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A "Geodetic Gap" in the Calabrian Arc: Evidence for a Locked Subduction Megathrust?

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Key Points:
- Geodetic data do not preclude that the Calabrian subduction is locked and loading
- Geodetic strain rates can be reconciled with seismicity by assuming high interseismic coupling but low seismic coupling of the subduction interface
- We refer to the destructive interference between extensional and compressional strain rates as a "geodetic gap"

Supporting Information:
- Supporting Information S1
- Table S1
- Table S2

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Abstract Subduction of old Ionian seafloor beneath the Calabrian Arc (southern Italy) is the geological process with the greatest mass flux in the central Mediterranean, yet its seismogenic behavior is largely obscured. No unambiguous evidence of subduction-related earthquakes exists in historical times, and local GPS velocities indicate very low strain rates. Nevertheless, the region hosted some of the deadliest normal-faulting earthquakes of the entire Mediterranean basin. We show that the low strain rates recorded in southern Calabria can be reconciled with the regional vigorous seismic moment release by assuming high interseismic coupling but low seismic coupling of the subduction interface. The alternative scenario of steadily creeping subduction cannot be ruled out but requires the historical seismicity record to be dismissed as unrepresentative. We refer to the peculiar spatial pattern of short-term strain rates in southern Calabria as a "geodetic gap" resulting from destructive interference between upper-plate extension and temporary compression due to locking along the subduction interface. Seismic hazard modelers must understand that within such gaps, the long-term seismic hazard is greater than that suggested by the low geodetic strain rates.

Plain Language Summary Active subduction zones are the most dangerous seismogenic areas on our planet. Some may be especially elusive, however, and assessing their earthquake potential may be fraught with substantial uncertainties. Subduction of the Ionian seafloor beneath Calabria, an earthquake-prone region of southern Italy, is one such case. Historically, Calabria has been struck by large earthquakes generated at crustal depth, that is, above the ongoing subduction, but no evidence is available for the activity of the underlying megathrusts. Is the subduction unlocked and creeping, thus posing no additional threat to the region or is it locked—at least partially—and capable of major yet very rare earthquakes? We used GPS velocities to address this issue and found that the recorded tectonic strain is well below the minimum needed to justify the known crustal seismicity. How so? Joint computer modeling of crustal and subduction-related deformation showed us that Southern Calabria may be the locus of a "geodetic gap," where subduction-related strains are temporarily canceled out by crustal strains. This may be an indication that the subduction is indeed locked and hence capable of major tsunamigenic earthquakes. Geodetic gaps are themselves extremely elusive and may occur in other subduction zones worldwide.

1. Introduction

Many subduction zones around the world exhibit a wide ribbon displaying a stick-slip rheology on their megathrusts, thus accumulating elastic strain in interseismic times and releasing it in large earthquakes. Such subduction zones are said to have high "coupling." For more precise terminology we can distinguish two kinds of coupling. "Interseismic coupling" occurs wherever/whenever the megathrust slips at less than the relative long-term plate velocity; full interseismic coupling occurs when the megathrust is locked. "Seismic coupling" is the ratio of the long-term rate of seismic moment generated on the megathrust (from an earthquake catalog) to the product of megathrust area, relative plate velocity, and shear modulus. If interseismic coupling is zero, then seismic coupling will be zero as well. However, high interseismic coupling does not always imply high seismic coupling; rather, accumulated elastic strain might be released in creep events lasting days to years, which would not appear in the earthquake record.

Geodetic measurements allow estimating the interseismic coupling of active faults, thus determining the elastic energy budget in the seismogenic crust. Geodetically derived crustal velocity fields can hence be used to calculate the energy budget because they are dominantly elastic and typically exhibit smoother map

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patterns than the long-term permanent strain rates, which include singularities along fault traces (Bird & Kreemer, 2015; Bird et al., 2015; Bock & Melgar, 2016; Elliott et al., 2016).

Although these concepts of elastic rebound and interseismic strain accumulation have been verified and accepted in different tectonic settings worldwide, the Calabrian subduction zone stands as a challenging exception. Published GPS measurements and deformation models of the forearc (Carafa & Bird, 2016; D'Agostino et al., 2011; Kreemer et al., 2014) exhibit rather low strain rates (~10–20 nanostrain/yr). The combination of slow trenchward motion with the lack of thrust faulting mechanisms in the instrumental record (Neri et al., 2009; Presti et al., 2013; Totaro et al., 2016) led some researchers to hypothesize that the Calabrian subduction is no longer active (Monaco et al., 1996; Perouse et al., 2012). Yet different clusters of earthquakes above $m = 6$ are reported for onshore Calabria (Rovida et al., 2016; Tiberti et al., 2017), that is, for the portion of the forearc lying approximately above the subduction megathrust, in open contrast with the low observed geodetic strain rates. Since clustering is a dominant character of seismic release of Calabria, is the seismicity of the past few centuries truly representative of its long-term pattern? If it is, how can it be reconciled with the low geodetic strain rates?

Using (a) updated GPS horizontal velocities (Devoti et al., 2017), (b) a detailed 3-D reconstruction of the subduction interface geometry (Maesano et al., 2017), (c) a recent release of the Italian earthquake catalog (Rovida et al., 2016), and (d) upper crustal fault geometries (Database of Individual Seismogenic Sources Working Group, 2015; Minelli et al., 2016), we investigated the short-term behavior of the Calabrian subduction zone and its potential role in explaining the observed, anomalously low strain rates.

2. Kinematic Modeling: Alternative Scenarios for the Long-Term Evolution of the Calabrian Arc

The 1783, 1905, and 1908 earthquakes are assumed to have ruptured the full length of the upper crustal layer of southern Calabria (Tiberti et al., 2017), that is, the portion of the Calabrian Arc lying between the Catanzaro Trough and the Tindari-Alfeo Line (see Figure 1a; Gallais et al., 2013; Gutscher et al., 2017). This is the only region where the underlying Ionian subducting slab is still continuous at depth (Maesano et al., 2017; Neri et al., 2012; Orecchio et al., 2014). Thus, in this work we model the behavior of the Calabrian subduction and its possible influence on upper crustal deformation in southern Calabria.

The geometry of active extensional faults in the forearc is a further unresolved issue of the Calabrian subduction zone. Some researchers have interpreted the intra-arc sedimentary basins as controlled by low-angle normal faults dipping to the east-southeast (Tiberti et al., 2017; Valensise & Pantosti, 1992), whereas others contend that the primary seismogenic sources are northwest dipping, high-angle normal faults (Galli & Peronace, 2015; Monaco & Tortorici, 2000). To prevent our analyses from being affected by these competing views, we model separately both fault scenarios, referring to them as the SE dipping and NW dipping data set, respectively (see Text S1 in the supporting information and Figure 1b).

We tested four scenarios. In Experiment #1 we inverted GPS measurements from Devoti et al. (2017) under the assumption that the megathrust is unlocked and creeping steadily, which implies that interseismic coupling is zero, to determine (a) the long-term heave rates of all upper-plate faults comprising the NW dipping data set and (b) the heave rate of the subduction interface. In Experiment #2 we replaced the fault model, using the SE dipping data set. In Experiments #3 and #4 we used the fault data sets as in #1 and #2 but kept the megathrust temporarily locked between 15 km and 35 km during the time interval spanned by GPS measurements; the interseismic coupling of the subduction interface is hence set to one. The top and bottom depths bound the portion of the megathrust that undergoes unstable frictional sliding and was labeled as "seismic" by Lay et al. (2012). For all experiments we adopted the three-dimensional geometry of the Calabrian subduction interface by Maesano et al. (2017) and based the modeling on a joint interpretation of a large number of seismic reflection profiles, on seismicity data, and on a 3-D tomographic model (Figure 1b and Text S2).

We modeled fault and continuum deformation using NeoKinema (Bird & Carafa, 2016; Bird & Liu, 2007) (see Text S3), a "kinematic" (or "inverse") finite element code. NeoKinema estimates long-term average (and also interseismic) horizontal velocities at the Earth's surface by weighted least squares fitting of data including GPS velocities, stress directions, fault traces, fault dips, and fault slip rates (with their uncertainties), within

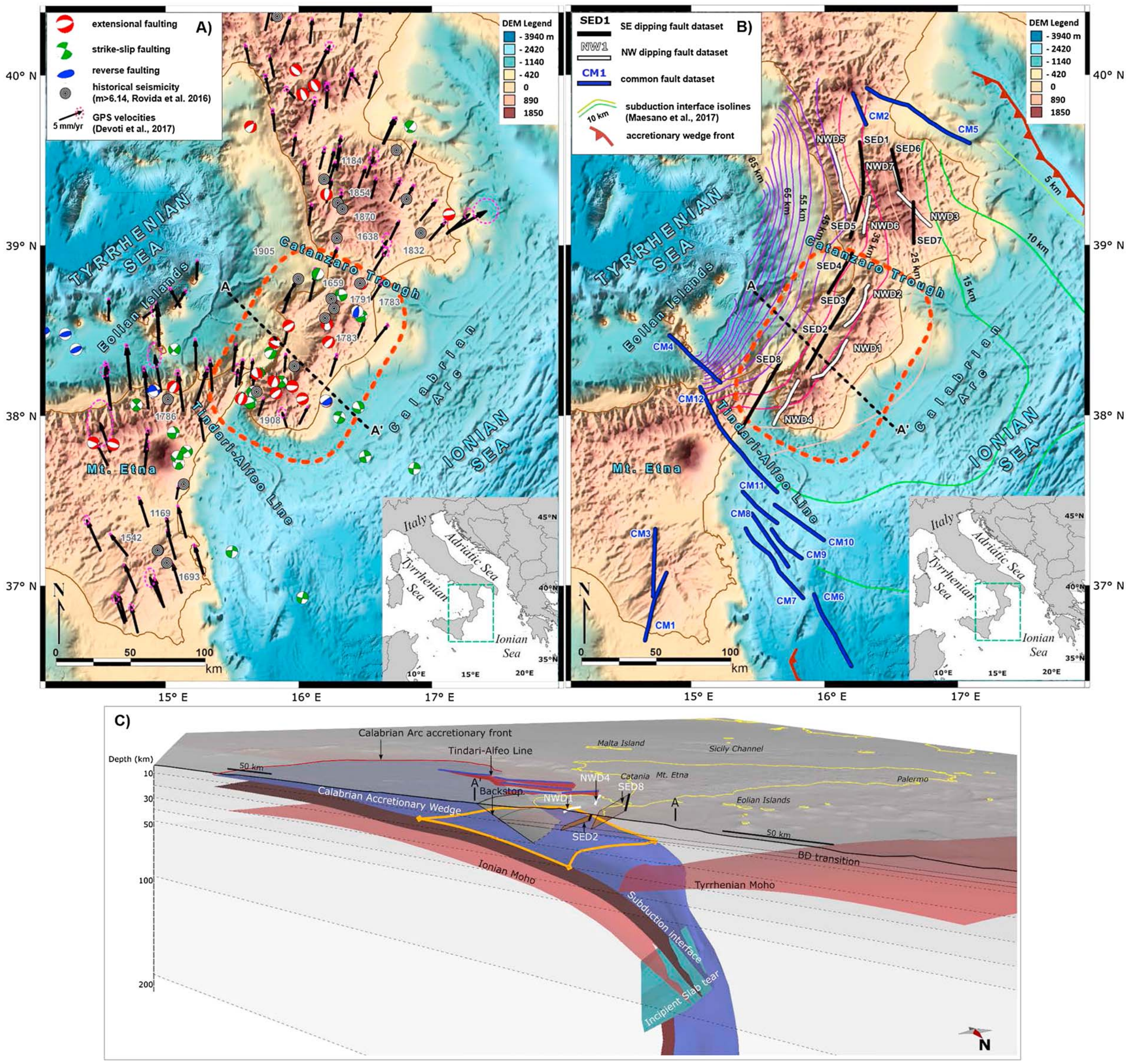

Figure 1. Geodynamic overview of the broader study area. (a) Seismicity and GPS data. Focal mechanisms for earthquakes of magnitude >2.6 (from Totaro et al., 2016) are shown in the dashed red polygon (southern Calabria). Outside this area we plot earthquakes with $m \geq 4.5$. The digital elevation model (DEM) is from Ryan et al. (2009). (b) NW (from Aloisi et al., 2012; Galli & Bosi, 2002, 2003; Galli & Peronace, 2015; Galli & Scionti, 2006; Minelli et al., 2016), SE (from DISS Working Group, 2015; Tiberti et al., 2017) dipping active fault data sets and subduction interface geometry. (c) Three-dimensional view of the broader study area is toward SSE. The area outlined with in orange highlights the portion of the subduction interface assumed to be locked. White lines mark the surface expression of NW dipping crustal extensional faults; the black lines represent the SE dipping fault planes, whereas the blue lines represent the faults present in both fault data sets. The brittle-ductile transition for the upper plate is from Carafa et al. (2015). Moho surfaces are modified from Grad et al. (2009).

the frame provided by plate tectonic velocity boundary conditions. NeoKinema makes a structural distinction between interseismic velocities (observed by GPS) and long-term average velocities. After each inversion for the map of long-term average velocities all quantities are known, so it is straightforward to convert interseismic GPS velocities at benchmarks into long-term velocities by adding the mean rates of coseismic displacements (based on the current model estimate of fault slip rates). This is done in NeoKinema by summing up standard analytical solutions for displacements in an elastic half space due to seismic slip on rectangular and triangular dislocation patches representing the seismogenic portions of the modeled faults. These corrections are iterated in each NeoKinema solution until it is fully converged to a self-consistent model. However, the model may not be consistent with seismicity data, since such data are not used as input data of the solution process. In Experiments #1 and #2, where the Calabrian megathrust is assumed to creep steadily, there is no additional contribution of coseismic displacement due to the

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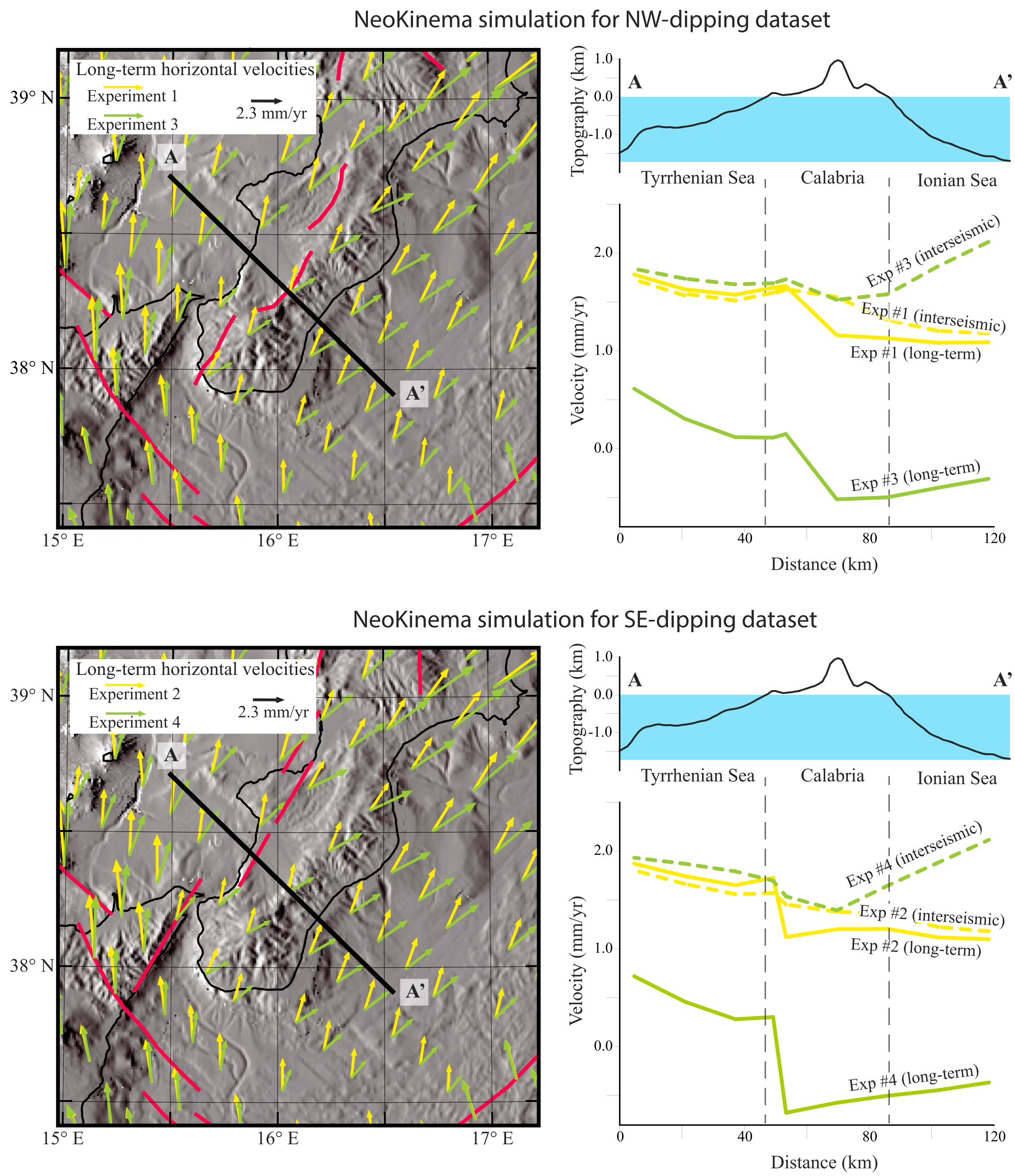

Figure 2. (left) Long-term horizontal velocities along A-A′ (Eurasia reference frame) for the NW dipping (a) and SE dipping (b) data sets (see text). (right) Differences between long-term (solid lines) and interseismic velocities (dashed lines); velocity is positive to the northwest.

subduction interface. Conversely, in Experiments #3 and #4, where the megathrust is assumed to be temporarily locked, its mean rate of coseismic displacement contributes to seaward velocities in the hanging-wall and landward velocities in the footwall. Thus, the experiments assuming a locked megathrust include larger corrections (from interseismic to long term) to the geodetic benchmark velocities that must be fit by the long-term velocity field we compute by inverse fitting.

For each experiment we made each scalar GPS misfit nondimensional by dividing it by the standard deviation of the observed velocity, then selected as a reference model the one with a root-mean-square of ~1.5 (Figure 2), which allows optimizing the information on strain rates stored in GPS measurements without over-fitting the data. The unfit portions of GPS measurements for each reference model are shown in Figure S1, whereas parametric analyses of the input data are shown in Figure S2.

Despite the significant diversity in the location and geometry of upper-crustal extensional faults in the NW dipping and SE dipping data sets, the largest differences in the long-term strain rates and heave rates among all four experiments clearly stem from the assumptions on the behavior of the subduction interface. Notably, the interseismic velocities of the reference models of all four experiments fit equally well the GPS measurements, regardless of the significant differences in deformation rates. If the megathrust is assumed to slip aseismically at a steady rate (Experiments #1 and #2), the subduction interface is expected to slip at 1.5–1.6 mm/yr, regardless of the adopted fault data set. Conversely, if the megathrust is temporarily locked, the total long-term heave rate of the subduction interface rises to 2.7–3.0 mm/yr (Figure S2 and Table S1). Moving from Experiment #1 to #3 and from #2 to #4, that is, correcting GPS velocities for a temporarily locked subduction, we observe a rise in the predicted off-fault deformation rate (see long-term horizontal velocity profiles in Figure 2) and in the heave rates of extensional faults (Table S1).

3. Seismicity Forecasts Versus the Earthquake Record: Possible Evidence for a Locked Subduction Beneath Southern Calabria

We find that the substantial increase of long-term deformation in the scenario of a locked and loading Calabrian subduction megathrust is largely independent of the location and dip direction of the active extensional faults overlying it (Figure 2). From this perspective, we may gain information on the role of subduction on the seismicity of the area through a retrospective comparison of earthquake forecasts with the total number of events in the earthquake record and their associated moment rate. It is important to compare forecast seismicity rates from each NeoKinema model to the actual record in order to select the best model, because NeoKinema does not use seismicity rates (either historical or instrumental) as input in its solution process.

Within a region of uniform tectonic style, the seismic moment rate of each NeoKinema model can be calculated as

$$\dot{M}_{\text{seis}} = G{\cdot}cz{\cdot}\left\{\sum_{e=1}^{E} A(e){\cdot}\left[\frac{\dot{\varepsilon}_{\text{med}}(e)+\dot{\varepsilon}_{\text{least}}(e)}{\cos(\theta_{\text{avg}})\sin(\theta_{\text{avg}})}\right] + \sum_{f=1}^{F} \text{l}(f){\cdot}\sqrt{v_{\text{p}}^{2}(f)+\{v_{\text{o}}(f){\cdot}\sec[\theta(f)]\}^{2}}\,\csc[\theta(f)]\right\} \quad (1)$$

by summing the seismic moment rate of each finite element *e* and fault *f*, where *G* is the elastic shear modulus, *c* the long-term seismic coupling, *z* the depth of the seismicity cutoff, $\dot{\varepsilon}_{\text{med}}$ and $\dot{\varepsilon}_{\text{least}}$ are the intermediate and smallest (in module) principal values of the long-term strain rate tensor of each finite element, *A*(*e*) is the area of the element *e*, θ_{avg} is the average angle between all missing fault planes and (either of) the noncoplanar principal axes of the strain rate tensor (Carafa et al., 2017), θ_{f} is the same angle for any modeled fault, l its length, and v_{p} and v_{o} are the parallel and orthogonal components of the fault slip rate, respectively. To determine the seismic moment rate due to extension in southern Calabria, we may assume that the majority of missing faults (if any) are dip slip; in this special case θ_{avg} represents the average dip, which we set at 50°.

For portions of the crust exhibiting homogeneous rheology and kinematics such as southern Calabria, Bird and Kagan (2004) suggested to determine the average coupled thickness ⟨*cz*⟩, which represents a realistic product of the long-term seismic coupling *c* and the depth of the seismicity cutoff *z*, even though each of them is inherently uncertain. For the Central Mediterranean *z*, defined as the maximum depth of normal faulting micoroearthquake hypocenters, is between 10 and 15 km. (De Matteis et al., 2012; Totaro et al., 2015). As for off-fault deformation, it is clear that part of the missing strain rate is seismic and is possibly associated with a few faults that are unknown to the used databases. In its turn, the relatively high heat flow along the Tyrrhenian side of Calabria (Carafa et al., 2015; Della Vedova et al., 2001) suggests a maximum thickness of 8–12 km for the upper-crust brittle/elastic layer. The long-term seismic coupling *c* depends on the variable occurrence of earthquakes or afterslip and aseismic slip or slow slip events (Avouac, 2015). It follows that assuming *c* = 0 is wrong by definition, and even more so in regions like Calabria where significant aseismic creep has been recently documented on normal faults (Cheloni et al., 2017). Assuming a realistic upper limit for the long-term seismic coupling of Calabrian extensional faults (*c* = 0.6–0.8) results in a plausible range of 7 km $< \langle cz \rangle <$ 10 km. Thus, in our preliminary calculations we assumed $\langle cz \rangle_{\text{extension}}$ = 8.5 km.

Finally, for each experiment we calculated the seismic moment rate due to extension. To this end, we used the reference models shown in Figure 2. As the subduction interface is completely unlocked in

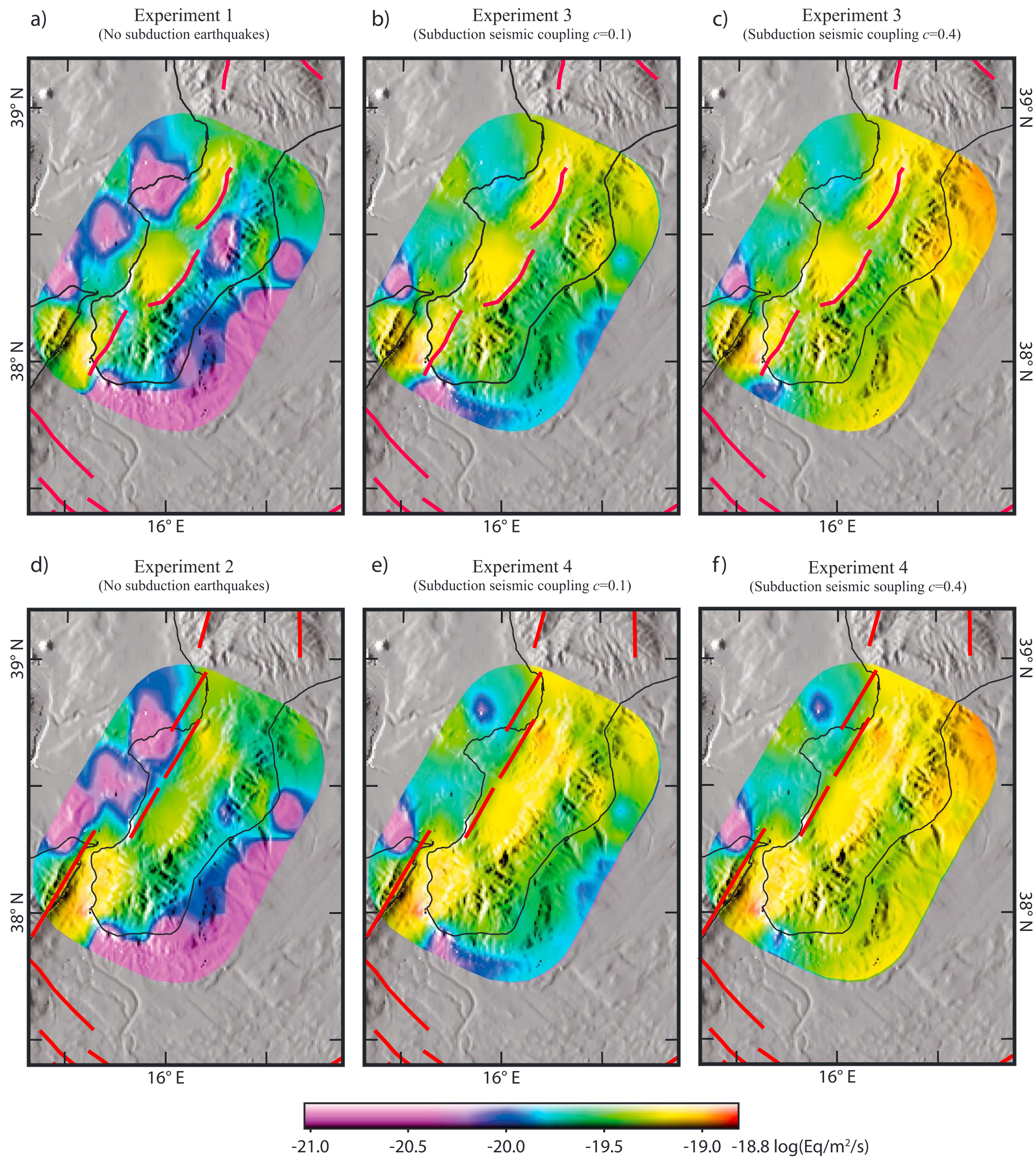

Figure 3. Earthquake rates calculated for the study area. In Experiments #1 and #2 (a and d) the subduction slips aseismically. Experiments #3 and #4 exhibit long-term seismic coupling c = 0.1 (b and e) and c = 0.4 (c and f), respectively.

Experiments #1 and #2, the resulting yearly seismic moment rate ($\dot{M}_{seis}^{Experiment}$) coincides with the seismic moment rate due to extension. If the temporarily locked megathrust is also seismogenic, as in Experiments #3 and #4, the regional seismic moment rate increases. Bird et al. (2009) analyzed the seismicity of different subduction zones and found that "slow" subductions exhibit c = 0.41, whereas Vernant et al. (2014) suggested c = 0.1 for the Hellenic subduction interface. This latter subduction zone underwent a geologic evolution similar to the Calabrian subduction zone (Faccenna et al., 2014); hence, it is expected to show a similar long-term seismic coupling, though slipping 1 order of magnitude faster. Thus, to compute the seismicity of the locked megathrust, we tested $\langle cz \rangle_{subduction}$ = 8 km and $\langle cz \rangle_{subduction}$ = 2 km and took the M_c value from Carafa et al. (2017) (Figure 3).

In Table S2 we report the resulting yearly seismic moment rate ($\dot{M}_{seis}^{Experiment}$) of the study area, which is similar for Experiments #1 and #2, where subduction is aseismic and steadily creeping ($\dot{M}_{seis}^{\#1} = 1.45 \cdot 10^{17}$ N m/yr for #1 and $\dot{M}_{seis}^{\#2} = 1.57 \cdot 10^{17}$ N m/yr for #2). Conversely, for Experiments #3 and #4, assuming $\langle cz \rangle_{subduction}$ =2 km

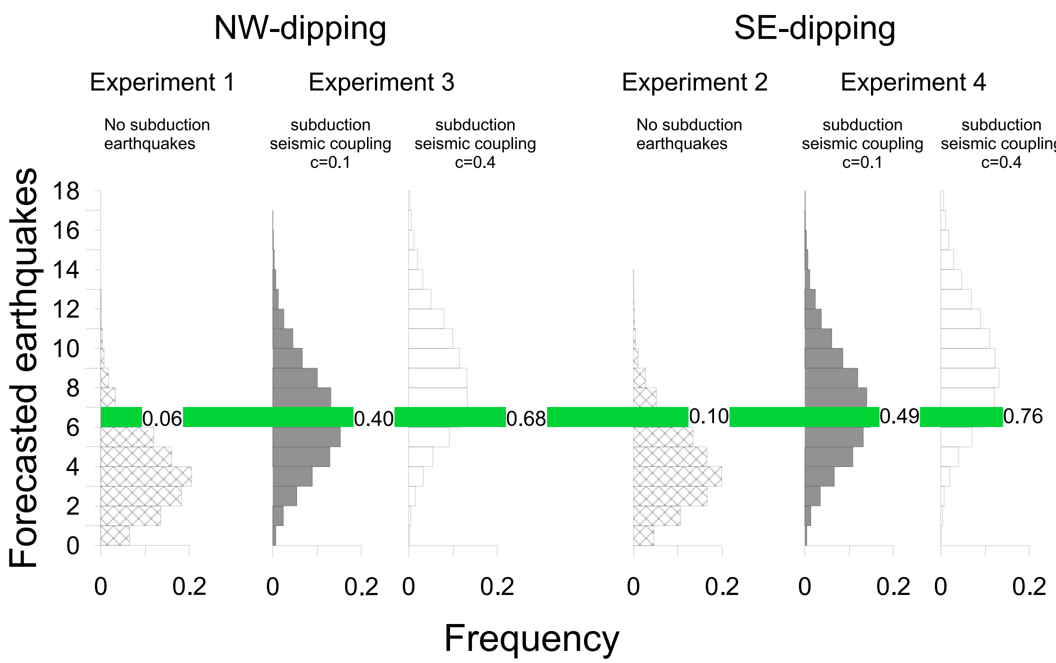

Figure 4. Histograms of pseudo N tests. Green bar refers to the seven earthquakes reported in Rovida et al. (2016) for southern Calabria (Figure 1). Along the green bar for each histogram we report the fraction of simulations forecasting more than seven earthquakes (see Text S5).

yielded $\dot{M}^{\#3}_{seis} = 2.40 \cdot 10^{17}$ N m/yr and $\dot{M}^{\#4}_{seis} = 2.63 \; 10^{17}$ N m/yr; $\langle cz \rangle_{subduction}$ =8 km yielded $\dot{M}^{\#3}_{seis} = 3.12 \cdot 10^{17}$ N m/yr and $\dot{M}^{\#4}_{seis} = 3.37 \cdot 10^{17}$ N m/yr.

For a threshold magnitude m = 6.14, the Italian earthquake catalog is assumed complete starting in 1530 CE (Stucchi et al., 2011), yielding a yearly seismic moment rate $\dot{M}^{catalog}_{seis} = 2.43{\cdot}10^{17}$ N m/yr for the past 480 years (Kagan, 2014 and Text S4). The difference between $\dot{M}^{catalog}_{seis}$ and $\dot{M}^{\#1}_{seis}$ or $\dot{M}^{\#2}_{seis}$ is rather striking and is unlikely to be due only to uncertainties in the seismicity parameters of equation (S3) because alternative estimates (discussed in Stucchi et al., 2011) make this discrepancy even more pronounced.

Another convenient way to establish whether these different models are equally valid is to compare qualitatively their forecasts with the number of observed earthquakes (Table S2). For the NW dipping data set, the number of earthquakes above m = 6.14 that occurred in 480 years varies from 4.2 (Experiment #1) to 6.9 (Experiment #3, $\langle cz \rangle_{subduction}$ = 2 km) to 9.0 (Experiment #3, $\langle cz \rangle_{subduction}$ = 8 km), and from 4.5 (Experiment #2) to 7.6 (Experiment #4, $\langle cz \rangle_{subduction}$ = 2 km) to 9.7 (Experiment #4, $\langle cz \rangle_{subduction}$ = 8 km) for the SE dipping data set.

The clustering of large Calabrian earthquake sequences makes it difficult to run statistical tests for determining the consistency of these different earthquake forecasts with the observations, as most such tests require that all events be independent (Schorlemmer et al., 2007). Nevertheless, we used these tests for ranking, at least tentatively, the reliability of the competing experiments. To this end, we derived the distribution of expected pseudo-likelihood scores by simulation (see Text S5 for further details); then we determined the quantiles of these distributions corresponding to the number of observed earthquakes (Figure 4). The number of earthquakes forecast for Experiments #1 and #2 is almost identical and equally too low, whereas a better performance is obtained from Experiments #3 and #4. Recall that the differences in earthquake forecasts obtained using the alternative fault geometries are much smaller than those resulting from the assumptions made on the behavior of the subduction interface.

4. Discussion and Conclusions

We have shown that assuming high interseismic coupling but low seismic coupling on the subduction interface may reconcile the low strain rates recorded in southern Calabria with the vigorous seismic moment release of the region. This implies that most of the elastic strain accumulated around the megathrust is released episodically in creep events. For the sake of simplicity, in this exploratory study we chose not to consider intermediate values of interseismic coupling of the megathrust, that is, cases where the megathrust creeps at a rate smaller than its long-term average rate. Also, in each model we did not consider multiple locked and creeping patches, but only a single locked strip. To a first order, the modeled interseismic velocities for benchmarks far away (on land) and faults on land are not very sensitive to these details but depend primarily on the seismic potency rate deficit (i.e., the area integral of the slip rate deficit compared to the long-term relative plate motion) of the megathrust as a whole.

On the one hand, our speculations suggest that inferring a limited seismic hazard from the low geodetic strain rates observed in forearc regions like Calabria may be incorrect, as the inferred deformation may result from the interference of two competing and possibly both seismogenic processes. On the other hand, we cannot reject the hypothesis that the seismicity of Calabria is markedly episodic without any influence by the subduction. This pattern could result from the coincidental occurrence of the biggest earthquakes that the largest extensional faults of Calabria may generate—each of which is generally characterized by a millenary recurrence interval—within a rather short time interval. The episodic seismicity scenario related exclusively to extensional faults could eventually fit GPS measurements assuming an aseismically slipping—or no longer active—subduction zone.

If this were the case, the past 480 years would be simply too short of an interval for determining reliable long-term seismicity rates. As the earthquake rates used in conventional probabilistic seismic hazard analysis (PSHA) are determined for the complete portion of the earthquake catalog and assumed to be stationary over longer time intervals, this inadequacy would cause the shaking levels predicted by the current seismic hazard map of Italy for southern Calabria to be unnecessarily high. This suggests that current approaches may be largely inadequate when dealing with the seismicity associated with largely aseismic subduction zones.

The episodic seismicity scenario of southern Calabria, however, contradicts also independent observations of more than 20 earthquake-related turbidites that were sampled in the Ionian seafloor and dated between 12 kyr and the present (Polonia et al., 2013, 2015). Further and hopefully conclusive indications on the interseismic coupling of the Calabrian subduction interface could be supplied by a GPS/acoustic network capable of measuring deformation of the Ionian seafloor above the accretionary prism and near the trench.

At this stage we wish to stress that there is no unambiguous geodetic indication that the Calabrian subduction is seismically inactive in the long term. Rather, given the increase of seismic moment rates after correcting GPS measurements for a temporary-locked subduction, we favor the hypothesis of a locked (high interseismic coupling) and partially seismogenic (relatively low seismic coupling) subduction. In this scenario, the pronounced clustering of large earthquakes would provide a further clue of an active role of subduction in triggering seismicity; finite—but not necessarily seismogenic—slip along the subduction interface might cause sufficient stress changes in the overlying upper-crustal extensional faults to generate a string of large earthquakes in a relatively short time interval. We therefore urge the seismic hazard community to be cautious when using the suspiciously low strain rates obtained from GPS in Calabria for their earthquake forecast models.

We emphasize that many studies carried out in other regions worldwide have singled out fault segments that exhibit a historically derived slip deficit with respect to the corresponding long-term slip rate estimates. These zones are commonly referred to as "seismic gaps" (McCann et al., 1979), are generally surrounded by regions struck by large earthquakes in historical or recent times, and are assumed to be more likely to host large earthquakes in the near future than adjacent zones. For Calabria we report a related circumstance, which we refer to as a "geodetic gap": a temporary minimum in GPS strain rates resulting from destructive interference between long-term upper-plate extension and temporary interseismic compression due to a nearby locked subduction interface. This transient is bound to disappear immediately when a portion of the subduction interface slips, either seismically or in a discrete creep event. The resulting reduction in horizontal compressional stress may trigger extensional seismicity within the geodetic gap region.

Over the past few years a similar behavior has been documented on different occasions: slip along the subduction interface triggered extensional earthquakes in the adjacent forearcs following both the 2010,

M_w 8.8 Maule, Chile (Aron et al., 2013; Ryder et al., 2012) and the 2011, M_w 9.0, Tohoku-Oki, Japan (Tsuji et al., 2013; Umeda, 2015) earthquakes. Similarly, slow slip events along the Calabrian subduction interface could trigger extensional earthquakes in its forearc. Another plausible way to fill the Calabria geodetic gap is through the propagation of seismic slip from the subduction interface to a contiguous and connected normal fault (Hicks & Rietbrock, 2015). Clearly, it is impossible to discriminate in the historical record which scenario of slip on the subduction interface applies to our case, but all could possibly explain the earthquake-related turbidites found on the Ionian seafloor. One should also note that given the limited width of the Calabria mainland, any historical or even archeology-inferred felt reports (Guidoboni et al., 2000) could have been assigned to a large upper crustal extensional earthquake, ignoring the potential role of the subduction megathrust.

Finally, we wish to stress that in subduction zones like the Calabrian Arc, where the extensional and compressional geodetic signal may be rather similar, the resulting low geodetic strain rates cast serious doubts on whether one can determine the extent of interseismic coupling along the subduction interface. Ignoring the internal deformation of the upper plate may result in wrong interseismic coupling estimations. We maintain that a complete geodynamic model should account for the role played by all large active faults, carefully separating their long-term and interseismic patterns.

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