GPS Imaging of Mantle Flow-Driven Uplift of the Apennines, Italy

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Introduction

Motivations:

- Distribution of active extension in the Apennines suggests an intimate relation with regional topography…
- Geological evidence shows that regional topography was formed during horizontal extension and crustal thinning in the Quaternary
- We use GPS imaging to investigate processes associated with formation of regional topography and its relationship with crustal deformation

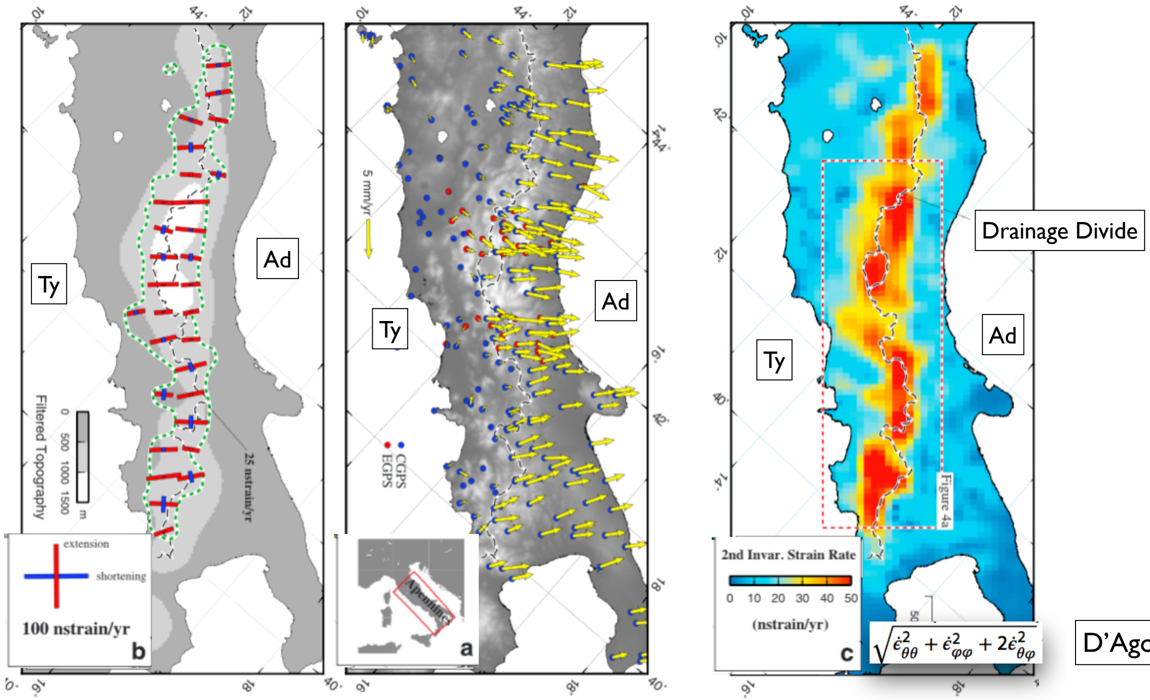
Key Points:

- A newly updated GPS velocity field reveals uplift of 1-2 mm/yr along the entire length of the Apennines.
- The uplift is aligned with the location of active extension, high topography, seismicity, high gravity, and an upper mantle seismic anomaly.
- These correlations suggest that mantle upwelling contributes to the ongoing increase of elevation and focusing of extensional strain.

Active Tectonics of the Italian Peninsula from GPS

Previous Work Shows Extension Focused Across the Apennines 3-4 mm/yr

Ty = Tyrrhenian Sea
Ad = Adriatic Sea

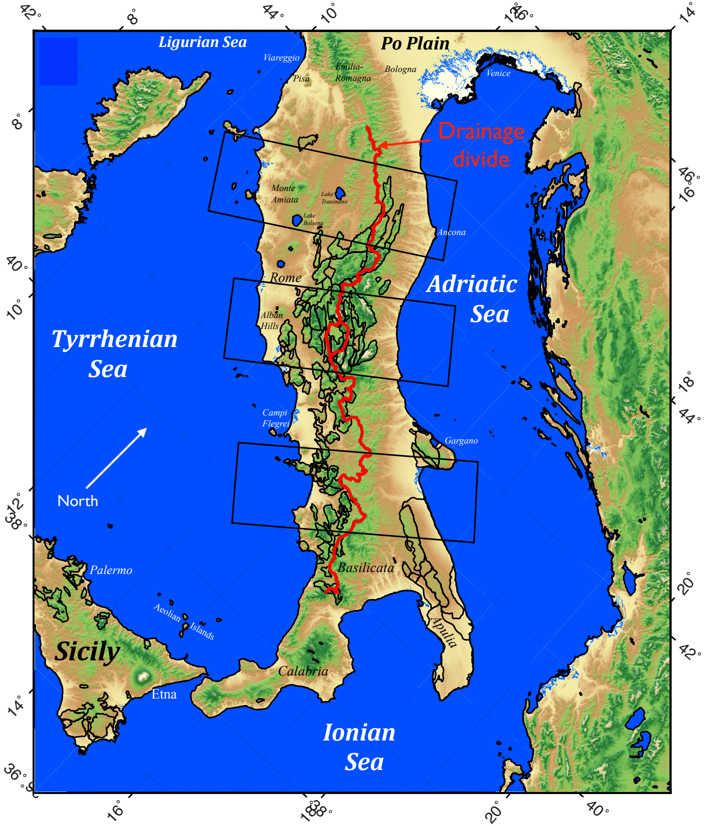


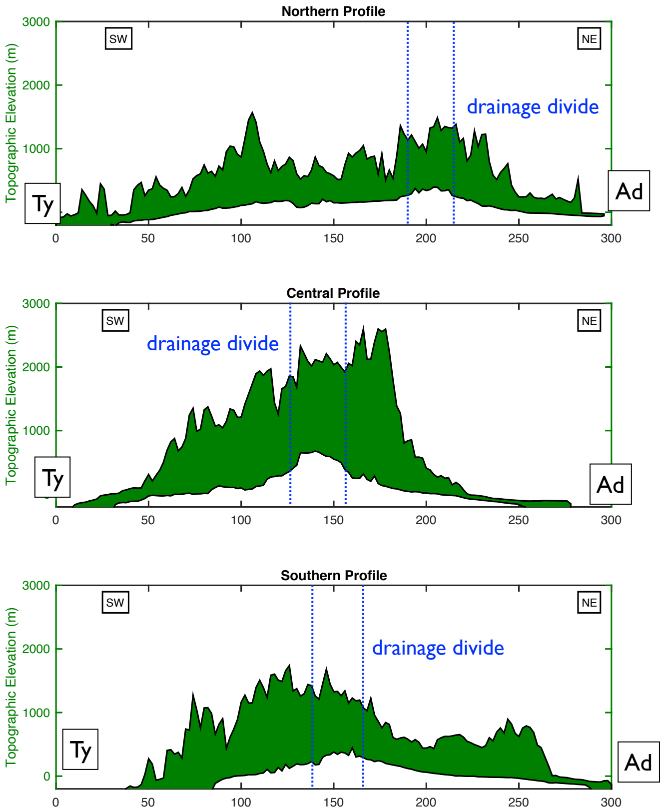
D'Agostino, 2014 GRL

GPS shows uniaxial strain rate normal to trend of Apennines

- Adriatic microplate pulling away from Tyrrhenian
- GPS velocity gradients and magnitude of strain rate focussed on Apennine <u>topographic crest</u> and <u>drainage divide</u>

Topography of the Apennines





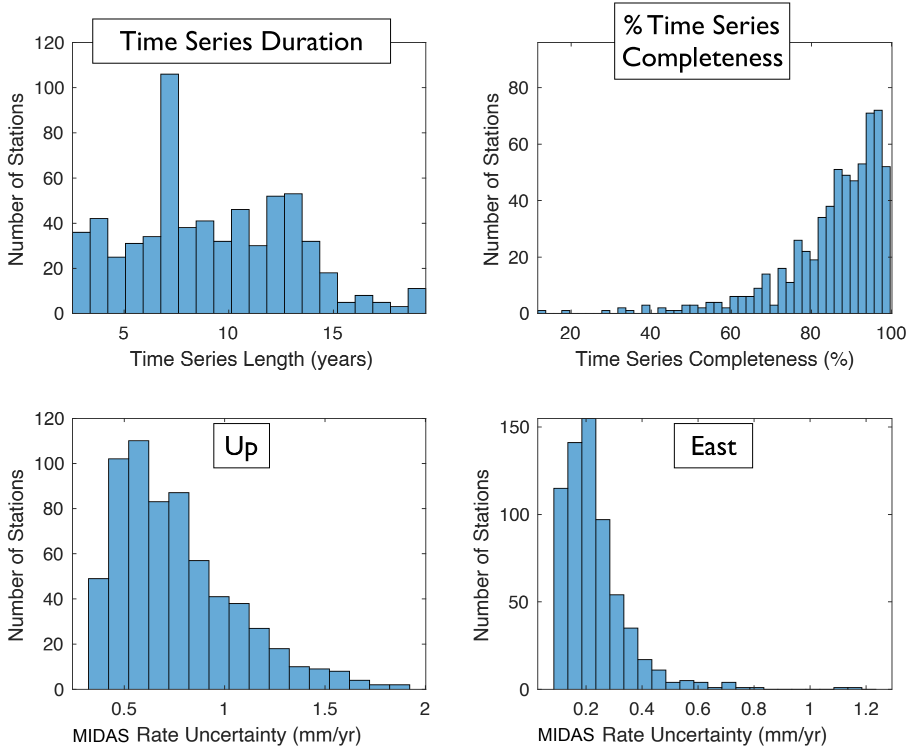
- Three profiles of Apennine topography normal to trend
- Location of drainage divide and carbonate aquifers
- Drainage divide important for long term erosional effects on topography

Goal: Study Contemporary Uplift with GPS Networks

GPS Time Series and Rate Statistics

Facts:

- 1647 time series, newly reprocessed with the JPL GIPSY software at INGV
- IGS14, based on latest version of the International Terrestrial Reference Frame
- Time series have long duration, >5 years, many cases >10 years
- High degree of completeness
- $\sigma_{Vhoriz.} < 0.4$ mm/yr
- $\sigma_{Vvert.} < 1$ mm/yr
- Good candidate for GPS Imaging of vertical and horizontal rate fields



Next figure shows network map

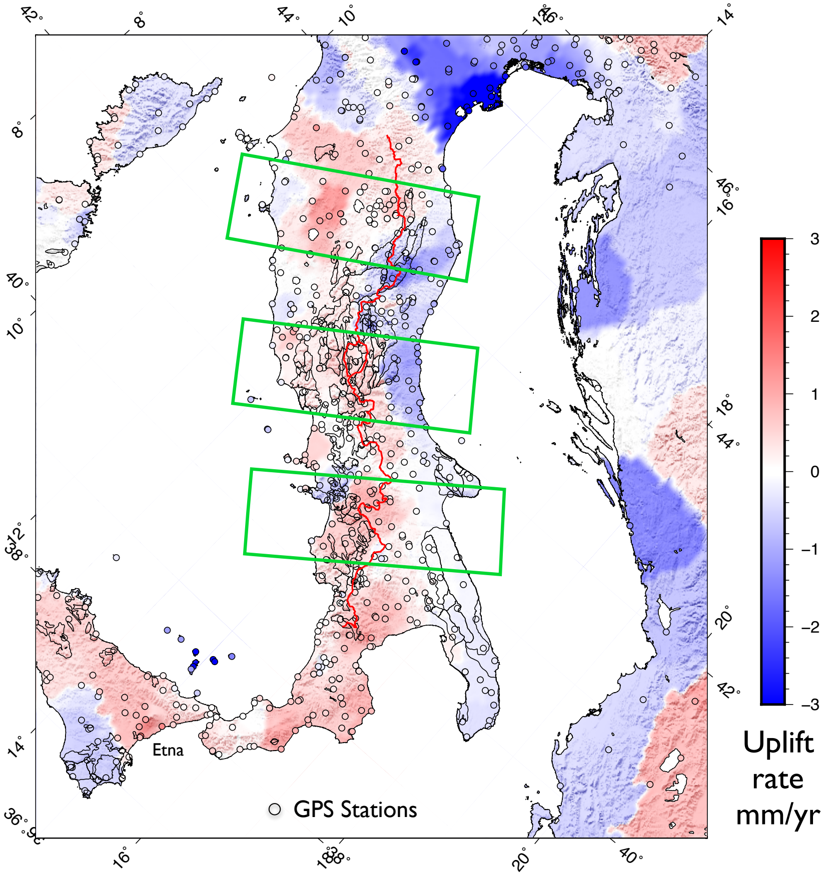
GPS Imaging of Apennine Uplift

Method:

- *GPS Imaging* uses weighted median spatial interpolation of MIDAS vertical trends for robust field estimation (Hammond et al., 2016 JGR)
- Red up/blue down
- Circles locations of GPS stations
- GPS vertical rate field shown with locations of:
  - Carbonate aquifers
  - Drainage divide
- Corrected for GIA with ICE6G model of Peltier et al., 2015, which predicts generally downward motion in the Mediterranean

Results:

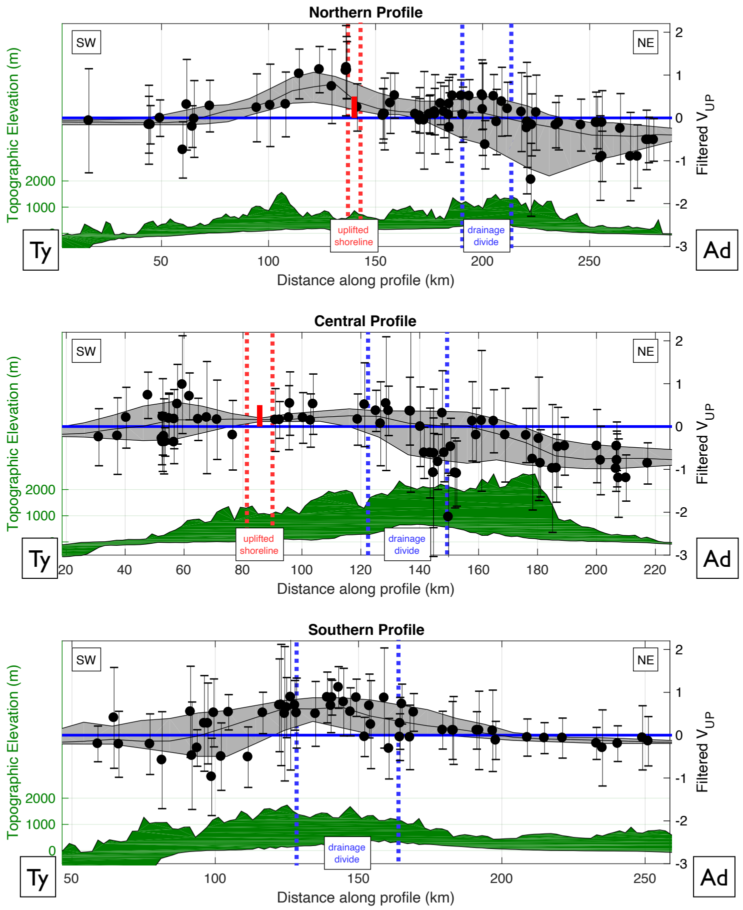
- Mostly continuous uplift from Northern Apennines to Calabria, crossing into Sicily
- Uplift of Sicily not only from volcanic transients at Etna
- Aeolian volcanic islands downward
- Very little data in Dinaric Alps east of Adriatic… resolution poor there.



Profiles of Vertical Velocity

Showing:

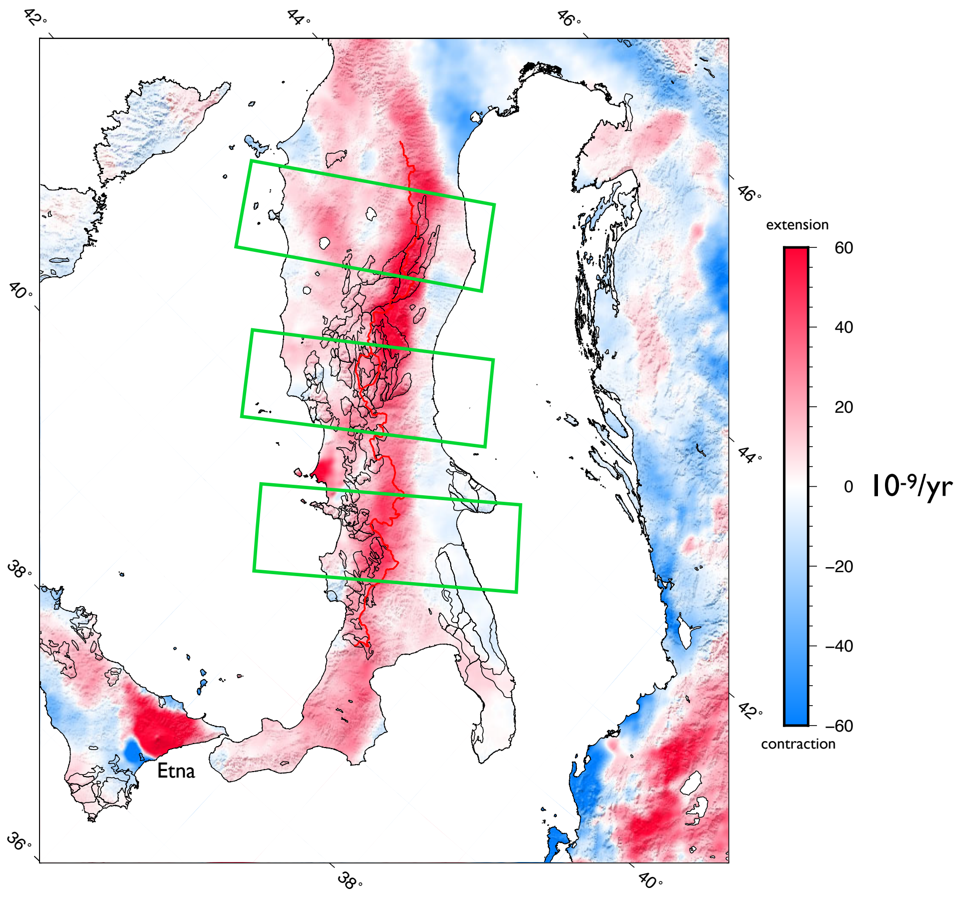
- Median filtered and smoothed envelope of vertical rate (gray zone)
- Near zero uplift to subsidence at both coasts
- Peaks in uplift near topographic high and drainage divide
- Broad arch of uplift 150-200 km wide
- Double peak in uplift… hold that thought
- Early Pleistocene shorelines (red dashed lines) uplifted ~500 meters imply similar uplift rate
- Small signals, 1-2 mm/yr. Uplift rate near level of uncertainties for individual stations
- Power of numbers and GPS Imaging resolving uplift pattern



GPS Imaging of Horizontal Strain Rates

Method:

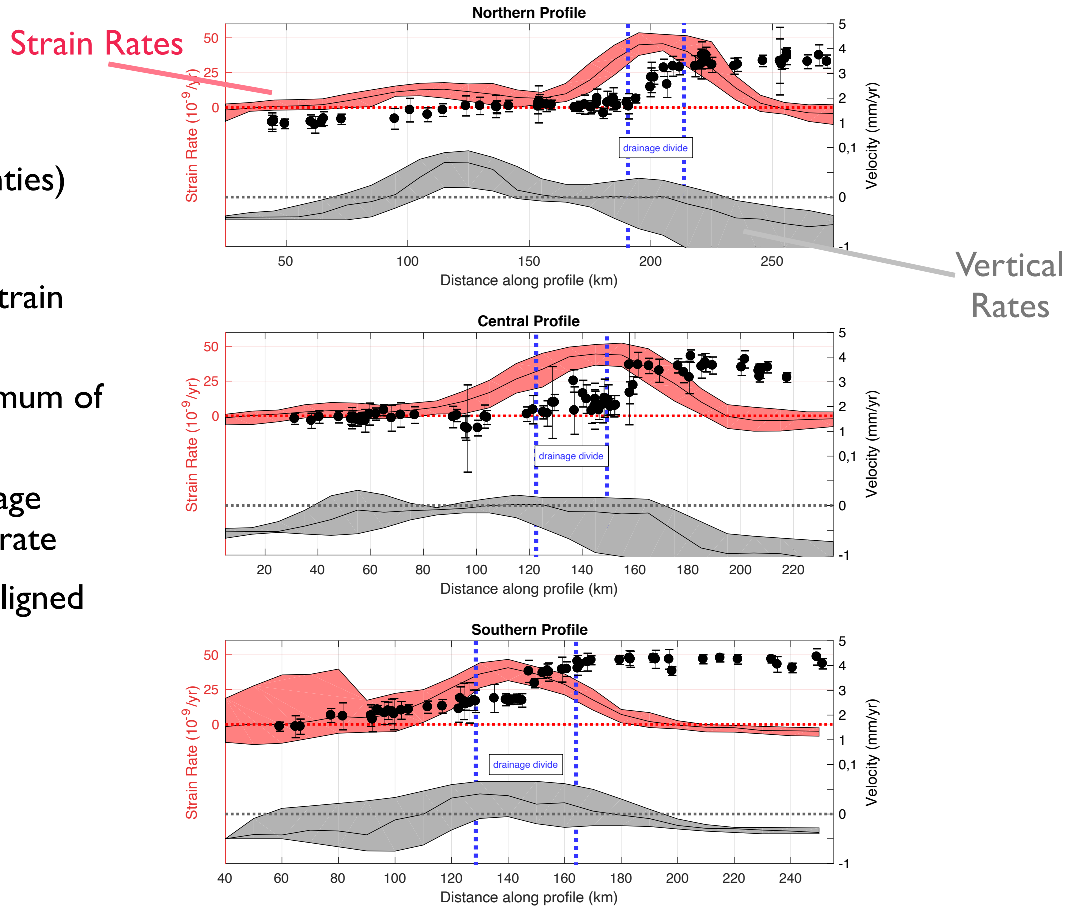
- Strain rates estimated from horizontal gridded velocity field
- Gaussian distance weighting 8 km length scale
- Colors are uniaxial component of horizontal strain rate
- Red extension, Blue contraction
- Large, well resolved signals
- Main band of extension follows Apennine crest and drainage divide very closely
- Secondary weaker though active band west of Apennines
- Roughly agrees with location of restive volcanic centers (e.g. Campi Flegrei, Alban Hills, and Lago Bolsena)
- Extension in Sicily, west of Etna



Strain Rate and Vertical Velocity Peaks are Aligned

Showing:

- GPS horizontal velocity (dots with uncertainties)
- Vertical rate envelope (gray)
- Median filtered and smoothed envelope of strain rate (salmon)
- See main peak in strain rate near local maximum of uplift near drainage divide
- Secondary zone of strain rate, west of drainage divide, aligned with western peak in vertical rate
- General pattern: Zone of active strain rate aligned with zone of uplift



Is Uplift Caused by Hydrological Unloading?

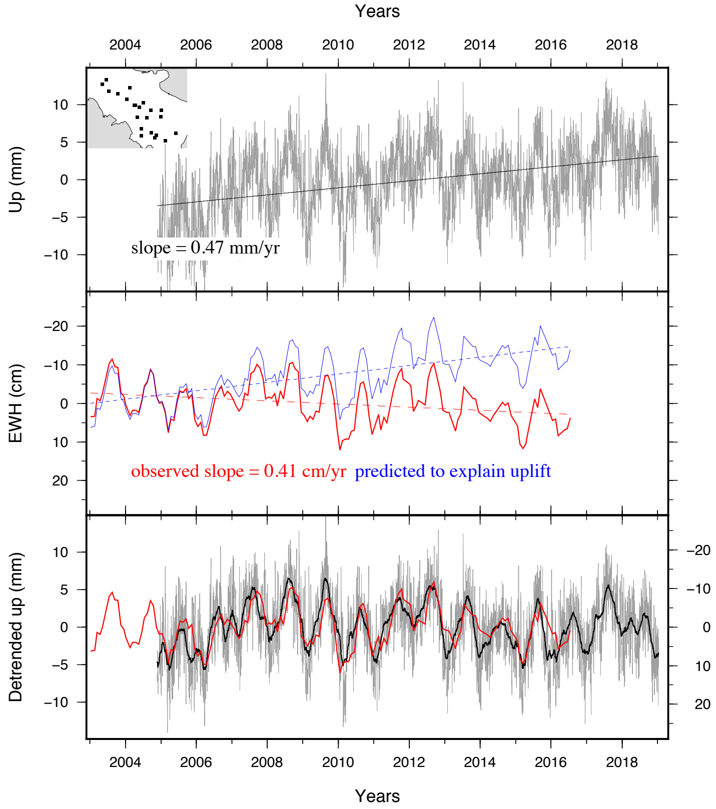
GRACE says No.

Summary of 22 GPS stations in Apennines has upward trend

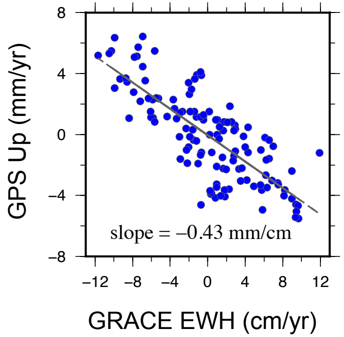
GRACE time series extracted using the MASCON viz. tool shows wetting trend

GRACE trend predicted by GPS using regression relationship shows drying trend

GRACE and GPS have similar structure, ***except for trends***



Regression between detrended GRACE EWH and vertical GPS finds close relationship



Conclusions

- Used GPS Imaging to show 1-2 mm/yr active uplift along entire length of Apennines
- Primary axis of uplift is aligned with highest Apennine elevation, drainage divide, and locus of active plate boundary extensional strain
- GRACE and GPS variability measures indicate uplift is not attributable to transient hydrological unloading, e.g. from drought or wet periods
- This and agreement with rate from uplifted early Pleistocene shorelines suggest the uplift pattern is a long lived feature
- Suggest sub-lithospheric support from mantle counteracts subsidence from crustal thinning and is increasing dynamic topography