# Slow-slip Events Destabilize Upper-Plate and Trigger Large-Magnitude Earthquake at the Western-end of the Hellenic Subduction System

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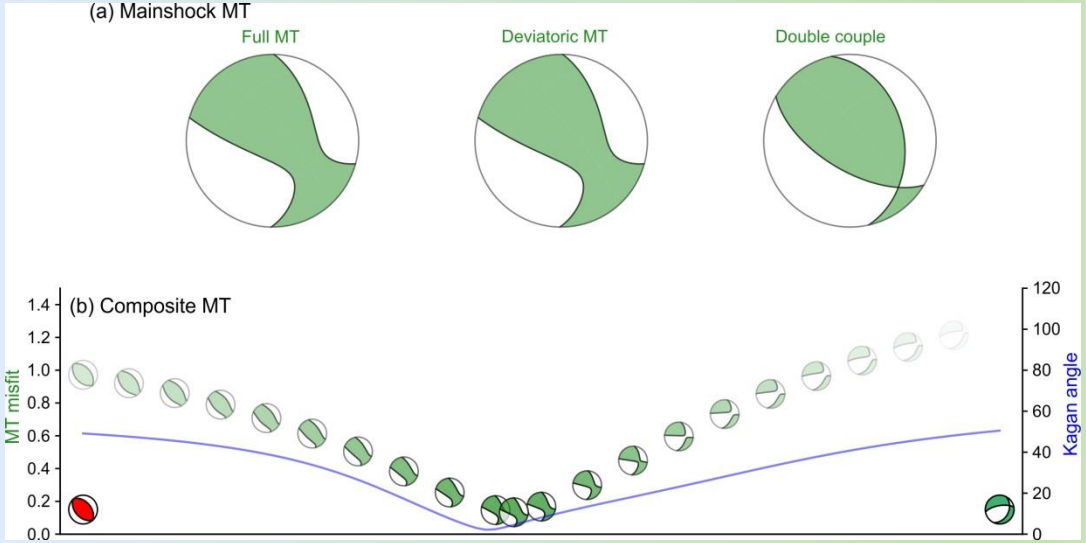
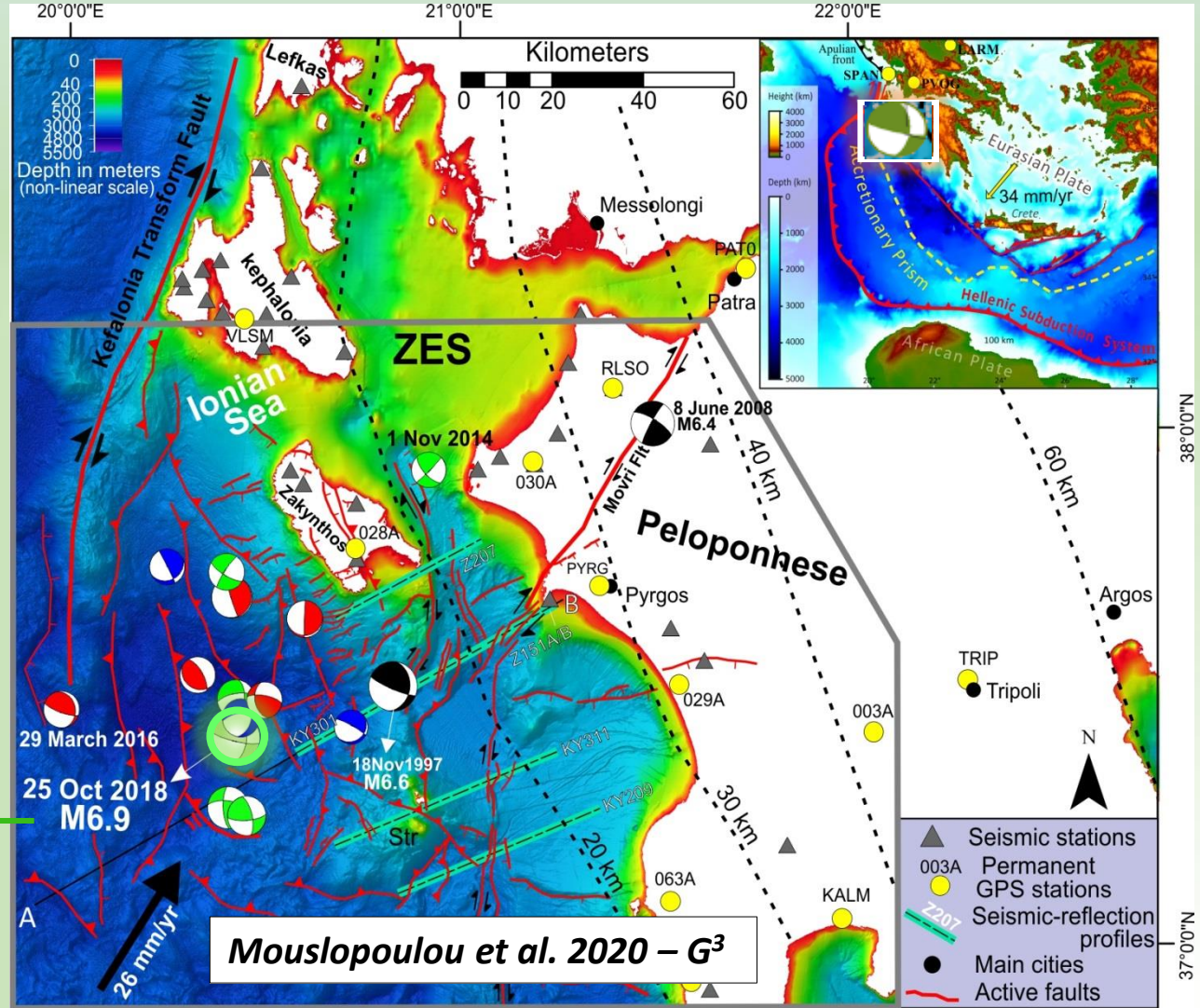
**We use a multitude of instrumental and geological data to explore the deformational processes that operated over a 5-year period at the western-end of the Hellenic Subduction System (HSS) and resulted in the gradual unlocking of the upper-plate, culminating in the 2018 $M_w$ 6.9 Zakynthos Earthquake.**

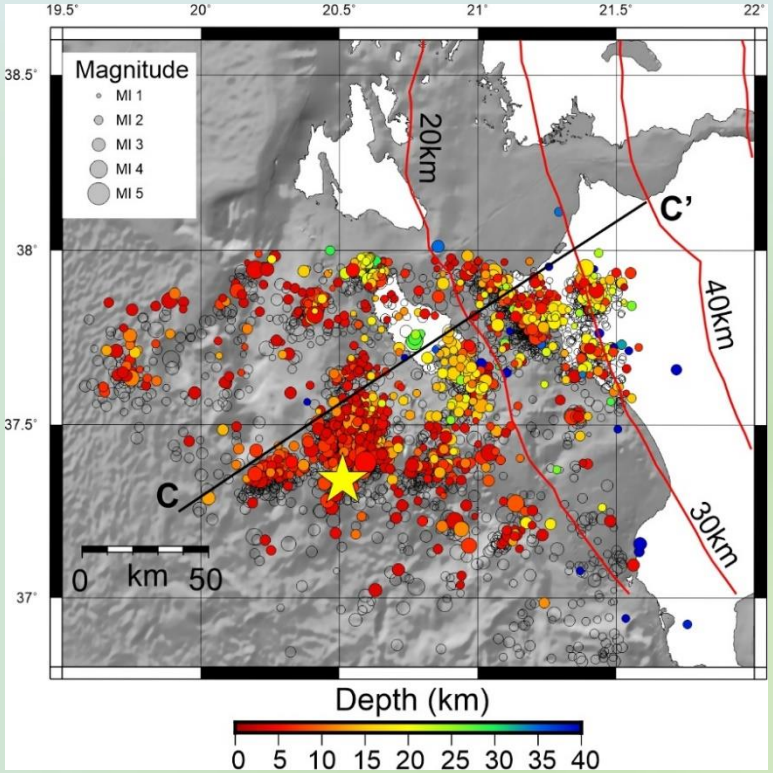


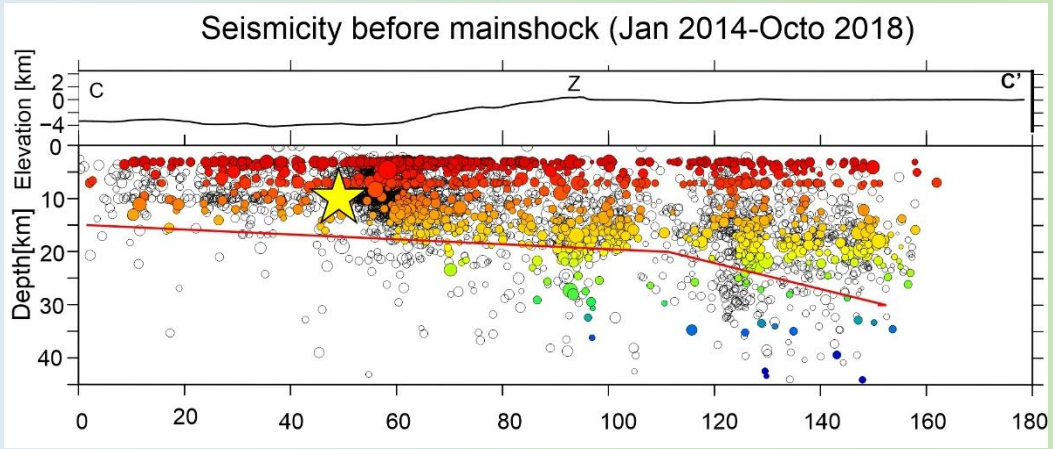

**25 Oct 2018 $M_w$ 6.9 Zakynthos Earthquake: a mixture of thrust and strike-slip faulting**

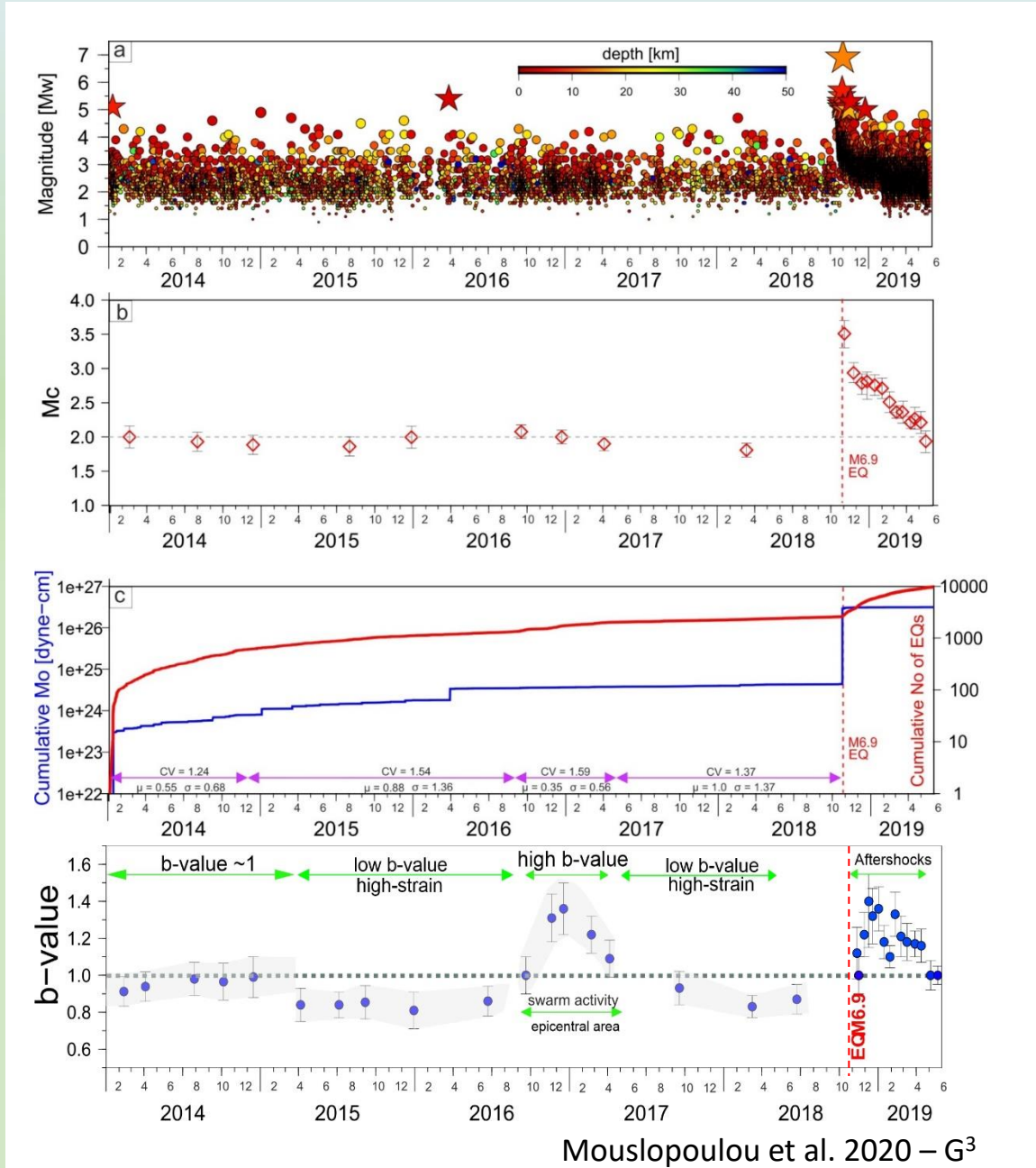


# Zakynthos Earthquake Sequence (ZES): Jan 2014 - June 2019

- >12,000 relocated events (2/3 aftershocks)
- Mainshock $M_w$ 6.9 Oct 2018
- 85% of $M_w$<3.5
- Mc: 2.0 to 3.5
- Non-uniform Mo release
- *Mo* $_{\text{prior mainshock}}$ → $M_w$ 5.8
- Total *Mo* → $M_w$ 7
- Fluctuations in b-value

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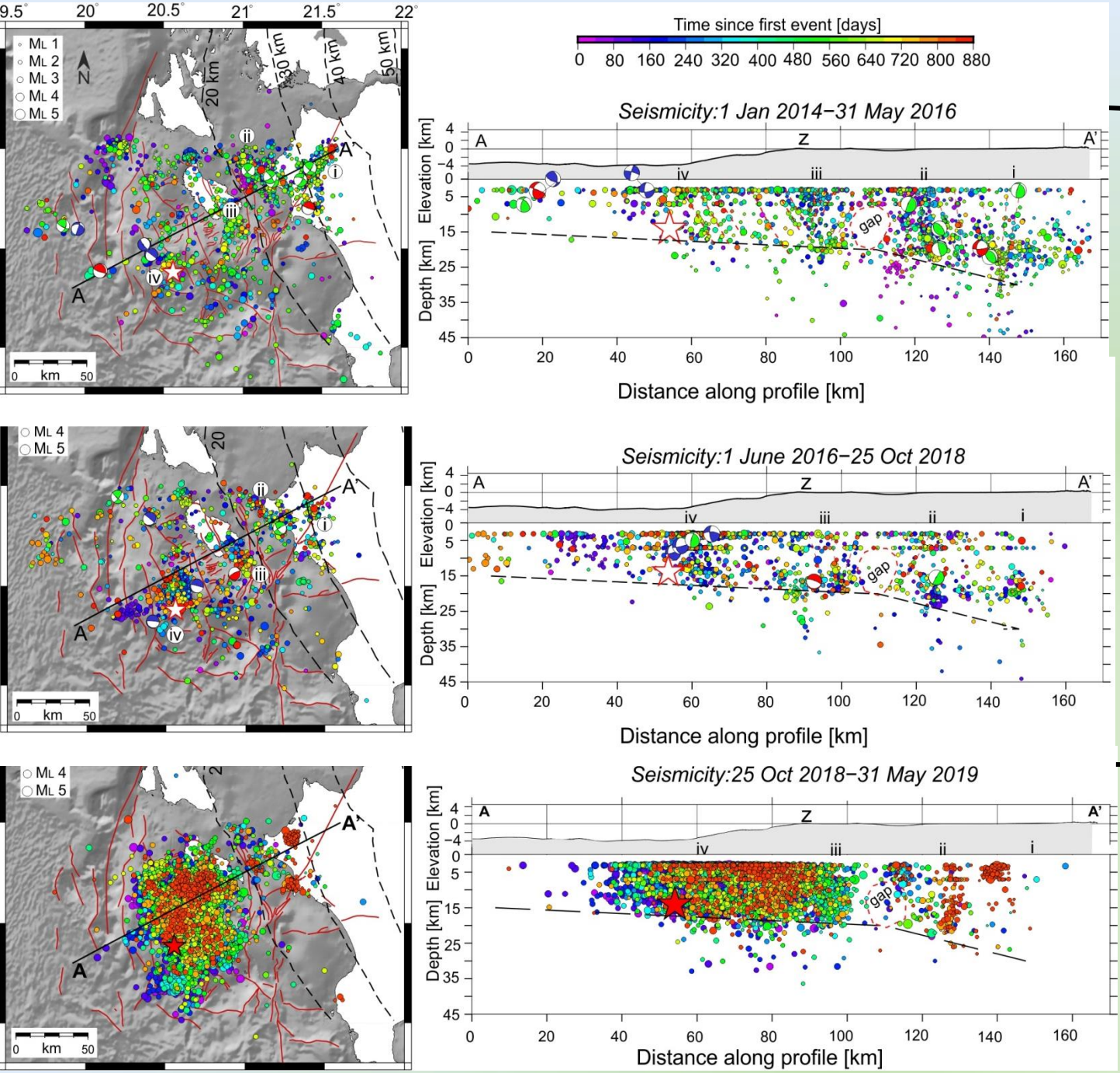
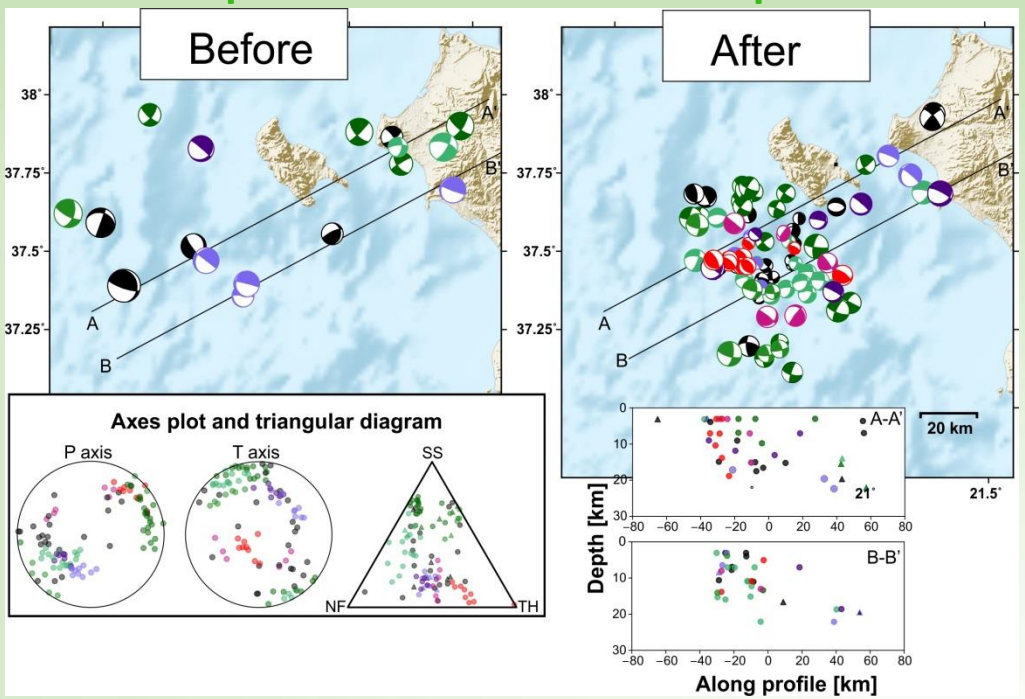
# Relocated microearthquakes & 102 MT inversions reveal upper-plate fault interactions




**Simultaneous activity on all fault types**

**Strike-slip**
**Normal**
**Reverse**

**Strike-slip** **Normal** **Strike-slip** **Reverse**

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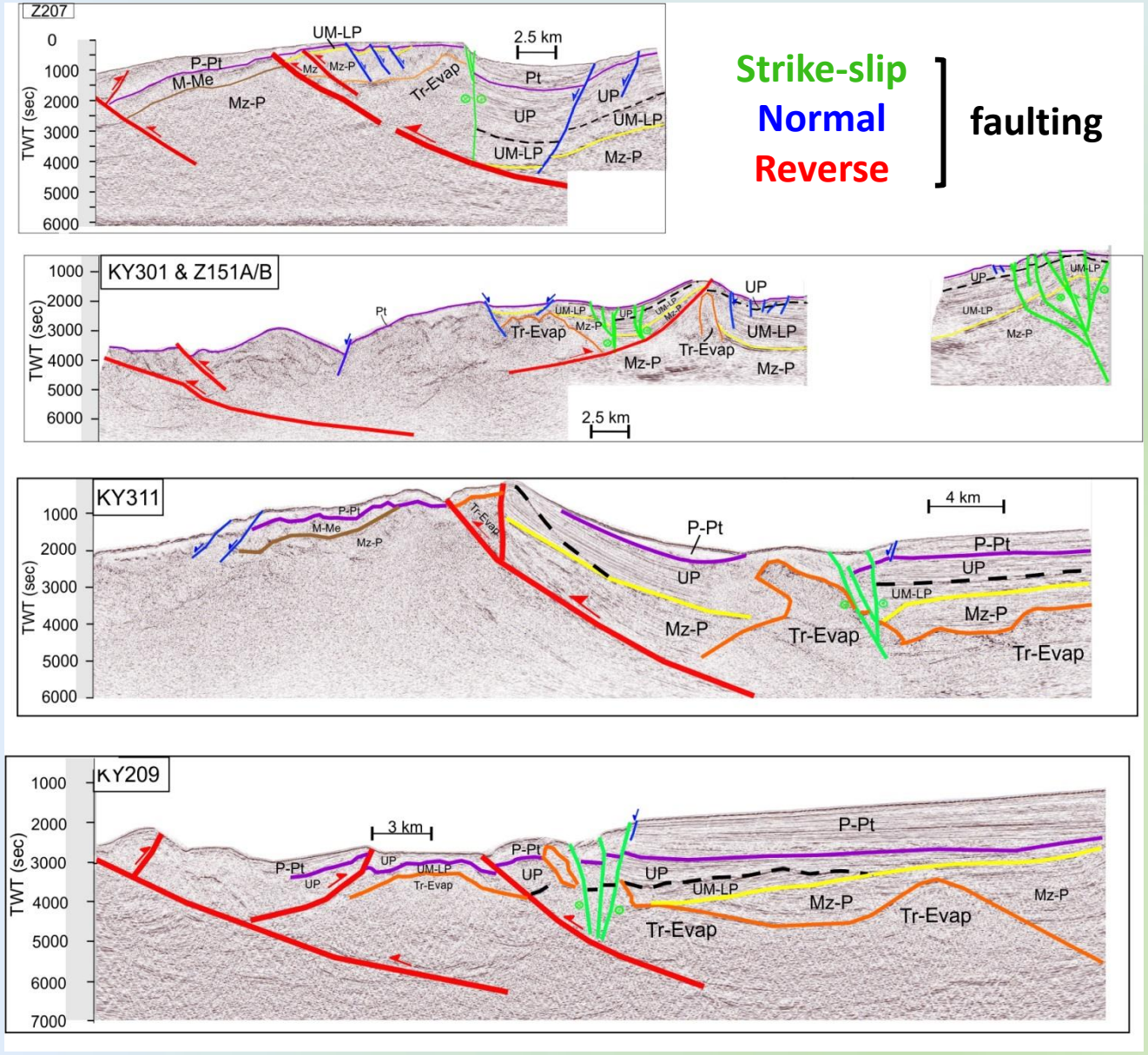
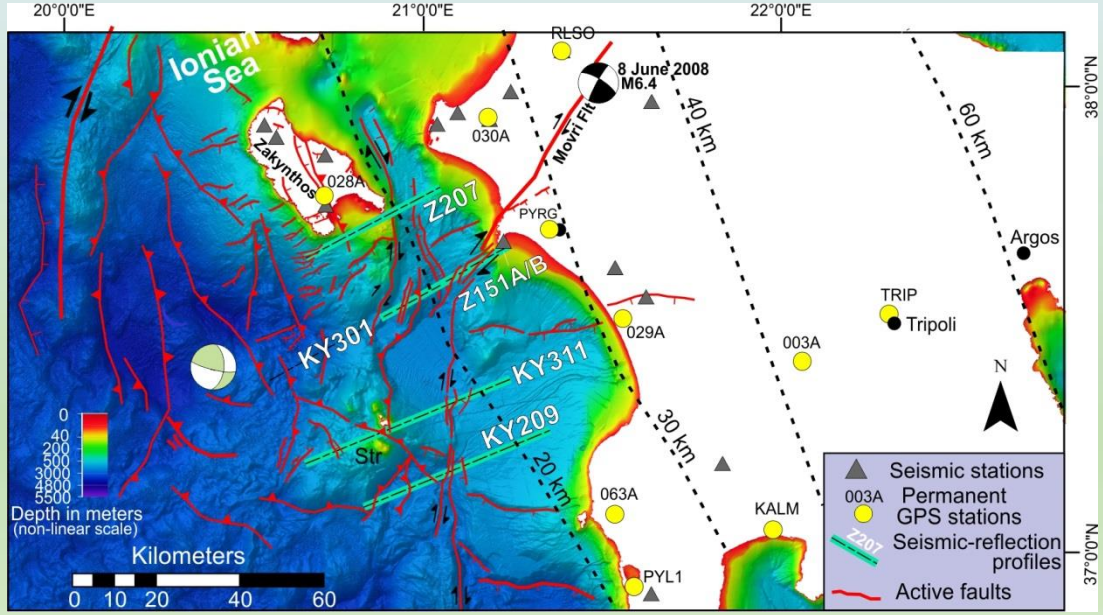
# Long-term faulting and kinematics within the ZES




Strike-slip
Normal
Reverse
faulting




**Seismic-reflection profiles from offshore Peloponnese support the occurrence of various fault types within the upper-plate. Faults simultaneously active over thousand to million year timescales.**

Reinterpreted from Kokkalas et al. (2013) & Wardell et al. (2014)

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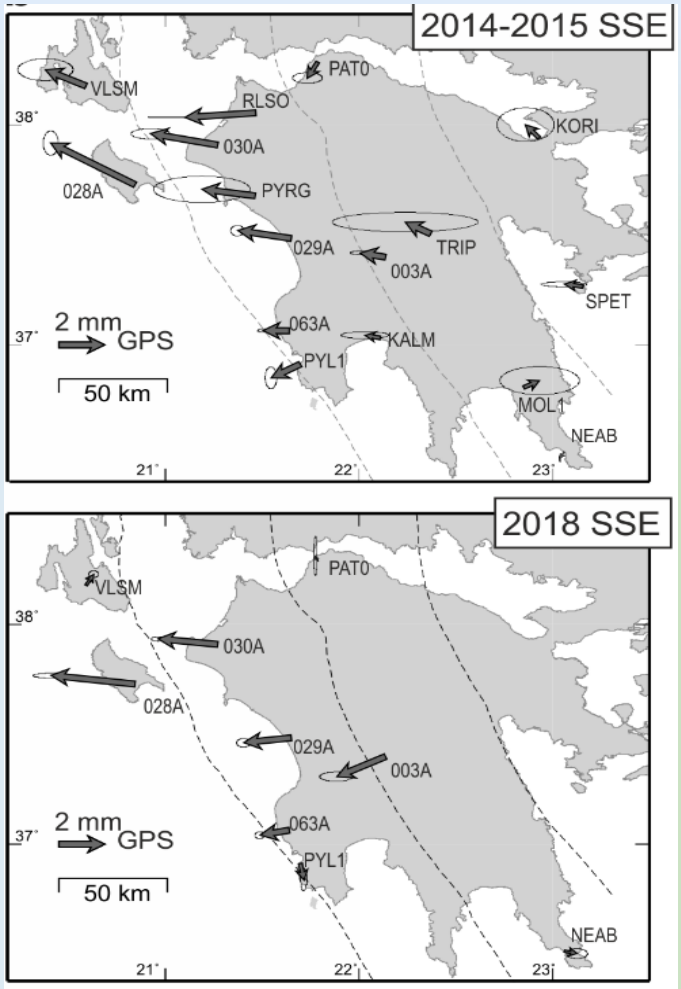
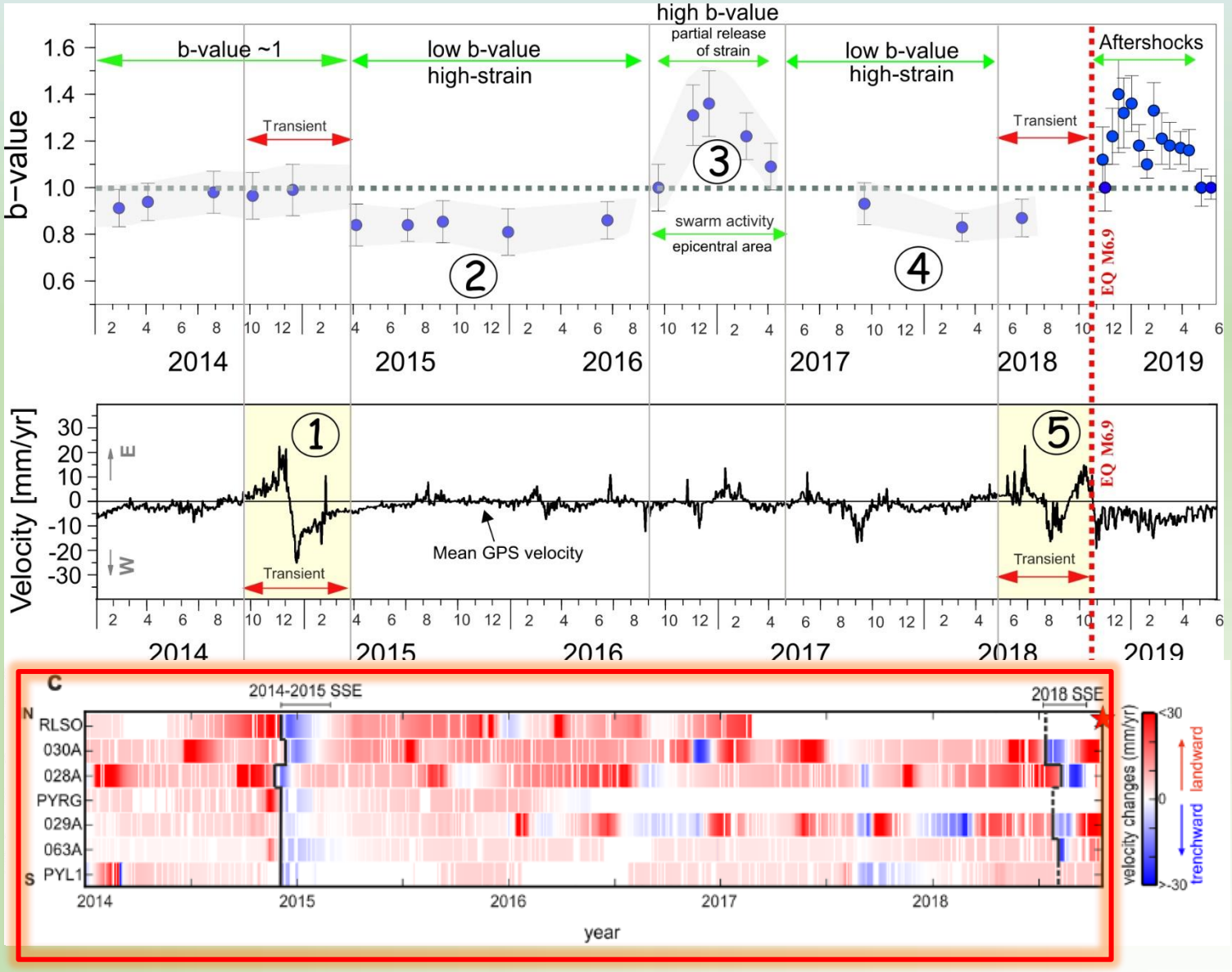
# Seismic and aseismic deformation *precede* the 2018 Zakynthos mainshock

Cumulative Trenchward Transient displacements




Seismicity

GPS




**Data record a ~6-month long SSE in 2014-2015 followed by a significant drop in b-values (<1). Depressed b-values lasted until the 2018 mainshock with the exception of a 6-month period (2016-2017) where swarm-like seismic activity accounts for high *b*-values. The main event was preceded by another long-lasting SSE.**

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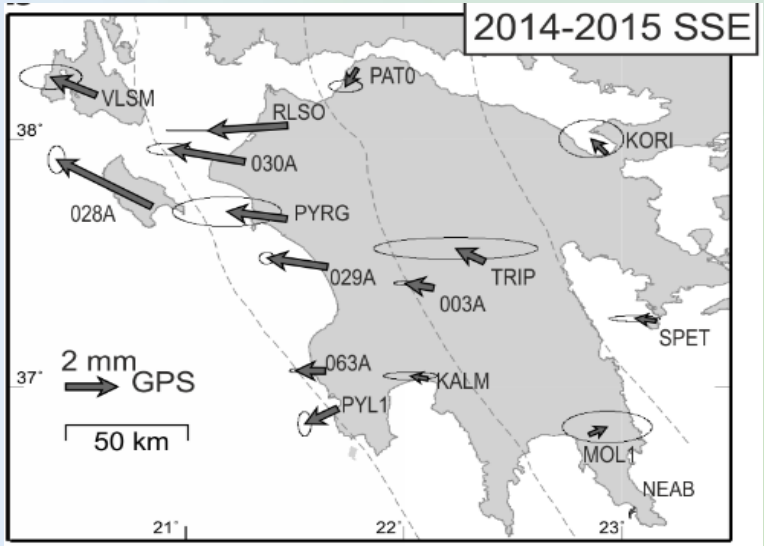
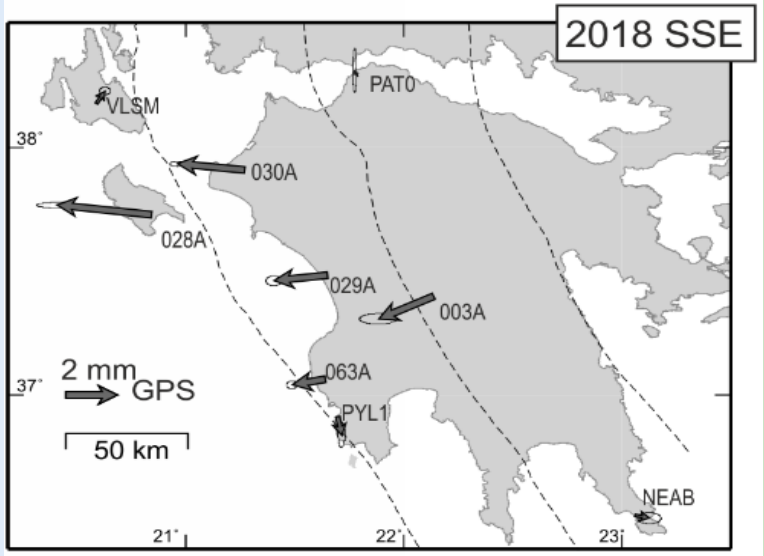
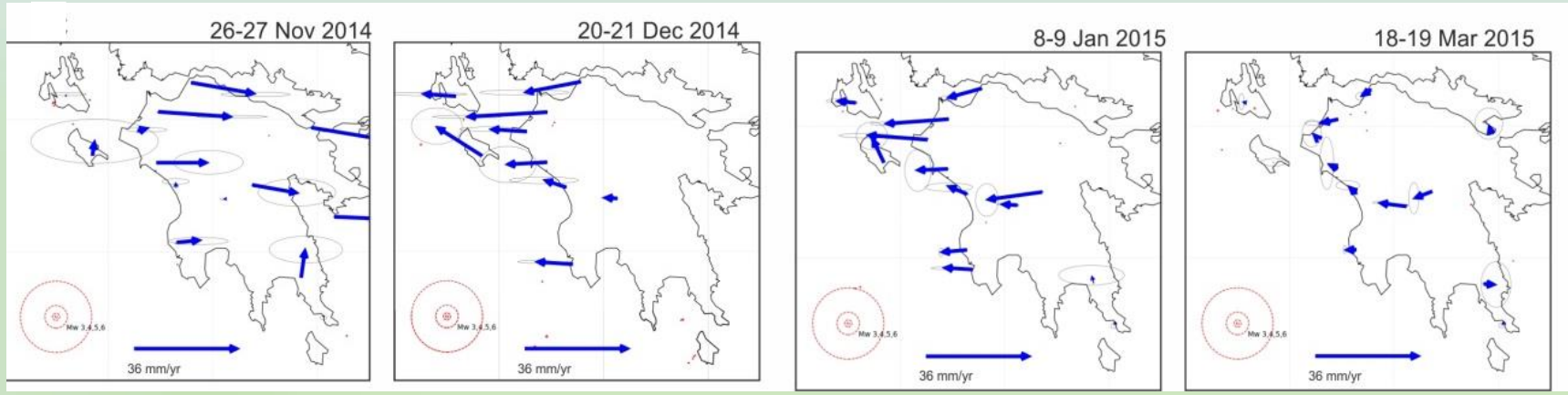
# The First Slow Slip Events reported in the Hellenic Subduction System

Cumulative Trenchward Transient displacements



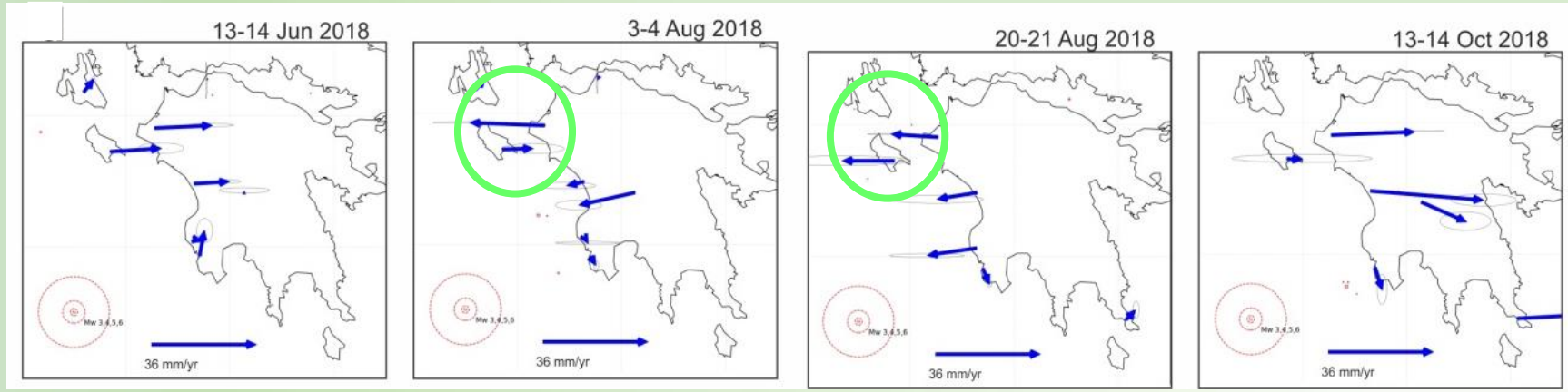




## Sept 24, 2014 to March 20, 2015 (~6 months / trenchward motion: 112 days)




Landward acceleration | Trenchward rotation | Trenchward rotation | End of SSE

## May 14, 2018 to Oct 25, 2018 (~5 months / trenchward motion: 107 days)




Landward acceleration | Trenchward rotation Zakynthos delays | Trenchward rotation | Landward acceleration before the M 6.9 event

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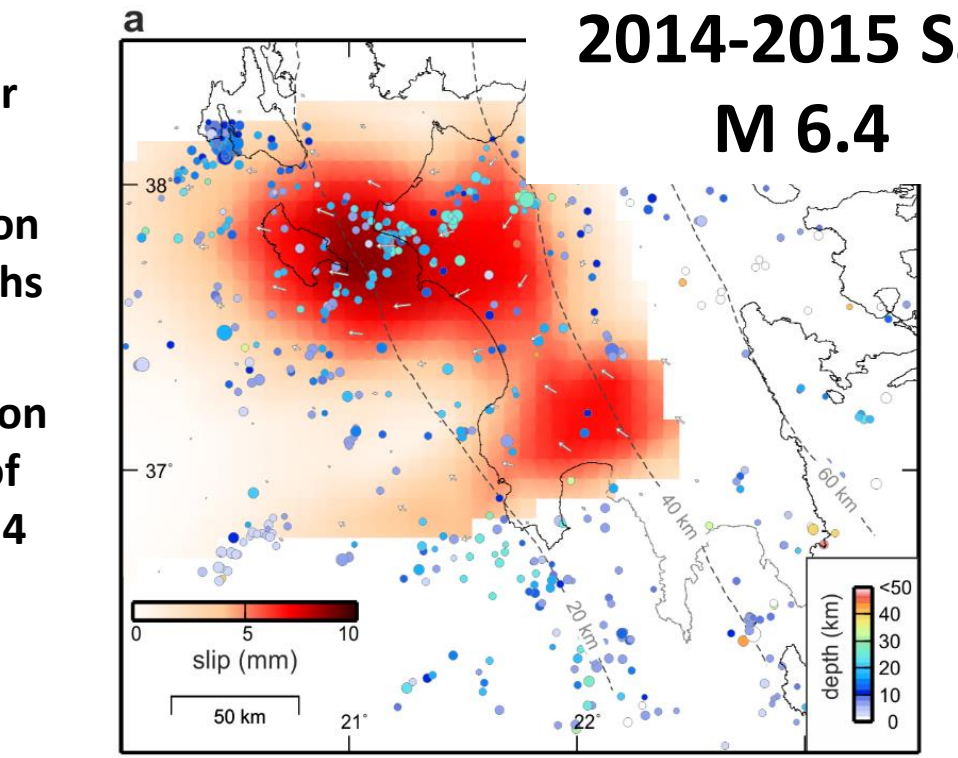
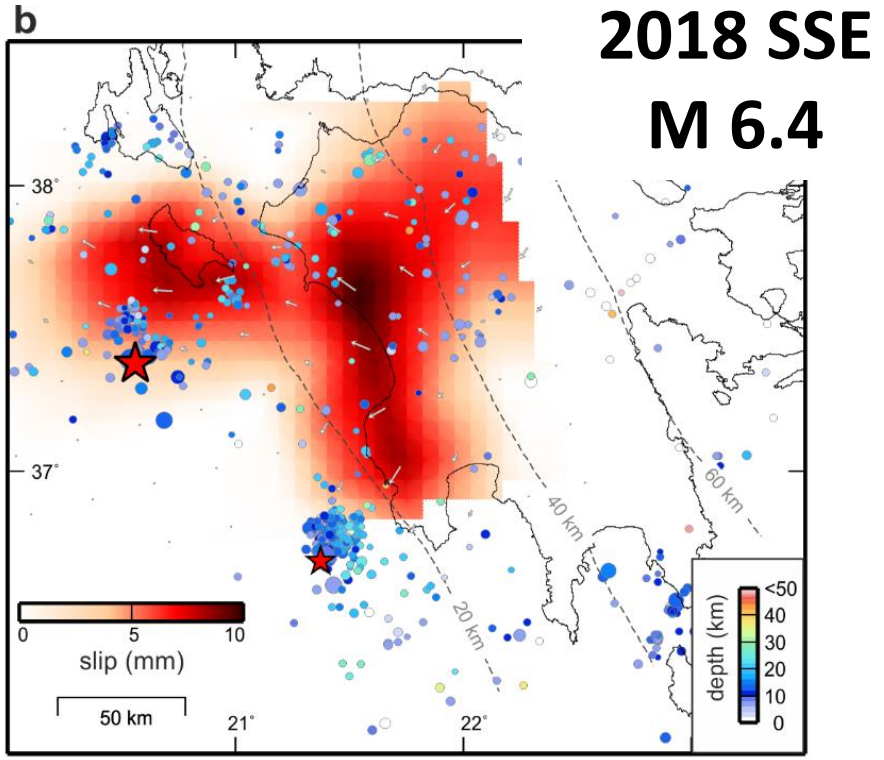
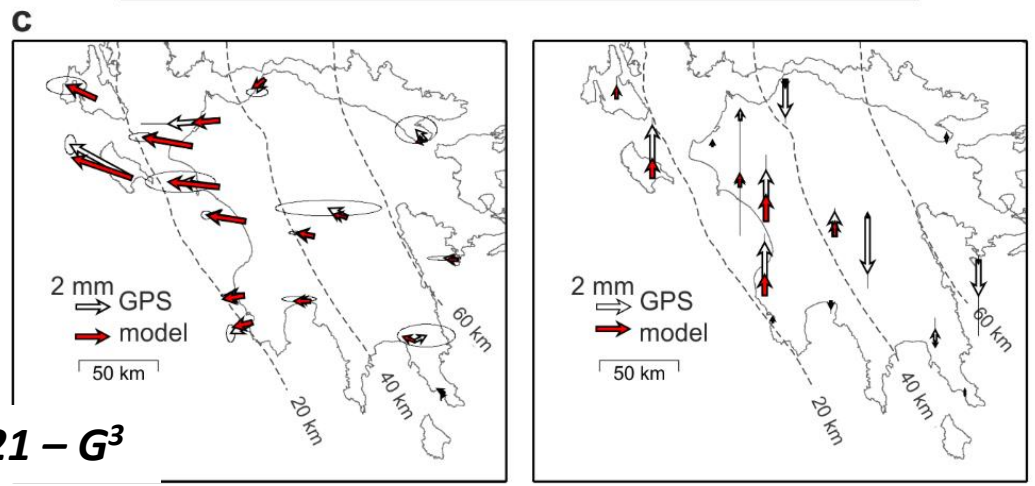
# Distribution of SSEs on the Plate Interface

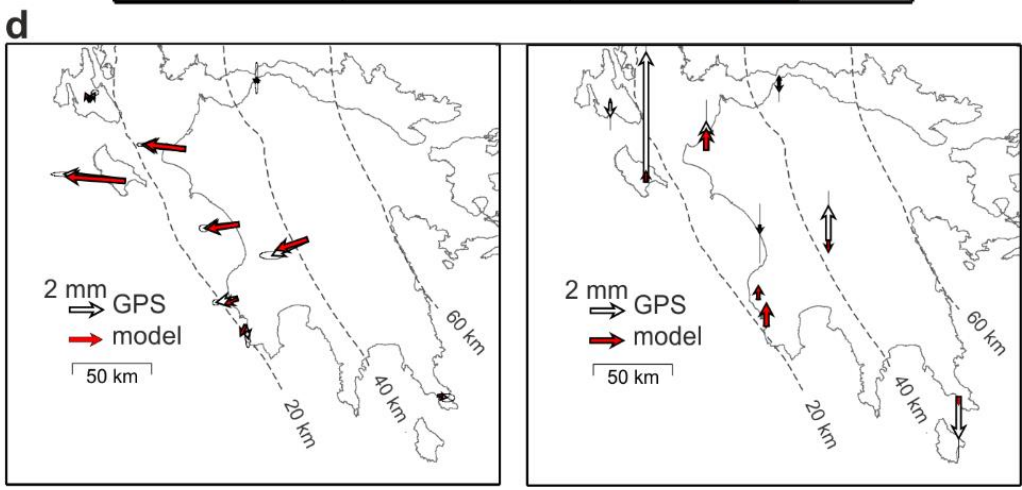
- Both SSEs similar patterns
- Bulk of distribution restricted to depths of 20-40 km
- Up to 10 mm slip on each at depths of 25-30 km → M6.4

- Frictional-to-viscous transition zone (i.e. downdip extent of locked zone) at ~30-40 km depth.

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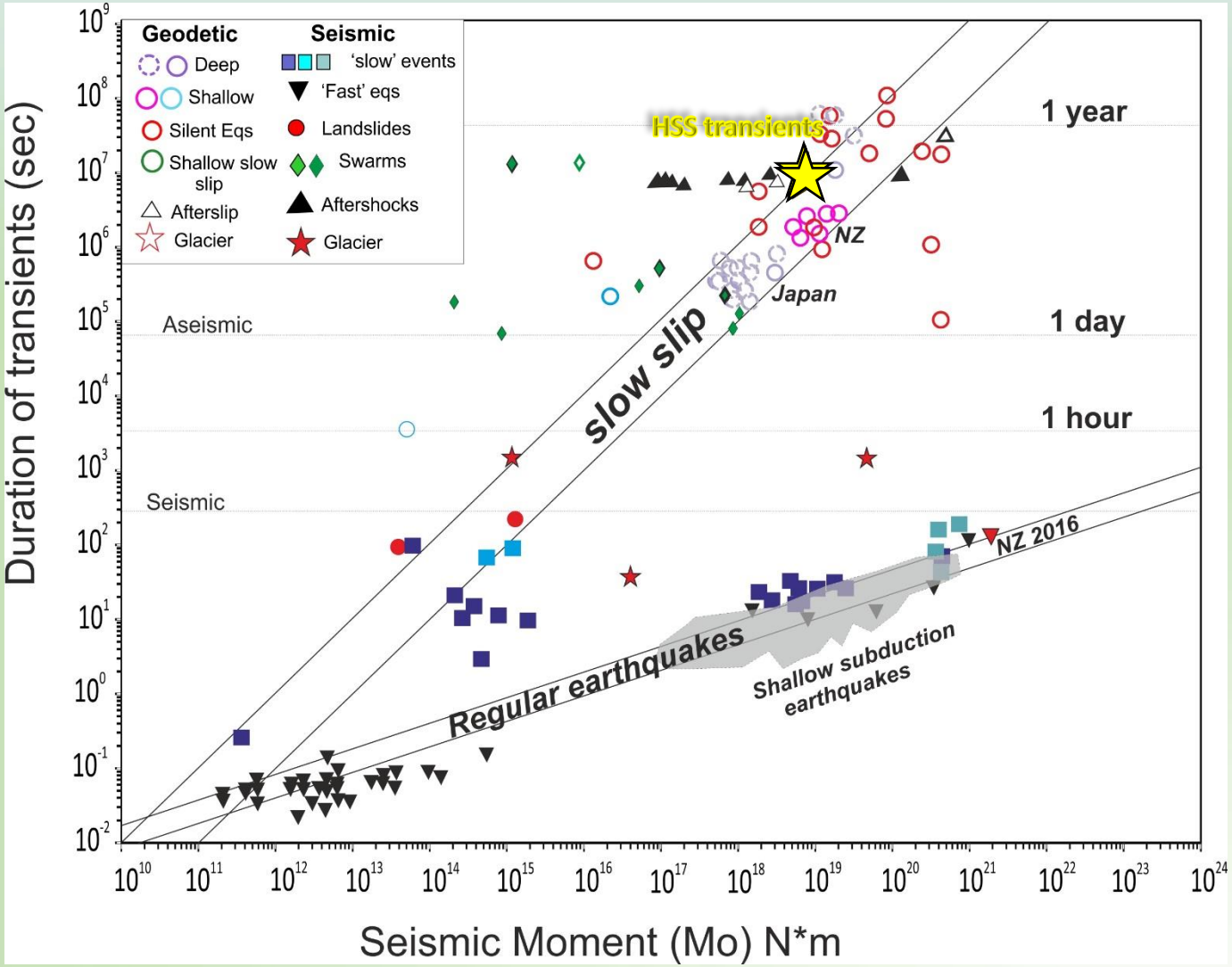
# Slow Slip Events in the HSS vs. Global data

**Duration and amount of seismic-moment released during the *Greek* geodetic transients in agreement with other slow-slip events recorded globally**




**Modified from Peng & Gomberg (2010) / Nat. Geoscience**

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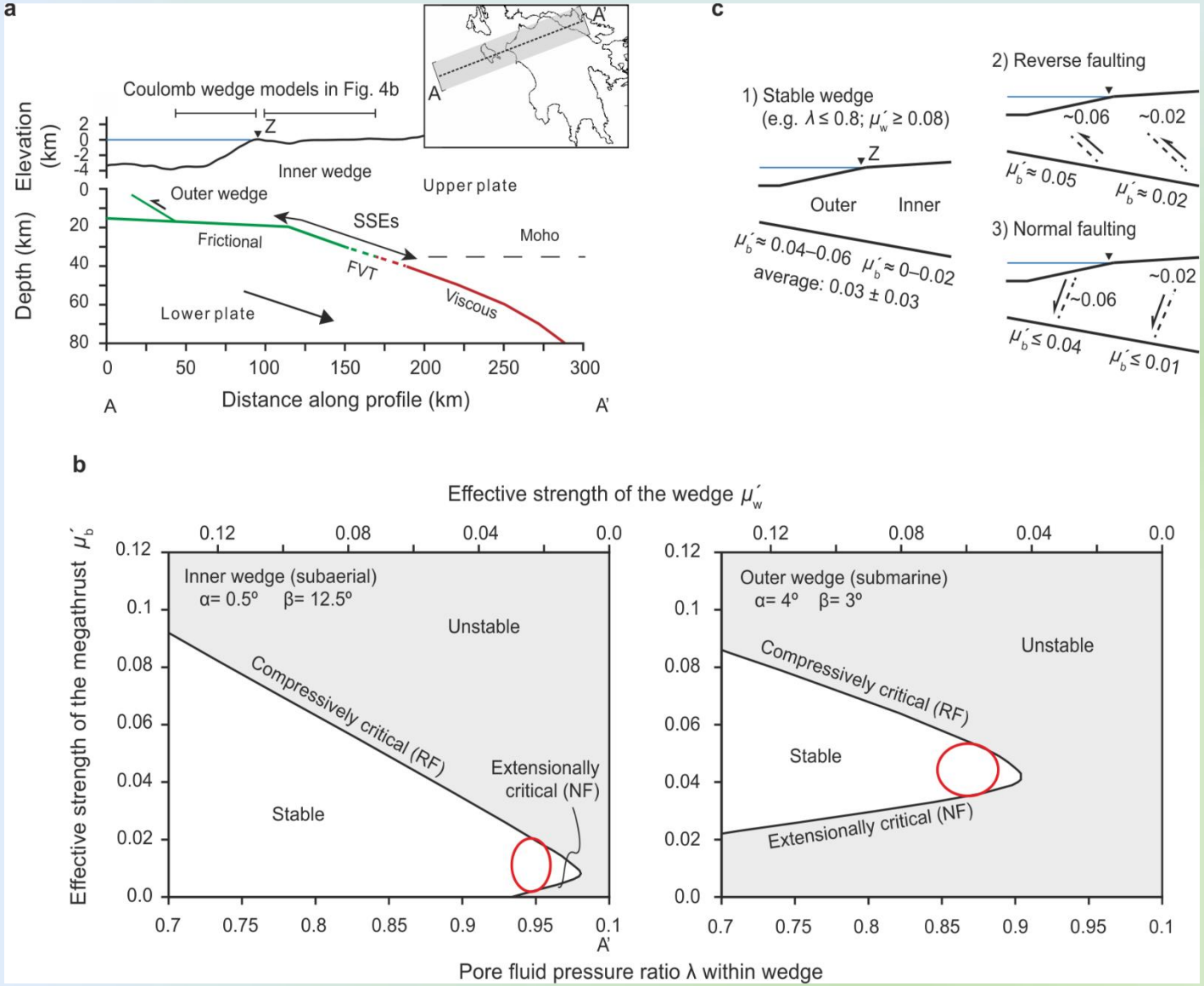
# Mechanical stability of the western Hellenic forearc




**Dynamic Coulomb Wedge Analysis** (Wang & Hu, 2006) in the western Hellenic forearc indicates:

- Effective strength on the Hellenic megathrust very low ($\mu_b$<0.02).
- Simultaneous reverse and normal faulting in the forearc requires that the effective strength of the forearc is as low as on the megathrust.
- Small changes in megathrust friction suffice to change the mechanical state of the forearc from compression to extension (and vice versa).

**Compatible with diverse style of faulting over small spatial scales in the western HSS**

$\mu$ is the coefficient of friction of the wedge material
$\lambda$ is the pore fluid pressure ratio within the wedge

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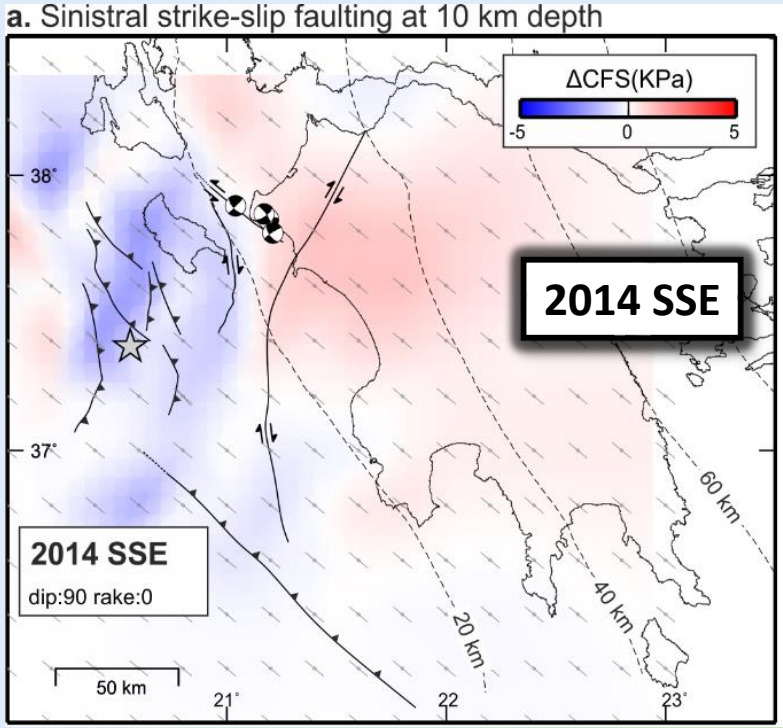
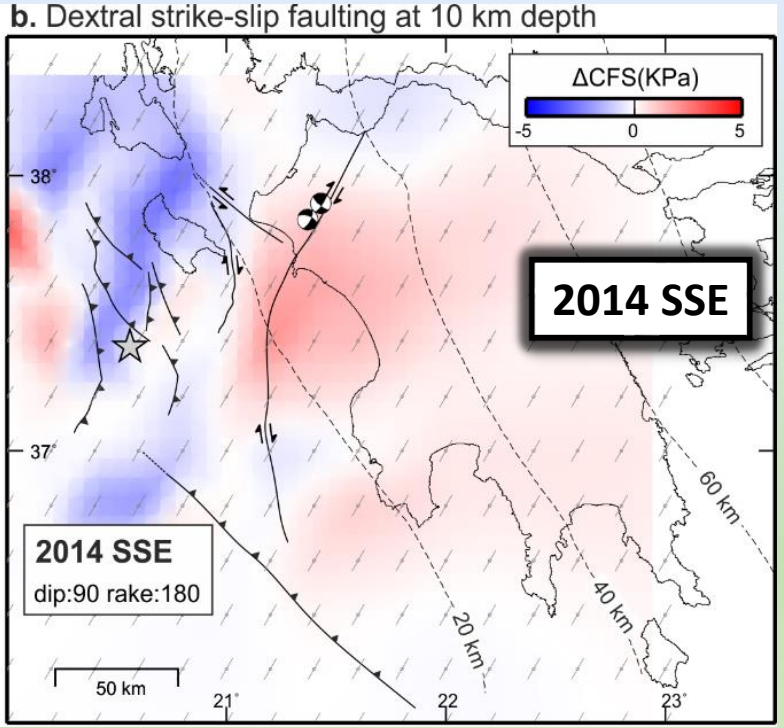
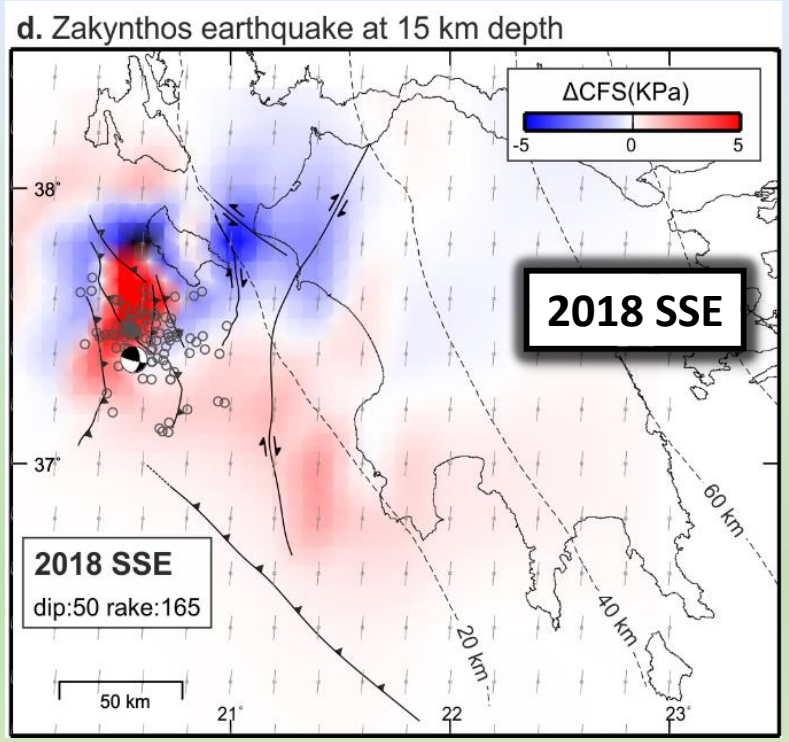


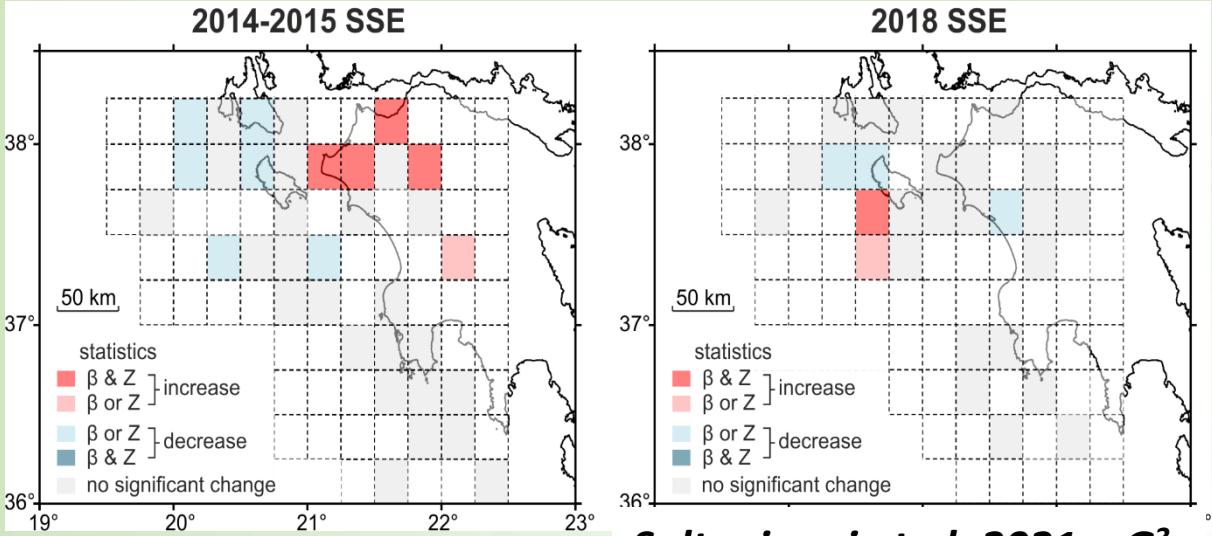




## Coulomb Stress Perturbations in the Upper-Plate

- Stress changes during both transients consistent with increases/decreases in seismicity rates
  - Stress changes due to the 2018 transient produced significant (up to 25 KPa) stress perturbations within the epicentral area that triggered the 2018 Zakynthos earthquake.

## Changes in seismicity rates during the transient episodes

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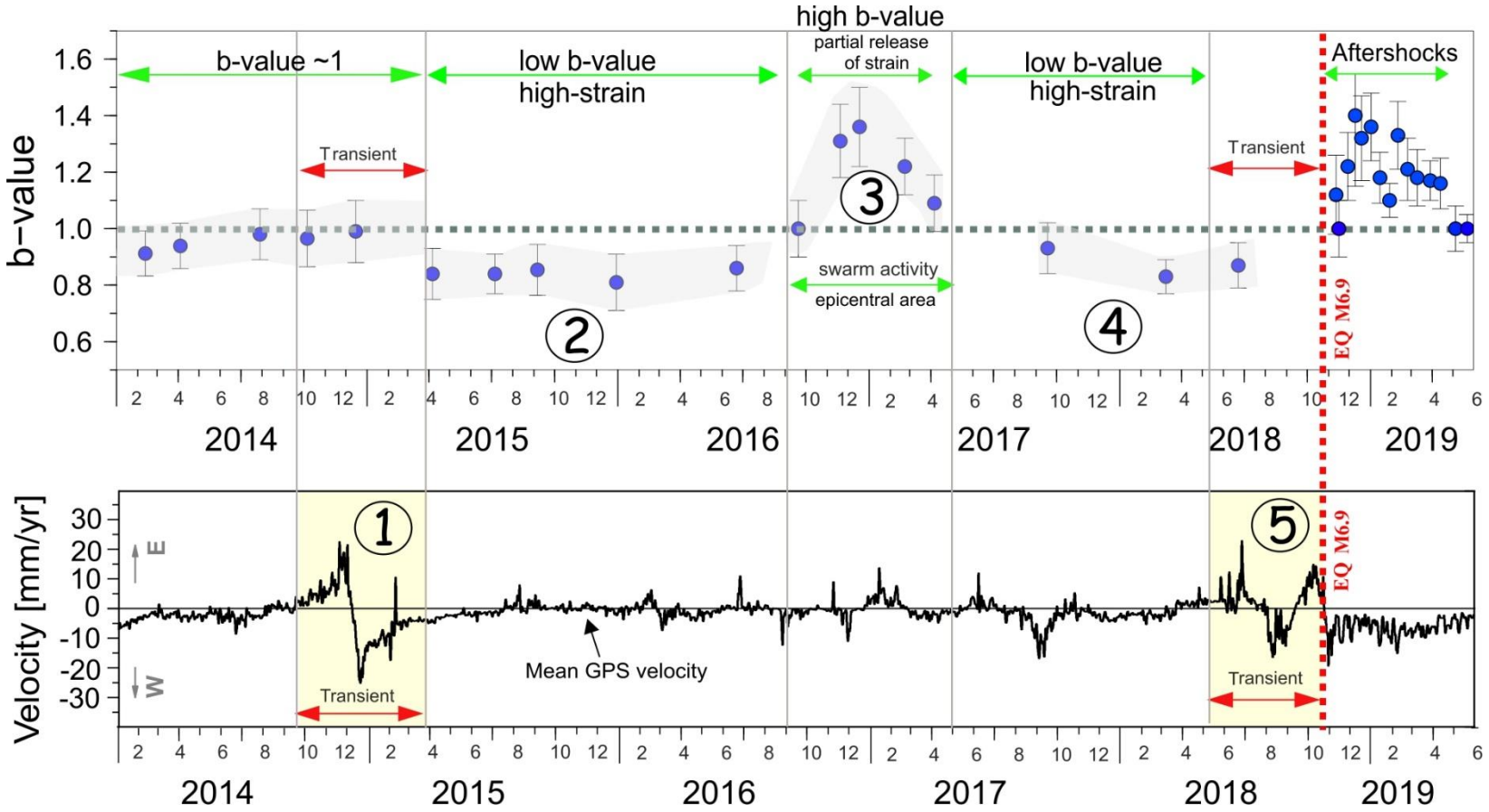
# Summary

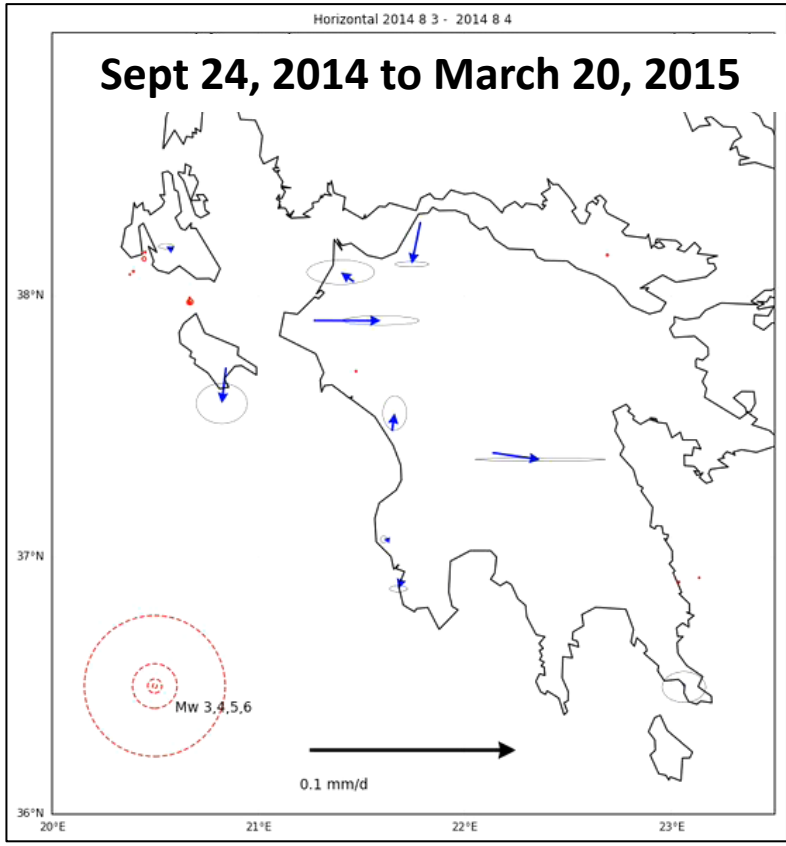
**Slow-slip on the subduction plate-interface gradually unlocks the upper-plate, producing episodes of seismic and aseismic deformation that culminate in the multi-fault 2018 Mw 6.9 Zakynthos Earthquake**

**Seismicity**

**GPS**




**The 1st SSE reported in the HSS**

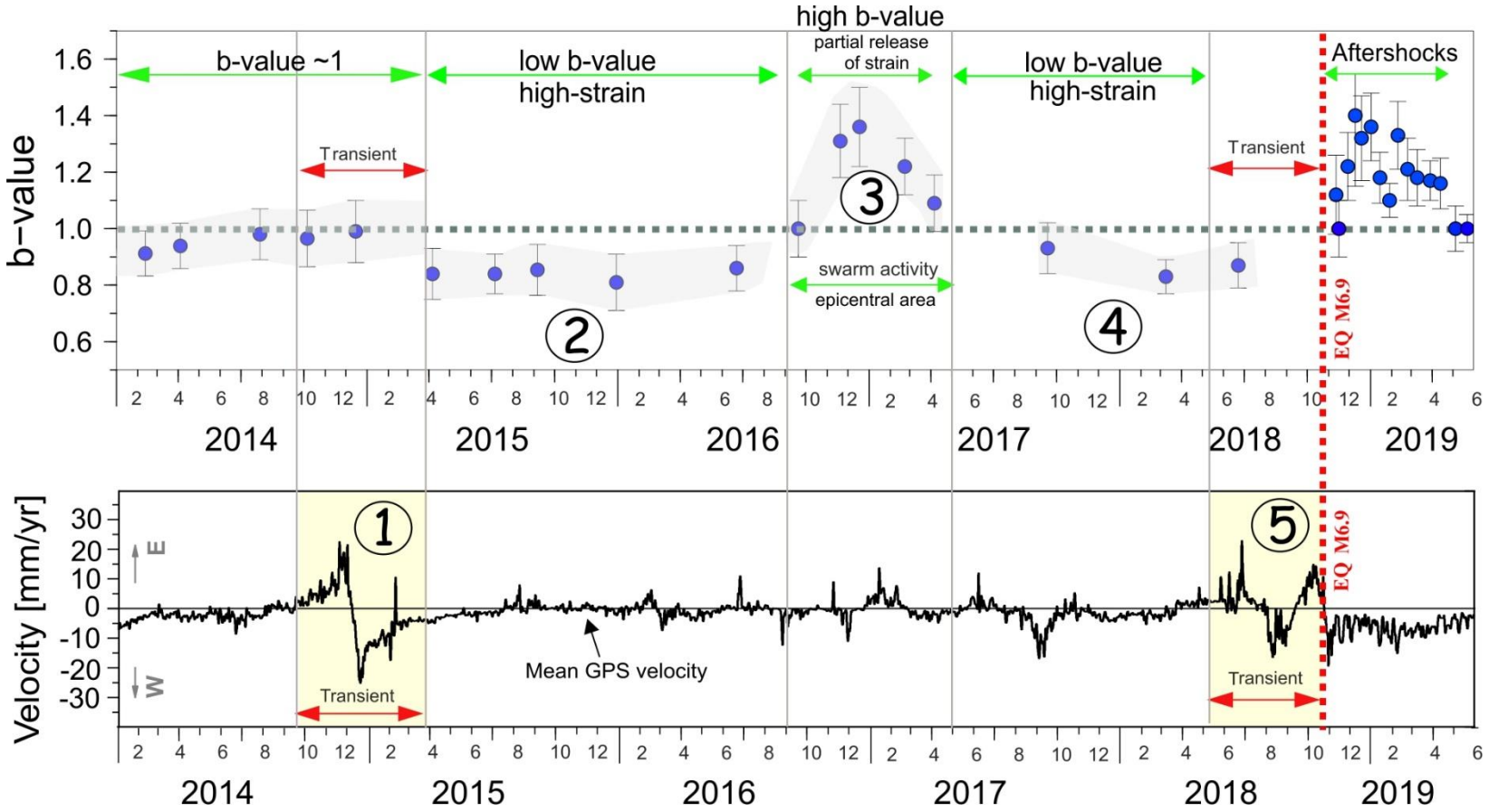


# Summary

**The western Hellenic forearc is mechanically weak and small friction changes on the megathrust, may completely reverse the stress-state in the upper-plate**

Seismicity

GPS




**The 1st SSE reported in the HSS**