The impact of serial cyclone clustering on extremely high sea levels in the Baltic Sea

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BACKGROUND

- Extratropical cyclones (ETCs) are responsible for the majority of coastal flooding events in the Baltic Sea.
- Damaging storm surges usually require three simultaneous factors:
  1) high water balance in the Baltic Sea,
  2) favorable wind direction and strength (the track of the storm)
  3) storm-induced seiche oscillation.
- Less is known about how clustering of multiple ETCs affects extremely high sea levels.

Are coastal floods in the Baltic Sea typically caused by a single ETC or a series of consecutive ETCs?

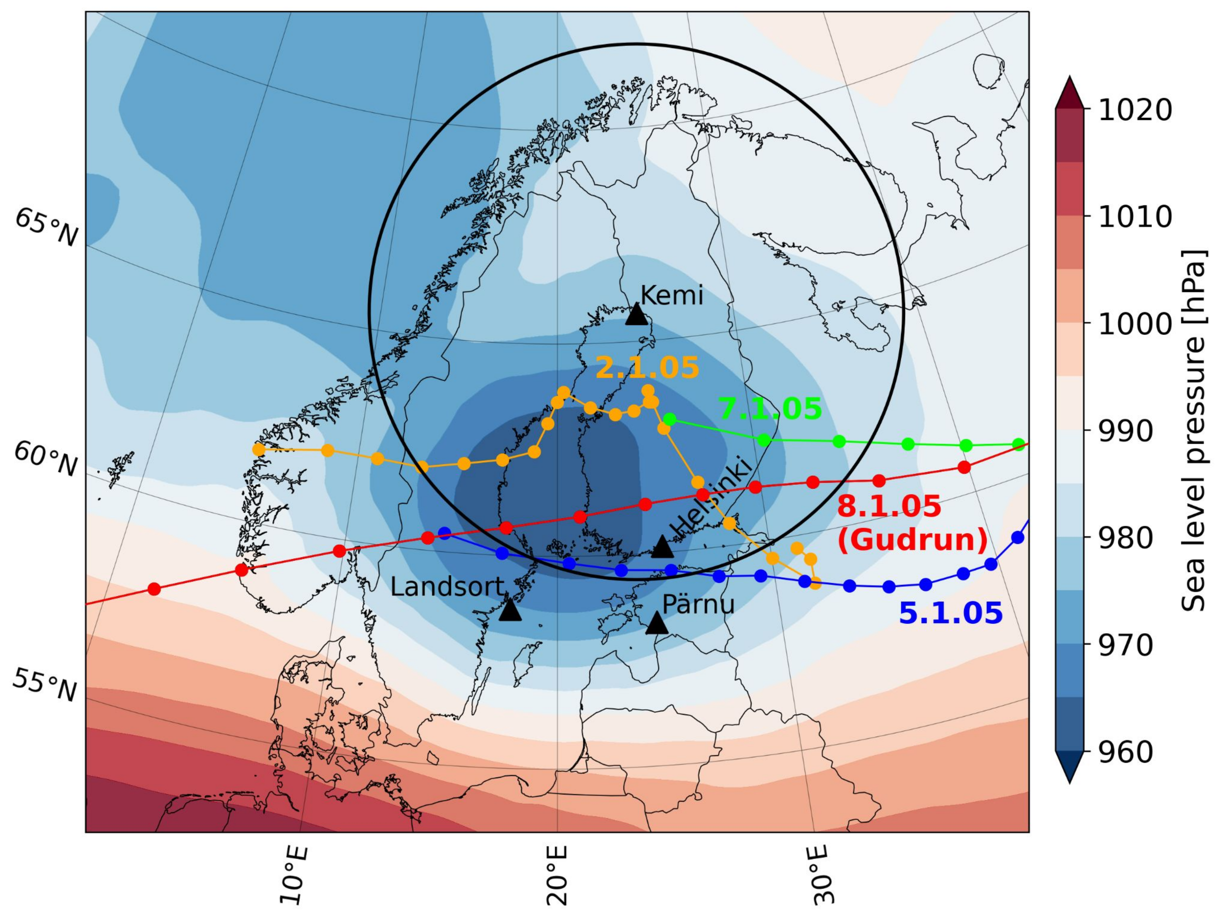

Fig. 1. Locations of the tide gauges used in the study. Background shading depicts mean sea level pressure on 9th January 2005 at 00 UTC. Coloured lines indicate the tracks of the four ETCs in the Baltic Sea in the beginning of January 2005.

DATA & METHODS

- Hourly sea level observations from four tide gauges in the Baltic Sea area (Fig. 1).
- Tracks and intensity of the strongest 50 % of the ETCs (**N=1349**) during the cold season (October-March) from 1979/1980 to 2021/2022 from ERA5 reanalysis.
- Serial cyclone clustering (SCC) is calculated from circular areas of **700 km** radius defined for each tide gauge location.
- Based on the 7-day running sum of ETCs, we identify SCC periods when **one**, **two** or **three or more** ETCs pass the tide gauge within a 7-day period (SCC1, SCC2, and SCC3, respectively).

JANUARY 2005 FLOODING

- Extremely high sea levels on 9th Jan 2005 co-occurred with a clustering period.
- Storm surges induced by the successive ETCs increased step by step due to water inflow to the Baltic Sea basin.
- The record-breaking flood caused by Storm Gudrun would likely have been lower without the effect of the previous ETCs.

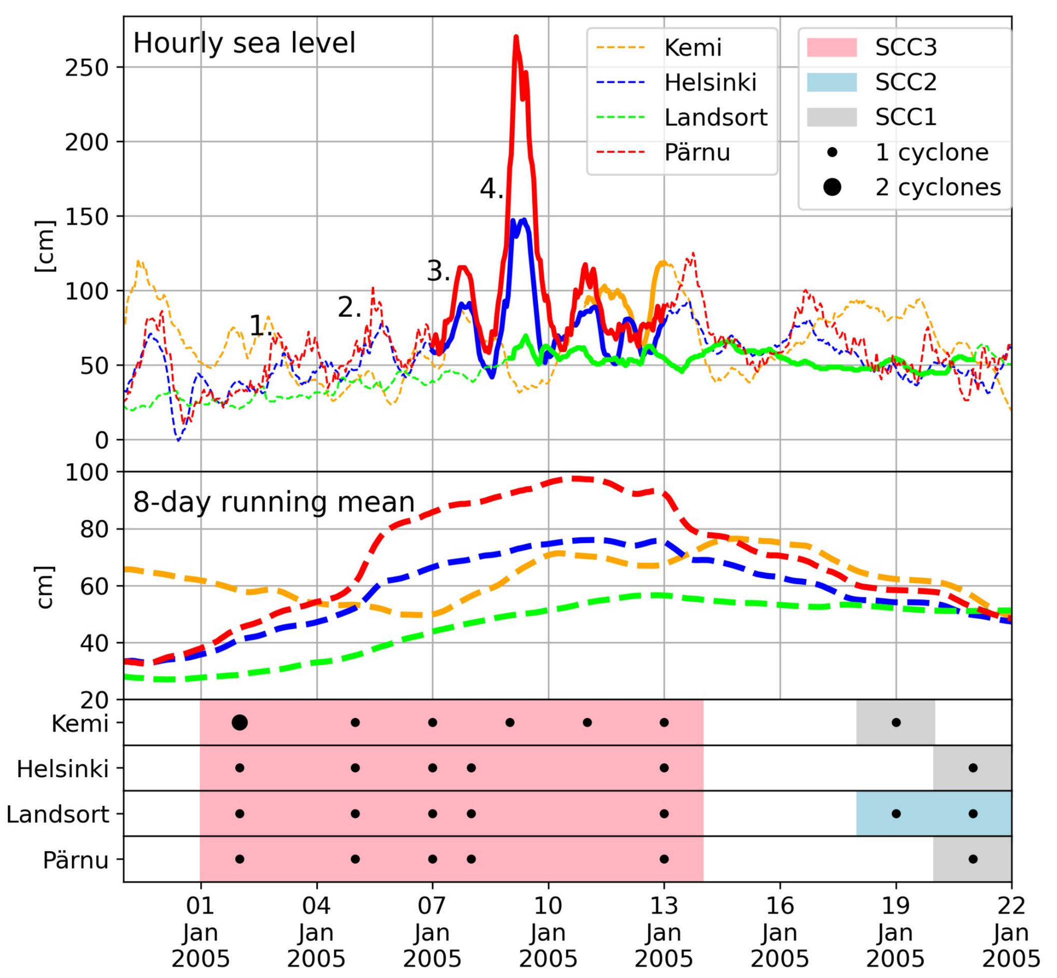

Fig. 2. Time series of hourly sea level at the four tide gauges in January 2005 (top), the 8-day running mean of the sea level (center), and serial cyclone clustering periods (bottom).

COMPOSITE SEA LEVEL AROUND CLUSTERING PERIODS

- We calculated composite daily maximum sea level of all clustering cases in 1979-2022.
- Clustering of at least 3 ETCs leads to higher sea levels on average than a single ETC.
- Higher than normal sea levels remain longer during clustering periods than during a single ETC.

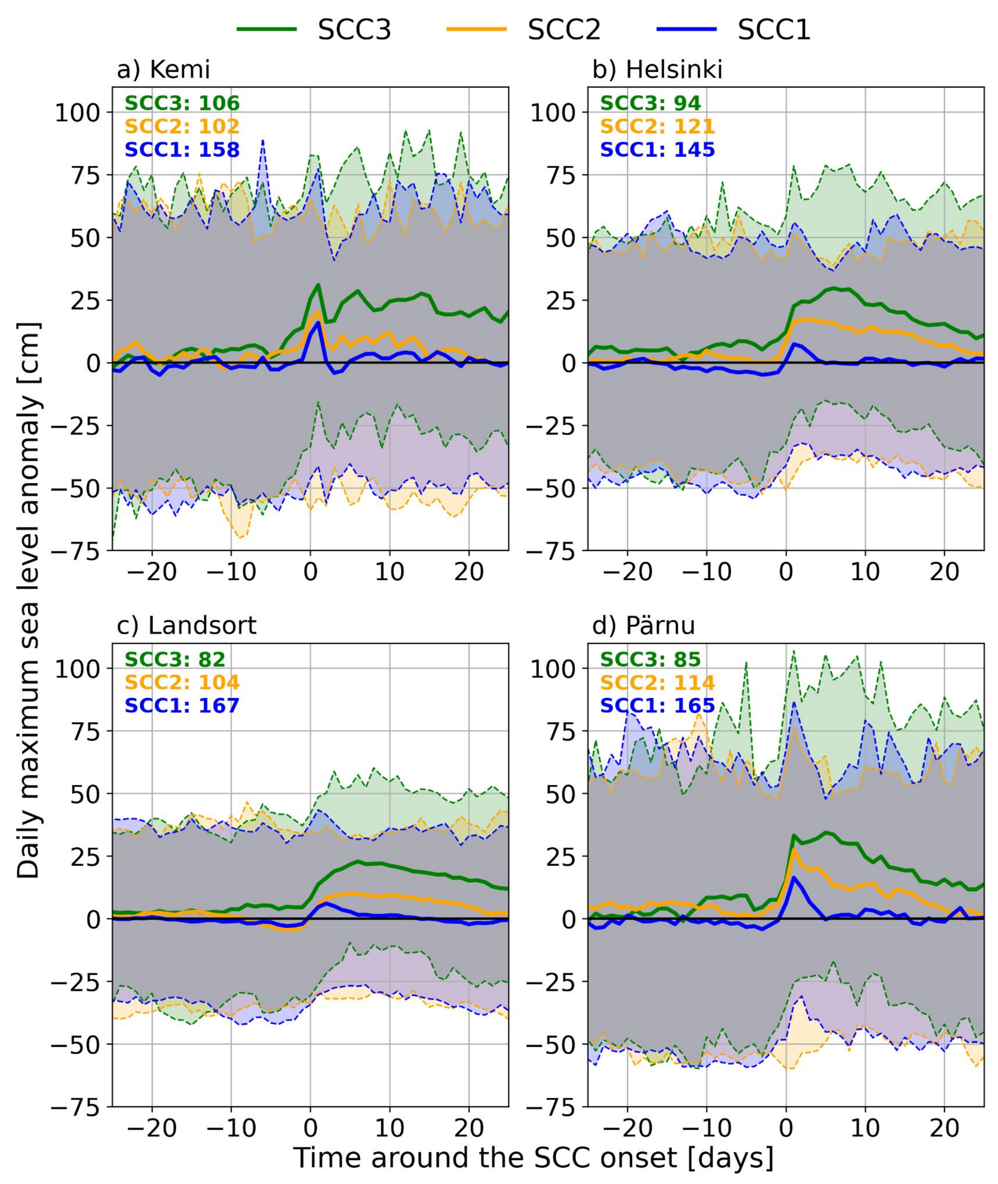

Fig. 3. Composite lagged sea level anomaly centered around cyclone clustering (SCC) onsets at Kemi (a), Helsinki (b), Landsort (c) and Pärnu (d) tide gauges. The shadings present 5-95th percentile intervals.

EXTREME SEA LEVEL EVENTS DURING CYCLONE CLUSTERING

- We went through all extreme sea level events and examined whether they had occurred during clustering periods.
- In most of tide gauges, the largest number of extreme sea level events have occurred during clustering of at least 3 ETCs.

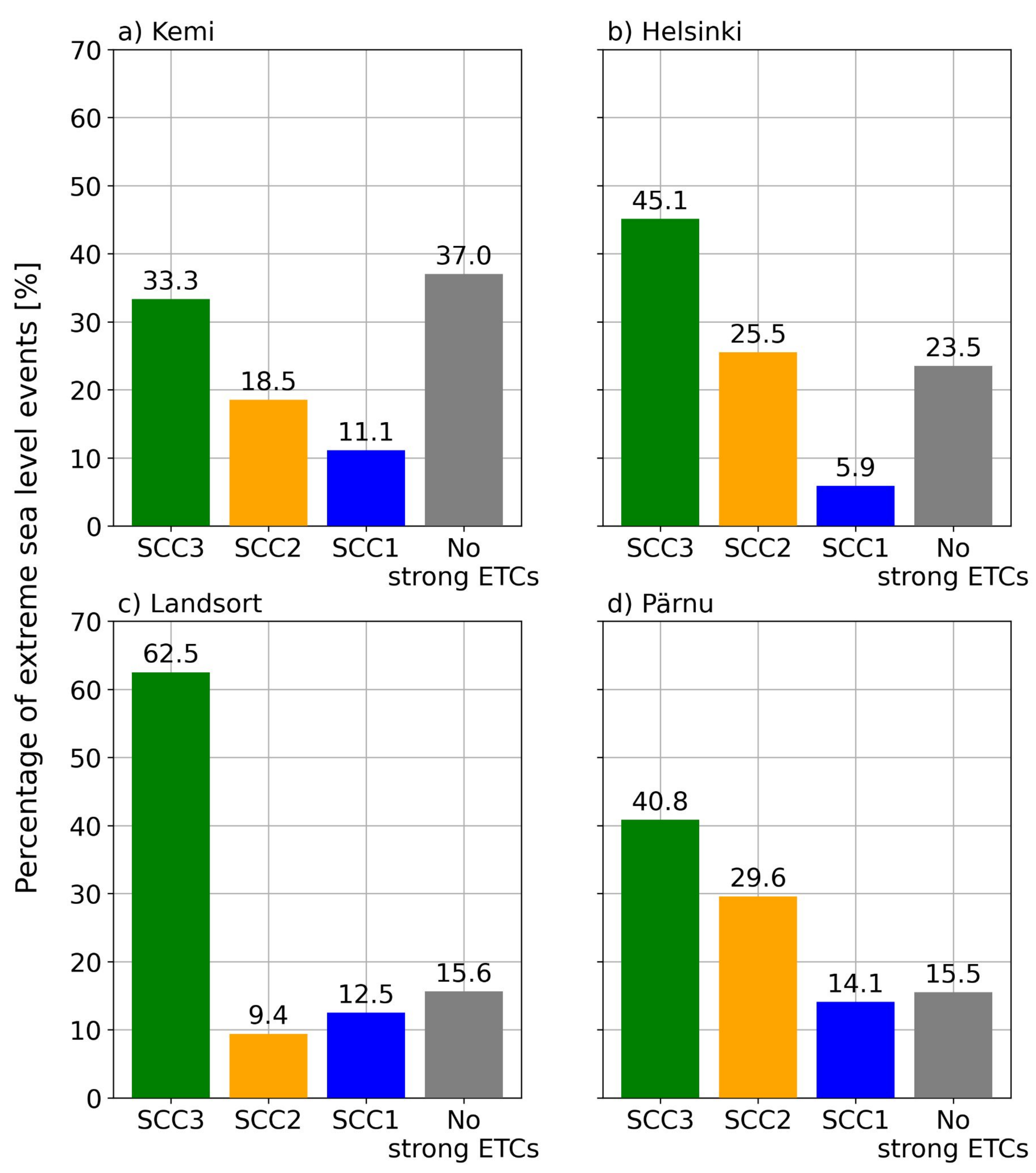

Fig. 4. Percentages of extreme sea level events co-occurring with different cyclone clustering periods at Kemi (a), Helsinki (b), Landsort (c) and Pärnu (d) tide gauges.

THE IMPACT OF CYCLONE INTENSITY ON SEA LEVEL

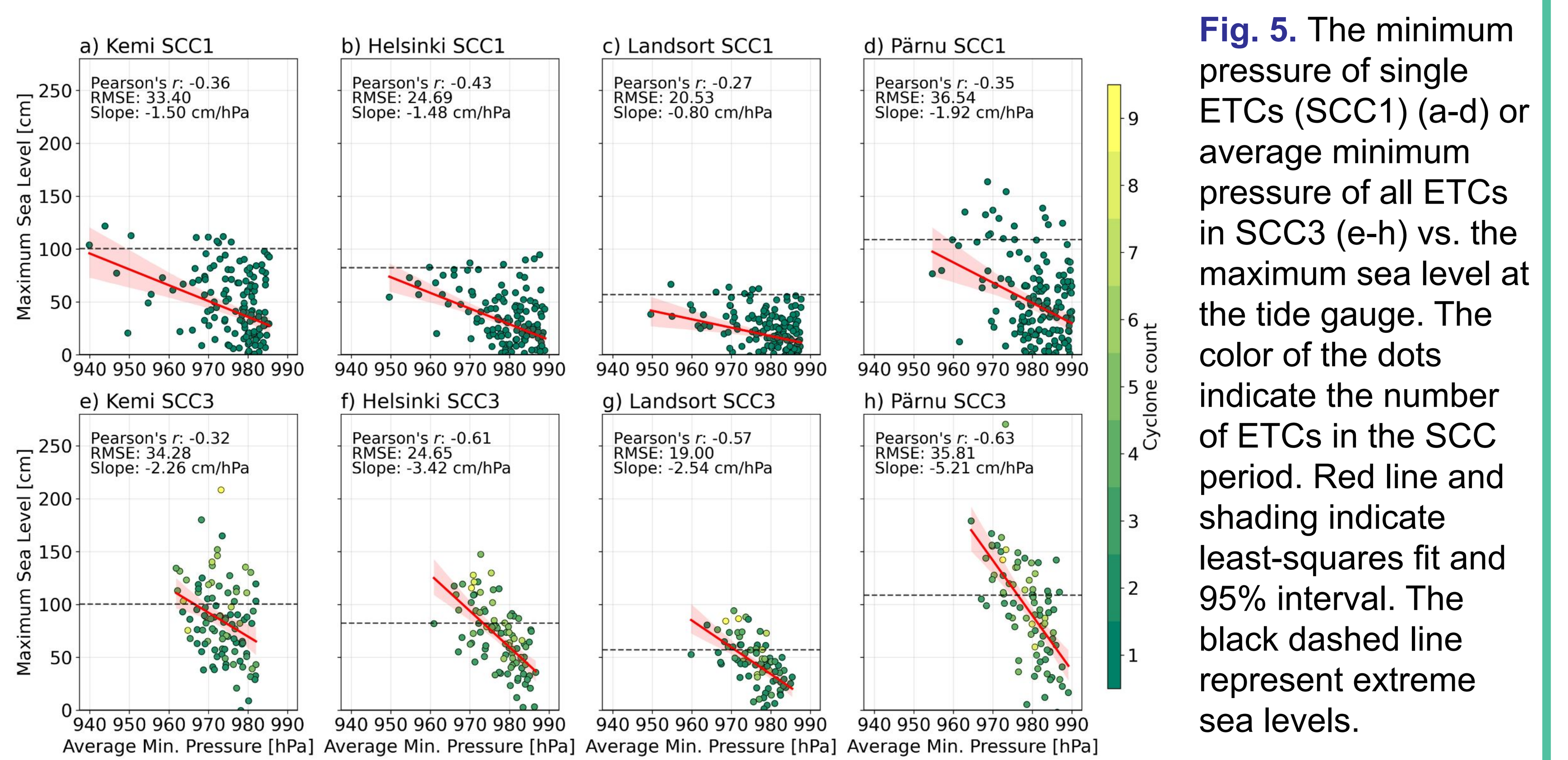

Fig. 5. The minimum pressure of single ETCs (SCC1) (a-d) or average minimum pressure of all ETCs in SCC3 (e-h) vs. the maximum sea level at the tide gauge. The color of the dots indicate the number of ETCs in the SCC period. Red line and shading indicate least-squares fit and 95% interval. The black dashed line represent extreme sea levels.

- Stronger ETCs (lower minimum pressure) lead to higher sea levels.
- The correlation is better for clustered ETCs than for individual ETCs (except for Kemi). Given a strong ETC, higher sea levels are more likely in the clustered case.

Acknowledgements
This research was funded by the Finnish State Nuclear Waste Management Fund (VYR) through the Finnish Research Programme on Nuclear Safety and Waste Management 2023-2028 (SAFER2028) (Dnro SAFER 6/2023 for the MAWECLI project). We thank Rain Männikus for providing sea level observations from Pärnu and Riga. CSC -- IT Centre for Science, Finland, is acknowledged for computational resources, and Copernicus Climate Change Service is acknowledged for making ERA5 reanalysis available.