 and M7.5 earthquakes there is a rotation of the directions of coseismic contraction and extension, similar to the rotation seen in the azimuth of interseismic strain rate axes, and moment tensor P-/T- axes . Significant coseismic displacement is detectible to at least hundreds of km from the epicenters. Displacement magnitudes continue to decrease until ~1000 km. The operational earthquake radius used by NGL (r_0 = 10^(M/2 - 0.79)) gives **1288 km.**

Poseismic Displacements

Example Daily Position Time Series



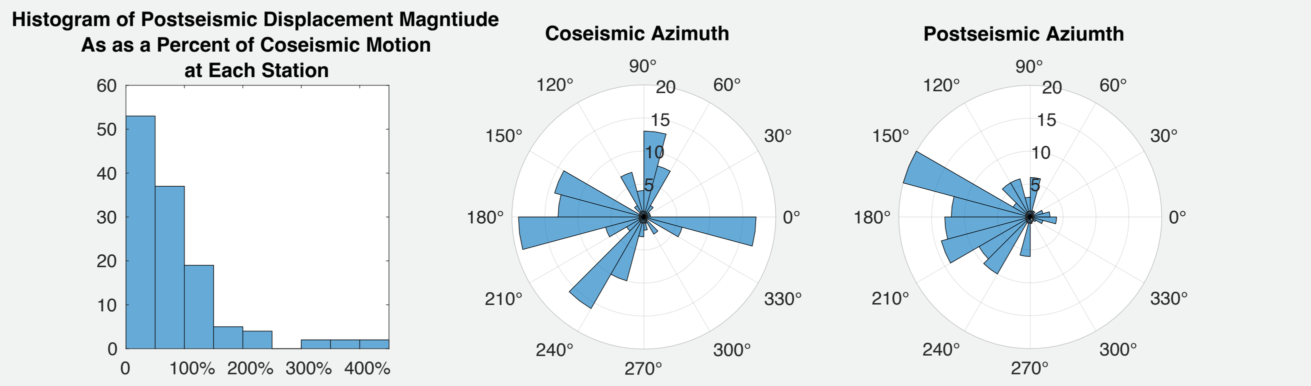


Take Away Points: The postseismic deformation is the cumulative response from both earthquakes which have a combined moment of M~7.9. The post-event time series are less complete than the pre-earthquake data, but at many stations show clear signs of ongoing stress relaxation. We solved for the amplitude of post-event transient motion and a time constant using the exponential decay model $x(t) = A*[1-\exp(-(t-t_0)/tau)]$. The solution using data from the first ~4 months after the event gives a relaxation time of ~0.1 year . Above we plot the east and north components of the estimates for A as vectors on the map.

The results show that the map-view pattern of deformation is similar to the pattern of coseismic deformation. Displacements are usually, but not always, smaller than the coseismic displacements (see histogram below left). Based on the azimuth of vector displacements the pattern is more similar to that of the M7.8 coseismic.

That pattern also shows left lateral motion across both faults decaying into the far-field. The response is very wide, with a coherent pattern extending hundreds of km from epicenter. These signals and the magnitude of the event are consistent with the presence of viscoelastic upper mantle response.

There may be asymmetry in the response across the faults. Could this be a function of sampling bias owing to the lack of station in Syria? A physical feature attributable to curvature of faults, interaction between the earthquakes or horizontal variation in material properties?



Conclusions

- GNSS data from ground networks constrain Earth deformation before, during and after the February 6, 2023 M7.8/M75 earthquake doublet in Türkiye.
- These data capture interseismic, coseismic, and postseismic parts of the seismic cycle on the EAFZ.
- Robust interpolations of interseismic velocities show that prior to the events the M7.8 epicentral area around the EAFZ fault experienced **transtensional** strain accumulation while the M7.5 epicenteral area around the Savrun-Çardak-Sürgü Fault experienced **transpression**.
- Lack of station coverage in Syria makes horizontal tensor strain rates somewhat uncertain, but the result is consistent for two choices of analysis method and many choices of radius (20 to 90 km) inside which to include interpolated observations.
- The directions of coseismic P- and T- moment tensor axes in the M7.8 and M7.5 are similar to the azimuths of maximum contractional and extensional interseismic strain rates from GNSS. Both rotate clockwise from M7.8 to M7.5. This rotation is similar to the difference in strike between the EAFZ and the Savrun-Çardak Fault.
- These alignments indicate the close relationship between interseismic strain accumulation, seismic strain release, postseismic stress relaxation, and long term evolution of the EAFZ systems.
- There may be asymmetry in the viscoelastic response across the EAFZ. This could be an apparent asymmetry owing to sampling bias because of poor station in Syria, or could be a physical feature attributable to curvature of faults, interaction between differently striking faults, or horizontal variation in material properties.

References and Further Reading

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