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Geoscientific Model Development Discussions

Interactive comment on "GLOBAL-FATE: A GIS-based model for assessing contaminants fate in the global river network" *by* Carme Font et al.

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We appreciate the thoughtful revision by Dr. Alberto Bellin, and want to make some precisions about our modelling strategy and additional clarifications that we think addresses the reviewer concerns.

First, we want to make clear that GLOBAL-FATE is not a revision or upgrade of the PhATE model, as the first comment by the reviewer seems to suggest. Although some assumptions and approaches are shared between GLOBAL-FATE and PhATE, and in fact with a number of other contaminant models, the development of our model has been totally independent of the former or any other contaminant model (except of course for the inspiration and guidance collected from all past work on large scale

modelling we found in the literature).

We totally agree that our modelling approach is simple, but we do disagree with the adjective "simplistic". We decided to work with such a simple model structure because we understand that working at global scales precludes any attempt to parameterize a complex model including a lot of processes, such as relationship with temperature or seasonality of releases. This is particularly true if the available information collected in the field is scarce, as it is the case. A limitation to the level of detail captured in GLOBAL-FATE is the need of consistent and complete datasets with global coverage and the variety of sources and unknown sampling methodologies that make difficult to use the data as reference datasets.

It is a piece of fundamental knowledge that any attenuation process in the river network depends on temperature one way or the other, but there are simply not enough data in the literature to parameterize this dependence at large scales. And the seasonality of releases, as modelled by GLOBAL-FATE, would need global, gridded information on seasonality of population. To the best of our knowledge, such a data product does not exist yet. All in all, our choices concerning model structure were not the result of a naive approach to the problem (and thus "simplistic"), but of a careful consideration of pros and cons considering the kind of questions we are anticipating to answer with a model like this and the information available to parameterize a model at such large scales.

There is no doubt that hydrology exerts a prominent role in defining pollutant concentrations in the river network, including seasonal variations. In fact, we already make this point clear in section 4 in the manuscript, where we discuss limitations of GLOBAL-FATE. However, working at annual, average streamflow conditions does not preclude the model being useful to answer many relevant questions concerning pollution in the river network. It precludes, for instance, to answer questions about the impacts of extreme events, although there is the possibility to run the model for different synoptic situations. We do not deny that seasonal and short-term hydrological variability is rel-

evant for contaminant transport, we simply do not intent to answer questions related to this variability with GLOBAL-FATE. Needless to say, the decision to work with annual averaged streamflow assuming steady-state was also related to the complexity and computing needs that come with a dynamical hydrological model working at daily or hourly time steps.

The model introduced by Diamantini et al. (2019) is a very fine work, and we agree that constitutes a basic antecedent that we must incorporate into the final version of our manuscript. It nicely incorporates time-varying forcing functions like population and hydrology. And, indeed, it links lakes and reservoirs with the river network. However, the fact that the authors simulated a small-medium watershed (12.000 km2) to exemplify the applicability of their model already shows which are the spatial scales for which this model has been conceptualized. In our opinion and making clear that we do not diminish in any way Diamantini and co-workers' approach, that we like very much, it is not fair comparing the complexity in terms of model structure of models devised to work at such diverging spatial and temporal scales. On one hand, we posit that applying Diamantini's model at the global scale using the same approach as in the original paper would imply a gigantic (and most probably unsuccessful) effort related to parameterization of the model and computing resources. On the other hand, we acknowledge that applying GLOBAL-FATE to answer the questions posed by Diamantini and co-workers in the Adige basin would be inappropriate.

We thank Dr. Bellin for his insightful comments on the spatial scales at which GLOBAL-FATE deliver meaningful and usable results. We agree that we were not particularly brilliant at this respect, as we introduced some ambiguity and vagueness that did not help to convey the message. This point arises from the fact that GLOBAL-FATE does not have pre-defined working scales, and the users can decide which data products to use to force the simulations. We already stated in the paper that GLOBAL-FATE outcomes depends on the available datasets, both in terms of quality and resolution. Considering that working resolution and input datasets are user-dependent in GLOBAL-FATE, the

criteria to assess model results quality and reliability are case dependent, and guidelines suggested in a given situation may not be convenient in all circumstances. Therefore, with the aim to be as conservative as possible, we stated in the discussion that: "we doubt that GLOBAL-FATE in its current formulation can be used for simulations at very local scales, like single watersheds". We were thinking in very small watersheds in the upstream sections of the river network, but we clearly added a lot of confusion here. We also stated that "Although this would depend on each model implementation, we suggest not using results from GLOBAL-FATE to draw conclusions below the country level". Clearly, this was too conservative, because we used GLOBAL-FATE to suggest patterns below the country level in the paper, and we are already drawing conclusions below the country level in non-yet-published applications of the tool. We included this statement to prevent users to draw conclusions at very local spatial scales (pixel) from GLOBAL-FATE applications using coarse resolutions (since the working resolution is user defined) and scarce supporting information, but again, in absence of a clear discussion of this topic this added even more confusion.

Considering this, we will rework the sections of the paper addressing this issue, to make clear that GLOBAL-FATE is not attached to a resolution nor to a data product, and because of this it is difficult to provide guidelines about working scales that would apply to any potential application. Therefore, a careful analysis of the outcomes and the implications of the spatial scale chosen is always a must. However, we understand the point of the referee when it comes to the example provided in the paper, and the revised version of the manuscript will include more precise indication of the spatial scales at which conclusions can be drawn. In particular, we will include an analysis showing the implications of working at the single-pixel scale in our example, consisting mainly in unrealistic very high concentrations in pixels draining small (1 or 2 pixels) watersheds in large urban areas (that would be connected to waterworks serving several pixels in most occasions). This effect greatly decreases when removing from the analysis all one-pixel and two-pixel watersheds, suggesting that the model results are unreliable when assessed in areas smaller than approx. 150km2. This roughly related to rivers

reaches of approx. 20km. We interpret this scale as the fundamental limitation of the GLOBAL-FATE model as applied in our example, clearly indicated by the available empirical information However, we also have to consider that beyond the limitation related to large urban areas and the lack of detail on water infrastructures, the application of GLOBAL-FATE in the examples includes other simplifications that do not leave such a conspicuous mark in the model output. For instance, consumption data is homogeneous at the country level, while variability inside large countries can be large (urban vs. rural, for instance). Also, we have averaged information on intensity of treatment also at the country scale, when this may change even at very local scales. Considering this, we do not want to oversell the former conclusion that GLOBAL-FATE can deliver meaningful results at a scale of 150km2 resolution. Although our analysis supports that the model delivers acceptable simulations at this scale, the comparison between observed and modelled values clearly indicates that there is high uncertainty that must also have a reflection in the spatial dimension.

For instance, we have an example of the limitations of our tool as implemented in the paper. This is the observed contaminant concentration along the main axis of the Rhine river (Fig. 1 in this revision). We can see that the model was able to spot a concentration increase at 300 km upstream the river mounth (in the sense that the model predicts an increase that goes beyond 100 ng/L, the basic thershold we were interested in). However, in the same basin close to the river mouth ($\sim$50 km) the model did not mimetize an increase in concentration beyond 100 ng/L.

FIGURE 1 HERE

Therefore, our opinion is that GLOBAL-FATE, as implemented in the example, should be used to answer questions which are general in nature. For instance, “contaminant concentration downstream large urban areas in Central Europe frequently exceeds 100 ng/L”, and related statements concerning remediation measures, for instance. We think that statements concerning particular places at or near the working resolution should be avoided (for instance “the remediation measures seem insufficient to lower con-

centrations below 100 ng/L downstream from Cologne”). However, we agree with the referee that the scale-free feature of GLOBAL-FATE is at the same time a strength and a limitation. However, to our understanding this limitation is not related to a fundamental flaw in the structure of GLOBAL-FATE, but just to the possibility that users may want to answer a given question using a spatial resolution and data products that could be inappropriate for that particular purpose, delivering misleading results and conclusions. Although this reasoning would apply to any modeling exercise, we understand the point of Dr. Bellin that claiming that GLOBAL-FATE is not tied to a particular resolution may promote bad modelling practices. Consequently, we will issue a warning in the paper to avoid improper applications using too coarse cells or poor/scarce information. In any case, we want to add at this point that the freedom that GLOBAL-FATE provides to choose the spatial scale also works in the other direction, that is, the user is free to work with a much finer resolution than the one used in the example.

Concerning the comment about the log scale used for comparing observed and modelled values, we had no other option considering that the magnitude of the errors was proportional to the modelled value. This effect in a modelling exercise spanning 3 orders of magnitude forced us to use the log scale for a proper calibration of the tool. Additionally, we spotted a typo in equation 19 that will be fixed.

We thank Dr. Bellin again for the nice revision, and we are happy to continue the discussion on the different aspects of the revision.

Carme Font and co-authors.

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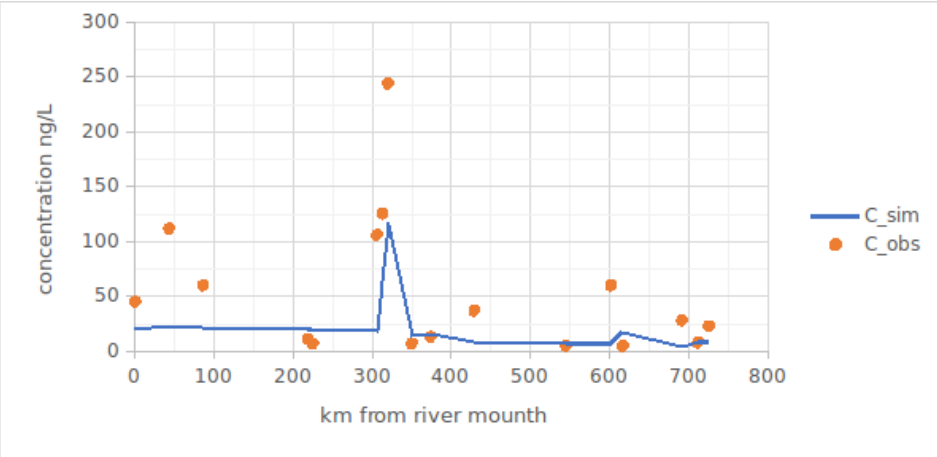

Fig. 1. Example of simulation along the Rhine river