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Geodetic and Seismic Constraints on Strain Accumulation on the Hellenic Subduction Zone off Crete

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Abstract
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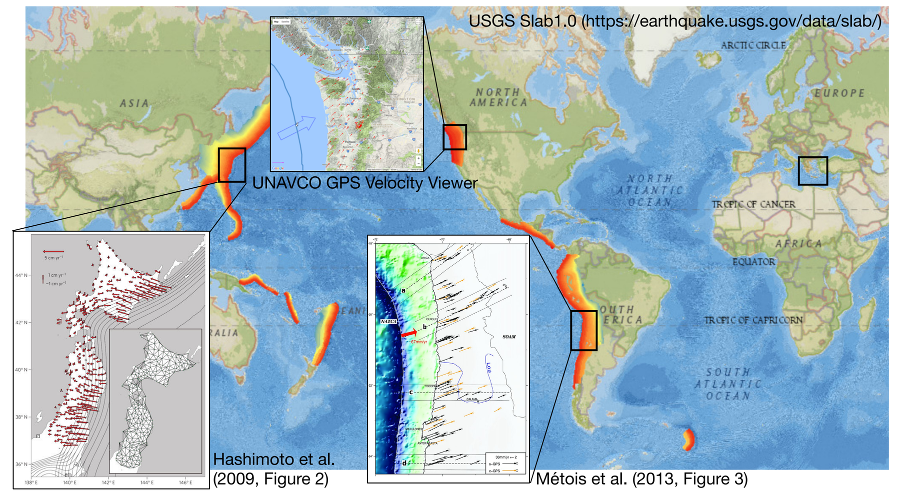
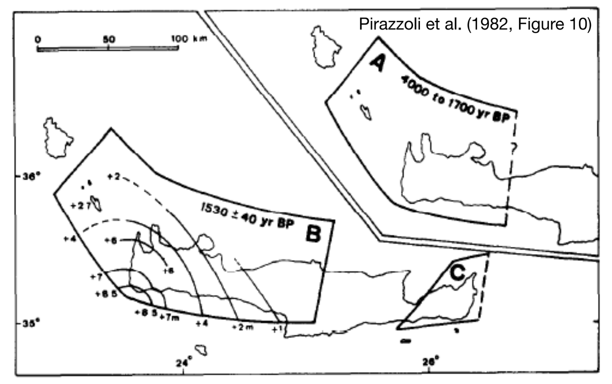
1. Introduction



Subduction zones produce the largest recorded earthquakes. During the inter-seismic period they tend to exhibit contraction on the upper plate, consistent with elastic strain accumulation due to locking on the thrust interface, which produces GPS velocities directed away from the trench relative to the overriding plate. These motions are commonly found to reverse episodically in slow slip events. However, the Hellenic Subduction Zone is observed to have inter-seismic GPS velocities towards the trench and no recorded slow slip events. We consider here the nature of deformation and elastic strain accumulation along the Hellenic Subduction Zone from recent GPS velocity observations.

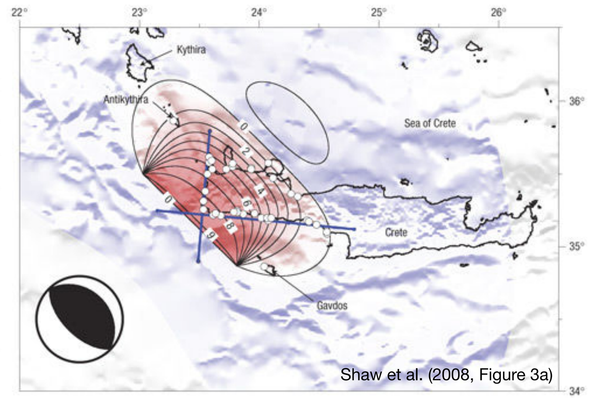
← *Figure 1* Typical GPS velocities above subduction zones around the world: Japan (left), Cascadia (top), Chile (bottom) and our study area, the Hellenic Subduction Zone (right).

2. Previous Thrust Earthquakes



← *Figure 2* Pirazzoli et al. (1982) reported significant uplift (up to 9 m) in south-west Crete. This uplift, when dated, coincides with an earthquake in 365 CE that was widely reported in historical records throughout the Mediterranean basin.

→ *Figure 3* Shaw et al. (2008) revisited and confirmed the result of Pirazzoli et al. (1982). If the uplift occurred in a single event, it was likely a M_w 8.3–8.5 earthquake.



3. Inter-seismic Strain Accumulation from GPS Velocities

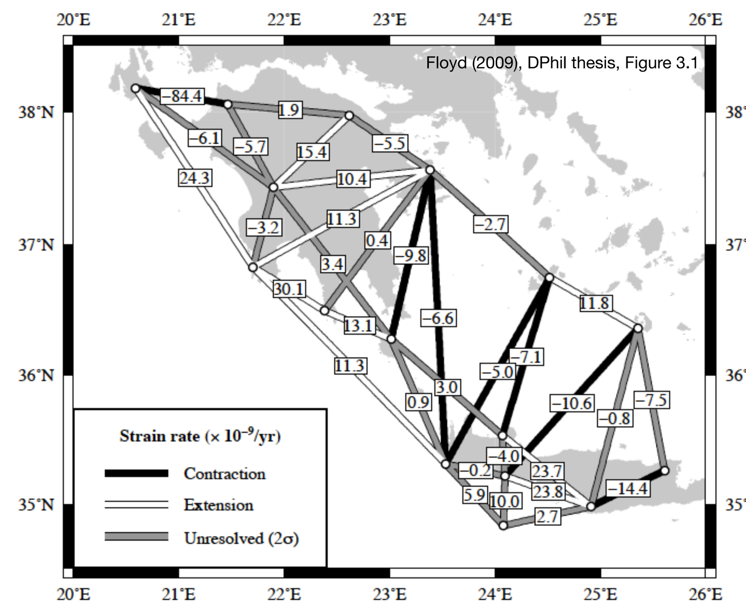


Figure 4 Inter-seismic strain rates derived from a network of continuous on baselines approximately perpendicular and parallel to the convergence azimuth (NNE) across the plate boundary (offshore to the southeast).

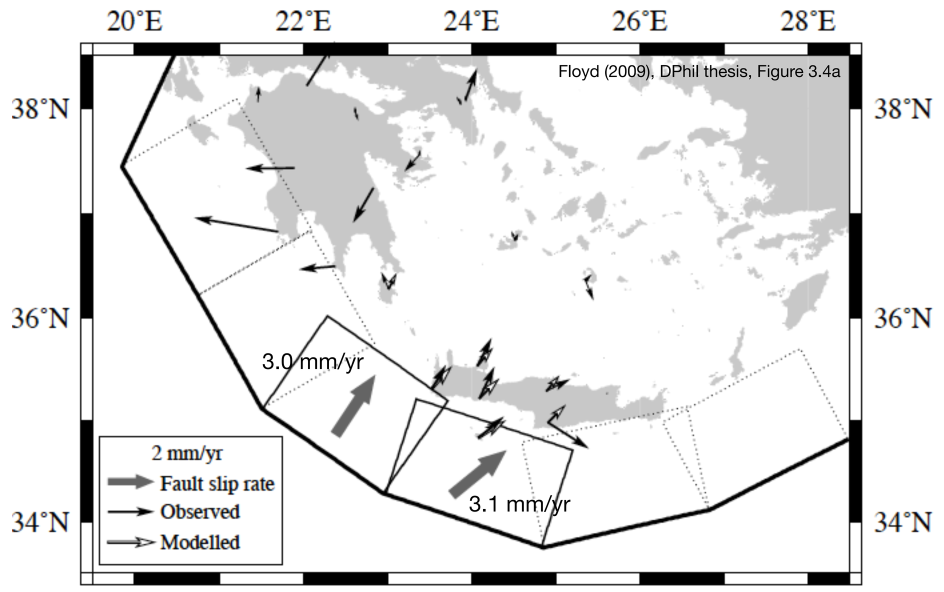


Figure 5 Inter-seismic strain accumulation model fitting the upper plate strain rates shown in Figure 4, left. Here, two patches near southwestern Crete require approximately 3 mm/yr slip rate deficit.

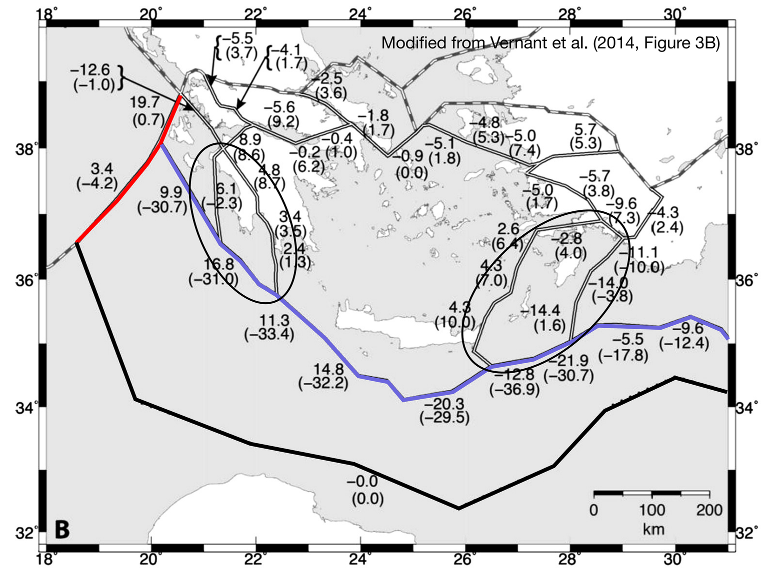


Figure 6 Block model of contraction (negative numbers in parentheses) across the Hellenic Subduction Zone and extension of the Aegean. Nubian subduction interface (black line), Hellenic Trench (blue line) and Kephalonia Transform Fault (red line) have their locking (coupling) coefficient systematically varied in the inversion to assess the effect of locking on fit to GPS velocities. Note that east-west extension is accommodated by two small blocks (circled).

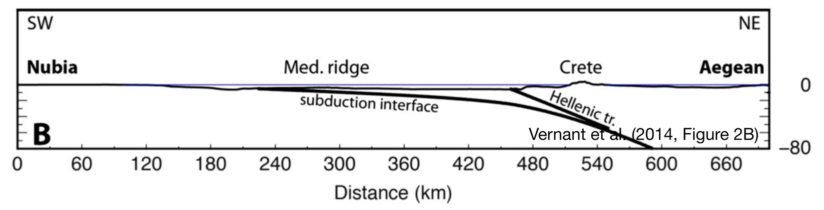


Figure 7 Schematic SW-NE cross-section through the interface geometry shown in Figure 6, left (letter B for reference).

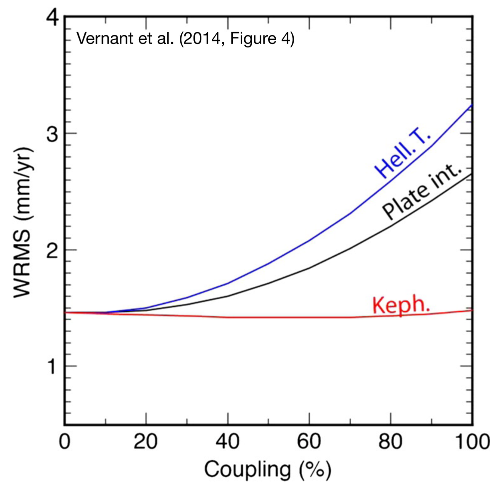


Figure 8 Misfit to GPS velocities as a function of locking (coupling) coefficient on the Nubian subduction interface (black), Hellenic Trench (blue) and Kephalonia Transform Fault (red). This model shows a general preference for low (< 40%) coupling, implying a slip rate deficit of < 15 mm/yr given the convergence rate of ~ 35 mm/yr.

4. Updated and Expanded GPS Velocity Solution

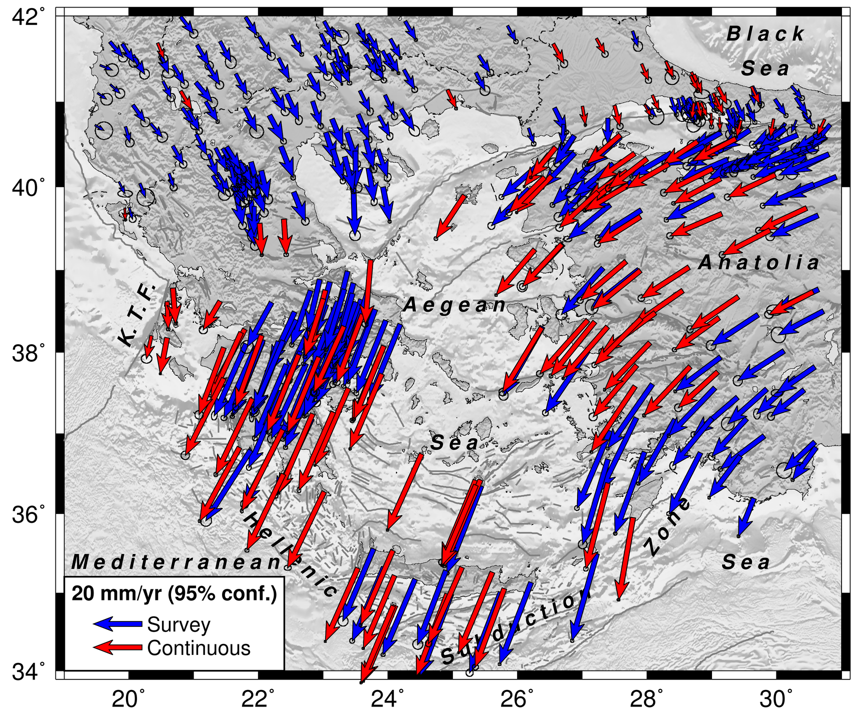


Figure 9 Latest iteration of the GPS velocity solution in the Aegean and western Anatolia relative to Nubia. The network consists of survey (blue) and continuous (red) GPS sites that have been observed by the institutions of the authors or is publicly available.

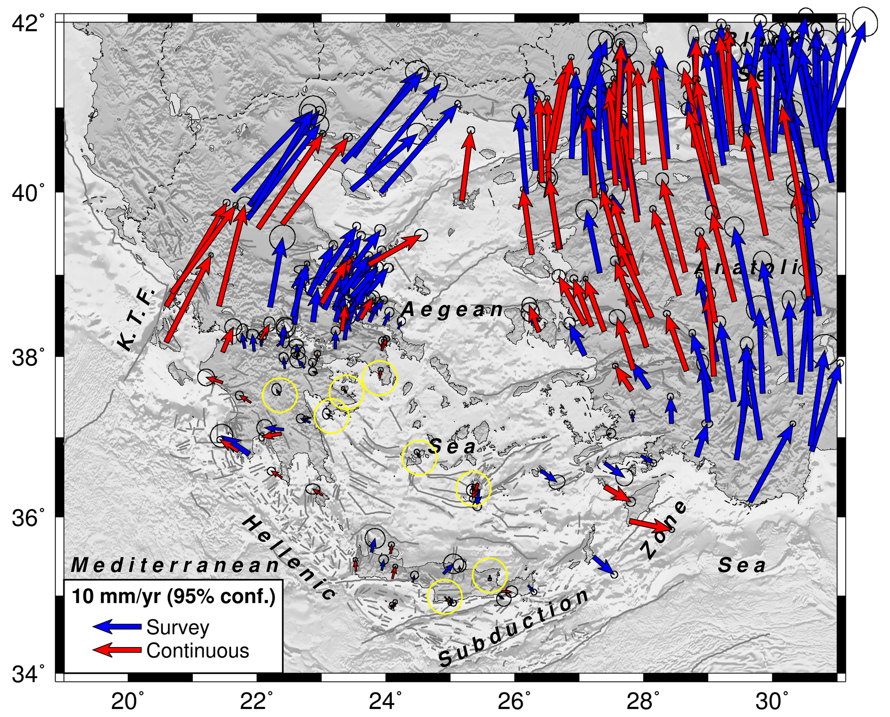
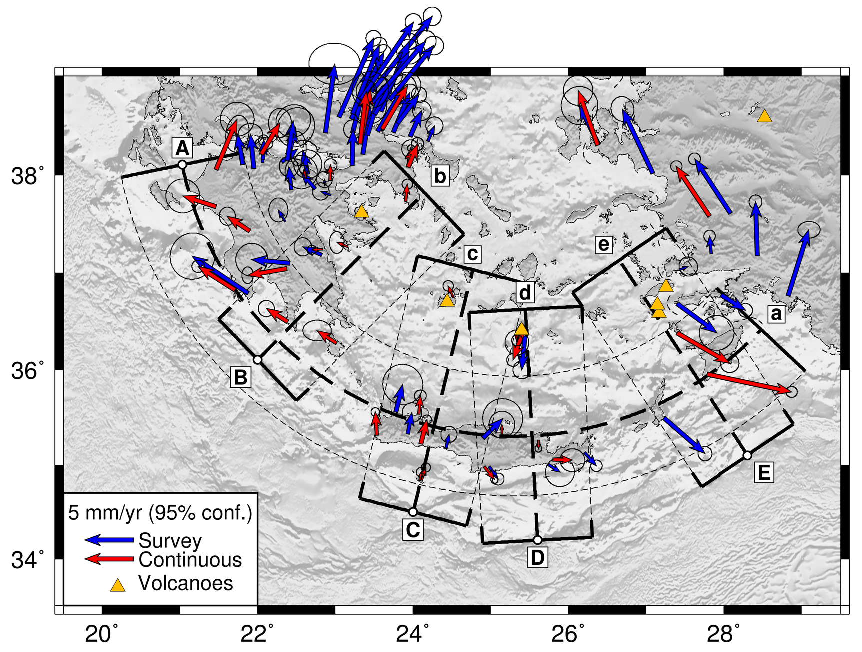
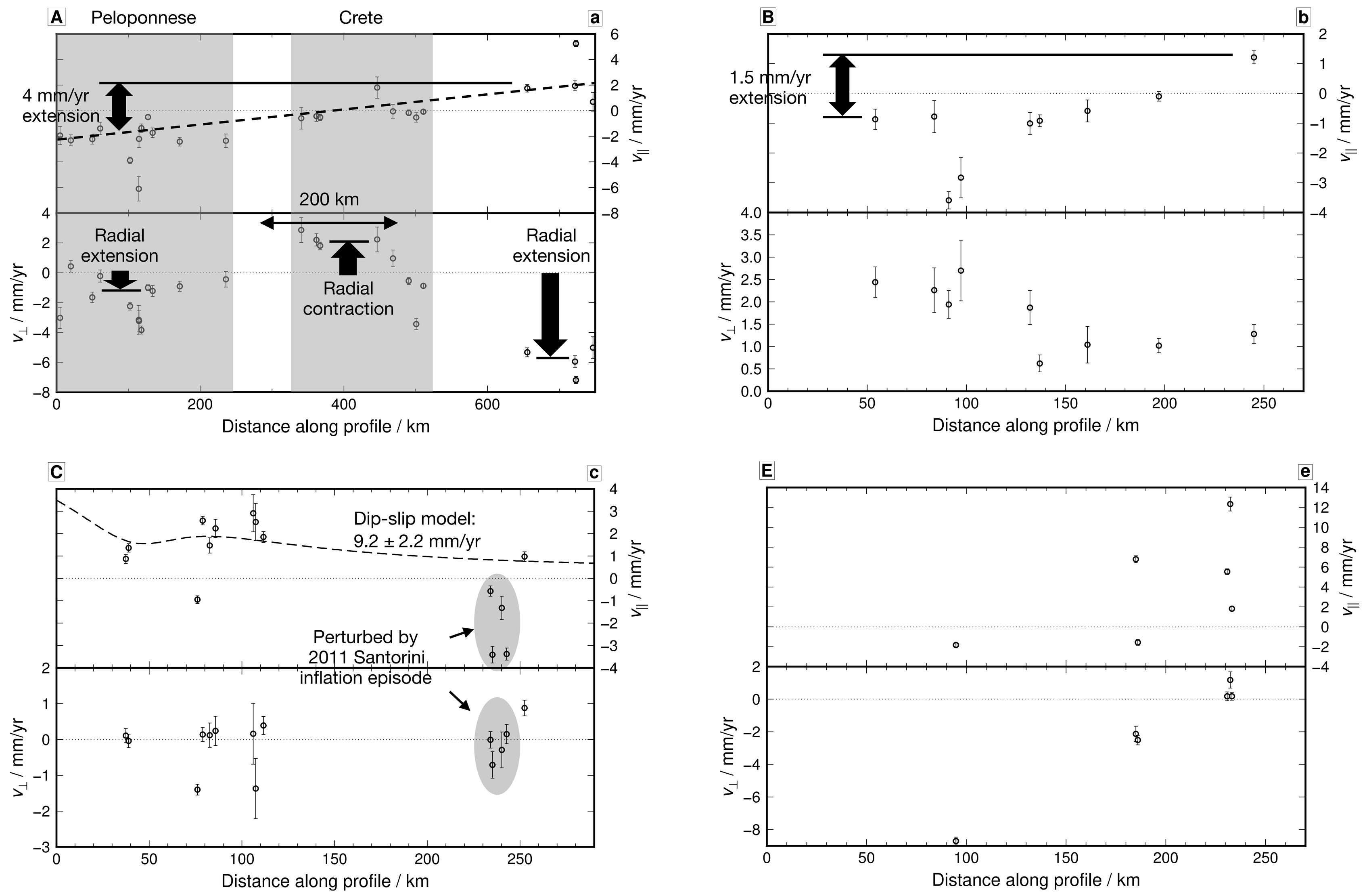


Figure 10 Same as Figure 9, left, but relative to the central Aegean, defined by minimising the velocity of the GPS sites circled in yellow.



Profiles through the new GPS velocity solution allow us to assess the relative contribution of extension in the upper plate and potential inter-seismic strain accumulation on the subduction interface. Profile A (Figure 11, below) shows the general pattern of tangential (arc-parallel) extension along the entire arc, as well as contraction around southwest Crete and radial (arc-perpendicular) extension elsewhere (Peloponnese in the west and Dodecanese Islands in the east). Profile C (Figure 11, below) shows this same contraction as well as a best-fit model assuming dip-slip on a fault dipping 20° that aligns with the Hellenic Subduction Zone. Profile B shows the extension (top) and a velocity gradient (bottom) consistent with block rotation and/or right-lateral shear of the Peloponnese.

←↓ *Figure 11* Profiles through the latest GPS velocity solution. Note the difference in scale from Figure 10, above, and that only velocities less than 10 mm/yr are plotted.

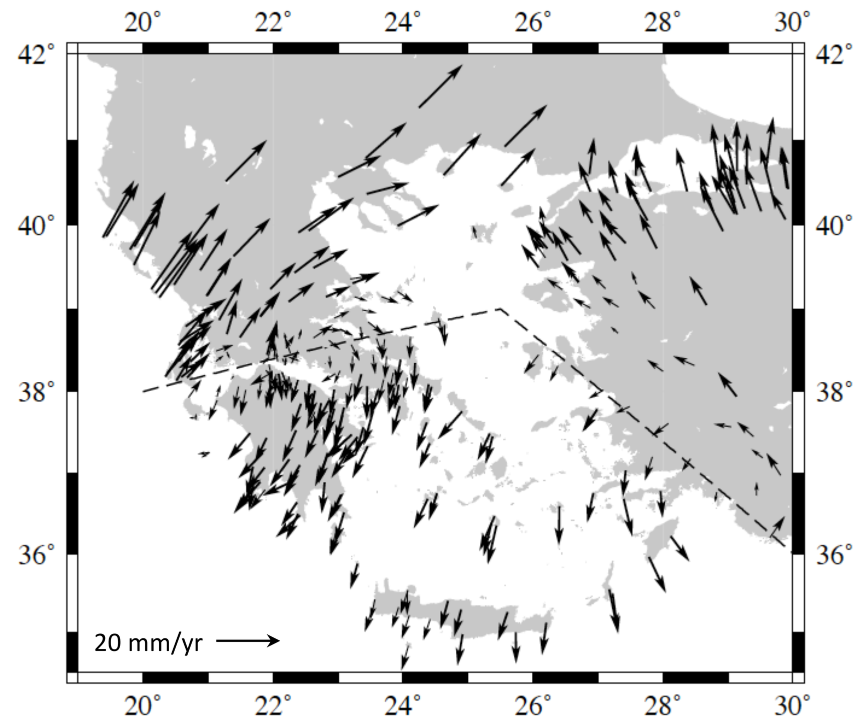


6. End-member Models of Upper Plate Deformation and Bounds of Inter-seismic Strain Accumulation

The Vernant et al. (2014) model, shown bottom-left of this poster, and previous block models such as Reilinger et al. (2006), provides a lower bound on elastic strain accumulation along the subduction interface by assuming that the upper plate is rigid, with elastic strain due to relative plate motions at the boundaries and no internal deformation. Viewing the velocities in an Aegean reference frame (Figure 12, right) shows broad extension both radially (perpendicular to the arc) and tangentially (parallel to the arc) throughout the southern Aegean. An upper bound on elastic strain accumulation along the interface may be found by a model or assumption of radial extension along the entire arc, including southwest Crete, which would then require a larger slip rate deficit on the subduction interface to produce the same observations.

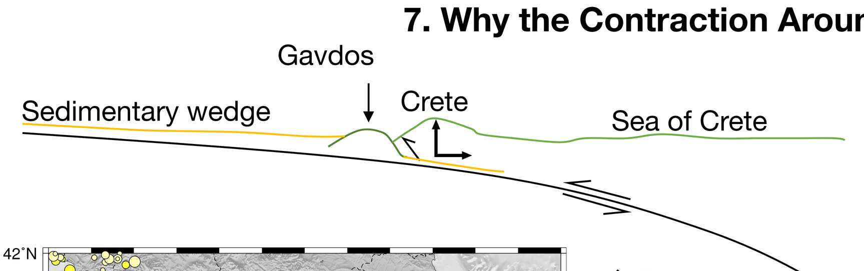
→ *Figure 12* Velocities in an Aegean reference frame.

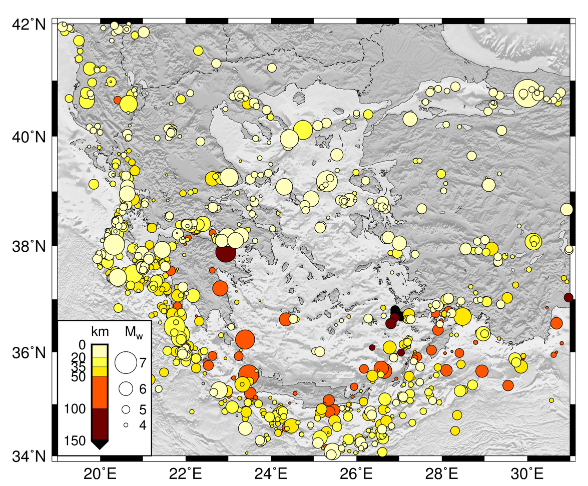
↓ *Figure 13* A schematic example of the summation of competing deformation signals—inter-seismic strain accumulation on the subduction interface and long-term extension of the Aegean—which may result in the overall pattern of observed GPS velocities.



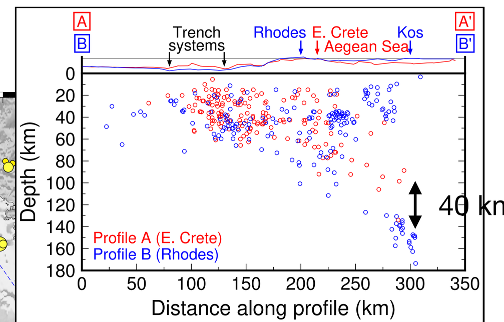
2 mm/yr observed contraction (*lower bound* of potential moment) = 1–5 mm/yr long-term extension (e.g. Figure 12; realistic physical model?) + 3–7 mm/yr potential contraction (*upper bound* of potential moment)

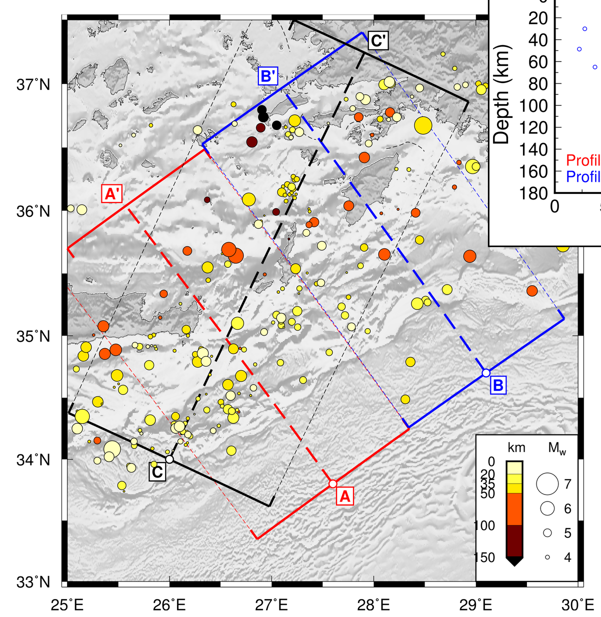
7. Why the Contraction Around Southwest Crete?





←↑ *Figure 14* Shallow seismicity (from ISC) associated with subduction is closest to land around southwest Crete, implying that any contraction due to elastic strain accumulation is most likely to be observed there. The Gavdos block may also be impinging, causing an asperity.





←↑ *Figure 15* Foundering of the downgoing slab may be more extreme further east along the trench system, as seen in cross-sections of seismicity (from ISC). Profile C is not shown, above.

Conclusions

- Contraction between southwest Crete and the central Aegean Sea is now a persistent and reproducible geodetic result
  - Coupling is at least 10–25% (3–9 mm/yr slip rate deficit) but may be greater, assuming extensional deformation of the Aegean is not confined to southwestern and southeastern Aegean
- Geometric constraints also suggest potential bounds of approximately:
  - 200 km along-strike
    - Wells and Coppersmith (1994) empirical relationships suggest maximum potential M_w7.8–7.9
  - Up to 40 km down-dip, but no resolution of offshore up-dip extent
  - 3 mm/yr of slip rate deficit, without accounting for possible long-term extension
  - *Lower bound* of moment accumulation rate equal to:
    - M_w7.0 every 50–100 years
    - M_w7.5 every 275–550 years
    - M_w8.0 every 1550–3110 years
- It has been 1650 years since last major interplate earthquake ($M > 7$, several m of slip) off southwest Crete
  - Most recent smaller event was M_w6.8 interplate thrust on 14 February 2008

References

Floyd, M. A. (2008), Continuous and survey Global Positioning System observations of the deformation of the Aegean, D.Phil. thesis, University of Oxford, 202 pp.

Pirazzoli, P. A., J. Thommeret, Y. Thommeret, J. Laborel, L. F. Montaggioni (1982), Crustal Block Movements from Holocene Shorelines: Crete and Antikythira (Greece), *Tectonophys.*, *86*, 27–43, doi:10.1016/0040-1951(82)90060-9.

Shaw, B., and J. Jackson (2010), Earthquake mechanisms and active tectonics of the Hellenic subduction zone, *Geophys. J. Int.*, *181*, 966–984, doi:10.1111/j.1365-246X.2010.04551.x.

Vernant, P., R. Reilinger, and S. McClusky (2014), Geodetic evidence for low coupling on the Hellenic subduction plate interface, *Earth Planet. Sci. Lett.*, *385*, 122–129, doi:10.1016/j.epsl.2013.10.018.