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Earth Surface Dynamics Discussions

Interactive comment on "Bias and error in modelling thermochronometric data: resolving a potential increase in Plio-Pleistocene erosion rate" *by* Sean D. Willett et al.

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Reply to comment esurf-2020-59-SC1

Although our paper (ESURF-2020-59) presents a number of models to illustrate the various errors in the GLIDE inversion, including resolution errors, model errors and their manifestations as spatial correlation bias or bias to the prior, van der Beek et al argue that these models are not adequate to provide a conclusive result and therefore offer their own examples (esurf-2020-59-SC1, Figures 1 and 2). However, these models were constructed using synthetic ages calculated using an incorrect geotherm, inconsistent with the thermal model included in the GLIDE model. We argued that

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this error is large enough to invalidate these models. Van der Beek et al. disagreed, arguing that the difference in boundary conditions was too small to account for the errors observed in their models (esurf-2020-59-SC1, lines 99-116). Relying on this contention, they presented an experiment in which they compared spatially uniform to spatially non-uniform data, where the difference was argued to illustrate the magnitude of the spatial correlation bias. From their comment, line 139:

COMMENT: “We illustrate the impact of the Bayesian prior bias alone with inversions that include data only from the NW side of the fault (Fig. 1 a-i) or only from the SE side (Fig. 1 j-l). As discussed above, when including only data from the rapidly but constantly exhuming NW side, the model returns constant rates or minor decelerations since 6 Ma (Fig. 1 a-i). The absolute rates depend on the employed prior, especially toward the edges of the model, where the resolution is lowest. A similar result (no acceleration) is obtained when only inverting data from the more slowly exhuming SE side of the fault, although in that scenario, the low resolution (< 0.25 everywhere) implies that both the 6-4 Ma and 2-0 Ma time bins largely revert to the prior erosion rate (Fig. 1 j-l). We illustrate the combined effects of the Bayesian prior bias and the spatial correlation bias for the synthetic western Alps case by including data from both sides of the fault and varying the uniform prior erosion rate (Fig. 2). These tests show that spatially variable exhumation rates add substantial bias to the inversion results (compare Fig. 1 and. Fig. 2). The bias in Fig. 2 contains elements of the Bayesian prior bias; the two biases are impossible to disentangle in areas of spatially variable exhumation. The compounded effects of both, nevertheless, are clear: accelerations occur when data from both sides of the fault are included in the inversion, regardless of the chosen prior erosion rate, suggesting a predominance of the spatial correlation bias. Furthermore, we see that by running an inversion with data from both sides of the fault, the resolution is higher on both sides compared to the resolution found when using data from only the NW or the SE (compare resolution 5 contours in Figs. 1 and 2). Thus, data are being combined from both sides to “better” constrain the exhumation history of each side, and that more highly resolved result produces the spurious increase we call the spatial correlation bias."

Although our models with correctly-calculated ages show little of the error they suggest is a spatial averaging effect, we thought it useful and more conclusive to reproduce their model juxtaposing the full data set and the half data set, but using ages calculated with the correct geotherm. Figure 1 below shows a reproduction of this experiment. There are three models in this experiment. All use a new data set that will be described in our revised paper, but is sparser than our data set A (esurf-2020-59, Fig. 5), but with data more uniformly distributed in space. The uniform spatial distribution is needed to distinguish between spatial averaging, which is maximum near the fault, from temporal averaging which is more uniform in space. A constant geothermal gradient model is used to eliminate geotherm model errors. The erosion rate function is identical to the Alpine model of Schildgen et al. (2018) and the van der Beek et al comment. We show all time steps from 0 Ma to 16 Ma to avoid the criticism that we provide preferential reference to specific timesteps. Ages in the low-erosion rate region go back to 30 Ma. The experiment compares an inversion using only the age data from the fast-uplifting side of the fault (NW) (Model 3) to models with data from both sides of the fault (Models 1, 2), with the argument that the difference between the two must be due to spatial averaging. The full data set models are shown in the left four columns. Two prior erosion rates are used, 0.35 mm/yr (Model 1) and 1.0 mm/yr (Model 2). Resolution and reduced variance do not depend on the prior erosion rate, so are applicable to both Model 1 and 2. The reduced data model (Model 3), using only the ages from the high erosion rate zone, is shown in the right three columns. We do not show the corresponding model with a prior of 1.0 mm/yr because it returns exactly and uniformly the true erosion rate of 1.0 mm/yr.

Models 1 and 2 are very similar to our models in esurf-2020-59, for example, Figures 6 and 9, but here are illustrated for a longer timespan, covering 8 time intervals. The high erosion rate region is well-resolved and accurate from 6 Ma to 0 Ma. At earlier times, there are significant errors in the model with the low prior, but very little error in the model with the high prior. This indicates that errors are a consequence of low resolution and bias to the prior, as confirmed by the low values of resolution, little reduction of the variance, and the sparsity of ages falling into or before these timesteps. The low-erosion rate region has low resolution everywhere, but is still reasonably accurate across all time intervals, as a consequence of having many old ages, which provide an integral constraint on the erosion rate.

Comparison between these models can be used to distinguish between low resolution errors with bias to the prior, and spatial correlation bias. Comparison of Model 1 and Model 2 demonstrates sensitivity to the prior model and thus resolution errors. Comparison between Models 1 and 3 shows spatial correlation errors. The solutions for the high-erosion rate region of Models 1 and 3 are very similar. The same first three time intervals are well-resolved and accurate. Solution accuracy begins to deteriorate at earlier timesteps, but both erosion rate and resolution in these two models are almost indistinguishable. There are differences, but these are limited to the immediate proximity of the fault (less than one correlation length). The region affected by spatial smoothing is indicated by red dashed lines in time interval 10-8 Ma. As in other models of our paper, the spatial correlation errors are largest where there are no data near the fault, indicating that the spatial correlation is not averaging age data so much as interpolating empty space between the data. Some spatial averaging error is there, but is small and limited to a smoothing effect directly across the fault. This error is also visible in the high prior model, again limited to immediate vicinity of the fault. There are much larger errors in the low erosion rate region, but these are resolution errors in Model 3, introduced by the removal of all data from this region.

These models are very different from the models shown in Figures 1 and 2 of the comment of van der Beek et al. Although the data sets are not equivalent in resolution (this is impossible to do), the data differences in terms of number and location of ages are not significant. The primary difference is that the van der Beek data contain errors due to the incorrect geotherm calculation. van der Beek et al. argued that this error is not significant, but this is clearly not the case. Their models contain large errors that cover most of their model domain on both sides of the fault, even for the case of ages restricted to the high erosion rate domain. We do not reproduce these errors. The errors that we do observe are mostly resolution errors and correspond well with low values of the resolution metric, and the small smoothing effect across the fault. The difference in result is conclusive; the models in Schildgen et al. (2018) and van der Beek et al. (esurf-2020-59-SC1) are dominated by their geotherm error and cannot be interpreted as demonstrating any other effect such as the spatial correlation bias. The correct quantification of “spatial correlation bias” is shown by the difference between columns 1 and 5 in our Figure 1, and is small and local to the fault.

This figure will be included in our revised paper, although to avoid lengthening the paper, we will put it in a supplement.

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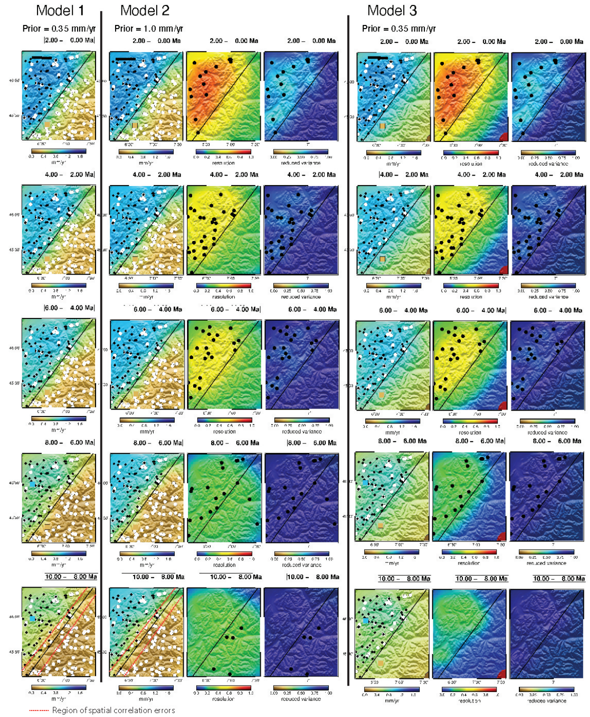

Fig. 1. Glide Models comparing data only from high uplift area and all data

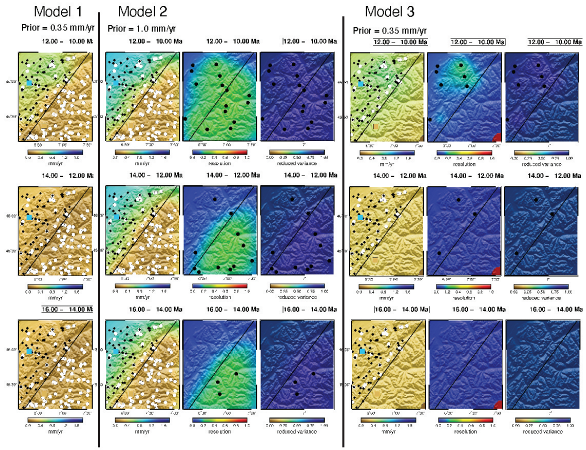

Fig. 2. Fig.1 continued

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