

Dear editor, dear referee, dear EGU sphere,

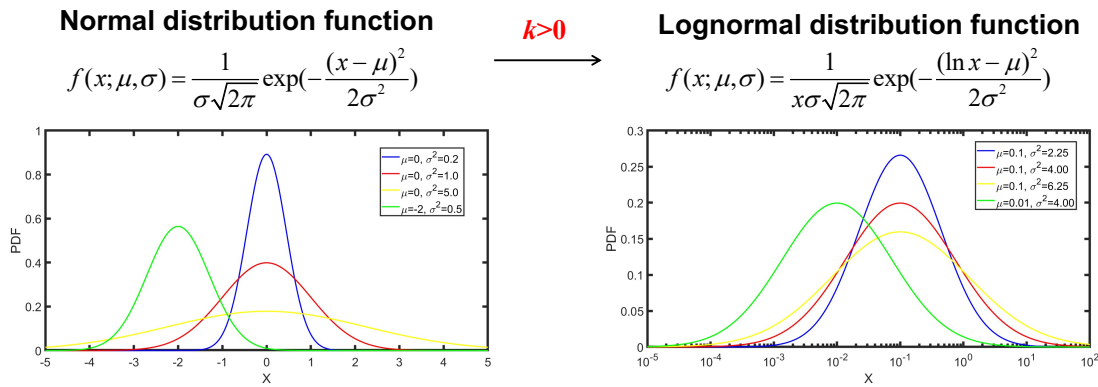
First, we would like to thank the referee for the time invested reviewing the paper, and the constructive comments and suggestions that were made. Here, we answer in detail some of the most important comments. We took notes of the other suggestions regarding language, or small additions.

**Question 1:** The mathematics is rather complex to understand, including terms as “gamma”-function and “lognormal”-function. According to Wikipedia: “In probability theory, a log-normal (or lognormal) distribution is a continuous probability distribution of a random variable whose logarithm is normally distributed. Thus, if the random variable  $X$  is log-normally distributed, then  $Y = \ln(X)$  has a normal distribution”. It should be thought through what physical meaning this has, i.e., what in the nature of a mix of organic matter gives rise to this function?

**Response:** Thanks for your valuable comments and suggestions. Based on the decay equation (Eq.1), reactive continuum models (RCMs) assume that OM compounds are continuously distributed over a wide range of reactivities and characterize the distribution of organic matter reactivity by a continuum distribution function.

$$\frac{dG}{dt} = -kG \quad \rightarrow \quad G(t) = G(0) \cdot e^{-kt} \quad (1)$$

Therefore, different continuum distribution functions can be selected to construct different RCMs. Statistically, the common continuum distribution functions include normal distribution functions, uniform distribution functions, exponential distribution functions, lognormal distribution functions, Kersey distribution functions, Gamma distribution functions, Rayleigh distribution functions, and Weber distribution functions. Considering the degradation process of organic matter, the  $k$  value in Eq. 1 must be greater than 0 ( $k > 0$ ), the distribution function used to construct the RCMs is preferably located on a positive semi-axial (Fig. 1, normal distribution (all-axial distribution,  $x \in (-\infty, +\infty)$ ), and lognormal distribution (semi-axial distribution,  $x \in (0, +\infty)$ )). Hence, some of the continuum distributions mentioned above are not appropriate for constructing RCM (e.g., normal distribution functions, uniform distribution functions, Kersey distribution functions, exponential distribution functions).



**Figure 1. Normal distribution and lognormal distribution**

Theoretically, lognormally distributed variables arise naturally from multiplicative processes (Limpert 2001). In other words, the process is generated by multiple variables in concert. The degradation of organic matter in marine sediments is controlled by several factors (e.g., the presence of electron acceptors, the presence of microbe, the conditions of hydrolytic enzymes), which coincides with the generation of lognormal distribution.

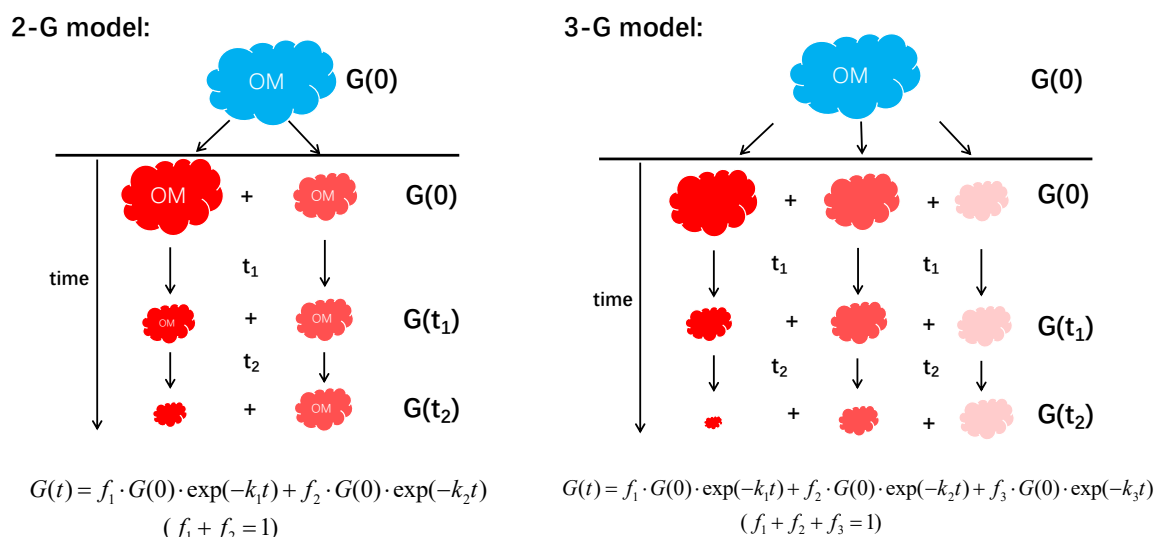
In fact, the lognormal distribution is widely observed in nature (e.g., the radioactivity of elements in the crust, the incubation period of infectious diseases, ecological species abundance). Some oceanographic studies show that the rates of ocean primary production and biological carbon export in the global ocean also follow the lognormal distribution. Moreover, inverse modeling of OM degradation data from 27 different types of litter, including leaves, wood, grass, and wheat, distributed across North America, ranging from the Alaskan tundra to the Panamanian rainforests, showed that OM reactivity followed a lognormal distribution. Based on the above, the lognormal distribution is suitable for characterizing the distribution of organic matter reactivity in marine sediments.

**Question 2:** It is understandable that microbial activity and abundance is ultimately controlled by the rate of decay of larger molecules via hydrolysis, then giving rise to a cascade of fermentation processes. While a single compound reacts with an exponential decay function (Berner, 1964), it has been the common tenet that a complex mixture of compounds results in an approximate power law decay function (see Tarutis, 1993). We

can therefore ask the heretical question why it matters, whether a gamma function or a lognormal function is used, if the physical meaning is anyway the one of power-law functions.

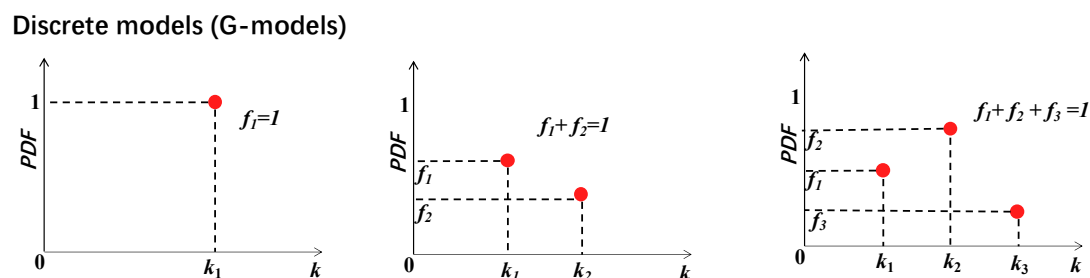
**Response:** Thank you for your suggestion. Here, we will elaborate on the differences between the G model and RCMs, and the advantages of RCM based on lognormal distribution (*l*-RCM) over the commonly used RCM based on Gamma distribution (*γ*-RCM).

In order to express the meaning of organic matter degradation model more clearly, we supplemented the schematic diagram, as shown in Figs.2- 4. Discrete models divide the bulk OM pool into a number of discrete fractions, and each fraction has its own constant reactivity. According to the decay equation, the OM degradation model can be expressed by Equation 1, and the schematic diagram is shown in Fig.1.



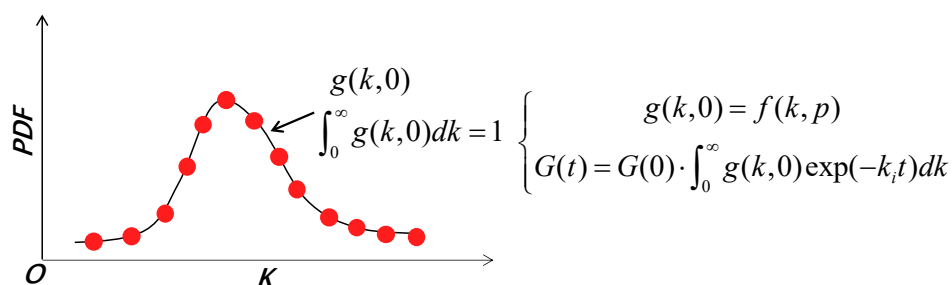
**Figure 2. Schematic diagram of multi-G modes (2G-model and 3-G model)**

Based on the Fig.1, we can map the reactivity of organic matter (*k*, *x*-axis) and its fraction (*f*, *y*-axis), which is shown in the Fig. 3.



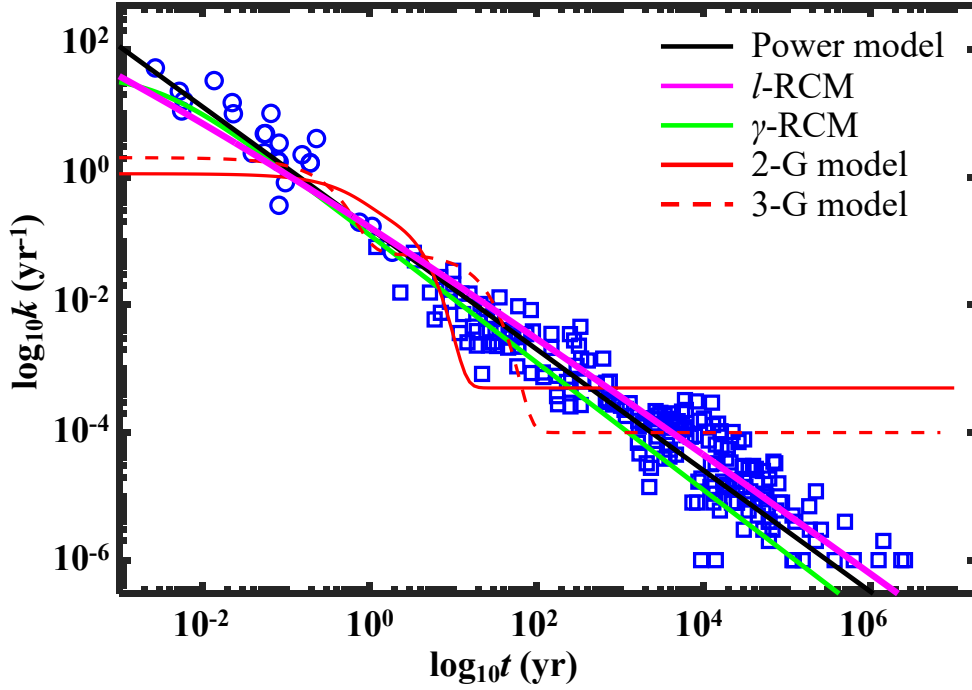
**Figure 3. Distribution of OM reactivity (x-axis) and their fraction (y-axis) in G-models**

Continuum model is an alternative to discrete model. Based on the assumption that OM compounds are continuously distributed over a wide range of reactivities, the reactive continuum models (RCMs) can be described by a continuous distribution function (Fig. 3).



**Figure 4. Distribution of OM reactivity (x-axis) and their fraction (y-axis) in RCMs**

The reactivity of organic matter showed an exponential decrease with time. However, The G model assumes that organic matter consists of a finite number of reactive components, and therefore cannot characterize the decline in organic matter reactivity ( $k(t)$ ) over time. As two horizontal lines at the earlier and later stages in multi-G model (Fig.5), the value of which is related to the choose of  $k$  in multi-G model. In the power model, an empirical relationship derived from a large number of datasets shows  $k(t) \sim t^{-1}$  ranging from over 8 orders of magnitude of apparent reactivity (Middelburg, 1989). By setting  $\nu=0.125$  and  $\alpha=0.0003$  in the  $\gamma$ -RCM (Boudreau et al., 2008) or  $\mu=0.3 \text{ yr}^{-1}$  and  $\sigma=6$  in the  $l$ -RCM,  $k(t)$  shows a similar result (Fig.5).



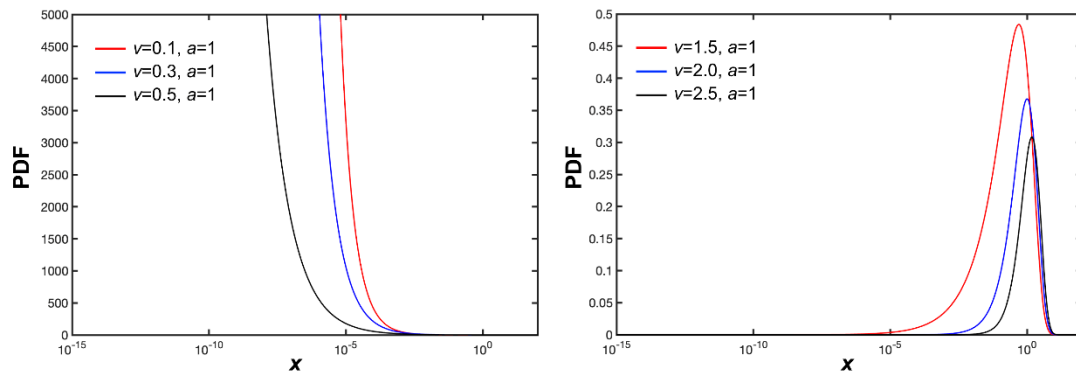
**Figure 5.** The relationship of organic matter reactivity ( $k(t)$ ) and time in different models. The data of laboratory experiments and field are summarized by Middelburg, (1989). The parameters 2-G model ( $k_1=2\times 10^{-1} \text{ yr}^{-1}$ ,  $f_1=0.68$ ;  $k_2=3\times 10^{-4} \text{ yr}^{-1}$ ,  $f_2=0.32$ ) are from (Luff et al., 2004).  $k(t)=0.16t^{-0.95}$  in power model (Middelburg, 1989) and  $k(t)=0.125/(0.0003+t)$  in gamma RCM (Boudreau et al., 2008).

The key to RCMs is to select an appropriate distribution function. At the current stage, the  $\gamma$ -RCM is usually used, where  $g(k,0)$  in the Fig.4 is the Gamma distribution function (Eq.2).

$$g(k, 0) = \frac{a^\nu \cdot k^{\nu-1} \cdot e^{-ak}}{\Gamma(\nu)} \quad (2)$$

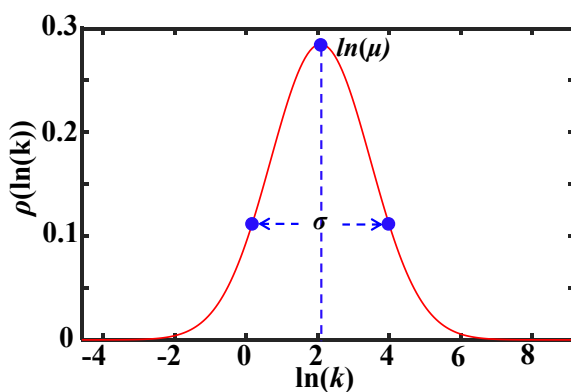
However, we found that the Gamma distribution function itself has some disadvantages in describing organic matter distribution.

For example, when  $\nu$  is less than 1, the Gamma function tends to  $+\infty$  at zero ( $x \rightarrow 0$ ), and when  $\nu$  is greater than 1, the gamma function tends to 0 at zero (Fig. 6). Given that the degradation process of organic matter simulated by RCM using Gamma function in two sites, the best simulation results at one site  $\nu$  values greater than 1 and the other one less than 1. Therefore, it is not feasible to use it to compare organic matter reactivity within these two sites. We have also discussed other disadvantages in Gamma function in detail in the **Section 3.1**.



**Figure 6. Gamma distribution function under different values of parameter  $\nu$**

In *l*-RCM, two parameters ( $\mu$ ,  $\sigma$ ) are used to describe the process of OM degradation. The position of the peak point  $\ln(\mu)$  is the most important factor for controlling its distribution range, and  $\sigma^2$  is the variance of  $\ln k$ . Fig.7 shows that the lognormal distribution does not exhibit different distribution characteristics as the gamma distribution when the parameters are taken with different values. Therefore, we can better compare the differences in organic matter reactivity at different sites by using parameters  $\mu$  and  $\sigma$  in the same axis.



**Figure 7. Schematic diagram of lognormal distribution**

Based on the above comparative analysis, we constructed the RCM using a lognormal distribution function.

Next, we will reorganize the above relevant description and add it to the main text of the revised manuscript. In addition, we will also fully consider other minor issues proposed by the Reviewer in the revised version.

## Preference

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- Middelburg, J. J., 1989, A simple rate model for organic matter decomposition in marine sediments: *Geochimica et Cosmochimica acta*, v. 53, no. 7, p. 1577-1581.