nature portfolio

# Peer Review File

## Parallel dynamics of slow slips and fluid-induced seismic swarms

**REVIEWER COMMENTS**

**Reviewer #1 (Remarks to the Author):**

Review of the paper NCOMMS-24-15148 submitted to Natural Hazards

Parallel dynamics of slow slips and fluid induced seismic swarms
by Philippe Danré et al

The present paper studies the scaling of migration velocity versus duration for several types of swarms and slow slip events observed in different tectonic environments. The main result in figure 1 is that slow-slip-driven sequences, scale differently from fluid induced swarms that occur when the swarm is forced" by fluid flow as has been identified in several examples in the literature. The effort to collect a large collection of data is excellent and the separation of the two families of swarms is quite convincing. The main problem that I find is that there is no estimate of error in this data collection. One can find discussions about many sources of error in the paper and in its supplement, but there is no quantification of errors something that in my opinion is really essential.

Major comments

1. The estimation of duration (T) and Velocity (V) in figure 2 have no hint of the errors committed in evaluating duration and velocity. The authors discuss several sources of errors in the text, but they do not provide estimates of these errors in figures 2 and 4. It is clear from these figures that SSD sequences are very different from FI but the errors in the estimation of velocity are not shown in the figures. The authors discuss in the text that errors in the determination of velocity may be large. I think the authors should revise the manuscript to give at least some hint of the errors involved, and how they could affect their estimates.

Minor comments

1. This is briefly mentioned in line 40: both refs. 7 and 8 have found that the scaling of

individual events in SSE sequences do not follow the scaling shown in Fig 4 for SSDs, but rather the classical M ~ T3 shown in the green band of Figure 4. If th authors cared to plot earthquakes along with SSD and FI sequences, they should discuss why did the authors of refs, 7 and 8 find a different result, as well as Supino et al (2020).

Ref: Supino, Poiata, Festa, Vilotte, Satriano, et al.. Self-similarity of low-frequency earthquakes. Scientific Reports, 2020, 10, p.367-371.

2. Figures 3 and 4 need changes so as toke them easier to read. The color and symbol choice is very difficult to read. Foreshocks are in a shade of purple that is difficult to distinguish from blue circles. In my version of Figure 4, the pink area is gray. The origin of earthquake data (Denolle et al) is not clearly described.

3. Figure 3d is very interesting since it shows that data is broadly dispersed, but clearly separate FI and SSD sequences. Its interpretation in terms of fault parameters should be interesting.

**Reviewer #2 (Remarks to the Author):**

This manuscript investigates scaling laws between migration velocity, sequence duration, and the total seismic moment of migrating slow slip events, earthquake swarms, and foreshock sequences. They compile previously reported migration velocities and durations of such events and either use previously reported seismic moments or a relatively new way to estimate seismic moment. They examine two scaling laws to compare the different types of earthquakes: migration velocity versus sequence duration and total moment versus duration. The authors find that slow slip events have higher velocities and total moments when compared with swarms induced by fluids (fluid-induced sequences). This manifests as slow slip and fluid-induced sequences having different intercept values in the scaling laws. Notably, the scaling laws for both the slow slip and fluid induced groupings have a near-identical slope. The authors interpret that this indicates that similar physical mechanisms cause these two different classes of earthquakes. More specifically, the authors argue that aseismic slip is the primary driver of both classes of earthquakes, including fluid-induced swarms. Similar scaling relationships are initially reported in Figures 4 and 6a of Danre et al., (2022, https://doi.org/10.1029/2022JB025571), though this paper is more comprehensive and provides additional interpretation.

The study aims to address an important topic in seismology: what physical processes drive earthquake sequences? Findings on the topic have implications regarding earthquake interaction and nucleation. However, the paper currently lacks details on data curation, which hampers the robustness of the findings. Additionally, the interpretations are abruptly claimed without clear reasoning. The authors make consequential claims about their findings and additional details are needed to make their claims more convincing and understandable to the wider seismology community.

General Comments:

One main concern is that the statistics are drawn from biased samples. This is not a criticism of the authors, but rather an observation that published papers tend to report extreme cases, potentially overlooking many swarms. Therefore, the proposed scaling relationships might not apply to general scenarios. For example, how are the migrating sequences selected for the analysis? Is there a minimum migration velocity, minimum number of earthquakes required, minimum duration? What is the global coverage? Are there any swarms included where the source paper concluded that a diffusive pattern fit the migration better than a linear fit? More information is needed to convince readers that your dataset represents a sufficient and representative sample size to draw statistically significant conclusions from.

The physical significance of the migration velocity-sequence duration relationship should be explained better. Why do slower sequences last longer and vice versa? Why would a similar slope in velocity-duration space indicate similar mechanisms? I think more context on V ~ T in the introduction, similar to what you already include for M ~ T, will make it easier for the reader to understand the results and your interpretations as you present them.

If diffusive swarms would theoretically have V ~ T-.5 is there a similar theoretical scaling for swarms driven purely by aseismic slip? If so, you should also comment on this.

L105-110: It is not clear why a wide range of durations and a relationship between apparent diffusivity and duration can rule out diffusive processes. This is important for your argument and warrants more explanation.

You could consider reorganizing the “A bimodal continuum of migration velocities” section to focus on results and then on interpretations:
-Similar slope but different positions/intercepts, result-oriented
-Discuss the meaning of both, including why diffusion wouldn’t work. So this paragraph could be same slope -> same mechanisms -> aseismic slip (not diffusion), different intercepts mean different parameters, and lastly how one could use this to infer driving processes.

L111: What are the aseismic transients observed in the FI group? Is this just referring to the fact that the sequences migrate, and if not more explanation is needed, perhaps when you introduce your data.

Is the boundary between the SSD and FI groups drawn arbitrarily or was that found quantitatively in Figures 2 and 4?

L161: “The parallel scaling observed between the FI and SSD sequences in both moment and duration, as well as the analogous pattern noted between migration velocity and duration (Fig. 2), is similarly evident in the relationship between moment and migration velocity (see Fig. S2).”
When I look at Figure S2 I do not see a parallel scaling. The FI events have a much shallower slope, maybe even constant.

L169: Could you add an annotation to indicate the locations of the Apennines, Pillino, Salton trough swarms, and Iquique precursor episode in Figure 4? Annotations could be similar format to the foreshock sequence annotations in Figure 2. You highlight many interesting features but the reader cannot see for themselves. If you prefer to keep such annotations out of Figure 4, a new supplementary figure could be used.

It may be interesting to readers if you also include the foreshock swarm for the 2024 Noto earthquake.

Table S1, could you add a column stating how you classify each of these? Which category of Transform + Subduction swarms, foreshocks, injection-induced swarms, natural swarms, SSEs / SSFs. Also include the year(s) of each swarm, its general location (California, Italy, etc), and add the unit for moment in the first row.

Minor Comments:

L20 Consider rewording sentence to be more direct, one idea “We highlight two different behaviors among these sequences: slow slip sequences with elevated migration velocities and moment, and fluid-induced processes featuring lower velocities and moment.”

You refer to a couple swarms by name throughout the moment section, could you add a year to them so it's more specific and doesn’t require looking at the references? E.g., “The 2005 Salton Trough swarm”

Figures 2 and 4 look blurrier than Figures 1 and 3, and the legend in Figure 4 is particularly blurry. The two supplementary figures are also blurry.

Figure 3A-B: mention that the errorbars/uncertainty is also shown in the figure. Consider mentioning how the uncertainty bounds are obtained.

Figure 3C: Could you color code the bars instead to show the distinction in the data more specifically? The way it is now, it is unclear if there is any overlap in this parameter or if there is a sharp cutoff separating the two groups.

Figure 4: Consider reducing the x and y bounds of the plot to focus on the data more. The

foreshock sequences are not plotted in Figure 4 but the legend entry remains.

**Reviewer #3 (Remarks to the Author):**

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

**Reviewer #4 (Remarks to the Author):**

This paper compiles several studies at a global scale on migrating sequences of seismicity in various context: injection-induced swarms, slow slip events, natural swarms and foreshock sequences. The authors analyse various scaling relations : migration velocities versus duration; Moment versus Duration. They reveal two different behaviors for the sequences, that they attribute to different dynamics, either fluid induced swarms (FI) or slow slip driven (SSD). They show that the scaling of migration velocity versus duration ($V \sim T^\alpha$) evolves with the same trend for FI and SSD (with $\alpha$ around 0.75 to 0.83), but with a different intercept, SSD being 2 to 3 orders of magnitude faster for a similar duration. The scaling of Moment versus duration is linear for both type of sequences, but also evolves on two parallel trends for FI and SSD sequences. The proposition of two different behaviors for those sequences (FI and SSD) was already presented in an earlier work from the same group (Danré et al. 2022 (JGR)), however, the current paper uses a more complete dataset and provides more details on the scaling analysis and its interpretation. This paper provides an important perspective for the understanding of the drivers of seismic and aseismic fault transients, and discards the diffusive process as the driving mechanism for FI sequences. The paper is generally well written and figures are clear. I recommand publication after minor revisions.

Main comments:

I think the authors should better clarify the added value of the current study with respect to the previous work by Danré et al. 2022 (JGR). In particular, a significant part of the points shown in Figure 2 were already present in Fig. 4 from Danré et al. 2022 (JGR), and that earlier paper also investigated the scaling between velocity and duration. The current work remains an important contribution since (1) new datasets have been compiled and used to estimate scaling relations in the current study and (2) the authors go further in the interpretation of the results. Nevertheless, a clarification of the differences and improvement with respect to previous work would be useful.

On the same note, the scaling coefficient α (in the relation V ~ T^α) estimated in the current study differs from Danré et al. 2022 (JGR), and this has implication for the physical interpretation since the new coefficients are not compatible with fluid diffusion. The authors did not clearly explain the origin of this discrepancy: does it come from the addition of new datasets over larger temporal scales ? On that point, see also my detailed comments associated to l.104-106.

Some studies have revealed the existence of migration velocities at different spatial/temporal scales (rapid tremor reversals, i.e. Houston. et al. 2011, and/or dual migration velocities [DeBarros et al. 2020, Dublanchet & De Barrow, GRL 2020]). These study show that the migration velocities can be defined at different time scales. This brings several questions: (1) how is the time-scale at which the observations are made selected, and how can we be sure that all datasets have been analyzed the same way ? (2) Could both migrations velocities be represented in the Figure 2 ? (global events with slow migration and smaller events within clusters with faster velocities) (3) Would the proposed mechanisms (FI and SSD) hold to explain events with dual migration velocities ?
I think this could be discussed at some point in the paper.

Minor comments:

l. 26-28: The authors should reformulate their One-sentence summary, the sentence structure is odd, and the second part of the sentence (« and what we learn… ») should be self-contained.

l. 39: a more recent reference (Beroza and Ide 2023) exist on the M0~T scaling, with the same authors. It could be cited here as well. That paper also provides a possible explanations for the observed scaling M0-T^3 on restricted datasets that could be due to detection bias.

l. 97-99: The distinction between these two groups « slow slip driven » and « fluid induced » was already introduced in Danré et al. 2022. This could be mentioned here.

Figure 3A and l.104-106: How are the error bar determined on the value of the slope here ? I have the same question for the Intercept (Fig.3B), and l. 115-116.

l. 104-106: Here the authors should compare more explicitly the values of the parameters obtained in this study with the previous work from Danré et al. 2022. I understand that « makes it less likely a diffusive process » refer to the higher exponents in this study compared to Danré et al. 2022, but this could stated more clearly. The reason for the change in scaling could also be discussed (how many orders of magnitudes have been added with respect to the previous work) ?

L. 154-155: « by assuming seismic slip as a proxy for the surrounding aseismic slip. »: You could be more specific here in describing the approach on how to estimate the total moment from swarm data. Reference 27, where the method is described, should be associated to the last part of the sentence.

L. 1999-200: shallow SSEs have also been detected at shallow depth in several subduction zones (Japan, Hikurangi …)

L. 205-206: the authors point out the uncertainties in estimating the migration velocity and total moment. It seems to me that uncertainties in the determination of the event duration is also large. This is especially true for geodetically detected SSEs, where the duration is defined from a noisy-emerging signal and is subject to large uncertainties due to noisy daily data that often require temporal smoothing. These uncertainties were evaluated in Michel et al. 2019 (Fig. 3a). In the catalog from Gao et al. 2012, even if not mentioned, uncertainties on the evaluation of the duration for SSE also exist and should probably be mentioned here as well here.

l. 224: Observations made Figures 2 and 4. => Observations made in Figures 2 and 4.

l.224-227: The authors could detail more how they deduce the alpha values from the two models proposed in Ide et al. 2007. In the sentence (l.225-226), it could be stated that the uniform slip model implied L^2 ~ T while the constant stress drop model implies L^3~T. This will help the reader to understand more clearly the relationship between the proposed models and the alpha values, without having to refer in details to Ide et al. 2007.

Below, we provide detailed responses to the reviewers' comments. Our direct answers are highlighted in blue, while red text indicates additions or modifications in the manuscript and supplementary materials. Additionally, we have included a tracked changes document where all revisions to the initial manuscript are highlighted in yellow.

**Reviewer #1 (Remarks to the Author):**

Review of the paper NCOMMS-24-15148 submitted to Natural Hazards

Parallel dynamics of slow slips and fluid induced seismic swarms
by Philippe Danré et al

The present paper studies the scaling of migration velocity versus duration for several types of swarms and slow slip events observed in different tectonic environments. The main result in figure 1 is that slow-slip-driven sequences, scale differently from fluid induced swarms that occur when the swarm is forced" by fluid flow as has been identified in several examples in the literature. The effort to collect a large collection of data is excellent and the separation of the two families of swarms is quite convincing. The main problem that I find is that there is no estimate of error in this data collection. One can find discussions about many sources of error in the paper and in its supplement, but there is no quantification of errors something that in my opinion is really essential.

We thank the reviewer for their helpful and constructive comments.

Major comments

1. The estimation of duration (T) and Velocity (V) in figure 2 have no hint of the errors committed in evaluating duration and velocity. The authors discuss several sources of errors in the text, but they do not provide estimates of these errors in figures 2 and 4. It is clear from these figures that SSD sequences are very different from FI but the errors in the estimation of velocity are not shown in the figures. The authors discuss in the text that errors in the determination of velocity may be large. I think the authors should revise the manuscript to give at least some hint of the errors involved, and how they could affect their estimates.

The reviewer raises an important yet challenging point, particularly when using works that compile results from various studies. As noted in other research (e.g., Passarelli et al., 2021; Gao et al., 2012), compiling observations from diverse sources complicates error estimation because (1) errors are not always computed, (2) data may not always be available, and (3) values are derived from different methods, leading to varying uncertainties.

Error estimates for velocities are not available in many studies. For instance, Roland and McGuire (2009) provide only direct velocity estimates without precise fitting. Gao et al., (2012), values for SSEs we use, suggest a velocity uncertainty of about 25% across the numerous SSE studies they compile. Similarly, Kuna et al. (2019), which we also reference, report velocity errors around ~10% of their values, noting that their velocity fits are based on relatively few points per sequence. Conversely, velocities determined for swarms with more data points and well-defined seismicity fronts, such as those in Danré et al. (2022), exhibit lower uncertainties. We have added these error values to the Supplementary Materials in Table S2 and provided more detail in Supplementary Materials Text S1. To maintain consistency across all datasets and ensure conservative observations, we have chosen to assume a 25% error margin for all velocity values considered in this study. As discussed in Gao et al. (2012), this approach also indirectly accounts for errors in duration. Also, errors in duration are expected to be small compared to the ones for velocity and moment as (1) it is easier to determine and (2) migration duration and injection duration are almost identical (see Danré et al., 2023) as well as seismicity duration and geodetical duration (citation). It therefore seems that determining transient slip episodes duration does not carry significant uncertainty compared to velocity or moment.

Error estimates for moment are also crucial. There are two types of errors to consider: those related to the estimated total moment for swarms, and those pertaining to moment measurements using geodesy. In the first case, Danré et al. (2023) discussed that total moment estimates are generally consistent with their theoretical expectations based on injected fluid volume, assuming a factor of 10 uncertainty. For moment obtained using geodesy, Gao et al. (2012) suggest that the uncertainty should be less than an order of magnitude. To maintain a conservative approach, we have opted to consider the error for moment to be up to an order of magnitude for both estimated or geodetic moments. However, it is likely that the error is lower for geodetical moments, especially in more recent studies, due to improvements in GPS coverage and the quality of InSAR data.

Following reviewer's comment, we added in the manuscript (Lines 101-114):

Error estimates for velocity and moment are often unavailable or challenging to compute from the works considered, as these values are derived using various methods (like for velocity : direct fitting[39], seismicity front fitting[30], direct estimate[32]). To maintain consistency across all datasets used in this study and align with previous research on scaling laws facing similar challenges, we adopt a conservative approach. We assigned a migration velocity uncertainty of 25% and a total moment error of up to 1 order of magnitude[2]. However, it is likely that the error is lower for geodetical moments, especially in more recent studies, due to improvements in GPS coverage and the quality of InSAR data. Errors in duration are neglected as they are likely to be small compared to those of velocity and moment. Indeed, migration duration is almost identical to injection duration for injection-induced sequences[40] while seismicity duration and geodetic duration are also closely correlated[35]. This correlation makes the determination of transient slip episodes duration reliable through the compiled values here. Detailed information on data sources, corresponding values, and uncertainties used in our analysis can be found in Supplementary Tables S1 and S2 and Text S1.

And in the Supplementary Materials, Text S1 we also provide more detail:

Given the diversity of sources used in this work, accounting for uncertainties in both velocity and moment (total or geodetic) is challenging, as these were either not computed in the studies considered or determined using different methods. To address this inconsistency, previous research on scaling laws has often used reasonable, conservative error estimates based on observations and theoretical results. For instance, Gao et al. (2012) suggest that the geodetic moment for SSEs should be constrained within a 1 order of magnitude of its value. Total moment estimates for natural and fluid-induced swarms, as found in Danré et al. (2022 and 2023), are consistent with limited geodetic observations and theoretical expectations, also considering a maximal error factor of 10. The error in moment was therefore considered as up to 1 order of magnitude here. Velocities determined from fitting the distance of earthquakes over time, such as in Kuna et al. (2019), carry an uncertainty of about 10%. According to Danré et al. (2022), most velocities uncertainties are below 10%, except for one sequence at 25% (see Table S2). Gao et al., 2012 estimate that SSE velocities should have an error below 25%. In contrast, velocities determined without fitting, such as those by Roland and McGuire (2009), lack available error estimated due to the low number of data points and absence of direct fitting. Consequently, we chose to adopt conservative uncertainties in our studies, assigning a 25% uncertainty to velocities and constraining moment (total or geodetic) within a 1 order of magnitude range.

Note that despite considering upper bound values for errors in velocity and moment, our results remain consistent : the distinction between FI and SSD sequences is still evident, as they are separated by 2-3 orders of magnitude, while the errors are up to 1 order of magnitude.

We added accordingly (Lines 219-220):

This offset between both group scalings exceeds the estimated moment uncertainty of 1 order of magnitude here (see Supplementary Materials Text S1),

We do not consider the error in moment – duration for earthquakes, as these values are included solely to illustrate their distinct behavior and are not the focus of this work.

We have updated Figures 2 and 4 to include error bars accordingly.

Minor comments :

1. This is briefly mentioned in line 40: both refs. 7 and 8 have found that the scaling of individual events in SSE sequences do not follow the scaling shown in Fig 4 for SSDs, but rather the classical M ~ T3 shown in the green band of Figure 4. If th authors cared to plot earthquakes along with SSD and FI sequences, they should discuss why did the authors of refs, 7 and 8 find a different result, as well as Supino et al (2020).

References 7-8 and Supino et al. (2020) examined specific sequences and identified cubic scaling between duration and moment within individual sequences. In contrast, we investigate a broader range of diverse slip sequences, revealing a more global trend. This broader trend is also illustrated in Ide and Beroza (2023) where the global trend emerges from the compilation of all individual scalings. These individual scalings might also result from observational gaps or interpretation of biased data. Consequently, our results are not incompatible with observations from References 7-8 and others; rather, they are complementary.

We have added in the manuscript (Lines 213-215):

While individual sequences of slow slip events or low frequency earthquakes may exhibit a scaling relationship of ($M_0 \propto T^3$) [7,8,56], the global trend of $M_O \propto T$ arises from the compilation of these individual scalings[5,47].

Also we have added in the discussion the importance of FI sequences in the scaling laws studies, as they are situated above the bounds of observability defined in Ide and Beroza, 2023 (Lines 277-279).

Moreover, incorporating fluid-induced sequences (FI) in our study adresses observational gaps identified in the litterature[55], thereby defining a new ensemble that runs parallel to SSEs.

2. Figures 3 and 4 need changes so as toke them easier to read. The color and symbol choice is very difficult to read. Foreshocks are in a shade of purple that is difficult to distinguish from blue circles. In my version of Figure 4, the pink area is gray. The origin of earthquake data (Denolle et al) is not clearly described.

We enhanced Figure 3 by adjusting the colors to improve the clarity of distinguishing between the FI and SSD domains. Additionally, in Figures 2 and 4, we replaced the markers for foreshock sequences with diamond shapes to enhance their visibility. Furthermore, we updated the color for the FI sequences in Figure 4 to ensure they no longer appear gray.

For the earthquake data's origin, we have added more detail in the caption of Figure 4:

Squares represent seismic moment and duration data obtained from a global earthquake dataset. The duration is determined through corner frequency analysis of nearly a thousand of earthquakes[3].

3. Figure 3d is very interesting since it shows that data is broadly dispersed, but clearly separate FI and SSD sequences. Its interpretation in terms of fault parameters should be interesting.

We have added a sentence to highlight that the scattering of points may reveal differences in fault and hydraulic properties (Lines 145-147):

It might also reveal a 2$^{nd}$ order dependency on fault and hydraulic properties, such as fault criticality concerning the stress state[41], or physical factors like frictional properties, temperature and fluid pressure[35].

**Reviewer #2 (Remarks to the Author):**

This manuscript investigates scaling laws between migration velocity, sequence duration, and the total seismic moment of migrating slow slip events, earthquake swarms, and foreshock sequences. They compile previously reported migration velocities and durations of such events and either use previously reported seismic moments or a relatively new way to estimate seismic moment. They examine two scaling laws to compare the different types of earthquakes: migration velocity versus sequence duration and total moment versus duration. The authors find that slow slip events have higher velocities and total moments when compared with swarms induced by fluids (fluid-induced sequences). This manifests as slow slip and fluid-induced sequences having different intercept values in the scaling laws. Notably, the scaling laws for both the slow slip and fluid induced groupings have a near-identical slope. The authors interpret that this indicates that similar physical mechanisms cause these two different classes of earthquakes. More specifically, the authors argue that aseismic slip is the primary driver of both classes of earthquakes, including fluid-induced swarms. Similar scaling relationships are initially reported in Figures 4 and 6a of Danre et al., (2022, https://doi.org/10.1029/2022JB025571), though this paper is more comprehensive and provides additional interpretation.

The study aims to address an important topic in seismology: what physical processes drive earthquake sequences? Findings on the topic have implications regarding earthquake interaction and nucleation. However, the paper currently lacks details on data curation, which hampers the robustness of the findings. Additionally, the interpretations are abruptly claimed without clear reasoning. The authors make consequential claims about their findings and additional details are needed to make their claims more convincing and understandable to the wider seismology community.

General Comments:

One main concern is that the statistics are drawn from biased samples. This is not a criticism of the authors, but rather an observation that published papers tend to report extreme cases, potentially overlooking many swarms. Therefore, the proposed scaling relationships might not apply to general scenarios. For example, how are the migrating sequences selected for the analysis? Is there a minimum migration velocity, minimum number of earthquakes required, minimum duration? What is the global coverage? Are there any swarms included where the source paper concluded that a diffusive pattern fit the migration better than a linear fit? More information is needed to convince readers that your dataset represents a sufficient and representative sample size to draw statistically significant conclusions from.

We thank the reviewer for the comments made on this work.  We agree with the reviewers that tapping form swarm sequences studied in literature can have a selection bias introduced by the authors. Anyway, to devise a systematic compilation of swarm like seismicity from seismic catalogs and define more objective selection criteria is difficult to attain due to the diversity of sequences and seismic catalogs. We tried to reduce the compilation bias by accounting for many sequences.

Many of the sequences under consideration have already been examined in prior compilation (Gao et al., 2012 for instance) or are part of specific sequences of interest. They encompass a variety of tectonic contexts, magnitudes, durations, moments, etc., thus reflecting the diverse behaviors observed in slip transients.

We did not impose any minimum requirements for magnitude, velocity, or number of events in our compilation, except from the inherent limitations of observability that initially enabled the study of these sequences. They span a wide geographical area, including many of the most seismically active regions globally. In response to a reviewer's comment on Table S1, we have also included rough geographical locations for the datasets considered, where relevant.

The shape of seismicity front, particularly in swarms, has long been a subject of research, often revolving around a square root diffusion-like model or a linear model. Our aim here is not to delve into this debate, but simply to getting an average migration velocity determined but rather to determine an average migration velocity based on the studies included. We did not select sequences based on their proposed migration mechanism in existing literature.

Regarding the importance to remind the reader of the representative nature of our dataset, we have added in the manuscript (Lines 92-99):

The diversity of tectonic or industrial fluid injection contexts, combined with a wide range of durations (spanning over 6 orders of magnitude, see Figure 2), velocities (also covering over 6 orders of magnitude, see Figure 2) and moments (encompassing over 7 orders of magnitude), alongside the various natures of migrating slip sequences (including SSEs, SSFs, swarms, fast transients, foreshocks), as well as the potential mechanisms proposed to explain such migrations (pressure diffusion[28], aseismic slip[32], poro-elastic effects[28]), collectively contribute to a dataset that offers a more comprehensive representation of migrating slip sequences compared to previous works[30].

The physical significance of the migration velocity-sequence duration relationship should be explained better. Why do slower sequences last longer and vice versa? Why would a similar slope in velocity-duration space indicate similar mechanisms? I think more context on V ~ T in the introduction, similar to what you already include for M ~ T, will make it easier for the reader to understand the results and your interpretations as you present them.

Scaling laws offer valuable insights into the driving mechanisms behind ruptures, particularly through the examination of exponents between correlated parameters. This approach has already yielded significant findings, such as in the correlation between moment and duration, which has been attributed to phenomena like constant slip or stress drop (Ide et al., 2007 for instance).

In order to provide further context to the study of duration/velocity scaling, we have reformulated and restructured the introduction (Lines 45-74):

Another crucial parameter of interest lies in the velocity at which transient slip episodes migrate over time. In subduction zones, slow slip events have been observed to propagate at velocities of a few kilometers per day[2], occasionally accompanied by faster transients known as secondary slip fronts [11]. Conversely, some episodes of seismicity migrate only a few meters per day[12]. This phenomenon is also characteristic of earthquake swarms, which are prolonged sequences of seismic activity lacking a distinct mainshock. Swarms manifest in diverse settings, including subduction zones [13], rift areas [14], mountain ranges [15–17], and intraplate regions [18]. They can also be induced by fluid injections during industrial activities such as Enhanced Geothermal System (EGS) development, carbon dioxide or wastewater storage [19–22]. Some earthquake swarms exhibit complex migration patterns, where alongside the overall migration of the sequence, faster and shorter seismicity transients have been observed and interpreted as indicative of aseismic slip[14,23]. Moreover, swarm-like seismicity can escalate into large earthquakes [24] and is retrospectively identified as a foreshock sequence which also exhibist migration patterns that unveil their underlying driving processes [24–26].

Swarms or foreshock sequences can persist for days to years, suggesting the need of an external driving force to sustain the seismicity rate and its migration. Studying seismicity migration conventionally involves the use of distance-time plots (Fig. 1) and has led to various mechanisms proposed to explain it, including pore pressure diffusion [27], poro-elastic deformation [28], earthquakes interactions [29] or transient aseismic loading [14,30–32]. Understanding the relation between migration velocity (V) and duration (T) can provide insights into these processes. For instance, migration following a fluid pressure diffusion law may exhibit a scaling of $V \propto T^{-0.5}$, while linear migration with constant velocity may indicate aseismic slip[30,33]. The absence of migration would be characterized by $V \propto T^{-1}$.

Recent studies focusing on swarms have revealed that their migration velocities scale across a wide range of magnitudes, notably with swarm duration for both natural and injection-induced sequences lasting from a few days to several years [30,34]. Conversely, certain swarms observed in subduction or transform faults display significantly higher migration rates, and behave more like Slow-Slip Events (SSEs) [32,35]. Therefore, fluid-induced swarms and SSEs may represent the two extreme behaviors of migrating seismic sequences [30].

If diffusive swarms would theoretically have V ~ T-.5 is there a similar theoretical scaling for swarms driven purely by aseismic slip? If so, you should also comment on this.

We have also added in the manuscript that aseismic slip may also leads to a diffusive-like behavior following results from prior work (Lines 183-185) :

Theoretical findings for specific FI sequences have obtained similar $\alpha$ values to those determined here[31], assuming that aseismic slip drives seismicity migration.

L105-110: It is not clear why a wide range of durations and a relationship between apparent diffusivity and duration can rule out diffusive processes. This is important for your argument and warrants more explanation.

For clarifications, we have reformulated (Line 170-178):

The extensive dataset, encompassing numerous sequences with a wide range of durations and velocities, along with the diversity of tectonic contexts and types of sequences examined, results in a more robust estimate of $\alpha$ compared to previous studies [30]. The inferred exponents ($\alpha \sim 0.8$) for both FI and SSD sequences notably deviate from $\alpha = 0.5$ which is characteristic of a diffusive pattern. This deviation is corroborated by the apparent diffusivity coefficient, derived from fitting a diffusion law to migration fronts[33,46], which exhibits a dependency on swarm duration [47] (see Figure S1). Such a dependence, in addition to the value of $\alpha \sim 0.8$ determined here make a diffusive relationship between time and distance, leading to a $V \propto T^{-0.5}$, less plausible.

You could consider reorganizing the "A bimodal continuum of migration velocities" section to focus on results and then on interpretations:
-Similar slope but different positions/intercepts, result-oriented
-Discuss the meaning of both, including why diffusion wouldn't work. So this paragraph could be same slope -> same mechanisms -> aseismic slip (not diffusion), different intercepts mean different parameters, and lastly how one could use this to infer driving processes.

We have reorganized following the reviewer's suggestion.

L111: What are the aseismic transients observed in the FI group? Is this just referring to the fact that the sequences migrate, and if not more explanation is needed, perhaps when you introduce your data.

Reformulated as part of the reorganization of the section.

Is the boundary between the SSD and FI groups drawn arbitrarily or was that found quantitatively in Figures 2 and 4?

In the caption, we mention that these areas were drawn arbitrarily to illustrate the two families. The division into two groups is supported by, for instance, Figure 3c, which shows a bimodal distribution of $VT^{0.8}$.

L161: "The parallel scaling observed between the FI and SSD sequences in both moment and duration, as well as the analogous pattern noted between migration velocity and duration (Fig. 2), is similarly evident in the relationship between moment and migration velocity (see Fig. S2)."
When I look at Figure S2 I do not see a parallel scaling. The FI events have a much shallower slope, maybe even constant.

Indeed, we should mitigate this argument. Reformulated to (Line 215-219):

The parallel scaling observed between the FI and SSD sequences in both moment and duration, along with the analogous pattern noted between migration velocity and duration (Fig. 2) may also manifest in the relation between moment and migration velocity. However, this association might entail more underlying uncertainty due to the methods and assumptions employed to compute both parameters (see Fig. S2), resulting in a less distinctly discernible trend.

L169: Could you add an annotation to indicate the locations of the Apennines, Pillino, Salton trough swarms, and Iquique precursor episode in Figure 4? Annotations could be similar format to the foreshock sequence annotations in Figure 2. You highlight many interesting features but the reader cannot see for themselves. If you prefer to keep such annotations out of Figure 4, a new supplementary figure could be used.

We have added arrows to indicate Iquique foreshocks, Salton trough swarm and Apennines swarm in Figure 4, as well as two additional arrows in Figure 2 to indicate the fast burst from De Barros et al., 2020 and Hatch et al., 2020.

It may be interesting to readers if you also include the foreshock swarm for the 2024 Noto earthquake.

We added a reference to this interesting swarm preceding two powerful quakes Lines 156-158:

This would also be the case of the seismicity preceding the 2023 and 2024 Noto earthquakes, which migrates of ~8km in depth for ~650 days before the first $M_w$=6.2 earthquake[44]

Table S1, could you add a column stating how you classify each of these? Which category of Transform + Subduction swarms, foreshocks, injection-induced swarms, natural swarms, SSEs / SSFs. Also include the year(s) of each swarm, its general location (California, Italy, etc), and add the unit for moment in the first row.

We have modified Table S1 accordingly.

Minor Comments:

L20 Consider rewording sentence to be more direct, one idea “We highlight two different behaviors among these sequences: slow slip sequences with elevated migration velocities and moment, and fluid-induced processes featuring lower velocities and moment.”
We have reformulated this sentence as:

Migrating earthquake sequences from a wide range of tectonic contexts exhibit two distinct behaviors: slow slip-driven transients characterized by elevated migration velocities and moment, and slower fluid-induced sequences.

You refer to a couple swarms by name throughout the moment section, could you add a year to them so it's more specific and doesn’t require looking at the references? E.g., “The 2005 Salton Trough swarm”

We have modified the text accordingly.

Figures 2 and 4 look blurrier than Figures 1 and 3, and the legend in Figure 4 is particularly blurry. The two supplementary figures are also blurry.

We hope that the new figures provided appear less blurry to the reader.

Figure 3A-B: mention that the errorbars/uncertainty is also shown in the figure. Consider mentioning how the uncertainty bounds are obtained.

Added in the caption:

Error bars indicate slope or intercept values intervals for a 95% confidence threshold computed assuming a Gaussian distribution of errors

Figure 3C: Could you color code the bars instead to show the distinction in the data more specifically? The way it is now, it is unclear if there is any overlap in this parameter or if there is a sharp cutoff separating the two groups.

There is an actual overlap. The goal of Figure 3c was rather to show the bimodal distribution of the parameter, even though no clear limit can be drawn due to the scattering of the datapoints.

Added in the caption:

Those areas are drawn for illustration purposes, as an overlap between both types of sequences may exist.

Figure 4: Consider reducing the x and y bounds of the plot to focus on the data more. The foreshock sequences are not plotted in Figure 4 but the legend entry remains.

We have modified Figure 4 accordingly.

**Reviewer #3 (Remarks to the Author):**

I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

We thank the reviewer 3 for the careful reading of this work together with reviewer 2.

**Reviewer #4 (Remarks to the Author):**

This paper compiles several studies at a global scale on migrating sequences of seismicity in various context: injection-induced swarms, slow slip events, natural swarms and foreshock sequences. The authors analyse various scaling relations: migration velocities versus duration; Moment versus Duration. They reveal two different behaviors for the sequences, that they attribute to different dynamics, either fluid induced swarms (FI) or slow slip driven (SSD). They show that the scaling of migration velocity versus duration (V ~ T^α) evolves with the same trend for FI and SSD (with α around 0.75 to 0.83), but with a different intercept, SSD being 2 to 3 orders of magnitude faster for a similar duration. The scaling of Moment versus duration is linear for both type of sequences, but also evolves on two parallel trends for FI and SSD sequences. The proposition of two different behaviors for those sequences (FI and SSD) was already presented in an earlier work from the same group (Danré et al. 2022 (JGR)), however, the current paper uses a more complete dataset and provides more details on the scaling analysis and its interpretation. This paper provides an important perspective for the understanding of the drivers of seismic and aseismic fault transients, and discards the diffusive process as the driving mechanism for FI sequences. The paper is generally well written and figures are clear. I recommand publication after minor revisions.

Main comments:

I think the authors should better clarify the added value of the current study with respect to the previous work by Danré et al. 2022 (JGR). In particular, a significant part of the points shown in Figure 2 were already present in Fig. 4 from Danré et al. 2022 (JGR), and that earlier paper also investigated the scaling between velocity and duration. The current work remains an important contribution since (1) new datasets have been compiled and used to estimate scaling relations in the current study and (2) the authors go further in the interpretation of the results. Nevertheless, a clarification of the differences and improvement with respect to previous work would be useful.

On the same note, the scaling coefficient α (in the relation V ~ T^α) estimated in the current study differs from Danré et al. 2022 (JGR), and this has implication for the physical interpretation since the new coefficients are not compatible with fluid diffusion. The authors did not clearly explain the origin of this discrepancy: does it come from the addition of new datasets over larger temporal scales ? On that point, see also my detailed comments associated to l.104-106.

Throughout the manuscript, we have made several modifications to emphasize the unique contribution of this study compared to previous research on similar scaling laws. See for instance :

Lines 149-150

This parallel, but distinct, behavior provides a valuable observable for distinguishing between the two groups and for inferring their driving processes.

Lines 117-119

While prior research has already identified a distinction between swarms and SSEs[30], this study underscores a broader spectrum of behaviors within migrating sequences, leveraging a larger and more diverse dataset.

We emphasize that the discrepancy in the exponents mainly come from the refined analysis, incorporating more data (Lines 170-172):

The extensive dataset, encompassing numerous sequences with a wide range of durations and velocities, along with the diversity of tectonic contexts and types of sequences examined, results in a more robust estimate of $\alpha$ compared to previous studies [30].

Some studies have revealed the existence of migration velocities at different spatial/temporal scales (rapid tremor reversals, i.e. Houston. et al. 2011, and/or dual migration velocities [DeBarros et al. 2020, Dublanchet & De Barrow, GRL 2020]). These study show that the migration velocities can be defined at different time scales. This brings several questions: (1) how is the time-scale at which the observations are made selected, and how can we be sure that all datasets have been analyzed the same way ? (2) Could both migrations velocities be represented in the Figure 2 ? (global events with slow migration and smaller events within clusters with faster velocities) (3) Would the proposed mechanisms (FI and SSD) hold to explain events with dual migration velocities ?
I think this could be discussed at some point in the paper.

We agree with the reviewer that datasets have not been analyzed in the same way. Different methodologies were employed to compute velocities, moment, and durations, adding complexity to the interpretation. Consequently, our choice of conservative error margins reflects a cautious approach to our result. This study is constrained by the diverse methods used (such as fitting of a seismicity front and direct velocity estimates based on limited data points), as well as the restricted availability of data hindering the implementation of a uniform methodology across all sequences. However, we have included a statement in the discussion highlighting the significance of such considerations for future research perspectives (Lines 291-302) :

Precisely determining the value of $\alpha$ and providing a comprehensive global explanation for the observed scalings presents a challenge due to the dispersion of data points. To address this, standardizing the methodology for determining velocity, duration, and moment could enhance the precision of observations in this study. This standardization would facilitate the development of precise metrics for quantifying uncertainties and potentially reduce the uncertainties observed in velocity and moment scaling with duration.

Achieving this would require implementing state-of-the-art detection location and relocation techniques to ensure accurate measurements of these parameters, by using openly available waveform data. Alternatively, examining the systematic differences between FI and SSD sequences, considering factors such as tectonic context, fluid presence and pressurization (e.g., during fluid injections) might provide valuable insights towards developing a generic model for migrating slip transients.

In response to reviewers' suggestion to include fast seismicity bursts observed during certain sequences, we incorporated two such transients into our study : one identified in De Barros et al. (2020) during the 2015 Gulf of Corinth earthquake swarm, and another studied by Hatch et al. (2020) in the 2014 sequence near Virginia City, Nevada. We included corresponding (duration; velocity) values for these events in Figure 2, labeling them with VGN and CRT. Subsequently, we updated the figure caption and main text to reflect these additions, along with discussing the behavior of these two examples. Additionally, we provided interpretations for these data points, suggesting that they behave like FI sequences.

Lines 53-56

Some earthquake swarms exhibit complex migration patterns, where alongside the overall migration of the sequence, faster and shorter seismicity transients have been observed and interpreted as indicative of aseismic slip[14,23].

Lines 161-164

However, contrary to previous interpretations based solely on their elevated migration velocity, our results suggest that these fast seismicity transients share the same underlying driving mechanisms as those governing the overall sequence migration, as they scale within FI sequences rather than SSDs (Fig. 2).

Minor comments:

l. 26-28: The authors should reformulate their One-sentence summary, the sentence structure is odd, and the second part of the sentence (« and what we learn… ») should be self-contained.

We have reformulated this sentence following reviewer 4 and reviewer 2 suggestions

l. 39: a more recent reference (Beroza and Ide 2023) exist on the M0~T scaling, with the same authors. It could be cited here as well. That paper also provides a possible explanations for the observed scaling M0-T^3 on restricted datasets that could be due to detection bias.

Indeed, we cited this paper in the discussion about the significance of the scaling (see response to reviewer #1).

l. 97-99: The distinction between these two groups « slow slip driven » and « fluid induced » was already introduced in Danré et al. 2022. This could be mentioned here.

Indeed. See our response to the comment of reviewer 1 above about the richness of the dataset used, which involves far more sequences and different types of those than the work of Danré et al., 2022.

Figure 3A and l.104-106: How are the error bar determined on the value of the slope here ? I have the same question for the Intercept (Fig.3B), and l. 115-116.

We computed the 95% confidence level (assuming a Gaussian distribution of errors) associated with the regression made on FI and SSD families. We added this precision in the manuscript.

l. 104-106: Here the authors should compare more explicitly the values of the parameters obtained in this study with the previous work from Danré et al. 2022. I understand that « makes it less likely a diffusive process » refer to the higher exponents in this study compared to Danré et al. 2022, but this could stated more clearly. The reason for the change in scaling could also be discussed (how many orders of magnitudes have been added with respect to the previous work) ?

For clarity, we have rephrased the sentence (Lines 170-174):

The extensive dataset, encompassing numerous sequences with a wide range of durations and velocities, along with the diversity of tectonic contexts and types of sequences examined, results in a more robust estimate of $\alpha$ compared to previous studies [30]. The inferred exponents ($\alpha \sim 0.8$) for both FI and SSD sequences notably deviate from $\alpha = 0.5$ which is characteristic of a diffusive pattern.

L. 154-155: « by assuming seismic slip as a proxy for the surrounding aseismic slip. »: You could be more specific here in describing the approach on how to estimate the total moment from swarm data. Reference 27, where the method is described, should be associated to the last part of the sentence.

We have provided more detail for the method used to estimate the total moment (Lines 200-207)

When deformation is too subtle to be detected by geodetic measurements, we estimate the total moment by drawing analogies with repeating events and creep episodes [30,54]. Here, we assume that seismic slip serves as a proxy for the surrounding aseismic slip. By using the seismic slip associated with the largest event of a sequence, we can estimate the average slip over the entire swarm area. This approach enables the reconstruction of the total moment released during the studied sequence[30], overcoming the detectability challenges posed by conventional geodetic methods. This method has been validated using values from the literature[30] or through injected fluid volume reconstruction[40].

L. 1999-200: shallow SSEs have also been detected at shallow depth in several subduction zones (Japan, Hikurangi …)

Added “generally” to mitigate our statement.

L. 205-206: the authors point out the uncertainties in estimating the migration velocity and total moment. It seems to me that uncertainties in the determination of the event duration is also large. This is especially true for geodetically detected SSEs, where the duration is defined from a noisy-emerging signal and is subject to large uncertainties due to noisy daily data that often require temporal smoothing. These uncertainties were evaluated in Michel et al. 2019 (Fig. 3a). In the catalog from Gao et al. 2012, even if not mentioned, uncertainties on the evaluation of the duration for SSE also exist and should probably be mentioned here as well here.

Indeed, Gao et al. (2012) addressed uncertainties in duration, incorporating them into estimation of velocity error. Thus, we adopted a 25% uncertainty in velocity, as explained in our answer to reviewer #1.

As we clarified in our response to reviewer #1, establishing a uniform determination of uncertainty is challenging due to the diversity of methods employed in duration, moment and velocity computations, as well as the availability of data. Consequently, we opted for relatively large uncertainties in velocity and moment.

We have included a statement in the perspective section addressing these challenges (Lines 292-296) :

To address this, standardizing the methodology for determining velocity, duration, and moment could enhance the precision of observations in this study. This standardization would facilitate the development of precise metrics for quantifying uncertainties and potentially reduce the uncertainties observed in velocity and moment scaling with duration.

l. 224: Observations made Figures 2 and 4. => Observations made in Figures 2 and 4.

Corrected accordingly.

l.224-227: The authors could detail more how they deduce the alpha values from the two models proposed in Ide et al. 2007. In the sentence (l.225-226), it could be stated that the uniform slip model implied L^2 ~ T while the constant stress drop model implies L^3~T. This will help the reader to understand more clearly the relationship between the proposed models and the alpha values, without having to refer in details to Ide et al. 2007.

We have added more detail on this sentence following the reviewer's suggestion (Lines 282-289) :

Among these models, those involving either uniform slip or uniform stress drop are consistent with the $M_0 \propto T$ scaling observed here [5]. These models yield a dependence of length (L) on duration (T) of $L^2 \propto$ T and $L^3 \propto$ T, respectively, resulting in values of $\alpha = 0.5$ or $\alpha = \frac{2}{3}$, respectively, in the $V \propto T^{-\alpha}$ scaling [5]. However, these exponents appear lower than those observed in our study, even when considering the significant scattering (Fig. 3). In particular, we can reject a diffusive relation ($\alpha = 0.5$), commonly assumed for FI sequences. An alternative explanation for Fig. 2 and Fig. 4, by considering $M_0 \propto T$ and $V \propto T^{-0.75}$, suggests $M_0 \propto R^4$, indicating slip that grows with the surface area of the sequence.

**REVIEWERS' COMMENTS**

**Reviewer #1 (Remarks to the Author):**

I thank the authors for revising the manuscript ans answering in detail my concerns about the erros in the data. I understand that it is very difficult to evaluate errors from data published by many different authors, but I am very satisfied by the revised mansuscipt and I recommend publication as it is.

**Reviewer #2 (Remarks to the Author):**

I thank the authors for their responses to my previous comments, the updates to the manuscript have mostly addressed my concerns and strengthened the manuscript. I have included some additional minor comments below.

I appreciate the added context in the introduction on the V-T relationship. I still think that an explanation of why we might expect the sequence duration to scale with migration velocity in the first place from a physics perspective would be useful to the general reader. If the physical mechanisms are not well understood, it is fine, but the authors might want to briefly comment on this.

L64-67: “For instance, migration following a fluid pressure diffusion law may exhibit a scaling of $V \propto T$-.5 while linear migration with constant velocity may indicate aseismic slip. The absence of migration would be characterized by $V \propto T$ -1.”

Could you insert the appropriate $V \propto T$.α relation for the asesimic slip to be consistent with the diffusion and absence of migration.

L117: I would move the new sentence that starts with “While previous research has already…” somewhere else perhaps towards the end of the paragraph or discussion. At its present location, I read the opening sentence of the paragraph, “A plot of the migration velocities against the durations of earthquake sequences studied here shows two distinct trends despite having similar slopes (Fig. 2).”, and expect to find out what the two trends are and learn about Figure 2.

L185: If there is no important reason why you switch to “V=f(T) scaling” as opposed to saying the “V=Tα scaling”, I think you should use “V=Tα“ to be consistent with the rest of the paper. Same comment applies to L238.

There are a couple spelling and grammar errors throughout, and so I encourage the authors to do another close check. Here are a few instances:
L278 “litterature” -> “literature”.
L143 “Fig.3c” -> “Fig. 3c”.
“Foreshock” is spelled wrong in the legends of figures 2 and 4 and in some entries of Table S1.
Table S1: “ForeshockIquique1” should have spaces “Foreshock Iquique 1”. Same for 2 and 3.
In Table S2 you use commas “,” to denote the decimal place but you use periods “.” everywhere else in the manuscript.

**Reviewer #3 (Remarks to the Author):**
I co-reviewed this manuscript with one of the reviewers who provided the listed reports. This is part of the Nature Communications initiative to facilitate training in peer review and to provide appropriate recognition for Early Career Researchers who co-review manuscripts.

**Reviewer #4 (Remarks to the Author):**
I read the revised version of the paper, as well as the response to the reviewer comments. The paper have been significatly improves based on teh comments from the different reviewers. I consider that the revised version is now acceptable for publication.

The revised version of the document has been considerably improved on the basis of the comments made by the various reviewers. the authors also adressed my questions and comments in their point to point response. I consider that the revised version is now acceptable for publication.

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Could you insert the appropriate $V \propto T$.α relation for the asesimic slip to be consistent with the diffusion and absence of migration.

We modified the sentence to refer to the work in Danré et al., 2023 as well :

while linear migration may indicate fluid-induced aseismic slip[30,31,33]

In this Danré et al., 2023 paper, the formula relating distance to injected volume is developed for a fluid-induced aseismic slip to explain the observed migration shapes. We believe that writing this formula here might not appear relevant to the reader, given the model assumptions and constants that need to be introduced making the text heavier for the reader.

In Danré et al., 2023 we indeed develop distance R as a function of injected volume V with time t :

$$R(t) = \sqrt{s_d V_{inj}(t)}$$

With :

$$s_d = -\frac{f_0}{2\pi \beta w_{fz} \Delta\tau_{\square}}$$

Where $\beta$ , $f_0$ , $w_{fz}$ and $\Delta\tau_{\square}$ are bulk pore compressibility, friction coefficient, conductive fault zone width and effective shear stress drop respectively.

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We indeed moved this sentence later in the paragraph.

L185: If there is no important reason why you switch to “V=f(T) scaling” as opposed to saying the “V=Tα scaling”, I think you should use “V=Tα“ to be consistent with the rest of the paper. Same comment applies to L238.

We changed the V=f(T) to "$V \propto T^{-\alpha}$" and “$M_O \propto T$ “ in the corresponding instances.

There are a couple spelling and grammar errors throughout, and so I encourage the authors to do another close check. Here are a few instances:
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