

Author response to the reviews of:

Constraining slip rates along Altay faults using GNSS data

Fabien Ramel et al.

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We sincerely thank both reviewers for their careful reading of the manuscript and for their constructive comments. Their suggestions helped us improve the clarity of the manuscript, better document the GNSS data and associated uncertainties, and provide a more cautious discussion of the block-model results and their limitations.

The response document is organized in two main sections. We first provide our point-by-point response to Laura Gregory (RC1), followed by our point-by-point response to Edwin Nissen (RC2). In each section, the reviewer's comments are reproduced first, followed directly by our author response describing the revisions made to the manuscript.

Author response to Laura Gregory (RC1)

REVIEWER :

Ramel et al. (submitted) present two new campaign GNSS transects across the Altay mountains in western Mongolia. This region undergoes far field deformation from the India-Asia collision, and is suggested to accommodate 10-20% of the total shortening strain. Accessibility is a challenge in the remote Altay mountains, and as a result, geodetic, Quaternary, and palaeoseismic data constraining the slip rates of individual faults are sparse. Due to the arid climate, evidence of past earthquakes and fault slip are very well preserved. Faults in the Altay are known to host large (up to M 8) earthquakes, with long recurrence intervals (>1000 years), and most have not had an earthquake in the historical or instrumental period. Constraining the rates and behaviour of the Altay faults is relevant to many important questions in active tectonics (e.g. on strain distribution, fault strength, intracontinental deformation, reactivation of faults, and large strike-slip faulting earthquakes), and more data is crucial for answering these questions.

Therefore, the data presented in Ramel et al. is a relevant and important contribution, but revision is necessary to realise the potential of this dataset. I suggest changes that I hope will clarify the significance and meaning of the results. I suggest that the uncertainties should be better quantified so that the data may be used by other researchers. While block modelling may be useful to view the data within the larger picture of deformation, the data could also be presented without influence of the modelling (e.g. in a profile), so the reader can better interpret how the strain rates vary across the mountain range. I have many questions about the research, and I hope that these will be considered in a revision of the manuscript.

Detailed comments

Setting the context

The introduction to the manuscript would benefit from a brief wider setting – why should we be interested in strain rates in western Mongolia from a broader perspective? E.g. why are these faults important?

AUTHOR RESPONSE :

We thank the reviewer for this helpful suggestion. We have therefore revised the Introduction to better place our study in the wider context of intracontinental deformation in Central Asia. The Introduction has been revised by adding a new contextual paragraph after the opening paragraph :

« Accurately quantifying fault motions and the associated strain rates in western Mongolia is essential for improving our understanding of intracontinental deformation processes occurring far from active plate boundaries (e.g. Molnar & Tapponier, 1975; Vergnolle et al., 2007). The Mongolian Altay fault system represents a key natural laboratory to investigate how deformation related to the India–Asia collision propagates and is accommodated across the continental interior (e.g. Huangfu et al., 2023). It also provides critical insights into how deformation is partitioned (e.g. Cunningham, 2005; Frankel et al., 2010; Ha et al., 2023), how it is distributed over multiple seismic cycles through complex processes such as fault interaction, static and viscoelastic stress transfer (e.g. Chéry et al., 2001; Pollitz et al., 2003; shao et al., 2024), and on the rheological properties of the continental lithosphere (Bayasgalan et al., 2005; England & Molnar, 1997; Meade, 2007; Vergnolle et al., 2003, 2007). Geodetic measurements have provided a significant contribution to these studies by improving kinematic models of active deformation. »

REVIEWER :

Section 2.1: This section requires clarification – you note that much work has been done on the Bulnay, Gobi-Altay, and Fu-Yun but neglect to mention the Altay mountains as a whole (despite referencing the Fu-Yun fault, which is part of the Altay). The following section focuses on the Altay, but the mountain range should be introduced as a whole rather than just the Fu-Yun fault, because other faults in the Altay are also ‘slow faults with slip rates of about 1 mm/yr capable of generating large earthquakes..’, and deformation across the main Altay massif contributes significantly to the 10-20% India-Asia convergence.

AUTHOR RESPONSE :

We thank the reviewer for pointing out this lack of clarity. We have therefore revised this section to explicitly mention the main Altay fault systems and the morphotectonic studies conducted on them. We added references to studies of the other major Altay faults and clarified the role of the Altay fault system in accommodating a significant fraction of the far-field India–Asia convergence.

REVIEWER :

Line 108 – is the GPS ‘slip rate’ from Calais et al., 2003 a horizontal shortening rate or has it been resolved onto a strike slip fault, to better compare with the Quaternary fault slip rates? The slip rate on a strike slip fault accommodating shortening (e.g. not optimally oriented) will always be greater than the shortening strain rate across it. The fault slip rates should be faster than the GPS shortening strain rate.

AUTHOR RESPONSE :

In our comparison with Calais et al. (2003), we did not use the fault-normal shortening component across the range. Instead, we considered two GNSS velocity vectors located on opposite sides of the Altay range and projected their relative motion onto the average strike of the main Altay fault systems (see table 1). We then calculated the difference between the components parallel to this mean fault direction in order to estimate the cumulative range-parallel, dextral strike-slip motion accommodated across the Altay. This value therefore represents the integrated strike-slip component across the whole range.

We have revised the corresponding sentence in the manuscript to make this point explicit and to avoid any confusion.

REVIEWER :

The background lacks mention of the rotational component of deformation in the Altay. Many authors have suggested that the region rotates anti-clockwise to accommodate NNE-SSW directed shortening on NNW-SSE oriented strike slip faults (e.g. Bayasgalan et al., 2005; Thomas et al., 2002; Gregory et al., 2018).

AUTHOR RESPONSE :

We thank the reviewer for this suggestion. A sentence has been added to Section 2.1 to mention the proposed anti-clockwise rotational component of Altay deformation, with references to Bayasgalan et al. (2005), Thomas et al. (2002), and Gregory et al. (2018).

REVIEWER :

Clarify the methods and uncertainties in the GNSS data

Section 3: This section would benefit from a brief explanation of how and why did you choose where to put the campaign? E.g. why did you choose to conduct two campaigns in the north and south rather than including the central Altay, where strain rates might be higher at the centre of major fault zones? Or collect more transects with fewer points, or vice versa? I suspect this is simply a problem of having enough time and easy access, but it would be good to have an explanation for the choice.

We have completed the manuscript to answer these questions.

AUTHOR RESPONSE :

We have revised Section 3 to clarify that the location of the two transects was primarily guided by three constraints: (1) the need to cross the Altay range as close as possible to the direction normal to the range axis, in order to sample the velocity gradient across the main fault-bounded blocks; (2) the need to distribute the sites so as to cover the different blocks separated by the major Altay faults; and (3) logistical and accessibility constraints, which are particularly important in this remote mountainous region. The transects were therefore placed along accessible roads, with a mean spacing of about 40 km between sites, representing a compromise between spatial resolution, field accessibility, and the limited duration of each field campaign.

REVIEWER :

(Line 142) Has the setup of drilling holes and not having a permanent marker been used before? Is there a reference, or some analyses of the uncertainties related to this style of data collection? It would also be helpful to plot the vertical data, so the reader can understand the level of noise (even if this just goes in the supplementary material).

AUTHOR RESPONSE :

Yes it has, but to our knowledge never explicitly reported in an article. Researchers like R. Bilham or P. Vernant have used it successfully in many regions (e.g. northern Tibetan region: He, et al., 2013, Himalayan region: Vernant et al., 2014). As stated in the manuscript, the vertical emplacement suffers from a larger uncertainty and therefore, specially over only few years of observation, vertical displacements should not be used. We prefer not to include these rates to avoid them to be misused.

REVIEWER :

(Line 167) More information is needed for how the raw GNSS data are processed, how the uncertainties are calculated, and how the velocity solution is calculated. I am not an expert in processing GNSS data, but perhaps an example figure of the linear fit for one of your station solutions (mentioned line 175) would help to show the goodness of fit (this could be included in the supplement). Did you filter any of the data from the velocity solution described from line 175, e.g. remove sites with large errors?

AUTHOR RESPONSE :

To better estimate the uncertainties, we recomputed them using the “real sigma” methodology described first by Reilinger et al. 2006 and used by several studies since then. We modified the text to make it explain it.

REVIEWER :

The GNSS data in all figures have uncertainty ellipses but there is no scale for the ellipse in any figure. It is not clear how reasonable the estimated uncertainties are for the new data. You mention that the northern transect is more heterogeneous (line 187), but this is not reflected in the formal uncertainties, and it should be. How can uncertainties be better quantified so that the data can be used by other researchers? At least one of your new sites is close to an existing continuous site – how do these compare? This could give a sense of the true uncertainty.

AUTHOR RESPONSE :

Unfortunately, this is not how uncertainty computation works for GNSS sites, as one site close to another is mostly independent and the sources for variations might not be related. Therefore, comparing continuous sites with survey sites won't bring a significant information that can be extrapolated to other sites. However, to better take this into account we have changed the way the uncertainties are calculated to take into account a regional noise model based on the numerous continuous GNSS sites (see comments above).

REVIEWER :

The two northeast most GNSS sites (two east sites in the northern transect) are along the Bulnay fault – how much are they influenced by the Bulnay fault?

AUTHOR RESPONSE :

The Bulnay fault is a left-lateral strike-slip fault with a rate of ~3 mm/yr. Given that the sites are at ~20km from the fault, which is equivalent approximately to one locking depth, we expect a perturbation of 50% of half the slip rate on the eastern component of the velocities. Which means about 0.7 mm/yr, given the azimuth of the fault this would only have incidence on the fault normal component of Har-Us-Nuur. And since we are at more than 50 km from the Har-Us-Nuur fault, this won't have any significant effect. As a side note, this is taken into account in the block models.

REVIEWER :

I suggest that you plot transects of the velocities in your profiles, to better illustrate how the data vary across the Altay. One way to do this would be to calculate the fault parallel velocities of each site (e.g. Figure 6 in Calais et al., 2003), or to plot the Junggar-fixed reference frame velocities as a profile (or both!). Error bars should also be included on the transect. This would, show the heterogeneity in the data, demonstrate how the velocity varies relative to all the mapped faults (not just the block boundaries), and how it varies smoothly across the whole mountain range.

AUTHOR RESPONSE :

In response to this comment, a new figure has been added to the results section (now Figure 6), showing the velocity transects for both the northern and southern profiles, together with error bars and the corresponding modeled velocities. The related text has also been expanded in the modeling results section to describe these profiles and their contribution to the interpretation of deformation across the Altay.

REVIEWER :

Block modelling

(Line 206) This section would benefit from a summary of the limitations or considerations when using block modelling. For example, how does heterogeneity and uncertainty in your GNSS data propagate into the modelling? Does the strain that is accommodated within the blocks on complex faults artificially migrate to the block boundaries (e.g. overestimate rates at boundaries)?

AUTHOR RESPONSE :

Many studies describe block modeling and this is beyond the scope of this study since we are only using the TDEFNODE software following a classical approach. We have completed the modeling part with an extended description of the studies using block models.

REVIEWER :

Why only allow one block (Hanguy) to deform internally in your second model – why not allow all of the blocks to do so given that we know there are complex active faults within each block?

AUTHOR RESPONSE :

In the extended modeling description, we precise that adding strain inside blocks will have consequences on the inversion process and therefore should be used with parsimony. While many studies report doming in the Hangay region and justify that a homogeneous strain rate tensor is estimated for this area, this is not the case for the other blocks.

REVIEWER :

Line 225: There is no scale on the figure with the residuals, so it is difficult to evaluate whether they are ‘low’.

AUTHOR RESPONSE :

We thank the reviewer for pointing this out. We have corrected this issue by adding a scale for the residual vectors in the figure showing the block-model results.

REVIEWER :

Line 232: I think this interpretation requires more explanation. It is confusing to include a ‘strain-free’ model, because there is strain in this model at the block boundaries. I suggest using a different label for the two models (rigid vs. internal deformation?).

AUTHOR RESPONSE :

Considering the investigations we had to do to answer to the reviewers, we decided that the model with internal deformation isn’t really needed for the discussion. We only refer to this model very shortly to explain that our dataset does not allow to evaluate if doming is occurring in the Hangay region. Hence there is no longer a need to change the terms.

REVIEWER :

(Line 240/280) One significant problem is the extension in the modelling in the northern part of the Altay, which is matched by compression in the south. This is most likely an artifact of the model (as noted in line 285). Can you quantify how much rotation/levering contributes to the strain at the edges of the model, and remove the artifact? There aren’t any notable normal faulting earthquakes in the catalogue for the Altay (e.g. Sloan et al., 2011), so it does not seem likely that there is a significant extension component to the deformation (though there certainly are normal faulting earthquakes in the Hanguy!).

AUTHOR RESPONSE :

We totally agree with the reviewer and we ran many more models by randomly removing GNSS data to explore that. We added these results in the manuscript.

REVIEWER :

How are compressive stresses distributed along the faults? Altay faults have field evidence for compression at large scale bends where they form flower structures with significant thrust fault components, but in between these structures they may have pure strike slip motion (and therefore a faster strike slip rate). How is this heterogeneity in fault kinematics dealt with in your modelling and interpretation? How many sites are located within a restraining bend compared to along a straight section of the faults?

AUTHOR RESPONSE :

This is all related to the fault geometry. Given the scarce coverage of the GNSS data we simplified the fault geometries. Therefore no “local” deformation related to restraining bend or pull-apart is considered. And given the uncertainties on the GNSS velocities one cannot use one or two sites to discuss this matter.

REVIEWER :

More explanation needed for interpreting the block modelling -how much of the slip rates plotted in Figure 5 are dependent on the models vs the GNSS data? What happens if you randomly remove some data (e.g. a bootstrap analyses?). Again profiles of the GNSS data would help with this.

AUTHOR RESPONSE :

We have run 4915 more models using this kind of approach and added some description and discussion about it in the manuscript.

REVIEWER :

L350: The Olgyi fault has a low slip rate in your model, but I wonder how much of this is because there are no GNSS sites on the western side of the fault – so most of the strain in the Fu Yun fault is concentrated (in the model) close to where there is data? In general, can you comment on how the site location introduces bias into the modelling?

AUTHOR RESPONSE :

Although a denser coverage would be better, the FYUN block is defined with 13 sites which allow to estimate its Euler pole more accurately than the HOVD one. Site location would introduce a bias if they were all located in the same corner of the block, which is not the case. This is part of the block model basis and has been covered in previous studies when GNSS velocities started to be used for plate kinematics and block models.

REVIEWER :

I think it is important to always consider that the GNSS data is a different measurement to Quaternary fault slip rates. Quaternary fault slip rates represent (mostly) strain released in earthquakes. They can be influenced by whether a fault is early or late in its seismic cycle (especially when dealing with long recurrence intervals and large earthquakes), but should at least represent earthquakes. GNSS data is interpreted to represent the slow accumulation of elastic strain (between faults). It is very important to compare between these different observations (as has been done in the manuscript), but it is also important to consider the assumptions in these comparisons.

AUTHOR RESPONSE :

We have added a more extensive discussion on block model, earthquake cycle and general comparison between geologically and geomorphologically derived fault slip-rates (e.g. Vernant 2015).

REVIEWER :

The discussion ends rather abruptly. I suggest you can improve the relevance of the work by ending the discussion with some points on the wider context of this work.

AUTHOR RESPONSE:

We broadened the discussion by adding the following paragraph : « More broadly, our results emphasize the relevance of the Mongolian Altay for understanding how active deformation is distributed across slowly deforming intracontinental regions. In such settings, where instrumental records are short compared with seismic-cycle timescales and geological slip-rate estimates remain sparse and methodologically heterogeneous, confronting GNSS-derived rates with geological constraints is particularly valuable. This comparison helps assess whether present-day strain accumulation is consistent with longer-term fault slip, while also revealing possible discrepancies related to data coverage, methodological differences, or deformation accommodated on secondary structures. Our GNSS transects provide new constraints on present-day deformation across the Altay and underline the need for longer geodetic time series and additional morphotectonic investigations on both major and secondary faults to better quantify strain partitioning and seismic potential in the continental interior. »

REVIEWER :

Minor

Be consistent in using Fig. vs Figure in your figure references.

Be consistent with spelling of Altay vs Altai, etc.

L70: The region also has significant compressional components of deformation.

Line 140: Change firsts to first

Line 206: I cannot find a reference to Figure 4 in the text, maybe it is supposed to be what is referenced as Figure 5 in this line?

Line 310: The phrasing of the second part of this sentence is incomplete.

AUTHOR RESPONSE :

We thank the reviewer for these careful editorial comments. The manuscript has been revised to ensure consistency in figure references and spelling, to clarify the transpressive nature of deformation in the region, and to correct the typographical and sentence-structure issues identified by the reviewer.

REVIEWER :

Figures:

It would help to put some key place names (towns) on one of your maps, to help the reader locate themselves.

All Figures with GNSS data need a scale marker for the uncertainty ellipses.

Figure 5 is missing labels for (a) and (b), there is no (c) but this is referenced in the text at line 224.

Fix references and labels associated with what looks to be splitting Figure 4 into two Figures.

What is the scale on the residual arrows in Figure 5?

It would be helpful to label the faults on Figure 5, since they are discussed with respect to the modelling results (e.g. the reader may not know that the Olgii fault approximately forms the boundary of the western side of the Hovd block (in the north)).

AUTHOR RESPONSE :

We thank the reviewer for these helpful comments regarding the figures. We have revised the figures accordingly to improve their readability and to make the presentation of the GNSS and modeling results clearer. The figures have been revised to include key place names, uncertainty-

ellipse scales, residual-arrow scales, and fault labels where needed. Figure panel labels and associated in-text references have also been corrected.

Author response to Edwin Nissen (RC2)

REVIEWER :

This paper presents an important new GNSS velocity dataset from a relatively understudied sector of the India–Eurasia collision zone in the Altai mountains of western Mongolia. The dataset itself is clearly valuable and, in my view, well worth publication. The spatial coverage and density of GNSS observations represent a significant contribution that will be of broad interest to researchers working on continental deformation, fault kinematics, and the mechanics of intracontinental mountain belts. However, while the dataset is strong, I have more substantial concerns about the block modelling and the way its results are interpreted and contextualized.

Before invoking a block model, the authors could extract more insight directly from the GNSS velocities themselves. For example, plotting profiles of shortening and strike-slip components along the closely spaced northern and southern transects would allow direct comparison with nearby geological slip-rate estimates and would provide an observational benchmark for later modelling.

AUTHOR RESPONSE :

We added the two profiles along with the modeled velocities (new figure 6). Given the low velocities, the time span of the measurements, the need to correct for interseismic loading (i.e. transient elastic strain), we strongly advise not to interpret the velocity differences between two sites, this must be treated in a more global approach looking at the whole dataset. Although we agree that block modeling is not flawless, it is less biased than an approach that would discuss velocity differences between 2 sites.

REVIEWER :

With respect to the block model, the authors state that “Block boundaries are designed from mapped faults, seismicity, historic earthquakes, and the GPS velocities,” and that all blocks must be closed. This immediately raises several issues. It is unclear whether all block boundaries are assumed to be vertical, and if so, how the sometimes large compressional and extensional components resolved along them should be interpreted. Along steep or vertical faults, such components would imply very fast dip-slip rates, for which there is little geological or seismological evidence. The assumed 15 km locking depth is also not fully justified. While this depth is broadly consistent with regional waveform modelling (e.g. Bayasgalan et al., 2005), deeper earthquakes at ~30–40 km are observed within the northern Junggar Basin in the Wimpenny & Watson (2021) Global Waveform Catalog, suggesting that fault bottom depths may vary significantly across the region.

AUTHOR RESPONSE :

We have added the fault characteristics in the manuscript and noted that changing the locking depth would not produce significant changes. We also precise that we use the tensional component of Okada's functions to avoid off behavior on steep faults due to significant fault-normal components.

REVIEWER :

More generally, there is little discussion of the limitations inherent in the block modelling approach. The requirement that all blocks be closed necessarily introduces artificial boundaries where no real faults exist, or produces boundaries with implausible kinematics. A clear example is the E–W trending, supposedly left-lateral block boundaries along the northern edges of the HOVD and FYUN blocks. To my knowledge, there is no evidence for left-lateral faulting along these trends. On the contrary, the 2003 Chuya earthquake sequence, which provides one of the best-constrained kinematic observations in this part of the NW Altai, involved E–W right-lateral and reverse faulting (Nissen et al., 2007). Although the inconsistency between the block model and the Chuya earthquakes is correctly noted, the modelled ~ 0.5 mm/yr left-lateral slip along this E–W trend is dismissed as a “minor discrepancy” (line 298). This is difficult to reconcile with the treatment of similar-magnitude discrepancies between geodetic and geological slip-rate estimates elsewhere in the Altai, which are highlighted as major results of the study. A more even-handed discussion of these inconsistencies would be appropriate.

AUTHOR RESPONSE :

As stated before (c.f. Author response to Laura Gregory (RC1)), we ran almost 5000 more models to see how well constrained the fault-parallel and fault-normal components along the main NW-SE faults are. It appears that the fault-normal components suffer from a larger dispersion which implies larger uncertainties on the E-W faults at the extremities of the NW-SE faults. Therefore, we cannot treat the slip rates with a more even-handed discussion since disparities exist between the fault segments.

REVIEWER :

A related issue is the widespread appearance of normal components along many block boundaries, including along what are clearly restraining not releasing bends (e.g. the northernmost Har Us Nuur fault—see Walker et al., 2006). The authors note that longer GNSS time series are required to determine whether this extension is significant, which is reasonable. However, this inference could also be evaluated against independent constraints. There is, to my knowledge, no geomorphological evidence for normal faulting in the Altai, whereas there is plenty of such evidence for reverse/thrust faulting (both distinct from and as dip-slip components of the main strike-slip faults). Nor are normal-faulting focal mechanisms observed; where dip-slip mechanisms do exist, they are uniformly thrust (Bayasgalan et al., 2005). These geological and seismological observations integrate deformation over longer timescales than the GNSS dataset and should be discussed in relation to the model results.

AUTHOR RESPONSE :

We agree that some of the geological observations integrate deformation over longer timescales than the GNSS, but this is not always the case and some “short-term” geological observations might suffer from clustering behavior (see for example discussion in Vernant 2015). As for the seismological observations they are far from integrating the deformation over longer time scales (there is always the question of the completeness of the catalog), but they do indicate the stress pattern of the region when sufficient focal mechanisms exist. The matter in our case is the short time span of observation and the network that should be denser. This leads to large uncertainties for some components/segments. But GNSS has proven to integrate deformation over long time scales is used properly (see for example, Reilinger et al., 2006, Vernant 2015 and many other studies).

REVIEWER :

At the same time, the block model appears to oversimplify areas where internal deformation is well documented. A good example is the southern part of the HUSN block, which contains the Baatar Hyarhan massif. This massif is bounded by clearly-expressed thrust faults on both margins and, based on OSL dating, may accommodate ~ 1 – 2 mm/yr of shortening according to Nissen et al., (2009, GJI). Although this paper is cited, it is not actually discussed (perhaps it is muddled with

another paper by the same lead author in the same year?), and the southern GNSS velocity transect actually crosses the Baatar Hyarhan massif without any mention of its tectonic significance. Internal deformation is only explicitly considered for the large MONG block in the east, despite clear evidence that other blocks are not rigid.

AUTHOR RESPONSE :

Simplification of the fault is required by the block model, the GNSS coverage and Occam's razor. As stated earlier we use the tensional component with translates into elastic strain in the fault vicinity that can either be on the modeled fault or could be accommodated by thrust fault nearby.

We agree with the reviewer that the southern part of the HUSN block is tectonically more complex than represented in our block model. In particular, the Baatar Hyarhan massif and the active Zereg and Tsetseg fault systems documented by Nissen et al. (2009a) represent important structures that may accommodate part of the internal deformation within this block. This point was already mentioned in the Discussion of the original manuscript, where we noted that the higher compressive slip rates modeled south of the Hovd and Har-Us-Nuur faults may partly reflect deformation occurring on active structures located inside the HUSN block, rather than only on the block-bounding faults.

REVIEWER :

The robustness of the block model also depends critically on the number and distribution of GNSS sites within each block, yet this is not discussed. While at least three sites per block are required to determine Euler poles and thus block boundary slip-rates, many more well-distributed sites are presumably needed to do so reliably. The "lever arm" effect is mentioned (line 286) but not adequately explored, and a discussion of site numbers per block and their spatial distribution would strengthen confidence in the modelling results. This issue is further exacerbated when additional effects of vertical-axis rotational deformation are also considered, as discussed next.

AUTHOR RESPONSE :

See replies above and the expended manuscript with the newly added histogram of the ~5000 models to explore this issue.

REVIEWER :

Counterclockwise vertical-axis block rotations are likely an important component of regional deformation (e.g. Bayasgalan et al., 2005; Nissen et al., 2007; Gregory et al., 2018), and are indeed required in order for NNW-trending right-lateral faults to be able to accommodate NNE-directed shortening. Not discussing rotational deformation at all is a major oversight of this paper, refuting the somewhat grandiose statement that "Our block model provides the first detailed GNSS kinematic description of Altay deformation" (line 279). Presumably the block model resolves vertical-axis rotation rates as well as slip rates, so these need to be discussed. Are these results consistent with independent paleomagnetic data (Thomas et al., 2002; Gregory et al., 2018)? It would be worth considering whether small errors in rotation rate might resolve into large errors in block boundary slip-rate; perhaps this could help explain discrepancies with some geological slip-rate data, which are not impacted by uncertainties in rotation rates in the same way?

AUTHOR RESPONSE :

As stated in Gregory et al. (2018): "The declinations are not significantly rotated with respect to the directions expected from Cretaceous and younger virtual geomagnetic poles, suggesting that faults in the eastern Altay have not experienced a large degree of vertical axis rotation and cannot have rotated $> 7^\circ$ in the past 5 m.y.". So no significant rotations on a local vertical axis are reported. One should not be misled by the term of rotation which is not the same for paleomagnetic studies which are looking for a sample rotated over a vertical axis in the region where it was collected, while the

rotation provided by the block model is an Euler pole relative to another plate and usually located far from the block which imply a very limited “local” rotation of the block. Given that Gregoy et al. (2018) reported that not significant rotations, we did not dug deeper in that direction.

REVIEWER :

Another important omission is any consideration of viscoelastic deformation. If most faults in the Altai are late in their earthquake cycles, as is likely except for the Fu-Yun fault, then because of visco-elasticity, interseismic deformation is expected be spatially diffuse rather than localized on faults. Modelling such deformation using a purely elastic framework can significantly underestimate true slip rates, a well-known issue in interseismic modelling (e.g. Zhu et al., 2020). This effect has been invoked to explain discrepancies between geodetic and geological slip rates in other regions, including eastern California, the Altyn Tagh fault, and NE China (Chuang & Johnson, 2011; Johnson, 2013; Wang et al., 2021), and should at least be acknowledged here as a possible explanation for similar discrepancies.

AUTHOR RESPONSE :

Based on a careful compilation of GPS data across many strike-slip faults Vernant (2015) showed that no significant change could be identified in the interseismic signal. Interestingly Zhu et al. (2020) did not refer to this study. Even though this has been used to explain the discrepancies on the Altyn Tagh fault, this debate has been closed since then, the problem wasn't the GPS, but how the geological evidence was interpreted. Some of the co-authors have more than 25 years of experience on GPS survey and processing across strike-slip faults at different stage of the interseismic period, and so far interseismic variations hasn't proven to affect slow strike slip fault to the point of drastically changing their geodetically derived slip-rate.

REVIEWER :

Overall, while the block model may reproduce the observed GNSS velocities quite well, its assumptions and limitations are substantial and need to be more clearly and critically discussed. The manuscript would benefit from a more cautious interpretation of model-derived slip rates and kinematics, and from placing greater emphasis on the high quality and intrinsic value of the GNSS dataset itself. This could also help clarify the broader tectonic significance of the Altai beyond slip rate estimates on individual faults.

AUTHOR RESPONSE :

We thank the reviewer for this important comment. As detailed in our responses above, we have revised the manuscript to provide a clearer discussion of the limitations of the block-model approach and have added new elements, including velocity profiles and bootstrap-like histograms, to better assess model uncertainties and support a more cautious interpretation of the modeled slip rates and kinematics.

REVIEWER :

Finally, there are a few issues with the figures. Faults are labelled on the zoomed-out Figure 1, but they are difficult to see at this scale and should also be labelled on Figure 2; for fairness, this should include faults studied in the literature but not used as block boundaries in the GNSS model (such as those bounding Baatar Hyarhan, discussed previously). Surface ruptures are essentially invisible in Figure 1 and should be shown more clearly perhaps on the more zoomed-in Figure 2; this includes those associated with the 2003 Chuya earthquake, which are well documented in Nissen et al.

(2007) but not plotted here at all. In addition, Figure 5 lacks a scale for the residual GNSS velocities.

AUTHOR RESPONSE :

We have revised the figures accordingly to improve their readability, in particular by adding surface-rupture labels, a residual-velocity scale, and clearer fault annotations. We have also clarified the corresponding figure captions.

REVIEWER :

References:

- Bayasgalan, A., Jackson, J. and McKenzie, D., 2005. Lithosphere rheology and active tectonics in Mongolia: relations between earthquake source parameters, gravity and GPS measurements. *Geophysical Journal International*, 163(3), 1151-1179.
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