ILMATIETEEN LAITOS
METEOROLOGISKA INSTITUTET
FINNISH METEOROLOGICAL INSTITUTE

D1.1.1 A literature review on future global mean sea level rise and ice-sheet instability

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20.12.2023

MAWECLI (MArine and WEather events in the changing CLImate as potential external hazards to nuclear safety) project

in the SAFER2028 Programme

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Abstract

In this literature review, we familiarized with the most recent article on mean sea level projections for the Finnish coast (Pellikka et al., 2023), which takes into account the accelerating global mean sea level rise (GMSL) as well as the internal Baltic Sea characteristics (post-glacial land uplift and the Baltic Sea water balance). Considering the range of different emission paths, the following mean sea level change up to 2100 is expected on the Finnish coast: -40 cm to +10 cm for the Bothnian Bay, -40 cm to +40 cm for the Bothnian Sea, and 0 cm to +60 cm for the Gulf of Finland. Because of the large uncertainties, sea level rise exceeding one meter cannot be ruled out.

In addition to the publication targeted for the Finnish coast, we reviewed 9 recent studies related to melting of the large ice sheets in Antarctica and Greenland, and their contribution to GMSL rise. These articles (Stokes et al., 2022; Hill et al., 2023; Reese et al., 2023; Grinsted et al., 2022; Bamber et al., 2022; van de Wal et al., 2022; Naughten et al., 2023; Horton et al., 2020; Box et al., 2022) utilized various methods, timespans and likelihood ranges, thus direct comparison between the study outcomes is not reasonable. However, we may summarize from the articles following larger-scale findings: 1) Future ocean warming and ice sheet melting in the Amundsen Sea area are expected to be markedly larger compared to the past behavior, 2) The West Antarctic Ice sheet (WAIS) is the main contributor to the global sea level rise by 2100, 3) Marine ice sheet instability (MISI) process is not ongoing currently in WAIS, 4) Western parts of Greenland are contributing to the sea level rise more than the eastern regions of the ice sheet, 5) Rates of sea level rise in projections based on models are smaller compared to the observed sea level rise rates, and 6) The most important uncertainty source related to GMSL rise projections is ice sheets, particularly the unknown response of Antarctica in a warmer globe.

1. Introduction

This report is part of MAWECLI task T1.1 (Coastal floods), which aims to sharpen extreme sea level estimation along the Finnish coast by 1) studying ice-sheet instabilities to understand better the behavior of the high tail of the mean sea level projections, 2) by exploiting newest climate model data on assessing wind and air pressure driven sea level variability in the future climate, and 3) by making use of non-stationary and process-based modelling on sea level observation data. In this document, the findings of the first point are presented by exploring and summarizing most recent scientific research.

Antarctic and Greenland ice sheets are the largest land-based ice reservoirs on the Earth. For this reason, understanding their behavior, potential instabilities and contribution to global mean sea level (GMSL) rise due to global warming are in a key position when assessing future coastal flooding hazards and planning safety of coastal areas (Intergovernmental Panel on Climate Change assessments: IPCC 2019 and 2021). The scientific knowledge of these phenomena is increasing rapidly, and a regular follow-up is needed to make sure that the Finnish coast is well prepared for the expected changes.

The world-wide mean sea level rise in the future depends on the chosen emission pathway. However, when we talk about committed sea level rise, we mean the amount of expected sea level rise assuming that the given climate prevails long enough such that the ice sheets come to an equilibrium with it.

The most prominent uncertainty in sea-level rise projections is connected to the unknown transformation of ice sheets in the warming climate. Particularly, melting of the Antarctic ice sheet will be influential to the Finnish coast. Sea level is rising more rapidly further away from melting ice sheet for two reasons: 1) the gravitational pull of a melting ice sheet is decreasing in the vicinity of the ice sheet and 2) land uplift effect raises the land below the vanishing ice sheet.

Processes leading to fast disintegration of the ice sheets are low-probability, high-impact events, which have a direct effect on the high tail of the mean sea level projections and for this, are of relevance for the nuclear power plants located on the coast. These kinds of dynamic processes include marine ice sheet instability (MISI) and marine ice cliff instability (MICI). In MISI, ice sheets grounded (in contact with land) below sea level destabilize when the grounding line retreats due to instantaneous melting, resulting in an increase of total amount of floating ice. In MICI, high vertical ice cliffs collapse under their own weight due to the loss of buttressing by floating ice shelves.

This report is initiated by a summary of a recent article by Pellikka et al. (2023) in Sect. 2. This paper is the most relevant publication in terms of the Finnish coast perspective due to its focus on projecting mean sea level behavior in Finland. Other relevant recent publications within the study area are reviewed in Sect. 3. The concluding remarks of all reviewed articles are summarized in Sect. 4.

2. Pellikka et al. (2023): Probabilistic projections and past trends of sea level rise in Finland

2.1 Background and methods

Pellikka et al. (2023) studied the past and future behavior of the mean sea level on the Finnish coast in their recent paper. They estimated the long-term relative mean sea level (MSL) on the Finnish coast as a combination of three main components: land uplift, absolute sea level rise (ASL), and the water balance of the semi-enclosed Baltic Sea. Of these, the land uplift was taken from the NKG2016LU semi-empirical model (Vestøl et al., 2019), and the water balance was modelled using its strong correlation with the geostrophic wind over the southern Baltic Sea (Johansson et al., 2014).

There are still challenges in the global sea level rise projections: published projections range from about 20 cm up to almost three meters of sea level rise during this century (Table 1 of Pellikka et al., 2023). Especially the upper end of the probability distribution is problematic. Thus, Pellikka et al. (2023) aimed at providing probabilistic projections, to accommodate different risk levels. Their study updated the earlier projections for the Finnish coast (Pellikka et al., 2018), which were also based on an ensemble of several global sea level rise projections.

2.2 Past sea level trends on the Finnish coast

The past changes of MSL on the Finnish coast were analyzed from its long observation time series. Given the MSL record, the authors then subtracted both the land uplift (provided by the NKG2016LU model) and the Baltic Sea water balance (modelled by using the correlation with the geostrophic wind) signals from the data. The remaining trend represents the ASL rise, which is mainly due to ocean thermal expansion and glacier melting.

The past ASL trends on the Finnish coast (Table 3 of Pellikka et al., 2023) from early 20th century to 2018 were 1.2 – 1.5 mm/a, in accordance with some recent estimates of the 20th century global average mean sea level trend. Recent trends (1993–2018) were 3.0 – 3.8 mm/a, again in accordance with the global mean trend of 3.25 mm/a (Fox-Kemper et al., 2021).

2.3 Scenarios for absolute sea level rise (ASL)

Pellikka et al. (2023) calculated ASL scenarios up to 2100 for three different emission pathways: RCP2.6/SSP1-2.6 (low emissions), RCP4.5/SSP2-4.5 (medium emissions), and RCP8.5/SSP5-8.5 (high emissions). The IPCC AR6 global mean sea level (GMSL) scenarios (Fox-Kemper et al., 2021) were included in the study, together with a wide range of other GMSL projections for this century, obtained by different methods.

The ASL rise is unevenly distributed around the globe due to glacier fingerprint effect, uneven distribution of thermal expansion, and ocean dynamical effects. Pellikka et al. (2023) found that the effects of uneven distribution of thermal expansion and ocean dynamics, and that of the glacier fingerprints cancel each other on the Finnish coast in the scenarios up to 2100: local ASL rise is close to the global average.

The combination of 8-10 different GMSL projections was compared with the IPCC AR6 projections. It turned out that IPCC AR6 manages to capture the scenario spread well, and thus cover potential SLR futures better than the earlier IPCC reports.

2.4 Future mean sea level on the Finnish coast

Pellikka et al. (2023) calculated the MSL scenarios for the Finnish coast by combining the effects of ASL rise, changes in the Baltic Sea water balance, and land uplift. The changes in the Baltic Sea water balance were estimated from the projected changes in wind climate. The land uplift was expected to continue at the present rate up to 2100. They presented the projections for the Finnish coast as probability distributions, so they can be widely applied for different purposes. The acceptable risk level depends on the application.

Median MSL projections (change from 1995-2014 to 2100) on the Finnish coast range: from -43 to +16 cm for the low emission scenario, from -28 to +31 cm for the medium emission scenario, and from +1 to +61 cm for the high emission scenario. Lowest values are for the areas of strongest land uplift, and the highest values for the Gulf of Finland where land uplift is weakest.

Uncertainties in the projections are still high, especially in the upper tail of the distribution. The 95th percentiles (upper tail) of the MSL projections range from -9 to +50 cm for the low emission scenario, from +24 to +83 cm for the medium emission scenario, and from +93 to +152 cm for the high emission scenario.

3. Other relevant publications on the topic

The largest uncertainties in the sea level scenarios for the Finnish coast are related to global mean sea level behaviour (Pellikka et al., 2023). The global mean sea level projections in turn have their largest uncertainties in the response of the large ice sheets of Antarctica and Greenland to the warming climate. This subject has been actively studied recently, and here we summarize 9 relevant articles on the topic.

3.1 Stokes et al. (2022): Response of the East Antarctic Ice Sheet to past and future climate change

In their review of articles related to the past, present and future behavior of the East Antarctic Ice Sheet (EAIS) under changing climate conditions, Stokes et al. (2022), form future picture by utilizing paleorecords and investigate the role EAIS plays in the global mean sea level rise up to 2500. EAIS contains most of the Earth's glacier ice, resulting in 52 m sea level rise if it melted in its entirety. It is often viewed as less vulnerable to global warming than the West Antarctic or Greenland ice sheets. However, some regions of the EAIS have lost mass over recent decades, prompting the need to re-evaluate its sensitivity to climate change.

In this review, the past response of the EAIS to warming is discussed referring to publications in the field of paleo sea level. The extent of EAIS is traced from the analysis of seabed sediment cores and terrestrial records from the Transantarctic Mountains. Also, ice sheet modelling studies are utilized.

The EAIS extent is compared with the global sea level records of past 40 million years. The retreat rate of EAIS edge and thinning of EAIS are today of the same order that they were during last deglaciation (from 20 000 years before present). Even if the ocean warms, parts of the EAIS floating in the sea (ice shelves) do not show significant melting that would lead to increased flow of the ice sheets towards the sea. There has been no increase in surface melting or rainfall in East Antarctica, making hydrofracture-driven ice shelf instability unlikely. In case of more frequent rainfall, such events might become more likely in the next century. In future climate projections, estimates for the contribution of the EAIS to GMSL rise vary. In more conservative approaches, EAIS contributes to up to 25 cm by 2100 in the 95 percentile. When possible MICI (marine ice cliff instability) is included, 95 percentile increases to 47 cm by 2100 and to 5 m by 2300.

Evidence from the paleorecord and numerical modelling highlight the sensitivity of EAIS to past warm periods, including substantial ice loss during the early to mid-Miocene (24–14 Ma BP), and a multi-metre sea-level contribution during the mid-Pliocene (3.3–3.0 Ma BP), when atmospheric CO_2 concentrations were comparable with the present day. This highlights the uncertainties in assessing the response of EAIS to the ongoing warming of climate. The timescale of the sea level rise due to EAIS varies in different studies, although it appears that the effect up to 2100 is limited to less than half a meter, even if MICI is considered.

3.2 Hill et al. (2023): The stability of present-day Antarctic grounding lines – Part 1: No indication of marine ice sheet instability in the current geometry

In the warming climate, the environment of the Antarctic is changing considerably. Considering the suggested marine ice sheet instability (MISI), Hill et al. (2023) study whether the Antarctic ice sheets are presently instable. The Amundsen Sea Embayment is an area where the ground below the ice sheet is below the sea level and the ground level is lower further away from the sea. Therefore, there is potential for MISI in which the ocean keeps melting the ice shelves at the grounding line, pushing it back towards inland until the point where the groundling line would be above sea level. With reduced buttressing, the ice sheet also flows towards the sea more rapidly as the grounding line moves further inland. They find that the grounding lines of Antarctica, including Pine Island and Thwaites glaciers, show no indication of MISI in their current state. They use three state-of-the-art ice sheet models for numerical stability analysis, applying short-term perturbations to sub-marine melting.

The results show that the grounding lines around Antarctica migrate slightly away from their initial position while the perturbation is applied, and they revert once the perturbation is removed. This indicates that presently retreating Antarctic grounding lines, including Pine Island and Thwaites glaciers, show no indication of MISI in their current state. The retreat is not yet irreversible or self-sustained. Thus, MISI is not causing the present-day grounding-line migration.

There is a consensus within the ice sheet modelling community that the West Antarctic Ice Sheet is susceptible to MISI. Here, Hill et al. (2023) have argued that the currently observed changes of the Antarctic Ice Sheet are not a manifestation of ongoing positive feedback related to MISI. While their experiments suggest that an internal instability threshold has not yet been crossed in Antarctica, future retreat driven by changes in climate conditions could force the grounding lines to cross a tipping point, after which retreat becomes driven by MISI.

3.3 Reese et al. (2023): The stability of present-day Antarctic grounding lines – Part 2: Onset of irreversible retreat of Amundsen Sea glaciers under current climate on centennial timescales cannot be excluded

In a study accompanying Hill et al. (2023), Reese et al. (2023) use an ensemble of numerical simulations with Parallel Ice Sheet Model to analyse the evolution of Antarctic grounding lines under present-day climate conditions. The possibility of the collapse of the West Antarctic Ice Sheet is studied. Currently the ice sheet is not in equilibrium, and it will therefore continue to evolve for some time. The model describes the ocean melting the base of the ice shelf.

They find that as the Antarctic Ice Sheet approaches a new equilibrium for current climate conditions, the grounding lines migrate inland in West Antarctica but remain close to their current positions in East Antarctica. In all runs, the grounding line enters phases of accelerated retreat in the Amundsen Sea. By conducting reversibility experiments, they have been able to demonstrate that these retreat phases are irreversible. They find that the timescale at which irreversible retreat starts is dependent on the model parameters of the initial configuration.

In the Amundsen Sea Embayment retreat becomes irreversible between 300 and 500 years. With the assumption of constant present-day climate, the collapse evolves on millennial timescales, with a maximum rate of 0.9 mm/a sea-level-equivalent ice volume loss. The contribution to sea level by 2300 is limited to 8 cm with a maximum rate of 0.4 mm/a sea-level-equivalent ice volume loss. In the end of the 10 000-year simulation, sea level rise is between 2.7 m and 3.5 m. None of their runs shows the onset of irreversible retreat within the first 300 years, but 3 of 15 runs show an onset between 300 and 500 years.

3.4 Grinsted et al. (2022): The transient sea level response to external forcing in CMIP6 models

Grinsted et al. (2022) constrain the transient sea-level sensitivity to global warming using observations and models. Transient sea level sensitivity is defined as the change in the rate of global-mean sea-level rise with respect to changes in global-mean surface temperature. In other words, sea level rise accelerates with rising temperatures, as observed in the historical data. Grinsted et al. (2022) build on previous efforts by considering the most recent generation of climate, ice-sheet, and glacier models, and by quantifying sensitivities of individual contributors to global sea level rise, including the ice sheets. The most recent climate projections are based on the CMIP6 models (Eyring et al., 2016). Here the rates of the projected mean sea level rise and the projected change in atmospheric temperature are compared.

The authors find that the sensitivities are nearly constant during the present century, meaning that rates of global mean sea-level rise scale linearly with global mean surface temperatures. The sensitivities of the steric expansion and Greenland Ice Sheet mass loss are similar in models and historical data, whereas the Antarctic Ice Sheet mass loss is smaller in models compared to observations. This highlights the uncertainties in the sufficient description of the behavior of Antarctic Ice Sheet in the model.

The study also shows that the balance temperature, at which sea-level rates are zero, is close to the preindustrial value of ∼1.1°C below present (IPCC, 2021), which demonstrates that halting sea-level rise would require substantial global cooling. Perhaps most intriguingly, Grinsted et al. (2022) find a significant discrepancy between models and observations, namely that observations show that sea-level rates are more sensitive to atmospheric surface-temperature changes than the models anticipate.

3.5 Bamber et al. (2022): Ice sheet and climate processes driving the uncertainty in projections of future sea level rise: Findings from a structured expert judgement approach

Bamber et al. (2022) use structured expert judgment to identify ice-sheet and climate processes responsible for uncertainty in future sea-level rise. This approach, based on a survey targeted to experts of the field, brings together calibrated expert responses to answer deeply uncertain questions when process understanding of ice-sheet behavior is limited.

Expanding upon earlier work by Bamber et al. (2019), this study quantifies the relative contributions of accumulation, ice discharge, and meltwater runoff for the Greenland, West Antarctica, and East Antarctica ice sheets to uncertainty in global-mean sea-level rise under low and high warming scenarios such that global-mean surface temperature stabilizes in 2100 at 2°C and 5°C above preindustrial.

For the 21st century, Greenland surface melting mainly driven by albedo effects (ice sheet surface reflecting the solar radiation) and dynamics of West Antarctic Ice Sheet (effect of ice shelf buttressing leading to MISI) are the largest factors in the uncertainty of projected sea level rise. The uncertainty of the contribution of the Greenland surface melting is 74 cm and respective uncertainty of WAIS dynamics is 91 cm by 2100 in case of 5 °C global warming. For 2200, largest factors in uncertainty are WAIS dynamics (323 cm) and East Antarctic Ice Sheet dynamics (436 cm) if the 5 °C warming is realized.

3.6 van de Wal et al. (2022): A high-end estimate of sea level rise for practitioners

van de Wal et al. (2022) generate high-end estimates of sea-level rise for risk-averse practitioners, who need to consider low likelihood, high consequence sea level rise futures that poses challenges to adaptation, in addition to median outcomes. Coproduced by scientists and practitioners meeting in a workshop and discussing the different factors contributing to sea level rise using a framework introduced by Stammer et al. (2019), the estimates generated by this study are distinct from, but complementary to, the corresponding values reported in the Sixth Assessment Report of IPCC (Fox-Kemper et al., 2021) because different approaches are taken to quantify the contribution of land-ice reduction to future sea-level rise. The different components affecting the sea level rise (glaciers, Greenland, Antarctica, steric expansion, land water storage change) are discussed separately.

They obtain high-end global-mean sea-level-rise estimates of up to 0.9 m by 2100 and 2.5 m by 2300 relative to 1995–2014 for a global warming of 2°C. Antarctica is the largest contributor to these values (0.39 m and 1.35 m). Respective estimates for 5°C of global warming by 2100 are 1.6 m and for 8-10 °C global warming by 2300 10 m. Antarctica contributes here by 0.59 m and 6 m, highlighting the effect of the long-lasting melting of the Antarctic Ice sheet and underscoring the benefits of mitigation.

3.7 Naughten et al. (2023): Unavoidable future increase in West Antarctic ice-shelf melting over the twenty-first century

In their analysis on future projections of melting of the Antarctic Ice Sheet, Naughten et al. (2023) addresses that Antarctica contributes to the sea level rise mostly through ocean-driven melting of floating ice-shelves in the Amundsen Sea. In terms of contribution to sea level rise, the West Antarctic Ice sheet (WAIS) is the most crucial sector to follow.

The projections of the study are simulated utilizing a regional ocean model of the Amundsen Sea (a setup of the Massachusetts Institute of Tecnology general circulation model, MITgcm) that is forced by atmospheric output from the CESM1 (Community Earth System Model) climate model. The simulations are not coupled to ice-sheet model, which implies that determination of actual sea level rise based on the outcomes is not doable. Instead, relevance of the results for the sea level rise is assessed through estimation of buttressing flux response number (BFRN), which indicates the capability of the ice shelf to induce sea level rise.

The results cover five different climate scenarios: historical (1920-2005), The Paris 1.5°C and 2°C (2006-2100), RCP4.5 (2006-2080) and RCP8.5 (2006-2100). Based on the outcomes, notable ocean warming as well as ice shelf melting is predicted for all scenarios due to the entry of warmer Circumpolar Deep Water (CDW) into the area.

In addition, warming and melting in the future is foreseen to be clearly larger compared to historical behavior in the Amundsen Sea region.

The study brings up that mitigation procedures might have limited capability to prevent ocean warming that effect to the sea level rise from WAIS. According to the findings, only the RCP8.5 scenario can be prevented through mitigation measures.

3.8 Horton et al. (2020): Estimating global mean sea-level rise and its uncertainties by 2100 and 2300 from an expert survey

In the research by Horton et al. (2020), global mean sea level (GMSL) change for two time periods (2000-2100 and 2000-2300) and for two different emission pathways (RCP2.6 and RCP8.5) is investigated. In addition, sources of uncertainties related to the projections are explored. As a method, a survey for sea level experts was conducted. Altogether 106 experts in the field answered the survey in 2019, which was a repetition of a similar survey executed 5 years before. Between the surveys, deeper understanding of mechanisms of ice sheet retreat and melting, e.g. marine ice cliff instability (MICI) has been gained.

According to the survey results, a likely range (17^{th} to 83^{rd} percentile) of GMSL rise of 0.30-0.65 m (RCP2.6) and 0.63-1.32 m (RCP8.5) is expected by 2100. In turn, by 2300, GMSL rise of 0.54-2.15 m (RCP2.6) and 1.67-5.61 m (RCP8.5) is foreseen. As expected, there is a larger difference between expert projections up to 2300 compared to GMSL rise estimates by 2100.

Based on the survey responses, the most common source of uncertainty related to the future GMSL rise is clearly the ice sheets. Limitations in model/data and uncertainty related to ocean-atmosphere (distribution of heat as a result of ocean circulation) are the next common factors causing uncertainty for the experts. Uncertainties related to Antarctica’s contribution to sea level rise (arising e.g. from modelling of MICI and MISI processes) overcome the uncertainties connected to Greenland. The study brings up that high upper-end predictions reflect Antarctic Ice sheet behavior in a warmer climate.

The results of Horton et al. (2020) stress also that many expert estimates for GMSL rise by 2100 are higher compared to the estimates of IPCC AR5 and SROCC reports.

3.9 Box et al. (2022): Greenland ice sheet climate disequilibrium and committed sea-level rise

Box et al. (2022) focuses in their study on the committed ice sheet melting in Greenland and the corresponding sea level rise. The disequilibrium is estimated by calculating ice extent and thickness perturbations needed to bring the current ice sheet into equilibrium with surface mass balance. In their method, the whole glacierized area of the Greenland Ice Sheet is taken into account by summing over volumes from 473 subregions of the ice sheet.

The study concludes that Greenland ice imbalance with the recent (2000–2019) climate already implies a commitment to at least 27.4 ± 6.8 cm of sea level rise without any future warming. In addition, a mean climate similar to the high-melt year of 2012 (with negative NAO) would imply an ice loss commitment of 78.2 ± 13.5 cm sea level rise. The latter case helps in estimating potential future extremes.

The results of the study show three different reasons for the committed changes: increasing mass turnover from precipitation, ice flow discharge and meltwater run-off. The trend and inter-annual variability of Greenland Ice Sheet mass budget during 2000-2019 is mainly caused by surface ablation (melting) via meltwater run-off. The findings of the study indicate that western parts of the Greenland Ice Sheet are more sensitive to warming climate than eastern areas.

4. Conclusions

Pellikka et al. (2023) recently published mean sea level projections for the Finnish coast. These probabilistic projections include a wide range of global mean sea level scenarios, combined with the local effects of postglacial land uplift and Baltic Sea water balance. The median projections for this century range from about 40 cm of sea level decline to about 60 cm of sea level rise, depending on the local land uplift rate and the chosen emission scenario. Due to the large uncertainties, even higher sea level rise exceeding one meter is possible.

Stokes et al. (2023) conclude that the contribution of the East Antarctic Ice Sheet (EAIS) to global mean sea level (GMSL) rise by taking into account marine ice cliff instability (MICI) is 0.5 m by 2100 and 5 m by 2300.

Hill et al. (2023) find that there is no marine ice sheet instability (MISI) ongoing at present in the West Antarctic Ice Sheet (WAIS).

Reese et al. (2023) conclude that 8 cm sea level rise by 2300 due to Amundsen Sea glaciers is possible, 3 m rise takes about 10 000 years.

Grinsted et al. (2022) discover that the temperature at which sea-level rise rates are zero is close to the preindustrial value of ~1.1°C below present. In addition, they conclude that projected rates of sea level rise based on models are lower compared to observed rates.

Bamber et al. (2022) summarize that the uncertainty in the 21st century projections of sea level rise is driven by surface melting in Greenland and dynamics of WAIS. In case of 5°C warming, Greenland is expected to contribute to sea level rise by 74 cm, and WAIS by 91 cm.

Van de Wal et al. (2022) conclude that under 5°C of global warming, high-end estimate of sea level rise of 1.6 m is expected by 2100, including contribution of Antarctica by 0.59 m.

Naughten et al. (2023) summarize that notable ocean warming and ice shelf melting of WAIS is projected for all scenarios. Additionally, ocean warming in the Amundsen Sea region in the future is foreseen to be markedly larger compared to historical behavior, increasing the WAIS contribution to the sea level rise.

Horton et al. (2020) conclude that within a likely range (17th to 83rd percentile), GMSL rise of 0.30-0.65 m (RCP2.6) and 0.63-1.32 m (RCP8.5) is expected by 2100. According to the study, the most common source of uncertainty of future GMSL rise projections are the ice sheets.

Box et al. (2022) find that imbalance in Greenland Ice Sheet with the recent (2000–2019) climate commits at least 27 cm of global sea level rise, irrespective of the future climate warming scenario.

Acknowledgements

We would like to thank Dr. Aleksi Nummelin for the internal review of this report.

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