Baltic Marine Environment Protection Commission

Third meeting of Joint HELCOM/ Baltic Earth Expert Network on Climate Change — EN CLIME 3-2019

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Background

The following document contains the draft key messages prepared by the Sea level and wind extremes Team under the joint HELCOM/Baltic Earth Expert Network on Climate Change (EN CLIME).

The Sea level and wind extremes Team experts are as follows:

Christian Dieterich (confirmed team lead)
Andreas Lehmann
Anna Rutgersson
Birgit Hünicke
Eduardo Zorita
Erik Kjellström
Jukka Käyhkö
Markus Meier
Peter Löwe
Ralf Weisse
Jan-Hinrich Reißmann
Jürgen Holfort
Wenyan Zhang
Janika Laht

Key messages for the following parameters are included in this document (available experts in the team presented on the right). Grey parameters are parameters for which there is as of yet no key messages:

Parameters	Experts
Sea level and sea level extremes, e.g. storm surges	Andreas Lehmann; Birgit Hünicke; Christian Dieterich ; Eduardo Zorita; Janika Laht; Jürgen Holfort; Marcin Kawka; Markus Meier; Peter Löwe; Ralf Weisse
Wind and wind extremes (storms)	Andreas Lehmann; Anna Rutgersson; Birgit Hünicke; Eduardo Zorita; Erik Kjellström; Jan-Hinrich Reißmann; Janika Laht; Markus Meier; Peter Löwe; Ralf Weisse
Waves and extreme events	Andreas Lehmann; Anna Rutgersson; Markus Meier; Peter Löwe; Ralf Weisse
Sediment transportation	Janika Laht; Jukka Käyhkö; Markus Meier; Wenyan Zhang

Guidance for preparing key messages and the fact sheet:

The following guidance has been compiled from discussions and outcomes of previous EN CLIME and Team meetings and from the background documents, e.g. Terms of Reference.

The fact sheet should present a consensus view by the regions climate experts on the climate change driven changes in the outlined parameters, as well as related issues identified as of relevance to the policy process. The intention is for the fact sheet to be a science driven exercise, relying exclusively on, and synthesizing, already existing detailed, peer reviewed information from leading marine and climate scientists. The information is to be condensed to key messages, including information on trends where possible. In the final fact sheet the information is to be present visually, in an accessible and stable way across years. To make the information as accessible as possible the parameters can at later stage of the process be combined under wider topics in order to make the fact sheet more usable for policy makers. Information to support the statements in the factsheet will be available as separate publications (BACC II, BACC III, BEAR reports etc.), clearly referenced and the fact sheet itself fully-citable. While already existing BACC reports should be used as supporting material for the EN CLIME work, that subsequent results coming out of BACC III can be used to amend the key messages where needed prior to publication.

The fact sheet will strive to be a concise and easily accessible resource from science to regulators and policymakers and will contain information, using agreed language, on what has happened and what can be expected to happen in the future. As discussed in EN CLIME 2-2019 wherever possible the information should be presented in approximate ranges (near term, medium term and long term) and that changes in extremes as well as in means should be taken into account for each of the primary parameters.
While the fact sheet should be made as approachable as possible, the overall complexity of the issue also needs to be communicated. In this respect the EN CLIME has highlighted the interlinkages between different parameters and supported the possibility to include some sort of info-graphic to visualize the interlinkages.

The titel 'Description' should be included to the fact sheet in a very concise manner, describing the underlaying factors, and linkages to other parameters.

EN CLIME has in previous meeting discussed the importance of describing the uncertainty of predictions and noted that uncertainty varies depending on the temporal ranges used and between parameters, which needs to be taken into account in the description. Hence different uncertainties can be given for different parameters and time intervals.

Action requested

The Meeting is invited to review and revise the draft key messages and agree on them, keeping in mind that the intention is to streamline he presentation of all messages to the extent possible.

Sea level and sea level extremes, e.g. storm surges

Give a brief description of the parameter sea level

Sea level is traditionally measured with a scale on the harbor wall. The earliest scales from the 18th century were marks on large, prominent boulders along the shoreline of the Baltic Sea (Ekman, 2009). Nowadays many automated stations all along the Baltic coast deliver this information with time intervals between 1 minute and 6 hours. Sea level changes when water is added to the global ocean, when it expands by warming or when the land is rising to which the scale is attached. These are the three most important contributions to long-term changes in sea level in the Baltic Sea (BACC I, Hünicke et al., 2015).

Due to an excess of precipitation and river runoff over evaporation the sea level in the Baltic is higher than in the North Sea and water flows out of the Baltic through the Danish straits into the North Sea. The amount of water flowing through this narrow strait depends to a large extent on the wind regime in the larger scale Baltic-North Sea transition zone. It is also over this way, that the global sea level rise has repercussions on the Baltic sea level. The fill factor is highly correlated with the local sea level at Landsort, showing maximal amplitude of about 1m. The longer term seasonal cycle shows a minimum in May and a maximum in December.

Changes in oceanic and atmospheric circulation cause variations of sea levels in the Baltic Sea on seasonal to decadal time scales (Chen and Omstedt, 2005). Winter sea level in the Baltic Sea is usually higher than summer sea level (Samuelsson and Stigebrandt, 1996). And mild winters with stronger than average winds show higher sea levels than severe winters (Andersson, 2002, Karabil et al., 2018). During the cold seasons from fall to spring the risk is higher for storms to produce storm surges along the coasts of the Baltic Sea (Lehmann et al., 2011). Storm surges are water masses pushed against the coasts by the wind of atmospheric low pressure systems. The lower atmospheric pressure in a storm can add to the amplitude of the storm surge. Storms also excite oscillations in the Baltic Sea that are highest at the ends of the different basins and lowest in the Baltic Proper (Weisse and Weidemann, 2017). The most effective wind for a storm surge in the western Baltic is a strong northeasterly wind over the southern Baltic. For the eastern Gulf of Finland it is more a strong westerly wind over the Central Baltic and the Gulf of Finland. So extreme sea levels have to be discriminated regionally.

Waves that are generated during storms can add to extreme sea levels measured along the coast (Eelsalu et al., 2014). The amplitude of tides is relatively small in the Baltic Sea and adds to extreme sea levels only in the Kattegat and Skagerrak.

Show links to other parameters.

The mean sea level of the global ocean is closely related to the volume of the ocean. The volume is changing due to geologic activity and to the addition of water that was previously frozen on land like the Antarctic and Greenland ice sheets and mountain glaciers. Melting rates of glaciers are sensitive to changes in air temperature, snow cover and the resulting brightness. Ice sheets in polar regions are affected additionally by contact with ocean water melting the ice from below, which can cause instabilities in the integrity and the flow of the ice sheets. Ocean temperatures affect the mean sea level because warmer water is lighter and takes up more volume than colder water. The continuous redistribution of heat from the tropics to the polar regions establishes the ocean circulation systems that form a sea surface relief along which the ocean currents are flowing. This sea surface relief modulates the global mean sea level by

Commented [A1]: I tried to combine the two available text suggestions for sea level. Now the combined text is too long but we can shorten later. First we should agree on the content.

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up to half a meter (e.g. Yin et al., 2009). The mean sea level in the Baltic Sea depends on the strength of the ocean circulation in the Atlantic (Yin et al., 2009, 2010, Yin, 2012, Balmaseda et al., 2013b). Temperature and freshwater distribution in the ocean leave their imprint on height of the sea surface and cause it to vary on decadal time scales (Balmaseda et al., 2013a). Atmospheric winds are another important driver of sea level variability on time scales from decades down to a couple of hours during a storm surge.

What is happening?

Mean changes

Global mean sea level rise is measured at 1.5 mm/year during the 20st century. It is estimated at a rate of 2.8 mm/year during the period since satellites are measuring (1993 to 2010). The rate of global mean sea level rise is increasing [high confidence]. During the second half of the past century thermal expansion of sea water and the addition of melt water from the Antarctic and Greenland ice sheets and from glaciers have contributed about equally to the process [high confidence] (Church et al., 2013). Sea level rise (relative to the ellipsoid) in the Baltic Sea in the past 50 years is estimated between 1 and 3 mm/year (Milne et al., 2001, Hill et al., 2010, Richter et al., 2011, BACC I, BACC II).

Commented [A3]: Uncertainty range from the literature. What are the latest numbers? Is there an acceleration since 1980?

For the last decades and centuries the land uplift is the most important factor contributing to sea level change in the Baltic. The highest rates of land uplift of 10 mm/year are found at Höga Kusten. The land uplift diminishes away from this center and is very small and even reaching negative numbers along the German and Polish coasts of the Baltic Sea. There the sea level rise is about plus 1-2mm/year; similar to the global sea level rise. Up in the northern Baltic the measured local sea level rise is more around minus 7-8mm/year. For the period 1886-2017, Swedish Baltic Sea records showed an eustatic increase (without land uplift) of about 24 cm corresponding to 1.8 mm/year (Source: SMHI).**Extremes**

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Return levels with corresponding return periods is a concept to assess the amplitude and the probability of extreme events. A storm surge with a 100-year return period will occur on average once in 100 years. The amplitude of the event depends on the location in the Baltic Sea. Storm surges at the end of the basins furthest away from the Baltic Proper are higher than those in the center of the Baltic Sea [high confidence] (Meier et al., 2004, Wolski et al., 2014, Dieterich et al., 2019). No long-term trend has been found so far that points to an increase of extreme sea levels in the Baltic Sea (EN-CLIME wind, BACC II). There are however studies (e.g. Suursaar and Sooäär, 2007) that confirm extreme sea level e.g. in the Gulf of Finland to be very sensitive to the position of the storm tracks.

Commented [A5]: What does this mean? Will the projected northward shift of the storm track have an impact on extremes? You should add the results by Land and Mikolajewicz (2019).

What is expected to happen in the future?

Mean changes

Since the ice has melted that covered Scandinavia during the last ice age the earth crust is rebounding. The highest rates of land uplift of 10 mm/year are found at Höga Kusten on the Bothnian Bay. The land uplift diminishes away from this center and is very small along the German and Polish coasts of the Baltic Sea. This process is expected to continue for thousands of years [high confidence]. Along most of the Baltic Sea coasts the land uplift causes sea level to fall. On top of this change, global mean sea level rise will continue to raise sea levels in the Baltic Sea at an increasing rate [high confidence] (Church et al., 2013). When the rate of sea level rise becomes larger than the land uplift, sea level will start to rise relative to land. First in the southern Baltic Sea and with accelerating rates of global mean sea level rise the line of rising sea level will move northward. During this century melting ice sheets in Antarctica and Greenland will contribute more to the total than in the past [medium confidence] (Church et al., 2013). The sea level rise due to melting ice is not distributed uniformly around the global ocean. Sea level rise from melting ice sheets in Antarctica is more pronounced in the northern hemisphere because the missing ice mass has a smaller gravitational pull on the surrounding water. As in Scandinavia, the missing ice causes the earth crust to

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rebound which makes the sea level rise slower where the ice is melting [medium confidence]. Based on these processes the mean sea level rise in the Baltic Sea is projected to amount to 80% of the global mean sea level rise (Grinsted, 2015). Recent efforts since the latest IPCC report that focused on the contribution of Antarctic ice sheets to global mean sea level rise have shown that the interaction of warming ocean water, melting the ice sheets from below can lead to instabilities in the ice sheet dynamics. The ice sheets flowing from land into the ocean are in contact with the ocean floor out to the grounding line. From there on outward the ocean is melting the ice from below and the ice sheets become thinner and lighter. If the weight of the ice sheet becomes less than the weight of the ocean water it replaces, it floats up and away. The grounding line retreats inland where the ice sheet is thicker and the ice flow larger and reinforces the ice loss (Mercer, 1978). This and related feedback loops could lead to an extra meter of sea level rise until the end of the century [low confidence] (e.g. Sweet et al., 2017). The most recent estimates (Bamber et al., June 2019) for global mean sea level rise in 2100 relative to 2000, including these potential contributions (including land water storage) are 69 cm and 111 cm for low and high sea level scenarios, respectively. For the high sea level scenario the likely range (5% to 95%) is between 62 cm and 238 cm.

Commented [A7]: Meier: Numbers for the Baltic Sea? Are there studies for the Baltic Sea that tried to combine all the effects?

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Changes in the Baltic sea levels will also be affected by possible changes in the fill factor but projected changes are very uncertain.

Extremes

How extremes will change is highly uncertain, as they are dependent on the strength, the position and the path of future low pressure systems. And the dependence also varies strongly with the position of the considered point along the Baltic coast.

In the Baltic Sea, return levels show a low to moderate increase for increasing return periods (HazardSupport, 2018)(true everywhere?). The 100-year return level for Stockholm for example is estimated at 102 cm, while the 200-year return level is 107 cm. Both estimates have a large uncertainty of 25 cm and 30 cm, respectively (SMHI report regeringsuppdraget). Even under moderate increase of mean sea level in the Baltic Sea, extreme events that are rare today will be much more common towards the end of the century. In the above example a sea level rise of 20 cm in 2100 will turn the 100-year storm surge in Stockholm into an event that occurs every 10 years on average [medium confidence]. Thus, the main driver of changes in Baltic Sea storm surges is the global mean sea level rise [medium confidence].

Commented [A9]: Is this available literature? Reference? Is land uplift considered?

Knowledge gaps

There is potential for mean sea level rise in the Baltic Sea that is caused by the freshening of the Baltic Sea. Under a warming climate precipitation patterns over the Baltic Sea drainage basin change (EN-CLIME precipitation) and the river discharge is expected to increase (EN-CLIME discharge). Fresher water in the Baltic Sea will take up more volume and sea levels in the Baltic Sea will rise. There has been no comprehensive study so far to assess the impact of halosteric contributions to the Baltic Sea level. Also the impact of changing land water storage for the Baltic Sea region on Baltic Sea levels needs to be assessed (Haasnoot et al., 2015 for the Netherlands).

On the global scale it has been shown (Bingham and Hughes, 2012) that sea level will raise proportionally more on the shallow shelf regions around the continents than in the deeper, open ocean. For the Baltic Sea no such study exists that could answer whether mean sea level rise applies to coastal regions in the same way as for the open Baltic Sea.

Storm surges and other hazards can turn into disaster if they occur concurrently. There have been some examples and studies (e.g. Zscheischler et al., 2018) that have shown that the impact of multiple hazards can be much worse than a single extreme event. Not much is known today about the interaction of extreme events with a focus on storm surges.

The coverage in time and space of sea level measurements in the Baltic Sea is among the best in the world. Many records date back to late 19th century. Nevertheless, the observational record tends to underestimate the natural variability that is inherent in storm floods (Lang and Mikolajewicz, 2019) in the Baltic Sea. One example is the Backafloden 1872. It is not clear which return period should be attributed to this event (Fredriksson, 2016, 2017). With today's observational time series it cannot be categorized. Two conclusions can be drawn here. First, more research is needed to investigate the influence of natural variability on storm surges in the Baltic Sea. Second, long measurement records are of vital importance to assess natural variability in coastal flooding around the Baltic Sea.

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Policy relevance:

Relevance is high, both for mean sea level rise and for extreme events.

Sea level rise influences and interacts with wind waves (EN-CLIME waves) and coastal erosion (EN-CLIME sediment).

What can be done about it (possible responses)?

The implementation of the COP 21 Paris agreement 2015 of the United Nations Framework Convention on Climate Change helps to reduce the risk of large contributions to sea level rise from the West Antarctic ice sheets.

Sea level changes have lead to the relocation of harbors in the past (Söderköping) and today (Lulea).

Especially focusing on avoidance, alleviation, adjustment and adaptation.

- Saint Petersburg Flood Prevention Facility Complex

- Stockholm Sluice

- Levees along the German and Polish coasts

What is already being done about it?

Existing agreements/policies:

The EU water directive has led to a Swedish ordinance and a directive (översvämningsdirektivet) by the Swedish Civil Contingencies Agency to chart areas prone to flooding (including coastal flooding) and how to deal with risks of flooding.

The Swedish insurance company Länförsäkringar has decided not to give out housing insurance anymore for new buildings in areas that are at a high risk for flooding (Länförsäkringar, May 2019).

How does it affect measures taken to reduce pressures on the Baltic Sea?

Policy gaps

Sea level rise for coastal cities around the Baltic Sea is more sensitive to the thermosteric expansion of the global ocean compared to coastal cities around the coasts of the Atlantic or Pacific Ocean (Larour et al., 2017). Also, ice sheet melt in Antarctica has a disproportional high impact in the Baltic Sea while ice sheet melt in Greenland has no effect. Sea level research focused on the Baltic Sea may take this into account.

Commented [A11]: Why? And why is there a policy gap related to this fact?

Commented [A12]: Missing reference

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Sediment transport and erosion

Sediment transport and erosion *Wenyan Zhang, HZG*	Give a brief description of the parameter Show links to other parameters. Sediment transport is triggered mainly by currents in marine environment, by waves in the nearshore and by wind in subaerial coastal environment. Its direct consequence is a gradual change of the earth surface landform, leading to erosion or accretion. Short-term and small-scale sediment transport is strongly hinged on a variety of local state variables including wind velocity and	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible. If the relative sea level rise in the southern Baltic Sea follows the mean value of RCP2.6 projection, which is ~0.24 m until 2065, the rate of sea level rise in this region (~1.2 mm/yr for the past few decades) would be accelerated. As a natural consequence coastal erosion would be regionally enhanced to fill the increased underwater accomodation space. The extent of	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible. A critical threshold, which distinguishes a linear and a non-linear (following a quadratic or a higher power law) relationship between foredune height and rate of relative sea level rise, seems to exist in the southern Baltic Sea coast. If a rise by 0.3 m in the relative sea level (RCP8.5) would occur by 2065 in this region, such critical threshold would probably be reached before 2050, causing drastic	What is happening? Provide information on already identified effects What are the direct consequences? Examples of effects can we already see, if available. Due to a combined effect of isotstaic adjustment and eustatic sea level change, the coastline change of the Baltic Sea is characterized by a North-South gradient from an uplift of max. 9 mm/yr in the North to a subsidence of min. -2 mm/yr in the south since the onset of the Holocene. The subsiding southern Baltic Sea coast is characterized by a	What is happening? Provide information on already identified effects What are the direct consequences? Examples of effects can we already see, if available. Many sandy beaches along the Gulf of Finland have recently been severely damaged by frequent storm surges, despite extensive protective measures. Soft cliffs in Latvia are eroded 3–6 m/yr after each storm, with a maximum of up to 20–30 m/yr at local sites. Extreme erosional rate along Lithuania and	We lack a comprehensive understanding of alongshore sediment transport and associated spatial and temporal variability along the Baltic coast. In general, an eastward transport dominates along a major part of the southern Baltic coast due to the impact of the prevailing westerly winds. However, the intensity of secondary transport induced by easterly and northerly winds is much less understood. Its combination with storm surges further complicated the understanding because in such circumstance the sandy dunes and cliffs are exposed to highest erosional impact. Another knowledge gap in understanding coastal	Policy relevance: Sediment transport and coastal erosion are relevant for coastal management, construction and protection strategies. What can be done about it (possible responses)? Especially focusing on avoidance, alleviation, adjustment and adaptation. In general two main types of management strategy: 1) coastal protection by soft or hard measures; and 2) adaptation to coastal change, accepts that in some

Commented [A13]: I do not understand the logic here. Do you mean that even in case of an optimistic scenario coastal erosion has to be enhanced? Why 2065? A present acceleration of 0.07 mm/yr2 and a sea level rise of 1.5 mm/yr would result for the period 2005-2100 in a 46 cm higher sea level at the end of the century, i.e. RCP 4.5 or?

	direction, water level, waves as well as the antecedent state of the system, while long-term and large-scale sediment transport and coastal erosion are primarily controlled by sediment supply modulated by large-scale processes, notably mean sea level, storms, the regional wind and wave pattern, and engineering structures.	enhancement in erosion depends on not only the sea level but also storms. Due to the impact of the prevailing westerly winds, the dominant sediment transport will remain eastwards along a major part of the southern Baltic coast, but with a high variability along some local coast sections which have small incidence angle of incoming wind-waves. Development of the foredunes will continue in prograding coasts.	change on the foredune characteristics and much stronger erosion on cliffs and old coasdtal dunes.	series of barrier islands and sandy dunes connected with soft moraine cliffs. The composition of soft, mobile sediments makes the southern Baltic Sea coast extremely vulnerable to wind-wave induced transport and erosion. Most coastline erosion along the southern Baltic Sea is caused either by storms or human-induced depletion of sediment supply (e.g. side effect of engineering structures). Mean erosional rate along Latvia and Lithuania for the sandy coasts and soft cliffs are 1–2 m/yr and 0.5-0.6 m/yr in the latter half of the twentieth century. Since 1980s erosional rates of certain sections have been enhanced to 1.5–4 m/yr;	Russia(Kaliningrad) for cliff are 10 m/yr. Poland: recent erosion after each storm surge reaches 3–6 m/yr; Germany: erosion by storms has reached 3 m/yr at some local coastal sections Maximum erosion rates along the dune coasts in the Kattegat are ~2 m/yr.	erosion in response to future climate change is on the impact of water levels and the submergence of the beach. Anthropogenic influence imposes one of the largest uncertainty in sediment transport and coastal erosion. An engineering structure (e.g. pier, seawall) influences coastline change at a much larger spatial scale than the dimension of the structure itself.	places the coast would be left in its natural state. What is already being done about it? Existing agreements/policies: Soft protection: 1) Beach nourishment; 2) Artificial planting of pioneer grass species in front of the foredune. Hard protection: 1) Groynes; 2) Dykes; 3) Seawall and/or revetments; 4) Artificial headlands; 5) Breakwaters How does it affect measures taken to reduce pressures on the Baltic Sea? Policy gaps Administrative efforts for coastal protection differ among Baltic Sea countries, even between

Commented [A15]: Very interesting but very complicated to understand.

Commented [A14]: Are there no scenarios for coastal erosion available?

				Mean erosional rate along Lithuania and Russia(Kaliningrad) for the sandy coast and cliff are 0.5-0.8 m/yr and 1-1.5 m/yr, respectively, and rates have increased over the past decade. The Polish coast is mainly formed of soft sandy sediments , with an average rate of retreat of 0.5–1.5 m $year^{-1}$. Coastal towns which experienced erosion of 0.3–0.7 m/yr now have a nourished beach. Mean erosion rate along the German sandy coast is 0.4 m/yr. In southern Sweden, the soft moraine cliffs have retreated 1–1.5 m $year^{-1}$ over the past 150 years. Erosion rates along the dune coasts in the Kattegat are within 2 m $year^{-1}$.			neighbouring states or nations. Management actions are complicated by morphodynamic changes caused by artificial coastal protection in some places and its consequent disruption in downstream area.

Commented [A16]: Very interesting. However can this information be summarized?

				Coastal erosion has the following direct consequences: 1. loss of coastal lands; 2. loss of coastal resilience; 3. loss of valuable natural habitats; 4. loss of economic value and private property; 5. increasing cost to society in terms of coastal protection.			

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