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Contemporary Kinematics of the South Aegean Area (Greece) Detected with Continuous GNSS Measurements

by

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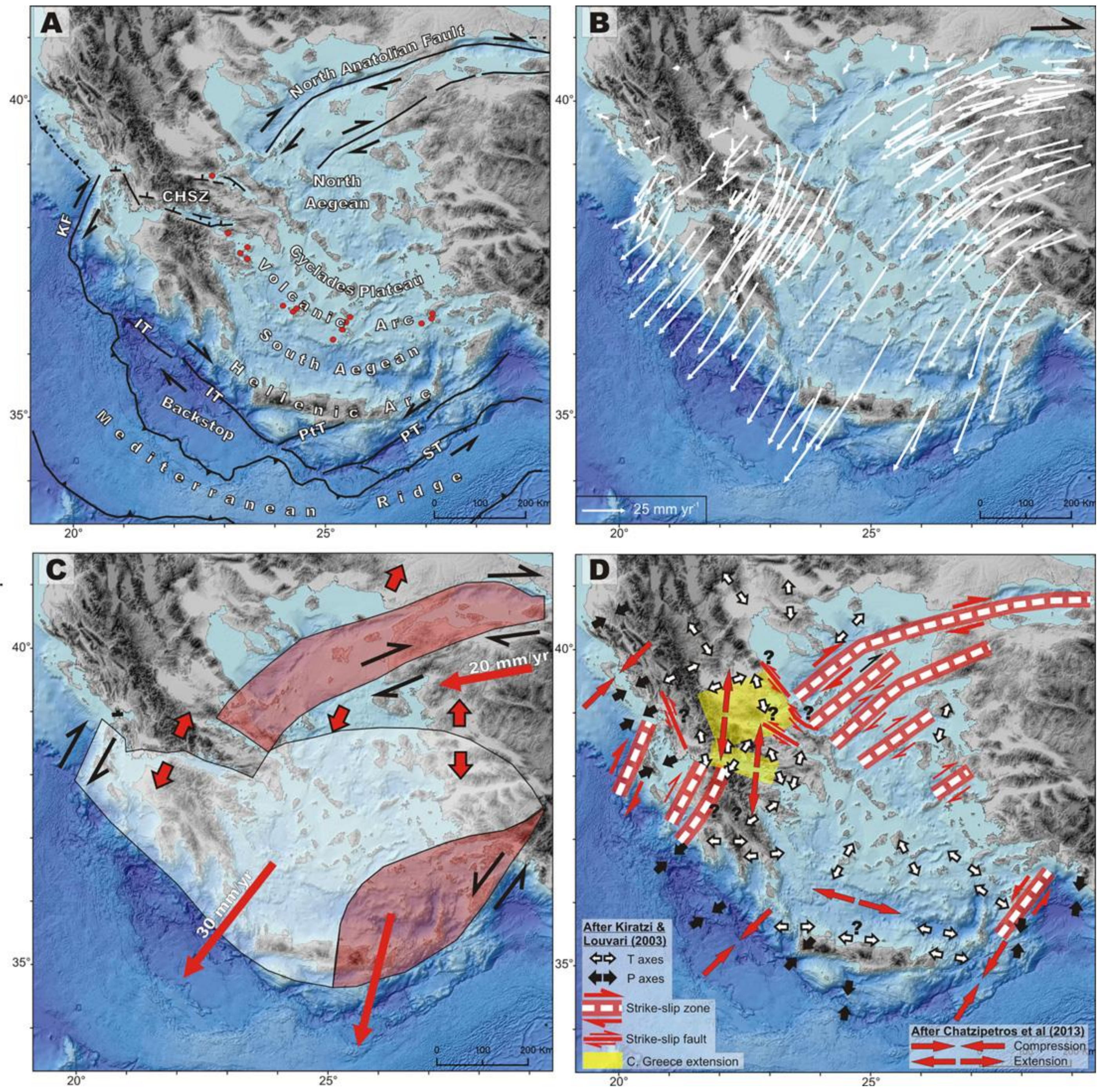


1. The Geodynamic Setting of the Aegean Region: A Review

A. Major geodynamic elements.
   - Red circles represent volcanoes; CHSZ: Central Hellenic Shear Zone; IT: Ionian Trench; KF: Kephallinia fault; PT: Pliny Trench; PtT: Ptolemy Trench; ST: Strabo Trench.

B. GPS velocities relative to Eurasia (from Kreemer and Chamot-Rooke, 2004).

C. Schematics of present-day tectonics (from Reilinger et al., 2010).
   - Long red arrows indicate rates of motion relative to Eurasia. The white shaded area shows the central Aegean and Peloponnese translating to the SW. Dark shaded areas indicate deformation zones in the SE Aegean and between the N and S branches of the North Anatolian Fault in the N. Aegean. Sense of motion across major tectonic boundaries shown by red thick and black half arrows.

D. P and T axes and major geotectonic elements after Kiratzi and Louvari, (2003) and Chatzipetros et al., (2013).
   - NE-SW dextral strike-slip prevails in N. Aegean, Ionian islands (KF) and NW Peloponnesus. E-W extension prevails in Crete and S. Peloponnesus – changes to arc-normal extension in the South Aegean and oblique compression/ left-lateral strike-slip motion along the Pliny and Strabo Trenches.

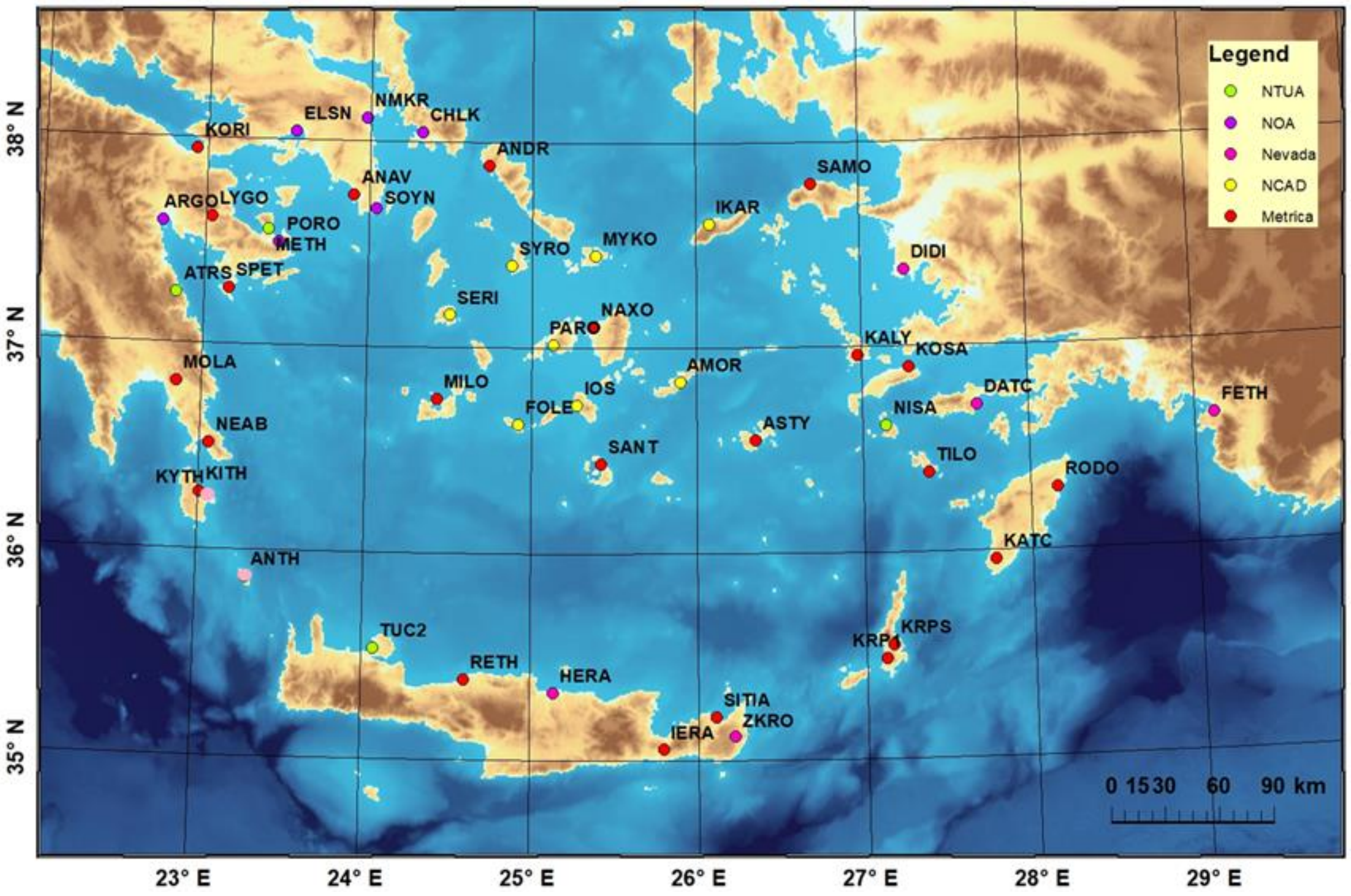
☞ Figure adapted from Sakellariou and Tsambouraki-Kraounaki, (2019).

2. Objectives and Methods

- Seismicity in the S. Aegean was sparse, scarce and of generally low intensity over the past several decades – it cannot assist in adequately resolving regional tectonics
- Hitherto knowledge of tectonic regime mainly was based on the sparse earthquake record, a singnificant number of shallow marine seismic surveys, minimal use of geophysical potential field data, bathymetry and Differential GPS measurements – it achieved remarkable results for the means employed.
- **Herein we use Differential GNSS measurements augmented with geophysical data in order to outline the regional tectonic structure and kinematics of the South Aegean Region.**
- Most hitherto work based on GNSS data (see Slide 1) has studied the deformation of the S. Aegean area by ***referring*** the velocity or displacement vectors to ***remote*** locations, usually in Eurasia (e.g. Potsdam, Germany), or to the ITRF system.
- While this approach is informative and very useful in studying the ***large-scale*** *(whole-plate)* deformation of the Aegean, ***it fails*** of itself to ***resolve*** the kinematics/pattern of relative block motions at local- and regional-scales and, therefore, assist in understanding the regional tectonics regime(s).
- Our present study ***departs*** from the norm by attempting to *study* ***relative block motions*** using ***local reference points*** and thus assist in resolving the regional pattern(s) of tectonic deformation.

3. The Data Set:

GPS network

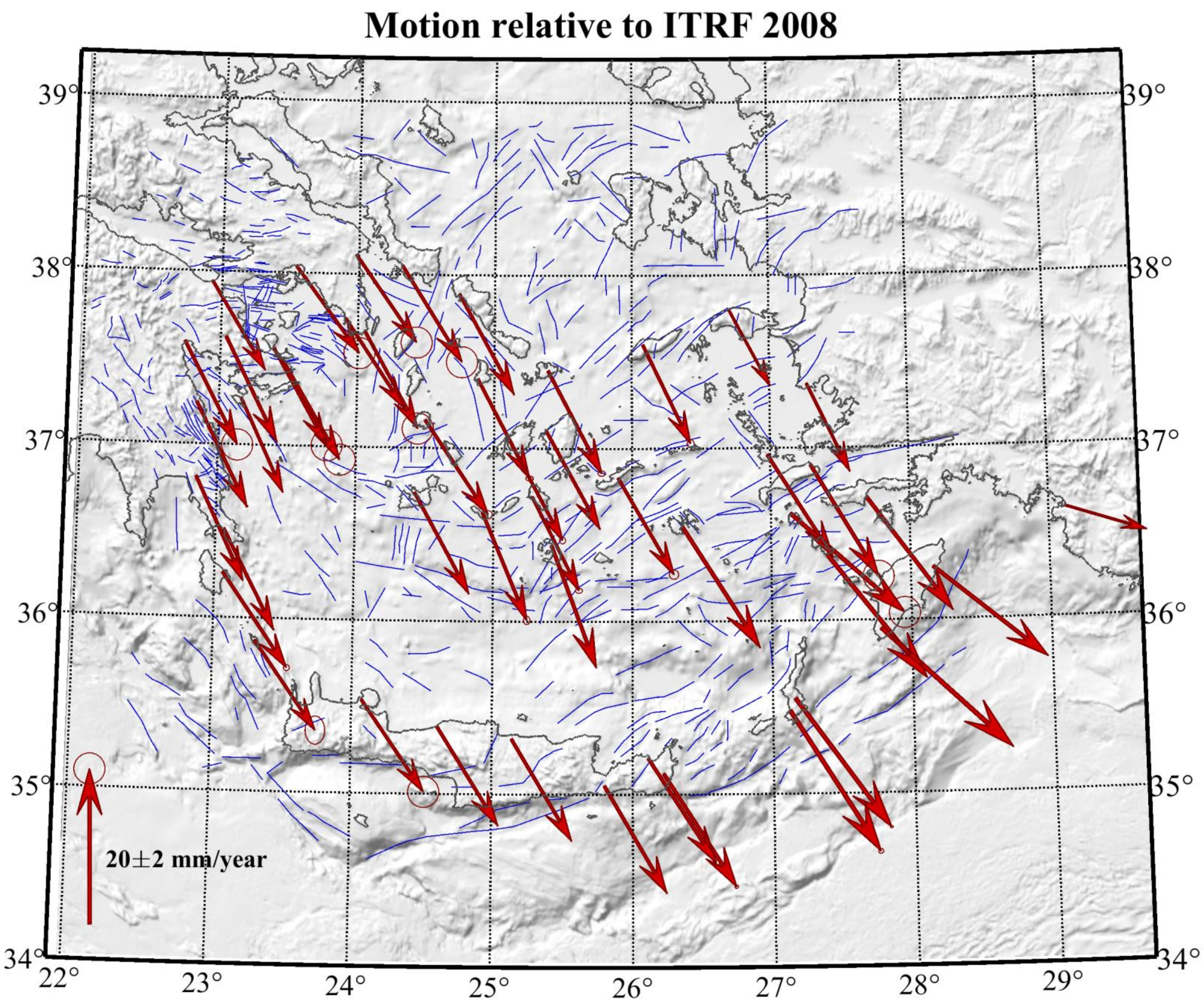


- *Primary* (*unprocessed*) data from *24 permanent stations* spanning the period 2011-2018, generously provided by METRICA S.A. (https://www.metrica.gr).
- *Primary* data, from *8 stations* spanning the period 2013-2017, generously provided by the HEPOS (Hellenic Positioning System) service of the Hellenic National Cadaster (http://www.hepos.gr);
- *Primary* data from *1 station* over the period 2017-2018, generously provided by the RING Rete Integrata Nationale GPS of Italy (http://ring.gm.ingv.it).
- *Primary* data from *1 station* over the period 2011-2017 and operated by UNAVCO (https://www.unavco.org/).

➢ **All primary data was processed with the Bernese v5.2 software** (Dach et al. 2007).

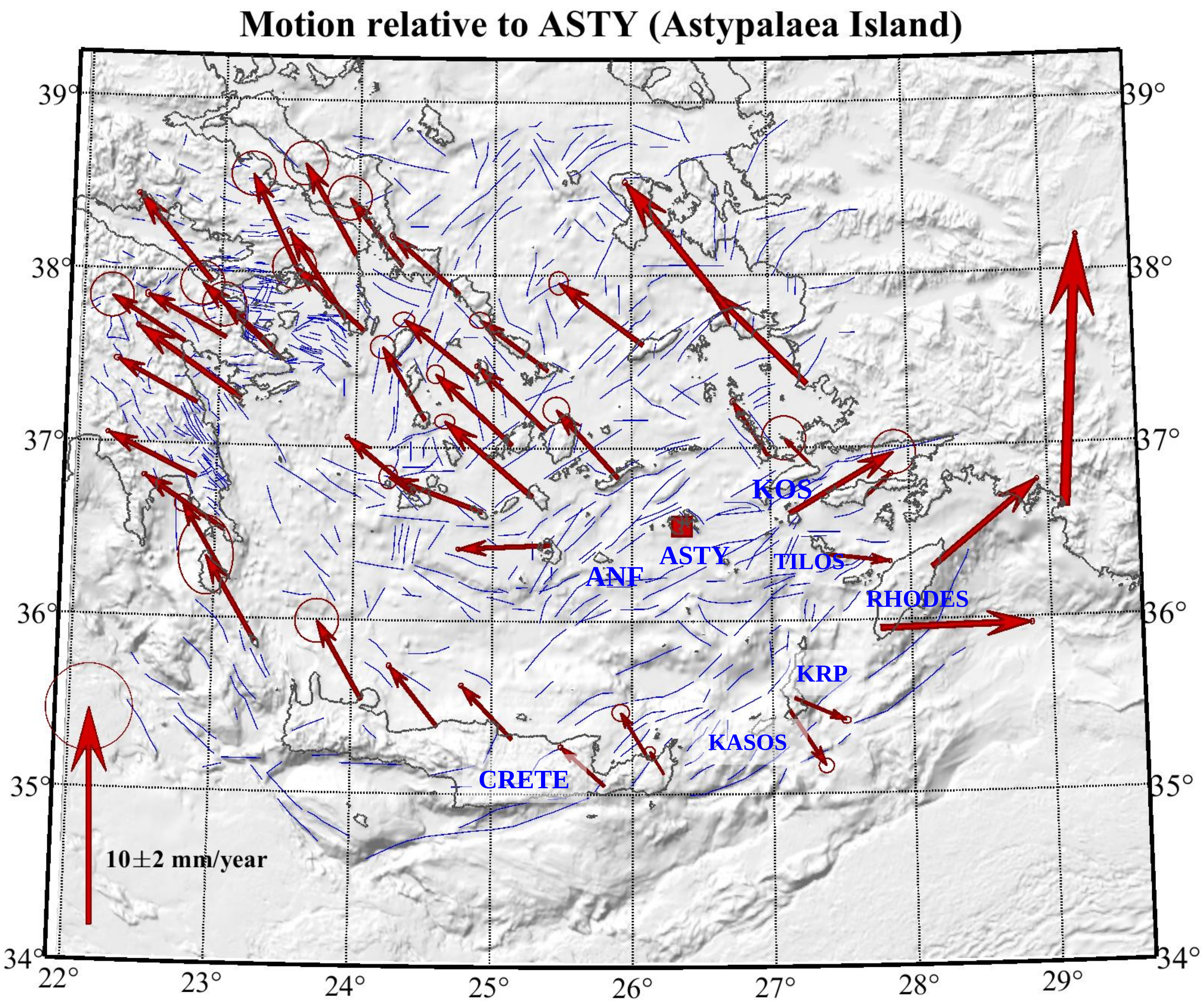
- *Processed data (displacement time series)* from *4 stations* spanning the period 2009-2018, available through the Geodetic Laboratory of Nevada.
- *Velocity vectors* from *7 stations* located in Attica, and spanning a period of approx. five years, extracted from Chousianitis et al., (2013).
- *Velocity vectors* from *2 stations* operated by the National Technical University of Athens (NTUA).

4. Motion in the ITRF 2008 frame of reference



- *Error ellipses* are drawn at the *tips of the velocity vectors* and at the *95% confidence level*.
- The *95% confidence level* is used *throughout* .
- *In the ITRF 2008 frame of reference*, the motion of the entire South Aegean area appears to be *quasi-uniform* in *a south-westerly direction* and at rates of the order of 20mm/year
  - Minor local differentiations in velocity are evident but their interpretation in terms of regional tectonics is not easy, if at all possible!
    - The *same* difficulty arises when the velocity is referred to a remote point on the surface, located in Eurasia or Africa.

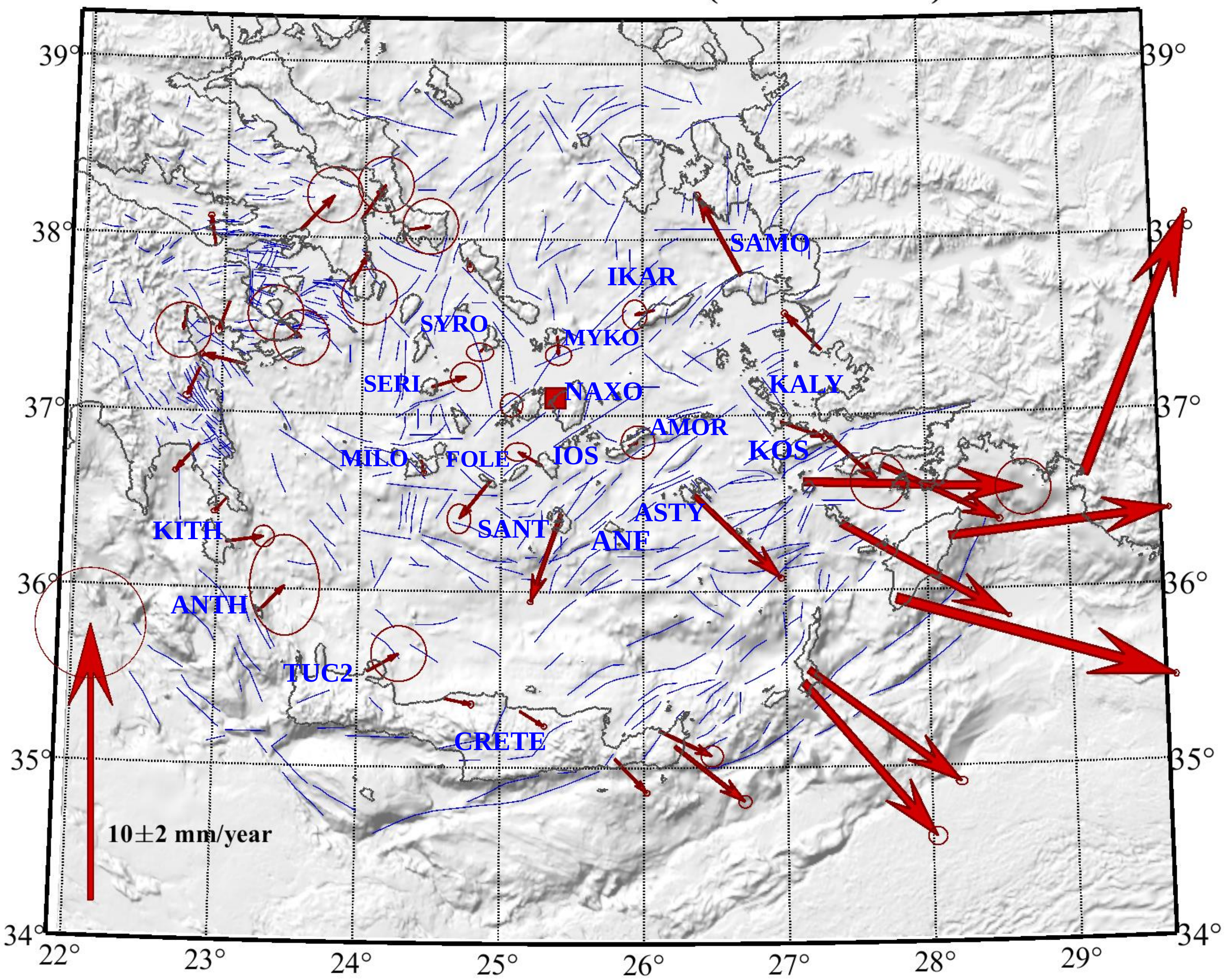
5. Motion relative to (26.36°E, 36.55°N) at Astypalaea Island, Dodecanese



- Very significant change in sense of motion ***relative*** to a NE-SW line joining the islands of Kos, Astypalaea (ASTY) and Anafi (ANF).
- Significant change of motion *relative* to a NW-SE between Anafi (ANF) and Kasos islands, passing between *Crete* and *Karpathos* (KRP).
- Stations to the N and W of these lines ***diverge*** from stations to S and E
- The SE Dodecanese (Nisyros, Tilos, Rhodes etc.) appears to comprise block moving to ENE relative to the Kos-ASTY-ANF and ANF-Kasos lines in a sense sinistral with respect to the Kos-ASTY-ANF line.

☞ The Kos-ASTY-ANF and ANF – Kasos lines appear to be parts significant tectonic boundaries.

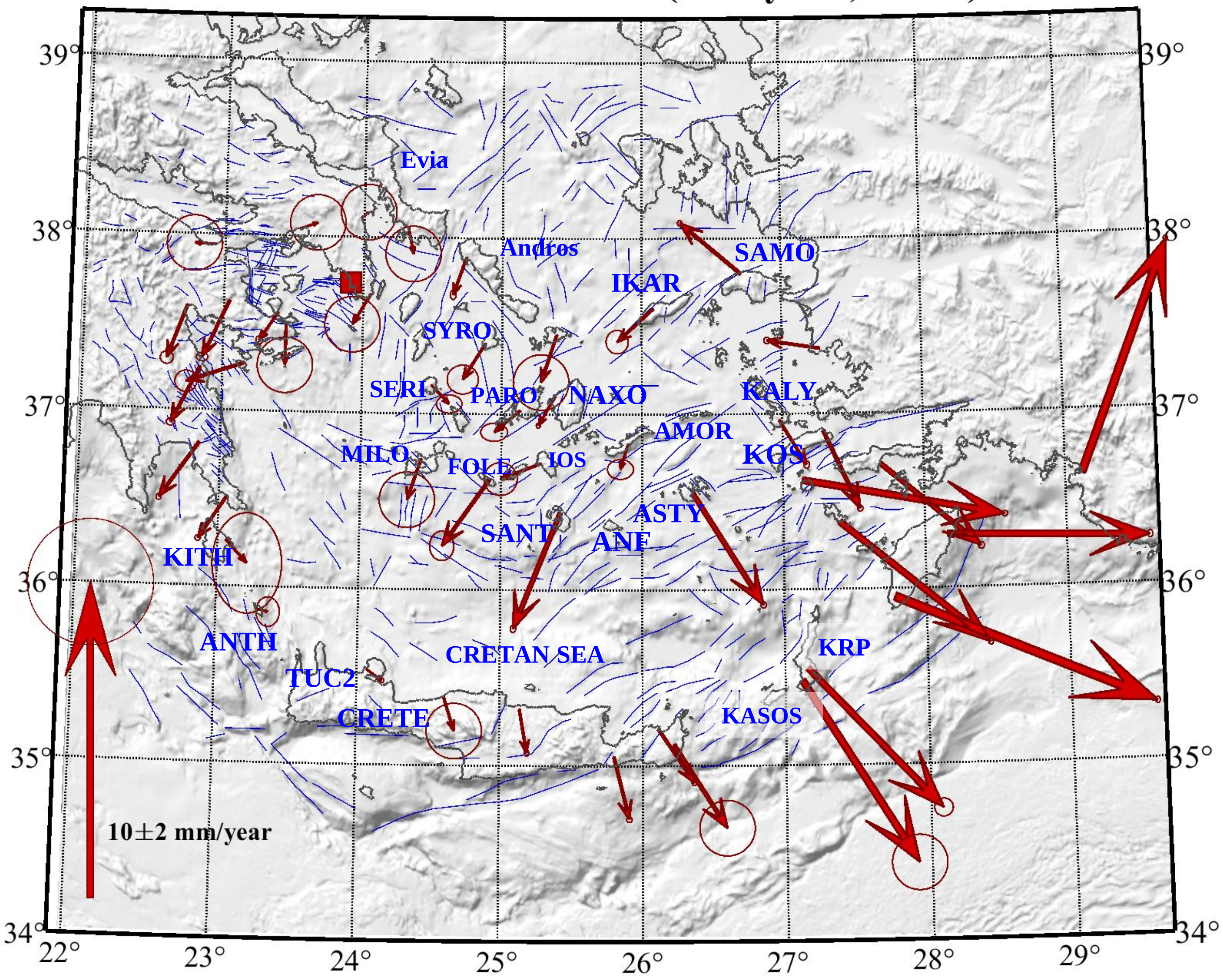
6. Motion relative to (25.38°E, 37.10°N) at Naxos Island, The Cyclades



- ➢ <u>Very significant</u> change in of sense of motion ***relative*** to a NE-SW line joining Kalymnos (KALY), Amorgos (AMOR) and Santorini (SANT).
  - ▪ The southeastern part of this line defines the boundary of the Anhydros Basin between Amorgos and Santorini
- ➢ Stations in the <u>Cyclades Archipelago show very small relative displacements</u> – small-scale distributed internal deformation is "Cyclades Block"?
  - ➢ **Exception:** Santorini (SANT and Folegandros (FOLE) diverge from rest of Cyclades relative to a NW-SE line between Anafi (ANF) and Ios (IOS).
- ➢ Evidence of convergence between east Crete (TUC2) - Anthikethyra (ANTH) – Kythera (KITH) <u>on one hand</u>, and Santorini – Folegandros <u>on the other</u>.
- ➢ The SE Dodecanese, to the S and E of the KOS-ASTY-ANF and ANF-KASOS lines respectively, ***diverge*** from stations to the N and W at *very high rates*.

7. Motion relative to (23.91°E, 37.74°N) at Anavyssos, S. Attica

Motion relative to ANAV (Anavyssos, Attica)



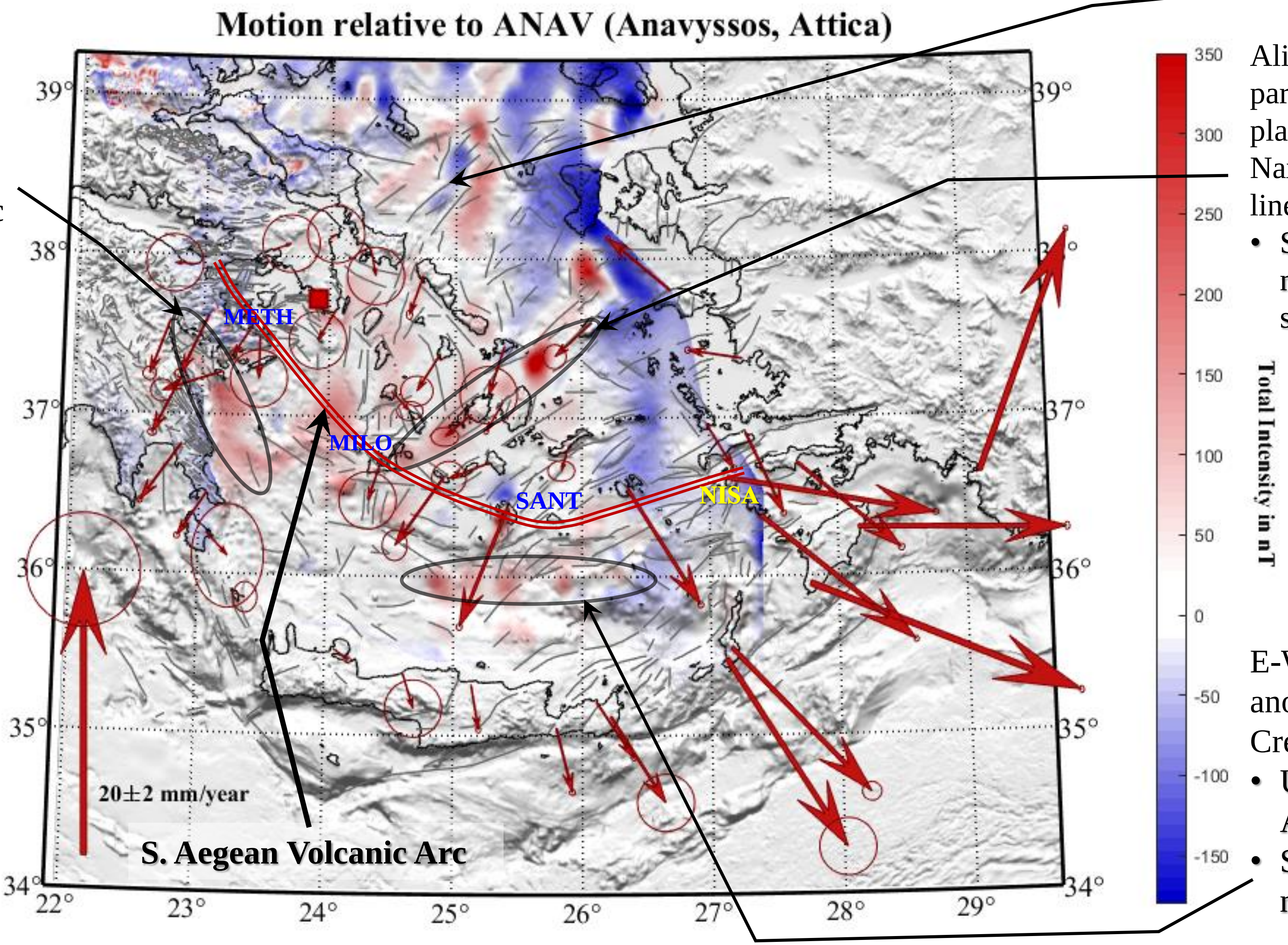
- The Ikaria (IKAR) – Naxos (NAXO) – Paros (PARO) – Milos (MILO) line *defines a boundary*:
  - Stations to the N of the line and to the W of 24°E describe NNE-SSW trajectories, approx. parallel to south branches of the westward extension of the North Anatolian Fault into the Aegean.
  - Stations *along* the line describe NE-SW trajectories.
  - Stations between the IKAR-NAXO-PARO-MILO and KALY-AMOR-SANT lines describe NE-SW to NNE-SSW trajectories.
- The zone between SANT-FOLE-MILO and CRETE appears to undergo ***counterclockwise rotation***.
- The SE Dodecanese, to the S and E of the KOS-ASTY-ANF and ANF-KASOS lines, ***diverges*** rapidly in a South-Easterly direction.
- With respect to the purported NE-SW tectonic boundaries, the sense of motion changes from *dextral* north of the KALY-AMOR-SANT line to sinistral south of the KOS-ASTY-ANF line.

8. Constraints from Magnetic Anomaly data

Syn-tectonic, possibly dioritic plutons at depths > 4km

- Unrelated to Volcanic Arc!

See ([Tzanis et al., 2018](#))



Anomalies (plutons?) possibly related to the *southern branches* of the North Anatolian Fault

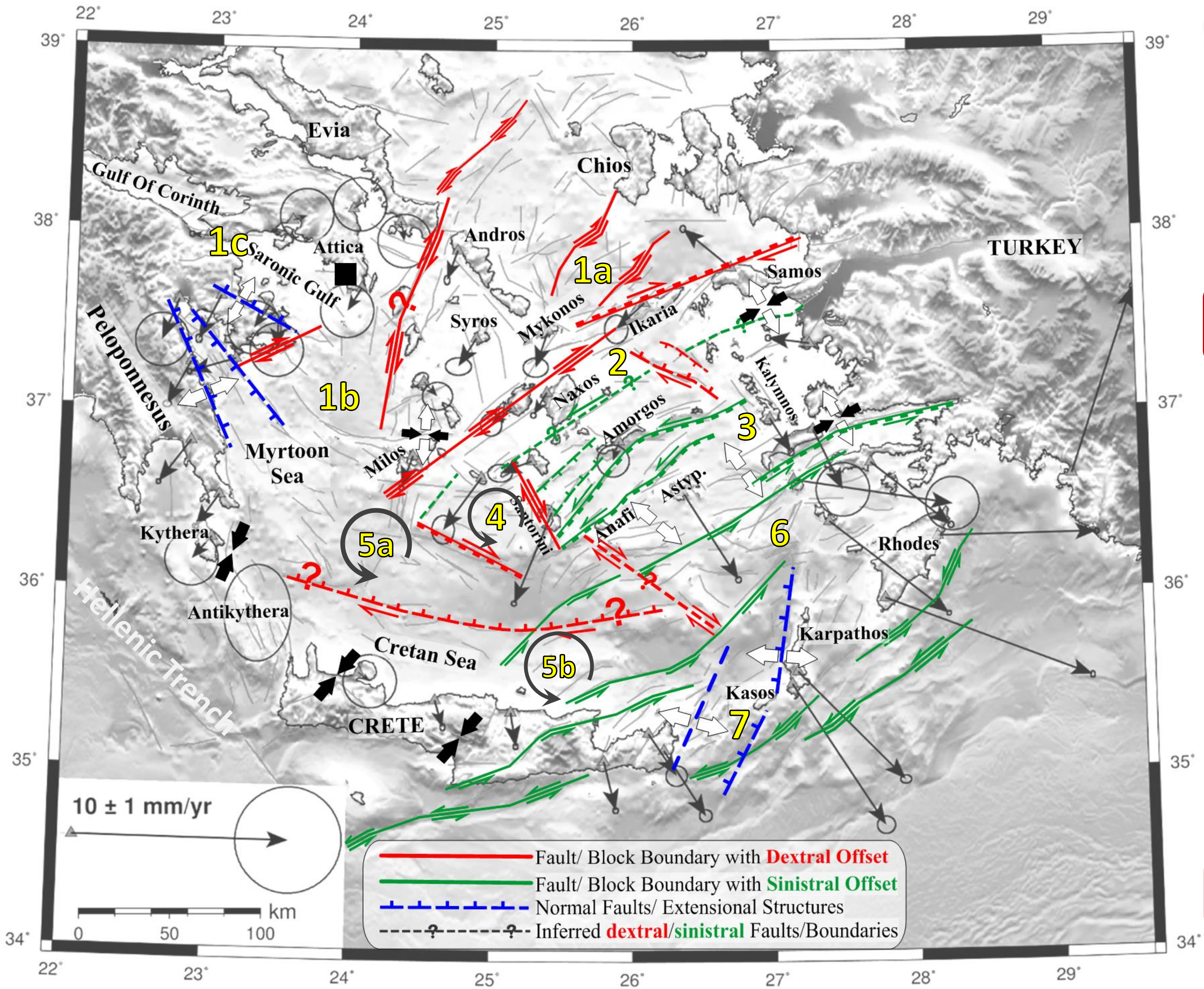
Alignment of anomalies parallel to dislocation planes along the Ikaria – Naxos – Paros – Milos line

- Syn-tectonic plutonic magmatism along major shear zone?

E-W alignment of anomalies central-eastern Cretan Sea

- Unrelated to Volcanic Arc!
- Syn-tectonic plutonic magmatism?

Reduced to Pole Total Field intensity. See [Chailas et al., (2010)](#); [Chailas and Tzanis, (2019)](#)



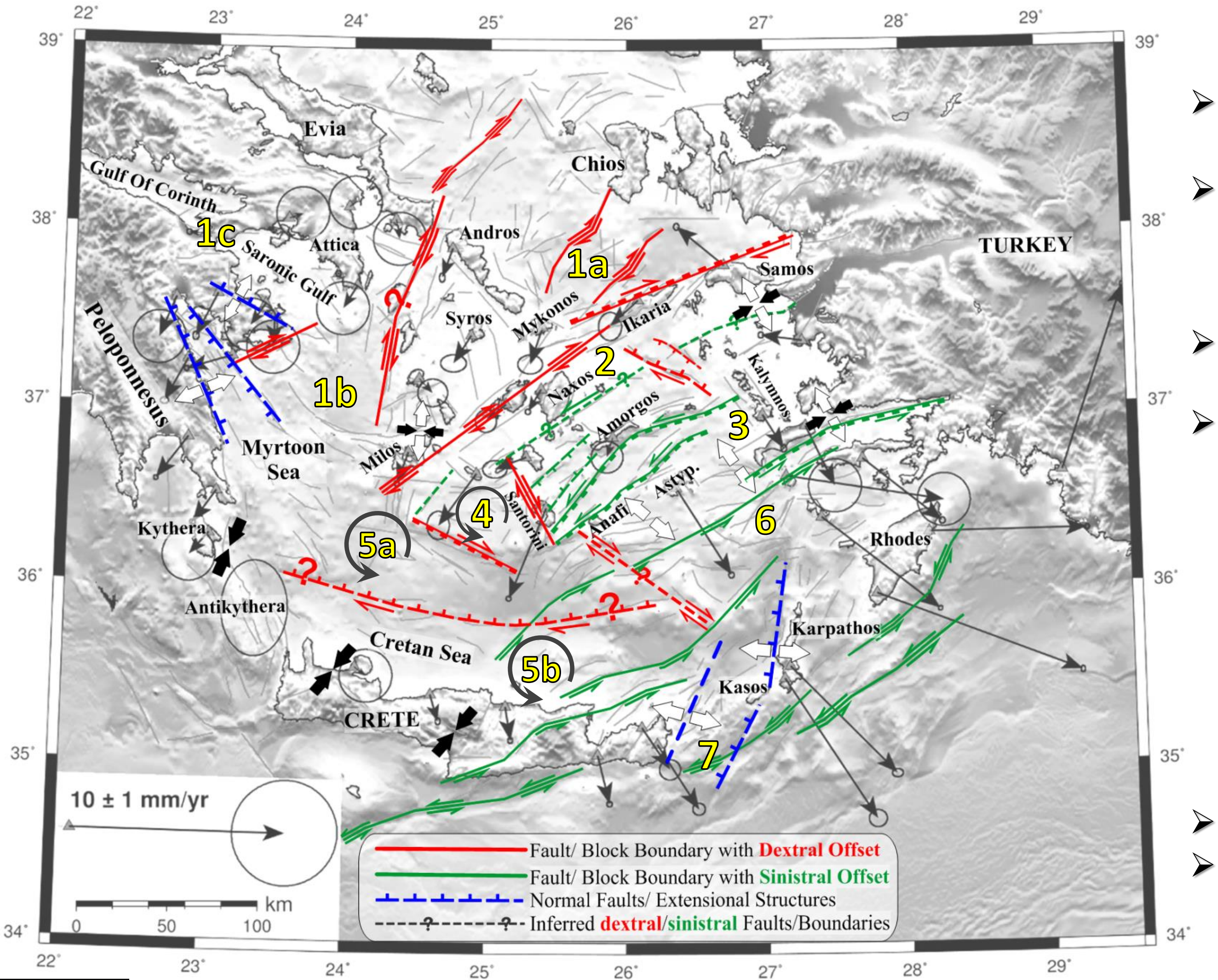
9. A Model of Contemporary Distributed Deformation

Extension/shortening directions

5a Tectonic Block Identifier with sense of rotation where applicable

- Emphasis on the horizontal component of fault/tectonic block motion
- Primary and internal tectonic boundaries may comprise faults from almost strike-slip (e.g. the Ikaria-Naxos-Milos line) to oblique-normal (e.g. Kalymnos-Amorgos-Santorini).
- Hitherto literature assigned dextral sense of motion to boundary and internal faults of Blocks 2 & 3 in the Cyclades (e.g. Sakellariou & Tsambouraki-Kraounaki, 2019).
- Tzanis et al., (2020) demonstrated that the NNW-SSE strike-slip faults at Santorini and the broader area are dextral.
- Accordingly, the NE-SW conjugate faults in the broader area **must** be left-lateral as shown herein.
- The model explains the GNSS-based and magnetic field observations

10. General Features of Proposed Model



- **Block 1c** is the broader *Corinth Rift System*; expectedly, the NE Peloponnesus diverges from ANAV.
- **Block 1b** extends over the Myrtoon Sea, to the east of the Andros-Serifos-Milos Line
  - Major tectonic boundary ?
- **Block 1a** is part of the Northern Aegean
  - Motion in Blocks 1a-1b is right-lateral, NW-SE oriented.
- **Blocks 2 and 3** define a zone in which NW-SE right-lateral motion *north of the Ikaria-Naxos-Milos* line **transitions** to NW-SE left-lateral motion *south of the Kalymnos-Amorgos-Santorini line*
- **Block 4** defines a *domain of counterclockwise rotation* at southeastern front of Blocks 2 and 3.
- **Blocks 5a, 5b** define an area of *counterclockwise rotation in the Cretan Sea* effected *by combined action* of NW-SE left-lateral displacement south of the Kalymnos-Amorgos-Santorini line and NE-SW right-lateral displacement along the western boundaries between Blocks 2, 3 and 6 on one hand, and 4, 5 on the other.
  - The right-lateral dislocation planes in the Cretan Sea are placed approximately and with reference to observed elongate bathymetric fronts, magnetic anomaly alignments and changes in the size and direction of velocity vectors. Their presenceremains to be identified with future research.
- **Block 6** is the *south-easterly diverging area of SE Dodecanese*
- **Block 7** is a NNW-SSE oriented area of *E-W extension*, identified by bathymetric features and significant changes in velocity between eastern Crete and Karpathos.

Thank you
for your Attention