REVIEWER #1

This review on sea level rise in Europe will be a very good reference for sea level scientists and users of sea level information. It is generally clearly written and covers all the important information. It is very long, to be completely honest I didn't get the stamina to read it all. I did not read sections 6.3, 6.4 and Box 2 so I hope that the other reviewer will cover these regions which I am less familiar with. I have a suggestion to make the review a little shorter (see detailed comments below) but almost all the material covered is relevant. I have no major comments on the review but I have many small comments to help improve it.

We warmly thank the reviewer for the time spent reviewing the manuscript, for her/his careful reading and constructive comments. We reply to each comment below in blue.

Comments on figures 14-18:

Please note that Figures 14-18 are now corresponding to Figures 15-19 in the revised manuscript.

- A "reconstructed" sea level time series is provided but no explanation for what it means is provided. Only a reference. I think this should be explained otherwise readers need to go to Dangendorf et al. 2019 to understand.

Thank you for the suggestion. As the second reviewer also requests more information on the reconstruction, we follow these recommendations and introduced a description of the global reconstruction of global mean sea level changes at the beginning of section 6.

- Which reference period is used to compare the time series? For the projections it is probably 1995-2014 which is the reference period of AR6 but it does not seem the be the case for the reconstructed sea level.

The vertical reference of the reconstructed sea level has been adjusted to match projected mean sea level records, as it is arbitrary (in the same way as tide gauges vertical datum). This is now specified in the introduction of section 6. Captions of Figures 15-19 (formerly Fig 14-18) have been updated.

- I don't think it is a good choice to add one tide gauge per basin in the same plot as the basin means. One can't help but compare the past and the projections and see some clear mismatches for some tide gauges. I suggest that if individual tide gauges are shown, they are compared with projection for this particular location, not basin average.

Fig 15-19 were redone without tide gauge records.

- It would be useful to have mean sea level changes for the coast of this region in Figure 14-18 in the same format as panel b and c.

We thank the reviewer for this suggestion. However, mean sea level changes for Europe are shown in Fig 6 and we chose to not replicate the information with an extra panel in Fig 15-19.

Abstract:

"Absolute sea-level change" -> I think geocentric sea-level change is now the standard terminology

Indeed, following Gregory et al. 2019. "Absolute sea level" has been replaced by "geocentric sea level" throughout the paper. To ease understanding of readers, it has also been defined in the introduction (first occurrence of "geocentric sea level" in the main text):

"In many coastal megacities, including European ones, VLM can induce relative SL trends similar to or larger than trends induced by oceanic and climate factors causing geocentric SL changes (Gregory et al. 2019, aka absolute sea level changes) (e.g., Nicholls et al., 2021; Wu et al., 2022)."

Introduction:

l.61-62: References are needed to support those numbers.

Indeed, we added a reference to Neumann et al. 2015. Numbers are given in their Table 5.

Neumann, B., Vafeidis, A. T., Zimmermann, J., and Nicholls, R. J.: Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment, PLOS ONE, 10, e0118571, https://doi.org/10.1371/journal.pone.0118571, 2015.

l.90: "contemporary solid Earth deformation due to land ice mass loss" would fit better in the anthropogenic category than the natural one.

As stated in IPCC AR6 (Fox-Kemper et al., 2021) "the SROCC reported limited evidence and medium agreement for anthropogenic forcing of the observed AIS mass balance changes. As stated in Section 3.4.3.2, there remains low confidence in attributing the causes of the observed mass of loss from the AIS since 1993, in spite of some additional process-based evidence to support attribution to anthropogenic forcing.".

Regarding the Greenland icesheet, IPCC AR6 states that: "The AR5 assessed that it is likely that anthropogenic forcing has contributed to the surface melting of Greenland since 1993 (Bindoff et al., 2013). Section 3.4.3.2 assesses that it is very likely that human influence has contributed to the observed surface melting of the Greenland Ice Sheet over the past two decades. There is medium confidence of an anthropogenic contribution to recent mass loss from Greenland.".
To avoid categorizing VLM due to the contemporary mass loss of ice sheets and mountain glaciers into either a natural or an anthropogenic origin, the sentence *"At more coastal scales, relative SL changes can be due to VLM of natural (e.g., sediment compaction in deltas, Earth tectonics, GIA) and anthropogenic origins (e.g., pumping of groundwater, weight of the built environment, solid Earth deformation due to contemporary land ice mass loss)." has been rephrased to:*

"At more coastal scales, relative SL changes can be due to VLM of natural and anthropogenic origins (e.g., sediment compaction in deltas, Earth tectonics, GIA and solid

Earth deformation due to contemporary land ice mass loss, pumping of groundwater, weight of the built environment)."

l.98 and l.106: What are those references? Sea Level Rise in Europe: knowledge gaps identified through a participatory approach, Sea Level Rise in Europe: A Knowledge Hub at the ocean-climate nexus.

These two references are two companion papers from the Knowledge Hub on Sea Level Rise Assessment Report (Special Issue of State of the Planet: https://sp.copernicus.org/articles/special_issue1286.html)

Jiménez, J. A., Bonaduce, A., Depuydt, M., Galluccio, G., Van Den Hirk, B., Meier, H. E. M., Pinardi, N., Pomarico, L. G., Vazquez Riveiros, N., and Winter, G.: Sea Level Rise in Europe: Knowledge gaps identified through a participatory approach, https://doi.org/10.5194/sp-2023-34, 2023.

The second paper: "Sea Level Rise in Europe: A Knowledge Hub at the ocean-climate nexus" is expected to be submitted. As this is not yet the case, the reference to this paper has been removed from our manuscript.

l.99: I don't think the concept of European Union (EU) is relevant to this review since the focus on Europe as a geographic continent rather political union.

Indeed. The text has been reformulated to:
"European regional seas (see Jimenez et al., 2023) and their bordering coasts along Europe are presenting contrasting environment (...)"

3 Regional observations

Figure 5: Was the data adjusted for GIA and TOPEX-A instrumental drift? This information is given in the caption of figure 6. I think it would be useful here as well.

The caption of Figure 5 has been updated notably to include this information.

Figure 6: Consider using a map projection that deforms less the area

The projection has been changed to match other maps in the manuscript.

l.318: "In Europe, sea level trends are slightly above the global mean rate, on average (Figure 6)."
I think this claim needs more foundations. Especially since it is also in the abstract. Which area is chosen here to represent Europe? What is the rate?
Given the large spacial difference between the Baltic Sea (~5mm/yr) and the Mediterranean Sea (~2mm/yr) I wonder if it is very useful to make conclusions about the European average.

That is right. The sentence is changed to *"In Europe, since 1993, geocentric sea level trends have been contrasted with high sea level rise in the Baltic Sea (see section 6.5 and Fig 7 for relative sea level rise in the Baltic), low sea level rise in the Mediterranean Sea and a sea level rise close to the global mean rate, in the Atlantic sector (Figure 6)."*

l.341: What is meant by “general circulation” here? Is it the ocean circulation in the Mediterranean Sea?

Yes, we reformulated this sentence:

“Strong differences in SL trends at the sub-basin scale are also recognized in the Mediterranean (...), in which variability and complexity arise from changes in ocean circulations.”

l.356: “The annual cycle amplitude ranges from 40 cm to 100 cm”
I think this is a typo, it should be mm instead of cm.

Additionally, Dangendorf et al. 2013 found mean amplitude of the seasonal cycle of 14 to 20 cm along the German Bight which indicates that the range provided here is too narrow.

Dangendorf, Sönke, Thomas Wahl, Christoph Mudersbach, and Jürgen Jensen. “The Seasonal Mean Sea Level Cycle in the Southeastern North Sea.” Journal of Coastal Research, no. 65 (10065) (January 1, 2013): 1915–20. https://doi.org/10.2112/SI65-324.1.
Thanks, this has been corrected:

“The annual cycle amplitude ranges from around 5 cm to 12 cm with the largest amplitude found in the North Sea, Baltic Sea, along the Arctic coast of Norway and in the western Mediterranean Sea (Fernández-Montblanc et al., 2020; Ray et al., 2021), going up to 20 cm in the German Bight (Dangendorf et al. 2013).”

4 Drivers of sea level rise and extremes

l.426-437: This paragraph is important but it is too vague at the moment. It would benefit from some numbers. How much does a melting to Greenland resulting in 1cm GMSLR influences the European coast? Same for Antarctica. For Greenland the influence is so different between North-West and South-East Europe that general sentences like “If the contribution from Greenland increases in the future, this has not very large consequences for European coasts, …” can be misleading.

We have further specified the difference between Southern and Northern Europe with respect to the Greenland contribution.

Additionally, only gravitational effects are mentioned here, why not discuss also solid earth deformation, which is very important for the influence of Greenland mass loss, and rotational effects?

We have added the sentence “*This contemporary GRD effect is sometimes referred to as a sea level fingerprint”* to make it clear than this is a GRD effect. For most of Europe it is the long wavelength signal of the gravity change that is important – which is why that is the focus of this section.

For some areas of Europe, notably the higher latitudes, the elastic Earth response to Greenland ice loss is important. This is discussed in the Section which covers the European Arctic (section 6.3), where we note the elastic uplift signal can be significant.

The next paragraphs of 4.1 are rather detailed but do not provide regional information and do not have a high added value compared to IPCC AR6 except that they are updated. So I would consider removing them.

The first of the two paragraphs explains which processes are important for the possibility of enhanced mass loss from Greenland. We don't reckon it is discussed as such in the AR6 report and decided to keep it because it provides a physical reasoning as to why the Greenland contribution can increase by a factor of two in the future.

The second paragraph explains that ice shelves play a critical role for the contribution of Antarctica to sea level rise. This is not described explicitly in AR6 and deserves highlighting in the context of future SLR in Europe, which is an essential part of the paper.

l.481: "will be dominate" -> will dominate

Thanks, corrected to: *"For some shelves, atmospheric process will dominate while for other shelves, oceanographic controlled processes will dominate."*

5 Projections of sea level rise and extremes

l.498: "the amount of outgoing radiation amount"

Thanks, typo corrected.

Figure 11 is for the whole world but in the caption it is written Europe. I think it would be better to zoom in on Europe.

Indeed. Fig 11 was redone with a zoom on Europe only.

l.681: "with consequences for enhanced SLR in the early 21st century" should be 22nd century

Thanks, corrected.

6 Key developments per region

6.1 Atlantic Ocean

L.810-816: This whole paragraph is missing references. In which paper was the slope current described? The upwelling?

Thank you for noting it. References were added:
"A slope current flows northward along the continental slope separating the deep ocean from the continental shelf (Huthnance and Gould, 1989; Clark et al. 2022). Strong summer upwellings of deeper, colder water occur along the coasts of Portugal (Fiúza, 1983)."

Huthnance, J. M. and Gould, W. J.: On the Northeast Atlantic Slope Current, in: Poleward Flows Along Eastern Ocean Boundaries, edited by: Neshyba, S. J., Mooers, Ch. N. K., Smith,

R. L., and Barber, R. T., Springer New York, New York, NY, 76–81, https://doi.org/10.1007/978-1-4613-8963-7_7, 1989.

Clark, M., Marsh, R., and Harle, J.: Weakening and warming of the European Slope Current since the late 1990s attributed to basin-scale density changes, Ocean Sci., 18, 549–564, https://doi.org/10.5194/os-18-549-2022, 2022.

Fiúza, A. F. G.: Upwelling Patterns off Portugal, in: Coastal Upwelling Its Sediment Record, edited by: Suess, E. and Thiede, J., Springer US, Boston, MA, 85–98, https://doi.org/10.1007/978-1-4615-6651-9_5, 1983.

This quote is also ambiguous without references: “On the continental shelf ocean dynamics are characterized by shorter timescales and spatial scales,” Especially the spatial scale. Since ocean meso-scale eddies can’t get on the shelf.
This sentence was notably referring to the fact that the dominant spatial scale of baroclinic ocean mesoscale eddies (characterized by the first baroclinic deformation radius, e.g., Stammer, 1997; Chelton et al., 2011; Klocker and Marshall, 2014) is smaller on the shelf than in the deep ocean as it scales with the buoyancy frequency integrated over depth (Chelton et al., 1998; Hallberg et al., 2013; Lacasce and Groeskamp, 2020).

However, we modified this sentence to rather highlight the importance of coastal processes: *“On the continental shelf, higher frequency processes have a more leading role on sea level variability (e.g., Woodworth et al. 2019) and can lead to sea level variability of larger amplitude (due e.g., to tides, storm surges). Although spatial scales of ocean mesoscale dynamics are smaller on continental shelves than in the deep ocean (e.g., Chelton et al., 1998; Hallberg et al., 2013; Lacasce and Groeskamp, 2020), sea level along north-eastern Atlantic European coasts northward of 25°N can also be coherent over thousands of kilometers at decadal timescales (e.g., Calafat et al., 2014), related to coastally trapped waves (Hughes et al., 2019). Along-shore wind forcing is a major contributor to such coastal sea level variability (Calafat et al., 2012).”*

Stammer, D., 1997: Global characteristics of ocean variability estimated from regional TOPEX/POSEIDON altimeter measurements. J. Phys. Oceanogr., 27, 1743–1769, https://doi.org/10.1175/1520-0485(1997)027,1743:GCOOVE.2.0.CO;2.

Chelton D., R. Deszoeke, M. Schlax, K. El Naggar, and N. Siwertz, 1998: Geographical variability of the first baroclinic Rossby radius of deformation. J. Phys. Oceanogr., 28, 433–460, https://doi.org/10.1175/1520-0485(1998)028<0433:GVOTFB>2.0.CO;2

Hallberg, R., 2013: Using a resolution function to regulate parameterizations of oceanic mesoscale eddy effects. Ocean Modell., 72, 92-103, https://doi.org/10.1016/j.ocemod.2013.08.007.

LaCasce, J. H. and Groeskamp, S.: Baroclinic Modes over Rough Bathymetry and the Surface Deformation Radius, Journal of Physical Oceanography, 50, 2835–2847, https://doi.org/10.1175/JPO-D-20-0055.1, 2020.

Hughes, C. W., Fukumori, I., Griffies, S. M., Huthnance, J. M., Minobe, S., Spence, P., Thompson, K. R., and Wise, A.: Sea Level and the Role of Coastal Trapped Waves in

Mediating the Influence of the Open Ocean on the Coast, Surv Geophys, 40, 1467–1492, https://doi.org/10.1007/s10712-019-09535-x, 2019.

l.850: "skew surge" is not defined in the paper. I don't think many users of sea level information know what it is.

We added a definition of skew surge when it is first introduced:
"A skew surge is the difference between the maximum observed sea level and the maximum predicted tide regardless of their timing during the tidal cycle – there is one skew surge value per tidal cycle (Pugh and Woodworth, 2014)".

Pugh, D. and Woodworth, P.: Sea-level science: understanding tides, surges, tsunamis and mean sea-level changes, 2nd ed., Cambridge university press, Cambridge, 2014.

l.854: MSL is not defined. Actually in the rest of the text mean sea level is written instead of the acronym.

MSL has been expanded to mean sea level.

l.860: decreased amplitude over which period? The previous sentence says that the trend depends on the period.

This sentence has been rephrased to specify the period:

"An analysis of tide gauges with at least 25-yr of data since 1960 indicates that the amplitude of extreme skew surges tends to have decreased along the north-eastern Atlantic coast (Marcos and Woodworth, 2017)".

l.880-883: Since this review is about sea level, I would suggest to either mention the relation between those ocean circulation changes and sea level or not mention them as all. I also wonder if it is useful to catalogue papers that did downscaling without mentioning important conclusions. If there was important information for sea level then write it down explicitly otherwise do not cite the papers.

The text has been modified: *"Sterodynamic SLR, which includes global mean thermal expansion of the warming ocean, steric and dynamic SL changes induced by ocean circulations (Gregory et al., 2019) remains the dominant contributor to total SLR along the European Atlantic coast. Regionally downscaled projections of SL changes over parts of the north-eastern Atlantic have been produced (Gomis et al., 2016, Hermans et al., 2022, Chaigneau et al., 2022). Hermans et al. (2020) and Chaigneau et al., (2022) have demonstrated the influence of dynamical downscaling on projections of dynamic SL over the 21st century for the northwestern European region. Hermans et al. (2020) have found that projected changes in dynamic SL in the downscaled simulations are up to 15 cm lower than in the GCM simulations for the RCP8.5 scenario. These differences are notably observed in the Celtic Sea, which is poorly resolved in the coarse resolution GCMs. In Chaigneau et al., (2022), the impact of the regionalization on ocean dynamic SL projections is weaker due to forcings from a higher resolution GCM, including more spatial details. In the same study, the impact of bias correcting the GCM ocean* *and atmospheric forcings on the regionally downscaled ocean dynamic SL projections is also highlighted."*

6.2 North Sea

l.999-1001: It is not clear which contributions this refers to and how this paragraph is linked to the previous one.

This paragraph has been rewritten to:

"Changes in water depth and other non-astronomical factors, such as changes in stratification and large construction measures, affect tides along the North Sea coast (e.g., Jänicke et al., 2021; A. Jensen, 1984; J. Jensen and Mudersbach, 2007; Mudersbach et al., 2013; P. Woodworth et al., 2017), including in estuaries (e.g., Amin, 1983; Keller, 1901; Jiang et al., 2020) and harbors (e.g., Doodsen, 1924; Marmer, 1935; Schureman, 1934; Vellinga et al., 2014). However, a comprehensive and generalized analysis is still missing."

6.5 Baltic Sea

l.1282-1283: What does "energetically insignificant" mean? The question to answer here is: what is the impact of seiches on sea level variability?

We have expanded the text: *"Seiches are not detectable as a peak in the spectrum. Combined with storm surges, seiches can lead to extreme compound events (Weisse et al., 2021)."*

l.1296-1306: In this paragraph there is no reference to Figure 6 with the trend in geocentric sea level from satellite altimetry while the Baltic Sea really stands out in that figure as the region with the largest rate of sea level rise, with most places rising faster than 5mm/yr. I think this should be discussed in this paragraph.

We added the reference to Figure 6. The following sentence explains why sea level rise in the Baltic Sea is probably larger than in the North Atlantic and elsewhere: *"Over the last 2-3 decades, global mean sea level rose at rates of 3-4 mm yr-1 (Oppenheimer et al., 2019; Weisse et al., 2021; Section 2.2; Figure 6). However, such rates are spatially non-uniform and include impacts of multidecadal variations in wind fields (Passaro et al., 2021)."*

l.1307: "no long-term rising trend was found for ESLs in the Baltic Sea compared to mean changes" I don't understand the logic of this sentence. Why "compared to mean changes"?

We revised the sentence: *"For the 20th century, ESLs in the Baltic Sea will probably not rise more than global mean SL."*

l.1320-1321: "Therefore, projections for this basin require high-resolution regional climate models". I think it would be useful to separate projection of MSL and projections of ESL. In lines 1285-1286 it is written "On time scales longer than 1 month, the mean sea level in the Baltic Sea approximately follows the sea level in Kattegat, outside the Baltic Sea" which would imply that there is no need for models to resolve the complex local physical processes to get the long term MSL projections right. It would be useful to clarify this contradiction.

We modified the sentence *"Therefore, projections of ESLs for this basin require high-resolution regional climate models."*

l.1329: “will approximately rise by about 87% of the global mean rate”. This is a good one. If it is “approximately” and “about” then the very precise number is not appropriate.

Thanks, we modified the sentence to: *“will rise by about 90% of the global mean rate”.*

Conclusion

l.1484: Two “Finally”

Thanks, corrected.

« A major uncertainty for SLR remains attached to ice sheets instabilities and overall contributions, and more robust projections beyond 2100 are needed. Finally, the interpretation of regional SLR variations for local perceptions and decision making is also an area needing improvement. »