

Interactive comment on “The mechanism of sapropel formation in the Mediterranean Sea: Insight from long duration box-model experiments” by Jan Pieter Dirksen and Paul Th. Meijer

Anonymous Referee #3

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Review for “The mechanism of sapropel formation in the Mediterranean Sea: Insight from long duration box-model experiments”

This manuscript uses a box model to run transient simulations to investigate mechanisms of Sapropel formation in the Mediterranean Sea. The transient changes in the water cycle is based on changes in density calculated from salinity and temperature changes. Oxygen is also modelled and is used to estimate when Sapropel formation occurred. Typically modelling studies investigating Sapropel formation use a steady state or time slice approach based on defined conditions and do not consider long term

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transient changes in circulation due to computational limitations. The box model presented by these authors investigate the impact of transient changes over 20,000 years so I believe this manuscript would of interest to the Mediterranean scientific community.

Although I believe that this manuscript is a novel and important study, I have some concerns. Firstly, the authors do not split the Mediterranean into Western and Eastern basins. The straits of Sicily are an important constraint on the circulation of the Mediterranean Sea and the limitation of not including this barrier to deep water circulation is barely discussed. An interesting feature of Sapropels are that they are much more dominant in the Eastern rather than Western basin so I worry about the impact of not separating them. Secondly I believe that the oxygen model is too simple. The authors use two different constant fluxes to describe oxygen consumption and these are implemented as a step function with a different consumption rate when oxygen is more than and less than 60uM. In models oxygen consumption should be proportional to oxygen concentration with either a rate constant or something like Michaelis Menton/Monod kinetics rather than the step function used here. In addition, Powley et al. (2016) show that oxygen consumption in the Mediterranean varies depending on source of the organic matter reaching the deep ocean, which ideally would be included in the oxygen model. This is important as they show that the Mediterranean has a self-regulating mechanism whereby oxygen consumption decreases when deep water formation stops due to a lower amounts of DOC reaching the deep waters. More comments concerning this can be found in the detailed comments below.

In general the written English is good and understandable but I feel that the paper is poorly organised meaning that it is hard to follow what is happening. There are methods in results and results/methods in the discussion. I suggest that the reference simulation and subsequent scenarios are introduced in the methods section with the possibility of a table detailing each simulation. In addition I suggest having separate sections for the oxygen model and building of the water cycle. Finally I suggest that the authors go through the manuscript carefully checking that all acronyms and parameter

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names are clearly defined somewhere within the paper in addition to using consistent terminology for the boxes and inputs throughout. Can the authors also please cross check that all values and figures presented in the text match those in tables and figure numbers in the figure section as there were numerous times where there were inconsistencies.

Detailed comments

Section 1.2: Please can you include some of the conclusions from the modelling studies

Line 71: Please can you explicitly say which areas are in the high latitude marginal basins i.e. does this include the Adriatic and Aegean Seas.

Line 79: Similar to above please can you say the locations where D1 and D2 refer to

Line 128: What about river discharge from Europe? I assume Rhone and Elbe go into the open ocean?

Lines 122-134: You report both present day and historic values. What are you using in your model? It is not clear to me here. You also mention that changes from Europe are not included but then talk about changes from Europe?

Section 2.3: Please include somewhere here technical details on running the model. Which method do you use to integrate forward in time, what time step was used, how frequent was the model output?

Line 145: Here you describe c_{13} and c_{23} as an efficiency constant but in Table 1 is described as conductivity between boxes. Please can you either add more description to the text or be consistent in descriptions

Lines 146-149: I am struggling to understand what is happening here, mostly because the processes such as D2 were not explained as mentioned above and it all seems rather abstract. What do you mean assuming the DWF in box 2 is the same as box 1?

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Please reference the sentence "D2 does not occur annually"

Lines 216-219: The consumption rates for biotic and abiotic oxygen consumption are not the same as in Table 1. I also suggest defining the acronyms for the terms in the text (i.e. biological consumption = OCB). This would also make the terms in equation 22 easier to understand as you wouldn't constantly have to refer to Table 1.

Lines 216-219: Please briefly explain the biotic and abiotic processes. Why is there no biological oxygen consumption below 60 μM ? Typically oxygen consumption is described using Monod kinetics (i.e. Vichi et al. (2015), Powley et al. (2016), Testa et al. (2014)) so that it still occurs below 60 μM but is slower. This implemented step function will likely produce the non-linearity found in the model. Line 217-218: Please describe how the oxygen consumption changes with river outflow.

Equation 22: Please define R_{tot} . It is not mentioned in the text or Table 1. I assume it is total river flow which looking at the units for OCR might be in m^3/s ? If it is then O_{CR} would then have to be changed to $\mu\text{M}/\text{yr}$?. It is also not clear to me why the oxygen consumption is divided by dt when over 60 μM .

Line 225: Initial water temperature? Or water plus air?

Line 229: What are TA_1 , TA_2 and T_0 ?

Line 231: Where are the winter air temperatures taken from?

Line 233 - 265: Before my next comment I wish to say that I am not used to reading model equations in matrix format, I am used to them as ODEs. However, I found it hard to follow this section and found description of the various matrices were poorly described in some cases, for example what is matrix F or matrix M? In regards to Equation 29, if written in matrix format I would like to see in words what the equation means because as it stands I am not following what is happening and cannot check simple things like units are correct. As a more general comment, I feel it may be better to put this section describing the matrix equations at the beginning of section 2.3 and

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then explain what how the fluxes and parameters are calculated afterwards.

Section 3: I suggest explaining the different runs in the methods section and potentially having a table describing each simulation and the model setup used.

Lines 268-276, 332-339 etc: The forcings applied to the runs should be described in the methods section, not here

Line 320-321: Which value is observational and which is from the model? Please reference the observational data

Line 343-345: "we find a sapropel from t=2900 years to 6500 years". I don't see this in figure 4E as O2 looks low from around 7000 to 12000 years. In fact to me figure 4E looks remarkable similar to the reference run and I would suggest that you may look zoom into the mark around 60uM for oxygen concentration. This also means that the conclusion that the addition of atmospheric temperature variability in the model has a large impact on Sapropel formation could be wrong.

Line 365: I can't see evidence of a positive freshwater budget in Figure 5A.

Line 365-366: "the maximum outflow of river 1 is increased from 6.7 .103 to 1.4 .104 ." In the reference simulation the maximum outflow of European rivers (I assume R1?) was 1.2×10^4 , so I don't understand: a) where 6.7 comes from and b) how this is different from the reference simulation. I can't see any noticeable differences in R1 between Fig 3A and Fig 5A either

Line 416: What do you mean by irregularities?

Lines 448-454: This should be in the methods (or maybe results), not opening the discussion.

Lines 456-464: The model timestep is not mentioned in methods so it rather comes out of the blue discussing it here. Also be specific in the writing. Temporal resolution of what? Model outputs or model timestep?

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Line 470: "Main hypothesis". What is your main hypothesis? This is not stated clearly either here or in the introduction.

Line 483: Please describe the two different mechanisms

Line 509: "A simple threshold analysis will not suffice either". Please explain what you mean by a threshold analysis. Surely the method you are implementing with oxygen is a threshold analysis?

Line 525-527: In the introduction you say Sapropels are caused by African monsoon whereas here you are saying that other mechanisms can cause them. Please clarify in the introduction and go more into depth of different mechanisms and hypotheses for Sapropel formation.

Line 529: Please can you quantify "within values", i.e. explicitly compare values in the literature with what you found.

Line 537: What do you mean by strait efficiency?

Line 539: Please explain what you mean by alternative regimes

Figures:

Figure 2: Please move to end of paper in line with when it is mentioned in the text.

Figures 3-6: Please label panels with A,B C, D and E. Please explain for what boxes E-P and E-P-R represent. It would be nice rather than use box 1, 2 etc, you could use marginal , open ocean etc and then it would match up with the text. I also suggest using the same scaling for axes across figures to make comparison between figures easier, for example the scale on the axis for outflow changes in Figure 6A compared to Figure 3A.

Minor Comments

Line 122: suggest putting R2 in brackets after box 2 for clarification

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Line 218: Add additional bracket after 2016

Line 295+304: Fig 3E rather than Fig. 3D?

Line 301: I assume "it " is oxygen concentration? Be specific

Line 273: Suggest putting R2 after Nile outflow for clarification.

Line 354: increase rather than increases

Line 370: Fig 5E rather than D?

Line 380: "Deep water oxygen largely behaves as the total DWF". I do not understand this sentence. Please rephrase.

Line 422: "subsection 3.2" The caption for Fig 7 says subsection 3.1

Line 456: annual resolution of what? model outputs?

References

Powley, H.R., Krom, M.D., Van Cappellen, P. (2016) Circulation and oxygen cycling in the Mediterranean Sea: Sensitivity to future climate change. *Journal of Geophysical Research:Oceans*, 121, 8230-8247, doi: 10.1002/2016JC012224.

Testa, J. M., Y. Li, Y. J. Lee, M. Li, D. C. Brady, D. M. Di Toro, W. M. Kemp, and J. J. Fitzpatrick (2014), Quantifying the effects of nutrient loading on dissolved O₂ cycling and hypoxia in Chesapeake Bay using a coupled hydrodynamic–biogeochemical model, *J Mar Syst*, 139, 139158, doi: 10.1016/j.jmarsys.2014.05.018

Vichi, M., T. Lovato, P. Lazzari, G. Cossarini, M. E. Gutierrez, G. Mattia, S. Masina, W. J. McKiver, N. Pinardi, C. Solidoro, L. Tedesco, and M. Zavatarelli (2015), The Biogeochemical Flux model (BFM): Equation Description and User Manual. BFM version 5.1. BFM Report Series N. 1, Release 1.1, August 2015 Bologna, Italy, <http://bfm-community.eu>, pp 104

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