Baltic Marine Environment Protection Commission

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

Stockholm, Sweden, 19 August 2019

Document title	Draft key messages prepared by the EN CLIME Water Cycle Team
Code	3-2 rev.1
Category	DEC
Agenda Item	Agenda Item 3 – Key messages for the primary parameters
Submission date	13.8.2019
Submitted by	Secretariat
Reference	

Background

The following document contains the draft key messages prepared by the Water Cycle Team under the joint HELCOM/Baltic Earth Expert Network on Climate Change (EN CLIME).

The Water Cycle Team experts are as follows:

Jukka Käyhkö (confirmed team lead)
Andreas Lehmann
Anna Rutgersson
Ari Laine
Birgit Hünicke
Christian Dieterich
Eduardo Zorita
Erik Kjellström
Harri Kuosa
Jan-Hinrich Reißmann
Janika Laht
Marcin Kawka
Markus Meier
Matthias Gröger
Urmas Lips

Key messages for the following parameters are included in this document (available experts in the team presented on the right):

Parameters	Experts
Salinity and saltwater inflows	Andreas Lehmann; Ari Laine; Christian Dieterich ; Jan-Hinrich Reißmann; Markus Meier; Matthias Gröger; Urmas Lipps
Stratification and ocean circulation (incl. large scale marine processes e.g. spring/fall circulation)	Andreas Lehmann; Jan-Hinrich Reißmann; Markus Meier; Matthias Gröger; Urmas Lipps
Precipitation and extreme events	Anna Rutgersson; Birgit Hünicke; Eduardo Zorita; Erik Kjellström; Janika Laht; Marcin Kawka; Markus Meier
Run-off and extreme events	Harri Kuosa; Janika Laht; Jukka Käyhkö; Marcin Kawka; Markus Meier

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.

Salinity and saltwater inflows

Topic	Description	What is expected to happen?		What is already happening?		Knowledge gaps	Policy relevance
		Mean change	Extremes	Mean change	Extremes		
		Level of confidence: Low confidence	*Level of confidence:*	*Level of confidence: Low confidence*	*Level of confidence:*		
Salinity and saltwater inflows *Markus Meier, IOW and SMHI*	Give a brief description of the parameter Show links to other parameters. Salinity is the dissolved salt content of a body of water and an important variable for density that controls the dynamics of currents in the ocean. Due to freshwater supply from the Baltic Sea catchment area and due to the limited water exchange with the world ocean, surface salinity varies from > 20 g kg^{-1} in Kattegat to < 2 g kg^{-1} in the	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible. Due to the projected increased freshwater supply from the catchment area by about 1 to 21% at the end of the century depending on the climate model, surface and bottom salinity is projected to decrease by about in the ensemble mean with a large spread among the ensemble members (Saraiva et al., 2019).	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible.	What is happening? Provide information on already identified effects What are the direct consequences? Examples of effects can we already see, if available. There are no statistically significant trends in salinity (Fonselius and Valderrama, 2013), river flow (Meier and Kauker, 2003) and MBIs (Mohrholz, 2018) on centennial time scales. However, salinity, river flow and MBIs showed a pronounced multi-decadal variability	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 uncertain changes in regional water cycles (precipitation) and global sea levels, the confidence in future salinity projections is low (BACC II Author Team, 2015; Meier et al., 2019). Changes in total salt import have not been sufficiently investigated. Ensemble studies taking also rising global mean sea level together with changes in wind fields and river flows into account do not exist but would be needed (Meier et al., 2018).	Policy relevance: Salinity and the ventilation of the deep water with oxygen are important drivers of the Baltic Sea ecosystem functioning, including reproduction of fish, e.g. cod, and biodiversity (Vuorinen et al., 2015) and are of major concern for marine policies (HELCOM). MBIs and their links to algal blooms and resuspension of nutrients from the deep basins.

Commented [A1]: Remember to check for contradicting information

Commented [A2R1]: Where have you detected contradicting information?

Commented [A3]: Remember to check for contradicting information

Commented [A4R3]: Where have you detected contradicting information?

Commented [A7]: Include historical trend information from recent paper

Commented [A5]: In general ensure that if there are possible contradictions these are explained to avoid missusderstandings.

Commented [A8]: Add reference (HELCOM 2018)

Commented [A6]: Rewrite to remove specific number as there is low confidence in the result

	Bothnian Bay. The dynamics of the Baltic Sea is characterized by a two layer system because of a pronounced, perennial vertical gradient in salinity. Meteorologically driven large saltwater inflows (so-called Major Baltic Inflows, MBIs) sporadically renew the deeper parts of the Baltic Sea with saline, oxygen rich water. Hence, MBIs are the only process that effectively ventilate the deep water. However, MBIs are estimated to contribute to the total salt important by only 20%.	The intensity and frequency of MBIs are projected to remain unchanged (with potential tendency of a slight increase (Schimanke et al., 2014).		with a period of about 30 years. Part of this variability is, for instance, the stagnation period during 1983-1992 without MBI and with decreasing salinity (Nehring and Matthäus, 1991). Model results suggest that decreasing salinity over ten years appear approximately once per century on average and belongs to the natural variability of the system (Schimanke and Meier, 2016). On longer time scales, Baltic Sea salinity is under the influence of the Atlantic Multidecadal Oscillation with a period of about 60-90 years (Börgel et al., 2018). Since about the 1980s, increased bottom salinities and decreased surface salinities were observed (Vuorinen			What can be done about it (possible responses)? Large-scale changes in climate will affect salinity in the Baltic Sea. Hence, mitigation of greenhouse gas emissions might be the only measure against anthropogenic changes in salinity on centennial time scales. Especially focusing on avoidance, alleviation, adjustment and adaptation. What is already being done about it? Existing agreements/policies: How does it affect measures taken to reduce pressures on the Baltic Sea? Policy gaps

				et al., 2015; Liblik and Lips, 2019).			

References (not complete):

BACC II Author Team (2015). Second assessment of climate change for the Baltic Sea Basin. Regional Climate Studies. Cham: Springer. https://doi.org/10.1007/978-3-319-16006-1.

Börgel, F., C. Frauen, T. Neumann, S. Schimanke, and H. E. M. Meier, 2018: Impact of the Atlantic Multidecadal Oscillation on Baltic Sea variability. Geophysical Research Letter, 45(18), 9880-9888, https://doi.org/10.1029/2018GL078943.

Fonselius, S., & Valderrama, J. (2003). One hundred years of hydrographic measurements in the Baltic Sea. *Journal of Sea Research*, *49*(4), 229-241.

HELCOM (2018): State of the Baltic Sea – Second HELCOM holistic assessment 2011-2016. Baltic Sea Environment Proceedings 155, ISSN 0357-2994. Available at: www.helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/reports-and-materials/

Kniebusch, M., H. E. M. Meier, and H. Radtke, 2019: Changing salinity gradients in the Baltic Sea as a consequence of altered freshwater budgets. Geophysical Research Letters, in press.

Liblik, T. and Lips, U. 2019. Stratification Has Strengthened in the Baltic Sea – An Analysis of 35 Years of Observational Data. Frontiers in Earth Science, 7. doi:10.3389/feart.2019.00174

Meier, H. E. M., and Kauker, F. (2003). Modeling decadal variability of the Baltic Sea: 2. Role of freshwater inflow and large-scale atmospheric circulation for salinity. Journal of Geophysical Research - Oceans 108(C11), https://doi.org/10.1029/2003JC001799.

Meier, H. E. M., M. Edman, K. Eilola, M. Placke, T. Neumann, H. Andersson, S.-E. Brunnabend, C. Dieterich, C. Frauen, R. Friedland, M. Gröger, B. G. Gustafsson, E. Gustafsson, A. Isaev, M. Kniebusch, I. Kuznetsov, B. Müller-Karulis, A. Omstedt, V. Ryabchenko, S. Saraiva, and O. P. Savchuk, 2018: Assessment of eutrophication abatement scenarios for the Baltic Sea by multi-model ensemble simulations. Frontiers in Marine Science, 5:440, https://doi.org/10.3389/fmars.2018.00440

Meier, H. E. M., M. Edman, K. Eilola, M. Placke, T. Neumann, H. Andersson, S.-E. Brunnabend, C. Dieterich, C. Frauen, R. Friedland, M. Gröger, B. G. Gustafsson, E. Gustafsson, A. Isaev, M. Kniebusch, I. Kuznetsov, B. Müller-Karulis, M. Naumann, A. Omstedt, V. Ryabchenko, S. Saraiva, and O. P. Savchuk, 2019: Assessment of uncertainties in scenario simulations of biogeochemical cycles in the Baltic Sea. Frontiers in Marine Science, 6:46, https://doi.org/10.3389/fmars.2019.00046

Mohrholz, V. (2018). Major Baltic Inflow Statistics – Revised. Frontiers in Marine Science 5, 384. https://doi.org/10.3389/fmars.2018.00384.

Nehring, D., & Matthäus, W. (1991). Current trends in hydrographic and chemical parameters and eutrophication in the Baltic Sea. *Internationale Revue der gesamten Hydrobiologie und Hydrographie*, *76*(3), 297-316.

Saraiva, S., Meier, H. E. M., Andersson, H. C., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R., and Eilola, K. (2019). Uncertainties in projections of the Baltic Sea ecosystem driven by an ensemble of global climate models. Frontiers in Earth Science, 6:244, https://doi.org/10.3389/feart.2018.00244.

Schimanke, S. and H. E. M. Meier, 2016: Decadal to centennial variability of salinity in the Baltic Sea. Journal of Climate, *29*(20), 7173-7188. http://dx.doi.org/10.1175/JCLI-D-15-0443.1

Vuorinen, I., J. Hänninen, M. Rajasilta, P. Laine, J. Eklund, F. Montesino-Pouzols, F.Corona, K. Junker, H. E. M. Meier, and J. W. Dippner, 2015: Scenario simulations of future salinity and Ecological Consequences in the Baltic Sea and adjacent North Sea areas - implications for environmental monitoring. Ecological Indicators, 50, 196 - 205.

Stratification

Description - Give a brief description of the parameter. Show links to other parameters.

Stratification denotes the vertical layering of water bodies according to different water densities mainly determined by layer specific water temperature and salt concentrations. Stratification controls vertical transports in the water column, e.g. the downward flow of dissolved oxygen from the sea surface into the deep layers. A number of parameters exist to characterize stratification. Pycnocline commonly denotes the strongest density gradient in the vertical water column. Corresponding definitions exist for the temperature gradient (thermocline) and salinity gradient (halocline) which highlight the governing parameters for the density layering.

The forces of the winds (i.e. wind stress working at the air water interface) can potentially homogenize the water column fully (some shallow water regions) or partly (deep water regions) and thus influence stratification.

In the Baltic Sea a pronounced halocline persists over the year between 60-80 meters in most regions. During the warm season a thermocline develops at much shallower depths (10-20 meter).

What is expected to happen?
Mean Change/level of confidence. - What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible.

Theoretical considerations imply that increased freshwater supply (precipitation minus evaporation, snow melt) over the Baltic Sea drainage basin accompanied by the supply of deep salt rich waters from the North Sea as well as warming of the surface layer would favor stronger stratification. Thus the future development of stratification mainly depends on how the Baltic Sea surface will warm up compared to deeper layers and how freshwater supply and saltwater inflow will change (which in turn is linked to large-scale atmospheric moisture transport to the region, regional wind patterns and global mean sea level rise).

Most model studies, however project increasing sea surface temperatures for the end of the 21st century for the Baltic Sea (BACC II). More recent scenarios with revised greenhouse gas emission pathways imply an increase of 2-3 °C depending on the emission scenario RCP 4.5 or RCP 8.5 (Saraiva et al., 2019). Most studies suggest rather moderate changes or slightly lowered surface salinities in the Baltic Sea (Meier, 2015). In certain weaker stratified regions like the Gulf of Finland or Bothnian Bay changes in deep salinity could lead to decreased stratification (Meier 2015).

Little is known about future trends in saltwater inflows to the Baltic Sea which mainly impact on deep water salinity (with positive effect on stratification). Favorable atmospheric preconditions i.e. the prevalent wind regime for salt inflows have been reported to occur slightly more frequent in future (Schimanke et al., 2014).

Few available studies suggest a tendency towards only slightly modified mean and extreme wind speed over the Baltic Sea at the end of the century (e.g. Kjellström et al., 2011).

The above described changes in governing parameters would favor stratification to increase. In fact few studies report that stratification is likely to increase in future climate (Gröger et al., 2019).

What is expected to happen?
Extremes / level of confidence. - What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible.
What is happening? Provide information on already identified effects
What are the direct consequences? Examples of effects can we already see, if available.

Commented [A9]: Needs to be "translated" for a broader audience.

Commented [A10]: Remove repetition/overlap with other parameters

Commented [A11]: add some "justification (one sentence) for why the parameter is important ("what does it mean for me?"), This should be added to all the sheets.

Commented [A12]: not just limiting the vertical transport but the gradient also determines the horizontal scales.

Commented [A13R12]: What do you mean? This will get very complicated.

Commented [A14]: add some information on the complexity of the parameter, it is a result of several parameters at several timescales, e.g. list the parameters that affect stratification.

Commented [A15]: Meier and Saraiva (2019). Would be good to specify the underlying scenarios? A1B, A2 or RCP 4.5 and 8.5. 2-3°C corresponds to ensemble mean changes under RCP 4.5 and 8.5 averaged for the entire Baltic Sea.

Commented [A16]: What time of year? Annual mean? Link to sea ice cover? Which region doe this refer to (in the Baltic)?

Commented [A17]: Why do we present an older projection if we have a newer more specific one?

Commented [A18R17]: Good questions. The newest scenario simulations are not necessarily more plausible than the older scenario simulations.

Commented [A19]: Make consistent with the text about water temperature

Commented [A20]: Move to include in salinity parameter

Commented [A21]: But there is a northward shift of the storm track (Gröger et al., 2019)

Commented [A22]: I suggest to specify whether thermocline or halocline changes are meant.

Commented [A23]: Not applicable

Commented [A24]: What is the implications for the depth of the permanent halocline?

What is already happening?
Mean Change/level of confidence.
What is happening? Provide information on already identified effects
What are the direct consequences? Examples of effects can we already see, if available.

Direct consequences of increasing stratification is that mixing between well ventilated surface waters and deep waters weakens. This makes the Baltic Sea more vulnerable against deoxygenation of bottom waters (haline stratification). An increase in seasonal thermal stratification can additionally lower the vertical nutrient transport from deeper layers to the euphotic zone thereby limiting nutrient supply and potentially facilitate cyanobacteria blooms in the Baltic Sea.

Commented [A25]: this is also relevant for policy

Commented [A26]: rephrase this paragraph to include information that this refers only to summer conditions etc.

During the historical past the haline stratification was dominated by the sporadic inflow events from the adjacent North Sea. No long term trend in the Baltic Sea salinity can be robustly deduced so far.
Sea surface temperatures have been risen between X and Y degree since (MAKE CONSISTENT WITH OTHER FACT SHEETS).

Commented [A27]: I agree

During 1982-2016 stratification has increased in the Baltic Sea (Liblik and Lips, 2019). The seasonal thermocline and the perennial halocline have strengthened in most of the sea during these 35 years.

What is already happening?
Extremes/level of confidence.
What is happening? Provide information on already identified effects
What are the direct consequences? Examples of effects can we already see, if available.

Commented [A28]: Not applicable

Knowledge gaps

Commented [A29]: Perhaps something from Meier et al. 2019?

Commented [A30]: move information from uncertainties here? Other knowledge gaps that need to be highlighted? Closely linked to the gaps under the salinity.

The complex interplay between temperature change, wind change and changing precipitation makes it difficult to predict future climate effects on stratification. Furthermore, stratification is subject to complex processes like winter convection which are likely to change with future climate change.

Uncertainties:
Trends in surface temperature can be expected to follow the change in air temperature due to air sea heat exchange. Here global models highly agree at least qualitatively. Under the assumption of moderate greenhous gas emissions high resolution model simulations project a warming of surface air temperature by up to 8 °C degree in winter and up to X °C during summer for the Baltic Sea region (Lind and Kjellström, 2008) at the end of the 20th century.

Commented [A31]: Missing number

Changes in salinity are more difficult to predict as this depends more on the ocean circulation and the atmospheric moisture transport to the Baltic Sea drainage basin. However, to robustly estimate future moisture transport and runoff to the Baltic Sea requires high resolution atmosphere models to resolve local orography along continental water sheds. Furthermore, even on a global scale the water cycle suffers from strong uncertainties (REFERENCES). This makes predictions for the future development of salinity highly uncertain.

Commented [A32]: We have an own row on salinity in the fact sheet. Should be synchronized.

Due to the pronounced multidecadal variability in measured water temperature and salinity any conclusion on long-term trends related to past changes in climate cannot be drawn.

Policy relevance

Commented [A33]: linked to the issue on reproduction of cod.

What can be done about it (possible responses)?
Especially focusing on avoidance, alleviation, adjustment and adaptation.
What is already being done about it?
Existing agreements/policies:
How does it affect measures taken to reduce pressures on the Baltic Sea?
Policy gaps

Vertical mixing of nutrients and cyanobacterial blooms

References

Meier H.E.M. (2015) Projected Change—Marine Physics. In: The BACC II Author Team (eds) Second Assessment of Climate Change for the Baltic Sea Basin. Regional Climate Studies. Springer.

Kjellström E, Nikulin G, Hansson U, Strandberg G, Ullerstig A (2011) 21st century changes in the European climate: uncertainties derived from an ensemble of regional climate model simulations. Tellus A 63:24-40

Liblik, T., & Lips, U. (2019). Stratification has strengthened in the Baltic Sea–an analysis of 35 years of observational data. Frontiers in Earth Science, 7, 174.

Lind P, Kjellström E (2008) Temperature and precipitation changes in Sweden; a wide range of model-based projections for the 21st century. SMHI Reports Meteorology and Climatology, 113

Saraiva, S., Markus Meier, H.E., Andersson, H. et al. Clim Dyn (2019) 52: 3369. https://doi.org/10.1007/s00382-018-4330-0

Elken J., Lehmann A., Myrberg K. (2015) Recent Change—Marine Circulation and Stratification. In: The BACC II Author Team (eds) Second Assessment of Climate Change for the Baltic Sea Basin. Regional Climate Studies. Springer, Cham

Precipitation and extreme events

Topic	Description	What is expected to happen?		What is already happening?		Knowledge gaps	Policy relevance
		Mean change	Extremes	Mean change	Extremes		
		Level of confidence:	*Level of confidence:*	*Level of confidence:*	*Level of confidence:*		
Precipitation and extreme events *Erik Kjellström, SMHI*	Give a brief description of the parameter Precipitation is water falling to the ground. It can take various forms including melted (e.g. rainfall and drizzle) or frozen (e.g. snowfall and hail) or in mixed forms involving both snow and rain (e.g. sleet). Precipitation is measured in mm of melted water over a certain time interval that could include one or several precipitation events. Show links to other parameters.	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible. A warmer climate leads to an amplification of the hydrological cycle. For areas with large amounts of precipitation this implies even more precipitation while for dry areas there is a risk of further drying. In the Baltic Sea region this implies increasing precipitation, most notably in the winter half of the year and	What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible. A warmer atmosphere that can hold more water vapor increases the potential for precipitation extremes. Both droughts and heavy rainfall events can become more intense. Recent climate model simulations performed for other regions in Europe and North America	What is happening? Provide information on already identified effects What are the direct consequences? Examples of effects can we already see, if available. On average, annual mean precipitation has generally increased over most of the Baltic Sea region over the 20th Century. Differences between different parts of the region and between seasons are prominent.	What is happening? Provide information on already identified effects What are the direct consequences? Examples of effects can we already see, if available. Precipitation increase in northern Europe is generally associated with an increase in the frequency and intensity of extreme precipitation events. Observed changes include increasing intensity and/or frequency of intense precipitation events, changes in duration of wet and dry spells.	Focus on different aspects of precipitation characteristics, different methods and different data sets used in various national studies in the Baltic Sea region implies that the picture of the precipitation climate including its past changes is not fully coherent. Even if climate scenarios are becoming more frequent and there is now a growing ensemble of relatively high-resolution regional climate scenarios for Europe the scenarios still only samples a subset of the global climate model projections assessed by the IPCC. This means	Policy relevance: What can be done about it (possible responses)? To suppress future changes in precipitation requires strong climate change mitigation action. To reduce impacts of future changes adaptation measures may be needed. For changing precipitation this involves both increasing precipitation with risks for flooding and decreasing precipitation and risks of drought.

Commented [A34]: Need to add references.

Commented [A35]: would it be possible to give ranges?

Commented [A36R35]: I agree. Numbers, regional and seasonal differences, and uncertainty ranges would be nice to have.

Commented [A37]: give example of extremes to illustrate change

Commented [A38]: Would it be possible to give ranges?

Commented [A39]: add a timescale (observed changes over XXX)

Commented [A40]: This presents general effects are presented but the direct link to the Baltic Sea needs to be highlighted. is there direct effects on the Baltic Sea? Eduardo and Birgit has a paper that could be used for this.

Commented [A44]: Does this mean averageover catchment area?

Commented [A45]: Here we have a disensus between the two text versions for precipitation. This should be discussed and in case of no agreement marked as disensus.

Commented [A43]: How much more intense? Are there differences between different regions of the Baltic Sea catchment area?

Commented [A46]: Regional variability means that this statement needs to be supported by references to available data (eg. EEA)

	Precipitation is strongly linked to other parameters describing the water cycle. The amount of water in the air is one of the most important factors implying that the history of an air mass including previous evaporation and precipitation events. As the amount of water that can be held in air depends on temperatures, precipitation has some temperature dependency (generally more precipitation in summer than in winter in large parts of the Baltic Sea region). Precipitation is also strongly modified by orographic features implying that the large-scale circulation of the atmosphere including wind direction and vertical	in the north in summer. There is a large uncertainty as whether precipitation will increase or decrease in summer in the southern part of the Baltic Sea region that is closer to the dry regime of southern Europe. A warmer future climate will lead to a shortening of the snow season. In winter, climate models project more precipitation and higher temperatures. In many areas this will likely be manifested as more rain and less snow but in some areas that are still cold increasing amounts of snow may be seen. The degree of change depends on the change in forcing conditions and the regional response of the climate system. Both	indicate that high-intensity rainfall events associated with summertime convection may generally increase with up to 10-15% per degree of temperature increase.			that the uncertainties of future climate change in the Baltic Sea region is not fully captured at adequate horizontal resolution for pursuing detailed studies of climate change impacts in the region. New, very high-resolution so called convective-permitting climate models operating at grid spacing of 1-3 km are lacking for the Baltic Sea region. In other regions such models have shown better agreement with observations in representing precipitation extremes and sometimes also a larger climate change signal compared to the more traditional "high-resolution" models operating at c. 10 km grid spacing.	Agricultural policies Urban flooding Urban flooding due to heavy rainfall. Effect on runoff, salinity and stratification. **Especially focusing on avoidance, alleviation, adjustment and adaptation.** **What is already being done about it? Existing agreements/policies:** **How does it affect measures taken to reduce pressures on the Baltic Sea?** **Policy gaps** Link to real life events (e.g. CPH)

Commented [A41]: sentence incomplete

	stability are important factors. Precipitation is a key feature in determining soil moisture conditions, runoff and discharge. The impact on soil moisture can represent a strong feedback mechanism as dry conditions lead to less evaporation and thereby less precipitation etc.	of these are associated with large uncertainties. In addition, internal natural variability of the climate system adds another level of uncertainty when addressing precipitation changes for a certain time period.					

Commented [A42]: rather general. Is it possible to identify certain processes?

Run-off and extreme events

Topic	Description	What is expected to happen?		What is already happening?		Knowledge gaps	Policy relevance
		Mean change	Extremes	Mean change	Extremes		
Run-off and extreme events *Jukka Käyhkö; Harri Kuosa; Janika Laht; Marcin Kawka; Markus Meier*	**Give a brief description of the parameter:** *Run-off* describes general, long-term and/or regional processes and is typically given as litres per second per square kilometre (l s^{-1} km^{-2}) (allowing comparisons between rivers of different sizes), or millimetres per year (mm a^{-1}) (allowing comparisons with precipitation and evaporation), whereas *inflow* and *discharge* typically refer to immediate channel flow and are given as cubic metres per second (m^3 s^{-1}).	**What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible.** Climate change is likely to have a clear influence on the seasonal flow regime as a direct response to changes in the form of the precipitation, as well as by altering the temperature-evapotranspiration regime. (BACC II) For areas in the northern Baltic Sea region presently characterized by spring floods due to snow melt, the floods are likely to	**What is expected to happen in the future? Present expected changes quantitatively e.g. through ranges whenever possible.** The decrease in snow melt induced spring floods in the southern Baltic rivers contrasts with the situation in the Nordic countries, where changes in winter snowmelt are not yet apparent in the river runoff data, although they are expected in the future. Simulations suggest that large (100-year) spring floods in the northern Baltic catchment (Finland)	**What is happening? Provide information on already identified effects** **What are the direct consequences? Examples of effects can we already see, if available.** Run-off to the Baltic Sea is governed by various systems and processes. In the northern region and Gulf of Finland, run-off is strongly linked to temperature, wind and rotational circulation components In the southern region, run-off is more associated with the strength and torque of the cyclonic or anticyclonic pressure systems. (Hansson et al. 2011)	**What is happening? Provide information on already identified effects** **What are the direct consequences? Examples of effects can we already see, if available.** MISSING EXAMPLES OF CONSEQUENCES	The impact of how climate model results are transferred to the hydrological model are still inadequately understood. More research is needed to quantify the accuracy and uncertainty associated with various bias correction methods. Several uncertainties are associated with impact modelling, including parameter uncertainty and model structure uncertainty. The values of the parameters of a hydrological model are normally found through calibration against historical data and are always associated with uncertainty. This	**Policy relevance:** Seasonal runoff changes will have an impact on sediment and nutrient load and thereby on the eutrophication of the Baltic Sea. Changes in the timing of extreme events will have consequences in flood hazard and risk in riverside settlements. Changes in total flow will affect salinity and consequently species distribution and food web composition, Land use implications Agricultural policies

Commented [A47]: Add references.

Commented [A49]: Needs to be shortened a bit, and possibly simplified.

Commented [A48]: Define what is meant by drought (or use a different term?)

Commented [A50]: Can we add information on what is happening and what has already happened for floods? What is an extreme and what are repeat periods? What is a floods (under Description).

Commented [A51]: Add references.

	Extreme runoff events refer to ***floods***, which typically occur during spring-time *snow melting period*, but can also be related to *precipitation extremes*. **Links to other parameters.** The magnitude of water flow in a river is the result of various complex hydrological processes including *precipitation*, *evapotranspiration*, *infiltration* and *storage* (e.g. in the form of snow, soil moisture, and sub-surface and groundwater storage). Therefore, explaining changes in streamflow requires an understanding of these parameters of which precipitation is often the pivotal one in the cool climate of the Baltic Sea region.	occur earlier in the year and their magnitude is likely to decrease owing to less snowfall, shorter snow accumulation period, and repeated melting during winter (Veijalainen et al. 2010).. In the southern part of the Baltic Sea area, increasing winter precipitation is projected to result in increased river discharge during winter. Groundwater recharge is projected to increase y, resulting in higher groundwater levels. During summer, however, decreasing precipitation combined with rising temperature and evapotranspiration is projected to result in a drying of	will decrease by 8–22% in 2070–2099 compared to the reference period 1971-2000. For other seasons, however, simulations suggest an increase of large floods by 12–40%. Variation between different sites and regions will be considerable (Veijalainen et al. 2010). MISSING QUANTITATIVE CHANGES	Although decadal and regional variability is large, no *statistically significant* long-term change has been detected in the reconstructed total river runoff to the Baltic Sea over the past 500 years. As a whole, over the past 500 years, the total river runoff to the Baltic Sea has decreased slightly in response to the rise in temperature; at a rate of 3%, or 450 m^{-3} s^{-1}, per 1°C (Hansson et al. 2011). The observed temperature increase has already affected stream flow in the Nordic countries. In general, changes in stream flow over the 20th century show a redistribution of the seasonal runoff. Higher winter temperatures bring about less snowfall at the expense of rain, plus repeated and earlier melting of accumulated snow. Together, these result in an increase of winter runoff and decrease of		uncertainty will translate into uncertainty in the projected changes. General lack of long time series information.	**What can be done about it (possible responses)? Especially focusing on avoidance, alleviation, adjustment and adaptation.** Sediment and nutrient extraction from the crop fields could be mitigated by careful planning and conduction of farming practices (e.g., timing of tillage). Flood hazard mitigation requires both short-term (rescue) and long-term (planning and construction) measures **What is already being done about it? Existing agreements/policies:** Directive 2007/60/EC on the assessment and management of flood risks requires Member States to assess the risk from flooding, to map the flood extent, assets and humans at risk in

Commented [A52]: Numbers of projected spring flood changes

Commented [A53]: This number is rather uncertain. The reconstructed runoff by Hansson et al. 2010 underestimates interannual variability considerably

Commented [A54R53]: should we drop this altogether, or add another view?

Commented [A55R53]: Leave out

		the root zone, which would drive increasing irrigation demands in the southern part of the Baltic Sea area. Projections with a hydrological model suggest that under RCP 4.5 and RCP 8.5 scenarios the total river flow will increase between 1 and 21% and between 6 and 20%, respectively, illustrating the large uncertainty in hydrological projections (Saraiva et al., 2019). Thereby, the future period 2069-2098 is compared to the reference period 1976-2005.		spring floods. This pattern has been apparent in the southern parts of the Baltic catchment (Reihan et al. 2007).and is gradually moving northwards as a consequence of climate warming (Veijalainen et al 2019 The impacts of both the observed and projected changes in precipitation on stream flow are unclear (Hisdal et al. 2010). MISSING EXAMPLES OF CONSEQUENCES			these areas and to take adequate and coordinated measures to reduce this flood risk. Regarding nutrient inflow, the 2008 marine strategy framework directive aims to achieve a good environmental status of the EU's marine waters by 2020. For the Baltic Sea, the relevant convention is the Helsinki Convention (governed by the Helsinki Commission (Helcom)) and its Baltic Sea action plan, which requires the reduction of nutrient loads from the signatory countries. **How does it affect measures taken to reduce pressures on the Baltic Sea?** So far, these actions have led to limited progress towards nutrient reduction in the Baltic Sea. (Combating

Commented [A56]: Add information about trends in rivers from selected areas. For instance, river flow to the Bothnian Bay show a statistically significant positive trend during 1921-2004 (Kniebusch et al., 2019)

Commented [A57R56]: As of consequences, we could add here, e.g. the potential increase of nutrient flows from unfrozen, snowless, and vegetation-free crop fields during winter (Saraiva et al 2018)

							eutrophication… 2016) Policy gaps The Member States' plans for achieving Helcom nutrient reductions are based on their river basin management plans prepared on the basis of the water framework directive. These plans lack ambition as they focus on 'basic measures' for implementing EU directives in relation to the specific activities causing nutrient pollution, mainly urban waste water and agriculture. Less focus is put on measures for the control of diffuse sources of nutrients and on 'supplementary measures' as set out in the water framework directive. Measures are established on the basis of insufficient information. They

							also lack targets and appropriate indicators for the assessment of achievements made in reducing nutrient loads into waters (Combating eutrophication… 2016).

References:

Combating Eutrophication in the Baltic Sea: further and more effective action needed (2016). Special Report no. 3. European Court of Auditors. 71 pp.

Hansson D, Eriksson C, Omstedt A, Chen D (2011) Reconstruction of river runoff to the Baltic Sea, AD 1500–1995. *Int J Climatology* 31:696-703.

Hisdal H, Holmqvist E, Jónsdóttir JF, Jónsson P, Kuusisto E, Lindström G, Roald LA (2010) Has streamflow changed in the Nordic countries? *Norwegian Water Resources and Energy Directorate*, No 1.

Kniebusch, M., H. E. M. Meier, and H. Radtke, 2019: Changing salinity gradients in the Baltic Sea as a consequence of altered freshwater budgets. Geophysical Research Letters, in press.

Reihan A, Koltsova T, Kriaučiūnienė J, Lizuma L, Meilutytė-Barauskienė D (2007) Changes in water discharges of the Baltic states rivers in the 20th century and its relation to climate change. *Nordic Hydrology* 38:401-412

Saraiva S., Meier, H. E. M., Andersson, H. C., Höglund, A., Dieterich, C., Gröger, M., Hordoir, R., and Eilola, K. (2019b). Uncertainties in projections of the Baltic Sea ecosystem driven by an ensemble of global climate models. Frontiers in Earth Science, Frontiers in Earth Science, 6:244, https://doi.org/10.3389/feart.2018.00244

Veijalainen N, Lotsari E, Alho P, Vehviläinen B, Käyhkö J (2010). Changes in floods in Finland due to climate change: General assessment on national scale. *J Hydrology* 391:333-350.