

Solid Earth Discuss., referee comment RC1
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Comment on se-2021-22

Anonymous Referee #1

Referee comment on "An analytical solution for the exhumation of an orogenic wedge and a comparison with thermochronology data" by Elco Luijendijk et al., Solid Earth Discuss., <https://doi.org/10.5194/se-2021-22-RC1>, 2021

Dear Authors,

The authors do present an analytical approach to model the particle motion in an compressional orogen and estimate related thermochronological ages. The model does allow to efficiently change the boundary condition and therefore adjust to fit observed thermochronological data and make inferences about the importance of e.g. compression, detachment velocities and frontal and basal accretion.

Although I personally like the approach and acknowledge the effort the authors did to implement this model, I do not like the focus of the manuscript given the simplicity of the their model.

For further information see my scientific comments:

Scientific comments

- There is a quite similar approach as the one presented here for accretionary wedges (not including 'compression') (Batt et 2001), but this should be mentioned in the introduction and the similarities and differences should be discussed in detail. I would also like to see both approaches applied and visually compared, e.g. for an example without compression.
- I am not very happy how the authors simplify the thermal model, using a constant geothermal gradient (lateral and temporally constant), especially because they apply their model to the Himalayas, which is characterised by significant amount of horizontal and vertical rock motion. This does strongly perturb the thermal field, both laterally and also temporally. Although the authors show that they can fit the general age trend, that does not mean the model is correct.
- Similar to the thermal model, the calculation of thermochronological ages is oversimplified and should not be used for the purpose stated. There are numerous of recent studies demonstrating the strong impact of different cooling rates and radiation damage on thermochronological ages. In this regard, exhumation of the Himalayas does include movement above ramps and flats that should result in cooling rates to vary temporally and different amount of radiation damage to accumulate. I do not see any reason why not using available annealing and diffusion models and include them in this modelling approach (even if the thermal field is set constant, which I do not like).
- The oversimplified thermal model and calculation of thermochronological ages does not allow to use this model to be applied to a real dataset. Instead it might be used to study the general trend in thermochronological ages in active orogens, and study the different age trends related to the importance of compression, frontal and basal accretion. If this model, however, should be applied to real datasets, it is mandatory to include a more exact treatment of the thermal field and state-of-the-art calculation of thermochronological ages.
- The authors state that they fit the thermochron data along the Kuru Chu cross section better than McQuarrie and Ehlers (2015). The general trend is fitted by the authors, but it seems that McQuarrie and Ehlers (2015) do a better job in fitting the details of data between 0 to 80 km better. I would also like to ask the authors to contact McQuarrie and Ehlers to get the raw data instead of taken the values from a figure. Anyway getting a better fit with a simple model that does neglect part of the complexity of the geological setting, thermal structure and analytical method does not necessarily mean their model is correct. Indeed it is usually easier to fit data with a simple model, since it can be adjusted easily to optimize fitting. This is often time consuming if all available geological constraints and sophisticated thermal-kinematic models are used. However, even complex models do become computational more efficient and can be adjusted with efficient search algorithms and running models in parallel. Please add a little paragraph and explain the applicability of the different model setups and limitation associated with it.
- The authors state that because they can reproduce the general trend in ages in the studied profile with a steady-state assumption, the Himalaya might be in steady-state. Showing that one model is fitting the data does not mean that others model do not fit the data as well or even better. Since the presented model is only working in steady-state the authors cannot prove that steady-state is the best model to fit the data. What their model however can be used for, is to study the relative importance of e.g. frontal and basal accretion, detachment transport and compression, which the authors correctly discussed.

In summary, I would suggest the authors to change the focus of their manuscript and

state the drawbacks and benefits of such an approach. I do see the real application of such an approach in testing large-scale boundary conditions that can afterwards be used in more sophisticated model setups. I do not see that this approach can 'compete' or 'replace' approaches like that of McQuarrie and Ehlers (2015). I hope you find my comments and suggestions helpful and find more details in the technical corrections.

Technical corrections:

Line 3: State what you mean with exhumation, amount or rate?

Line 20: Change to 'fault blocks'.

Line 23-24: That is not correct a similar approach for accretionary wedges (frontal and basal accretion) has been published already in 2001 by Batt et al. Please cite their work and discuss the similarities and differences with your model.

Line 91: I guess it should be $v_{xc} = \dots$

Line 99: State that you also use Eq. 7 and use the normalized compression velocity.

Line 101 and 103: It is not clear why you are defining the horizontal and vertical components in Eq. 1-4, but not all equations are used in Eq. 8 and 9.

Line 106-107: Should be '...internal deformation and basal and frontal accretion...', this is what the figure captions says. In this case, shouldn't the velocity vectors decrease towards the interior of the model since the accretion is only occurring along the tip of the wedge and vectors should show divergence!?! The integral of the vectors along x should be similar along the wedge, or not?

Line 137-139: It is not clear why you do provide the 'simplified solution', please explain and if there are no good reasons, just do not show. Can you provide the difference between the analytical and the numerical solutions as figures, that would help the reader to check what you have wrote here (instead of showing the difference between the two provided analytical solutions). Maybe you only show the difference between the simplified

analytical (if you want to keep showing it) against numerical since the other one are nearly identical.

Line 165: A uniform geothermal gradient is really not what can be used in such setting. Depending on the model setup, and especially the horizontal and vertical rates the thermal field will be strongly perturbed. For instance do have a look on the cited manuscript from McQuarrie and Ehlers (2015) Fig. 1a).

Line 168: This approach is also much too simplistic especially since you do have significant horizontal particle motion and cooling rates of samples might vary significantly throughout their exhumation. This and the knowledge of the importance of the amount of radiation damage on He diffusion kinetics in apatite and zircon (e.g. Flowers et al. 2009; Guenther et al. 2013) has to be taken into account for the transformation of particle trajectories, cooling histories and final thermochron ages.

Line 208-209: Please provide details and justification how you calculate the misfit, what is the MAE? Your model indeed fits the general trend of the data, however, the details are better fitted by McQuarrie and Ehlers (2015), with the exception of data >100 km away from the frontal tip. You may want to mention this.

Line 209-210: Please ask the authors to provide the data, fortunately we do not need to digitize data from figures anymore!!!

Line 212: Please not that a model that fits data better is not automatically correct. The model of McQuarrie and Ehlers (2015) is based on numerous independent geological information that has been incorporated in a much more realistic model, but complex model. It is always easier to fit a simple model to data compared to complex model, but does that mean the simple model is more realistic, I would say not! There is a trade-off between complexity and fit to the data, your model and the one from McQuarrie and Ehlers (2015) are endmembers in this relation. From both model setups we can learn and they do have their eligibility. Please add a bit of this in your discussion and not just say your model is better...

Line 225: That orogens are in steady-state has been described already by others (e.g. Willett and Brandon 2003, Bernet et al. 2001) and that was highly discussed and even often this has been disproved by additional data and more in-depth interpretation (e.g. Michel et al. 2019). Since the thermal field of the crust is slow in responding to changes in the boundary conditions the resulting thermochronological data are often 'smooth' and the real/complex exhumation history is difficult to constrain. Fitting a steady-state pattern through data is therefore often easier compared to finding the real/complex exhumation history.

Line 239: What kind of steady-state do you mean, flux, exhumation, topography?

Figures:

Fig. 1: Can you draw a few more particle path and continue them to the surface. From the figure it is also not clear what is above the wedge, water, air? Also add 'erosion' below the precipitation on the surface.

Fig. 3: In caption change to 'Panel shows...'

Fig. 4: The heading of the panels are wrong, please correct.

Fig. 5: Use '5 Ma' instead of '-5 Ma'. Change panel d to Error between numerical and analytical solution.

Fig. 6: Change panel d to Error between numerical and analytical solution.

Fig. 7: Is the scale correct, I thought you speak somewhere from 200 km profile length. Looks shorter?

Fig. 8: What does MAE mean?