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FINNISH METEOROLOGICAL INSTITUTE

Final Seminar of the SAFIR2022 and KYT2022 Research Programmes

23.-24.1.2023 Dipoli, Espoo

Kirsti Jylhä, Ulpu Leijala, Milla M. Johansson, Marko Laine, Terhi K. Laurila, Anna Luomaranta, Taru Olsson, Meri Virman, Mika Rantanen, Jenni Rauhala, Olle Räty, Jani Särkkä

Finnish Meteorological Institute (FMI)

PREDICT - Predicting extreme weather and sea level for nuclear power plant safety

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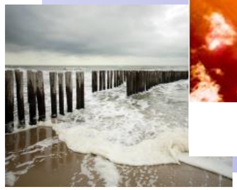
Background, goals and use of results

Background

Any **exceptional weather and sea level event or combination of events** that might affect any component of the safety system of a NPP unit is a potential threat to nuclear safety



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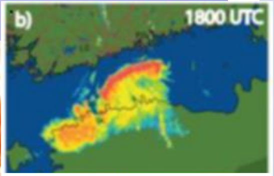


FMI

Objectives

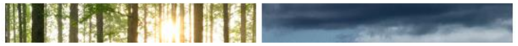
- To produce **hazard curves** of safety-relevant single and compound extreme weather and sea level events in the **changing climate**
- To **develop methods** for assessing probabilities of occurrence of the events at various time scales

Exploitation of results

- The determination of the **design basis for a new NPP unit**
- **Probabilistic risk assessments** (PRA) of new and existing NPPs
- Periodic **safety reviews** of existing NPPs

THE IMPACT OF CLIMATE CHANGE ON NUCLEAR POWER

REPORT 2021:744



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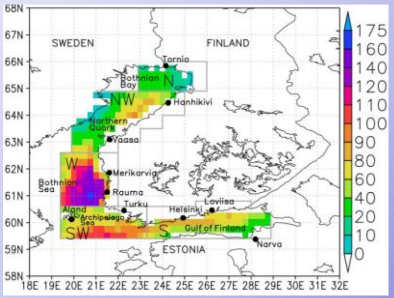
Recent meteorological and marine studies to support nuclear power plant safety in Finland

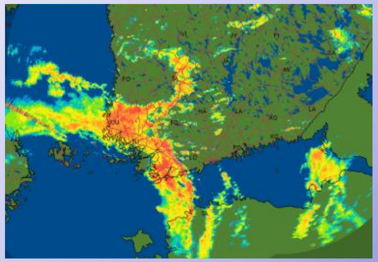
Research topics & NPP relevance

The topics to be studied have been selected based on **feedback** and requests for information from the end-users (e.g., via annual ad-hoc meetings)

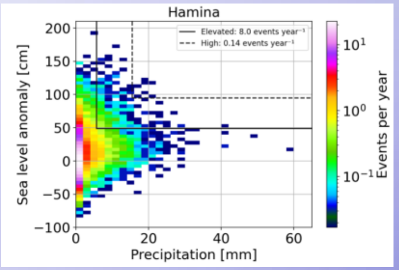
Climatology of intense coastal snowfall



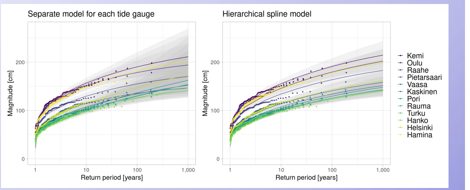
Downbursts and large-scale windstorms



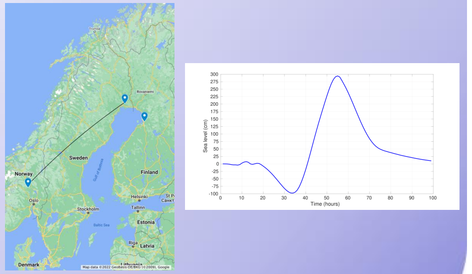
Compound extreme events



Uncertainty in exceptional sea level estimates



Simulated low-pressure systems and extreme sea levels

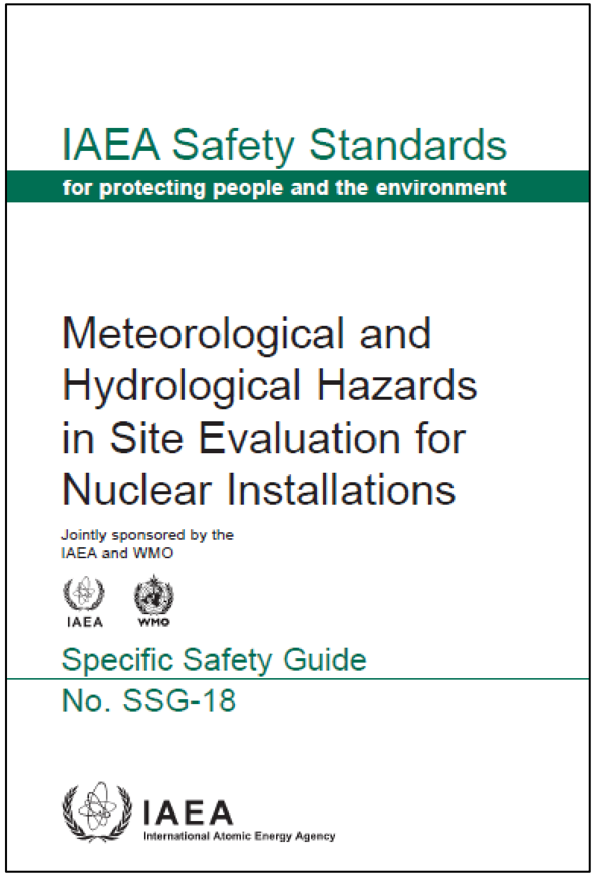


NPP relevance of very intense snowfall:
Loss of offsite power; possible blockage of ventilation air intakes depending on the site; isolation of the plant

NPP relevance of of very strong winds (10-min and gusts):
Loss of offsite power due to objects carried by wind to the switchyard or due to structural damage of power line pylons; possible damage to buildings; Dispersion of radioactive releases

NPP relevance of flooding:
If beyond the design basis: flooding of safety-critical compartments, especially electric power supply and control systems; severe consequences if the seawater has time to enter the buildings. Reactor trip at lower sea levels.

Nuclear safety -relevant weather and sea level events



- Very high and low atmospheric temperatures
- **High winds** including tornadoes and **downbursts** (+ tropical cyclones, typhoons, hurricanes)
- **Very high and low sea water levels**
- **Floods due to exceptional precipitation**
- Tsunamis
- **Snowfall**, hail, freezing rain
- Snow depth
- Frazil ice in sea water
- Lightning
- Drought
- etc.

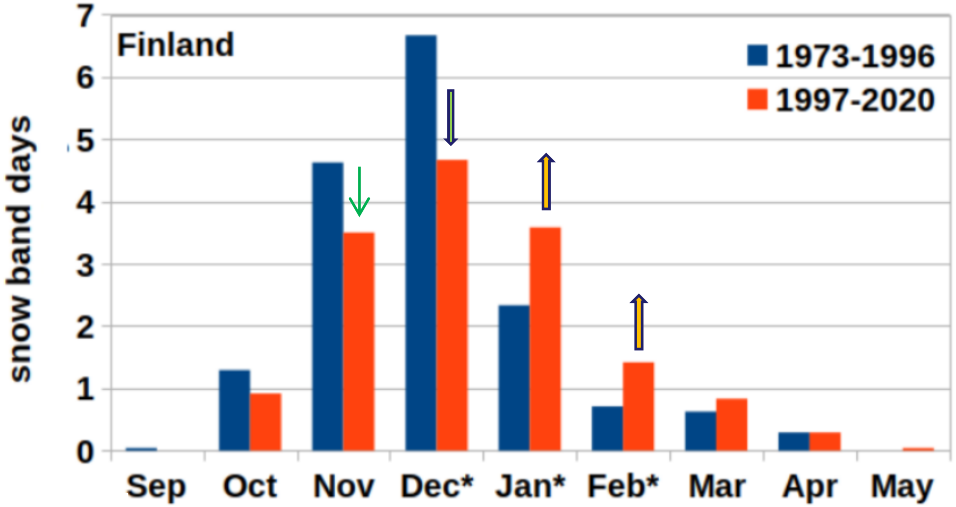
stuk

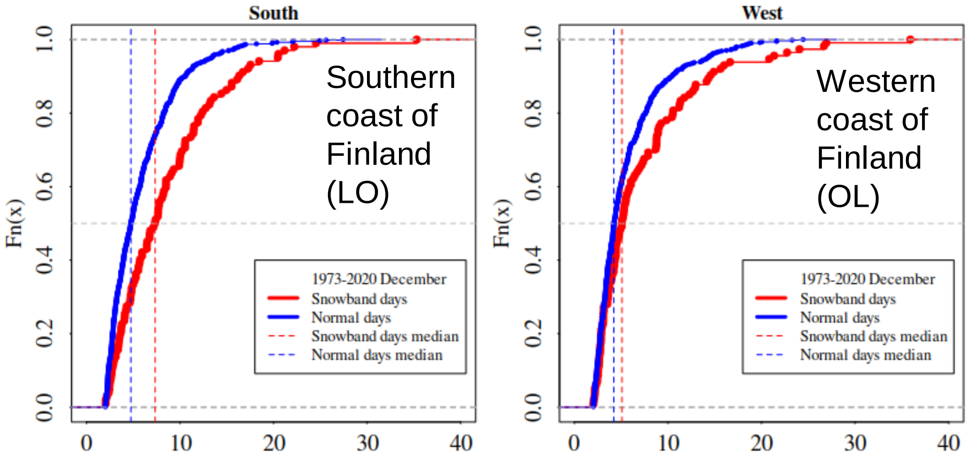
https://www.stuklex.fi/en/ohje/YVLB-7#a5

Hazard curves showing occurrence frequencies

https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1506_web.pdf

Sea-effect snowfall (SES)





Daily maximum snow depth increase (cm/day)

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— SES days
— "normal" stratiform snowfall days

- The national record of snowfall: 73 cm of snow (31 mm as liquid water) on 8 Jan 2016
- On average, 16 SES days annually in Finland
- SES days most frequent in December
- 1-month shift forward of the SES season since the 1970s
- Accumulated snow depth typically larger on SES days than on "normal" days of stratiform snowfall

SES detection method (Taru Olsson et al., 2022) applied to two data sets for the past decades: reanalysis (31 km grid) and regional HCLIM climate model (3 km) data

~Similar annual and monthly mean distributions of SES days based on the two data sets
=> supports the use of the HCLIM climate model in our future work:

How is the occurrence of sea-effect snowfall likely to alter due to climate change?

Refs. Olsson et al. (2022), Rutgersson et al. (2002), Olsson (2022), Virman (2022)

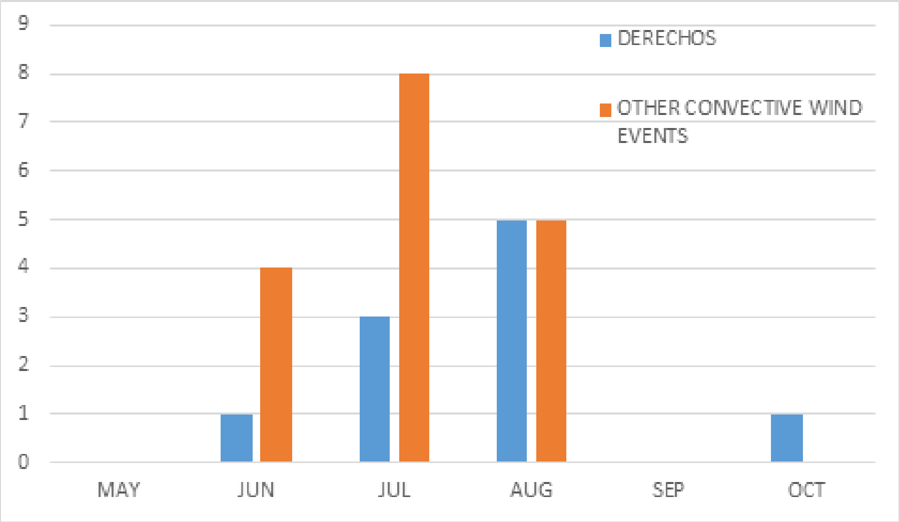
Derecho occurrence and classification in Finland

Derecho:
- An extremely damaging mesoscale convective system, consisting of downburst clusters.
- Have an impact on a very large area.
- Damage mostly correspond to F1 (33 m/s) intensity, but sometimes up to F2 (50 m/s).

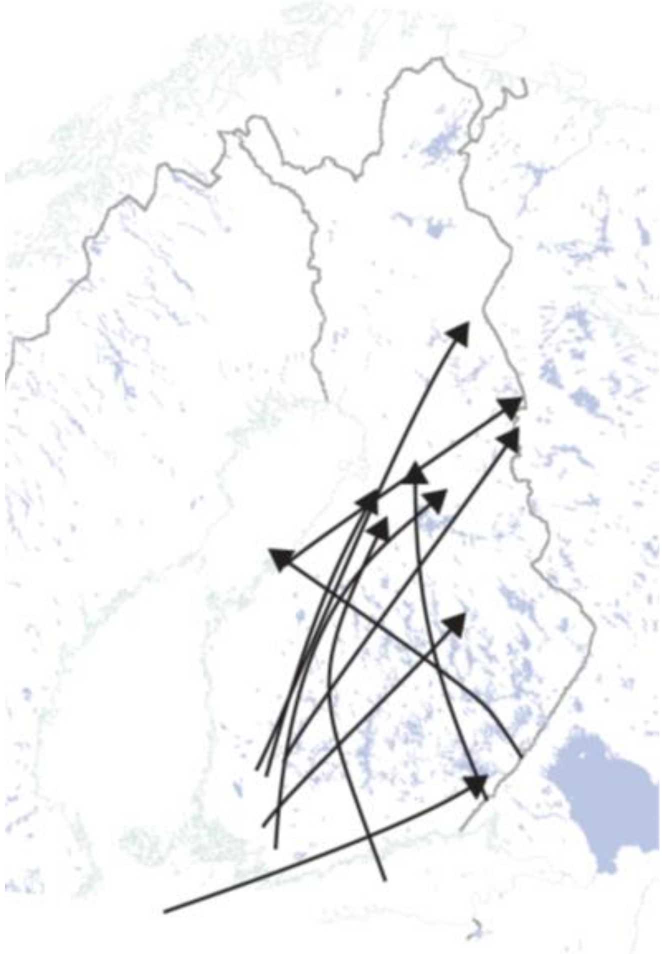
This study discovered 27 convective wind events causing large damage in Finland. These included 10 derechos and 17 other major convective wind events.

Confirmed derecho cases in Finland:
- Long lasting events, with duration ranging from 4h 30 min to 9h 30 min.
- Start time in most (70%) cases in the afternoon, between 12 and 18 local time.
- Length of the observed derecho tracks in Finland varied between 400 km and 660 km.

Monthly distribution derechos and other convective wind events in Finland



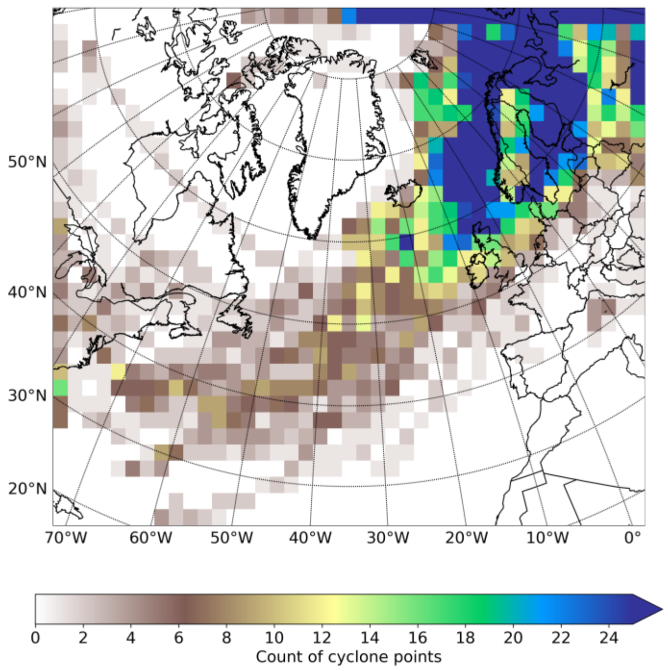
Damage tracks of 10 documented derechos in Finland



Rauhala (2023)

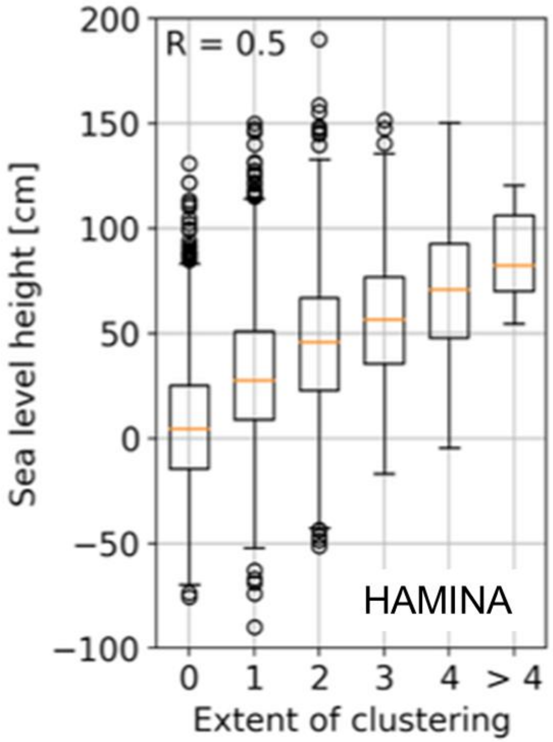
Windstorms and high sea level

Characteristics of low-pressure systems causing extreme sea levels in Finland



On average, during their whole lifetime, cyclones causing extreme sea levels have longer lifetime, propagate faster, have lower minimum air pressure and stronger wind gusts than all cyclones.

The role of low-pressure systems and cyclone clustering for the sea level extremes in Finland



X-axis: the number of storms passing the Hamina tide gauge during a week

In most cases, coastal flooding events require more than one bypassing windstorm to occur.

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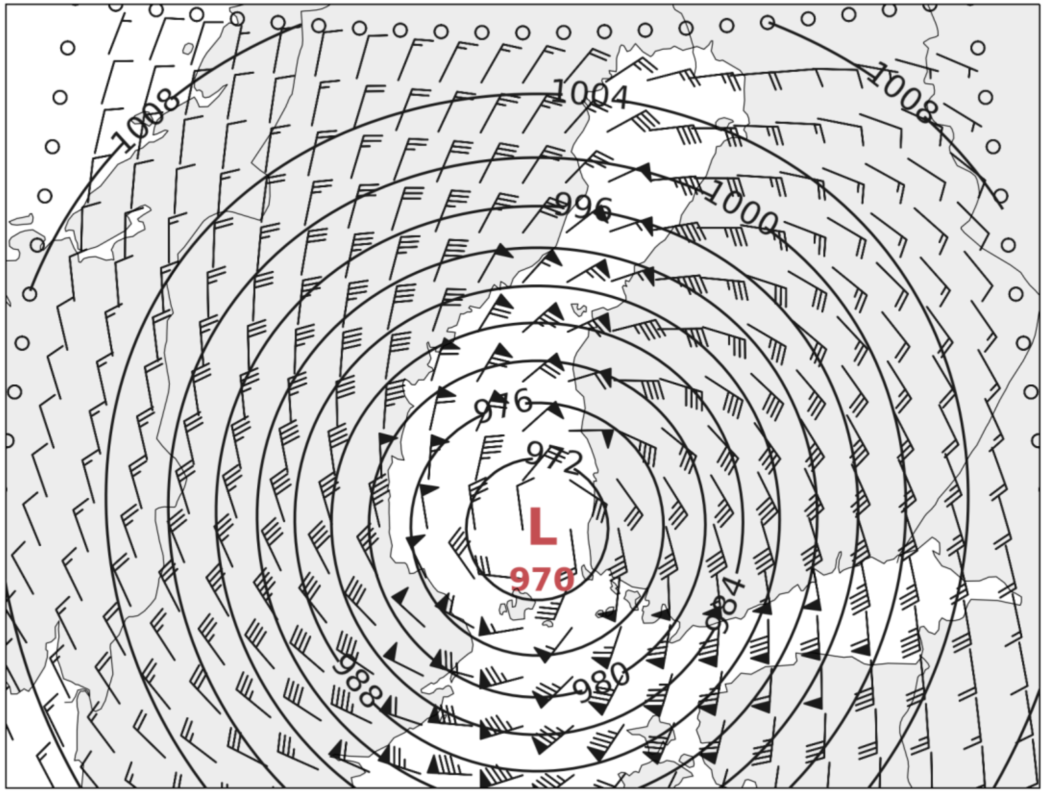
Laurila (2022)

Rantanen et al. (2021)

Simulation of extreme sea levels with synthetic low-pressure systems

Särkkä et al. (2022)

- How severe the coastal flooding could be, if the weather conditions are optimal?
- A synthetic ensemble of moving low-pressure systems was generated
- This ensemble was used as input for numerical sea level simulations
- The objective: to find the low-pressure system causing the highest storm surge



An example of a synthetic low-pressure system

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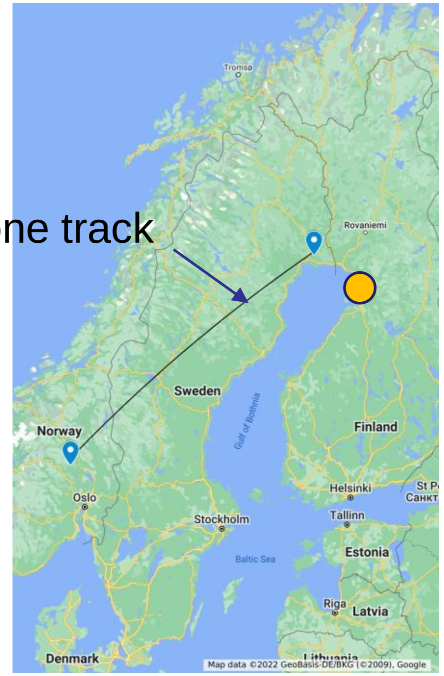
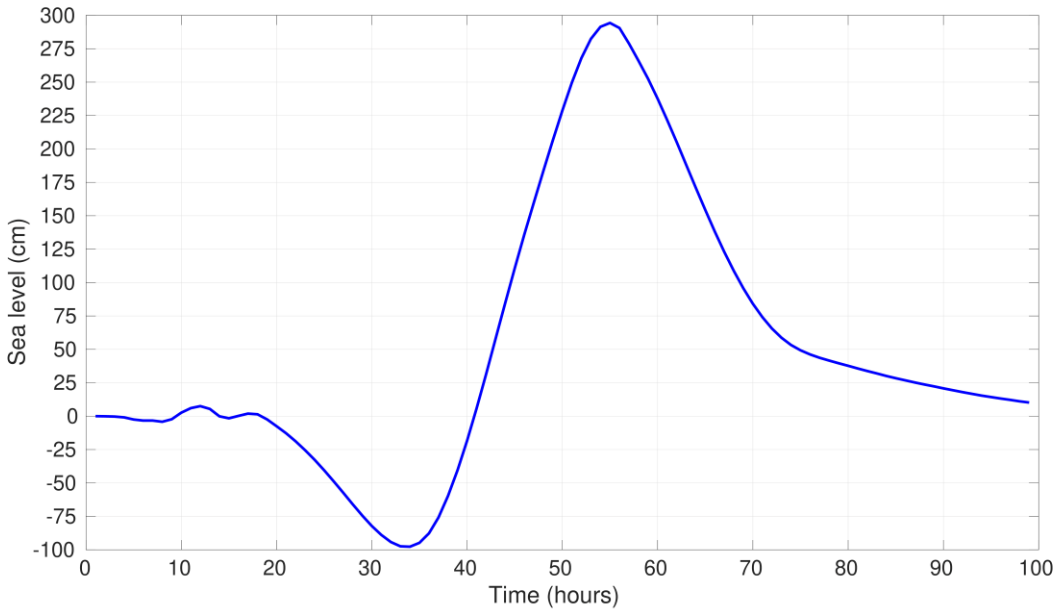
Example: maximum sea level at Oulu



Särkkä et al. (2022)

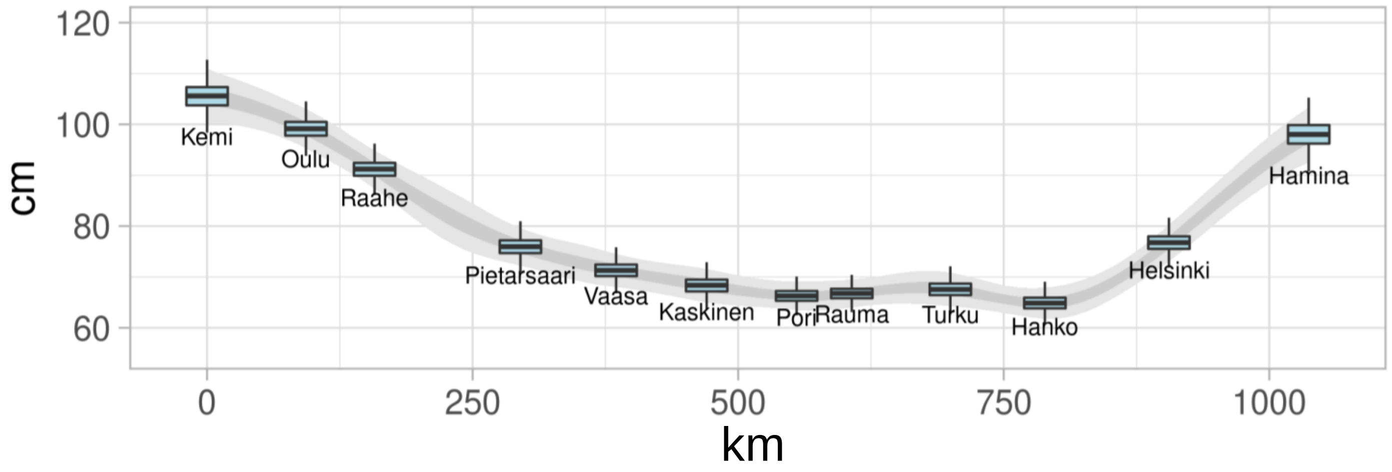


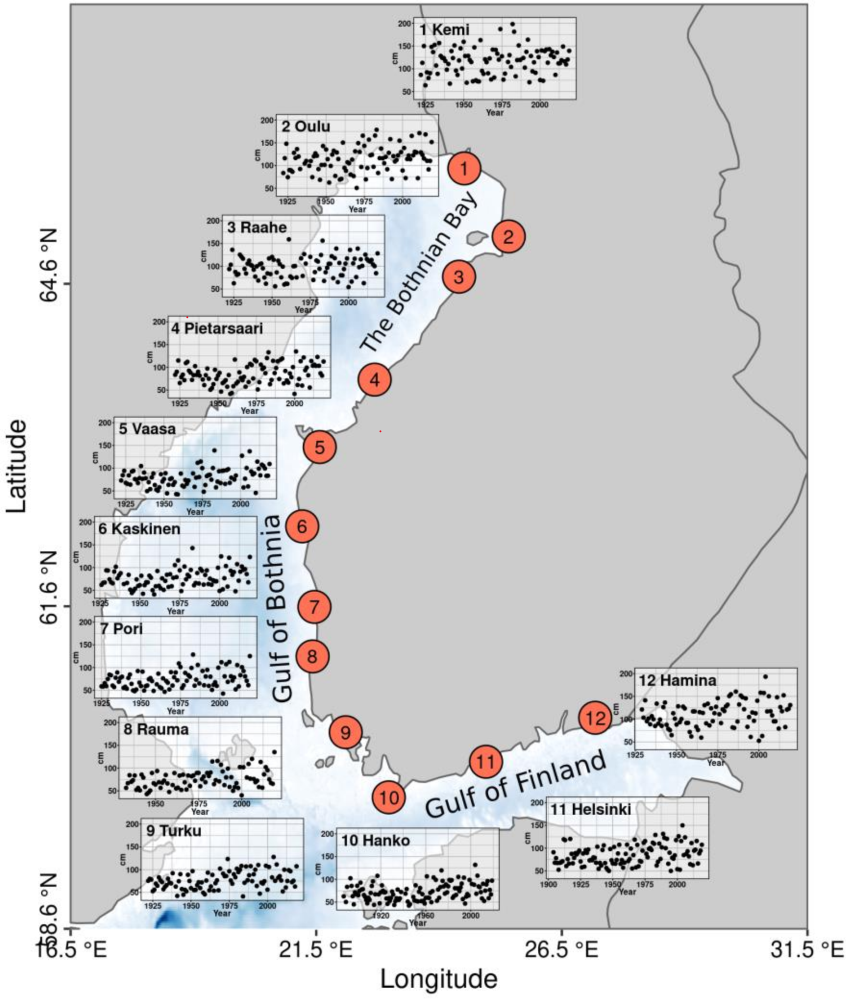
- The highest extremes are caused by large-scale windstorms propagating slowly over the Baltic Sea region
- Mean water level of the Baltic Sea (up to 100 cm) should be added to the storm surge
  - The highest simulated sea level extremes are over 300 cm at the Finnish coast
- Probabilities of extremes are not assessed with this method (no weighting for the storm tracks)

Bayesian hierarchical modelling of sea level extremes

- **Generalized extreme value distribution (GEV)** fitted to (detrended) annual maximum sea level collected from 12 Finnish tide gauges
- **Three hierarchical descriptions** for the three GEV distribution parameters
  - Allow estimation between tide gauge locations
- **Site-specific** GEV fits used as a reference
- Fitting done in a Bayesian framework using Stan probabilistic programming language

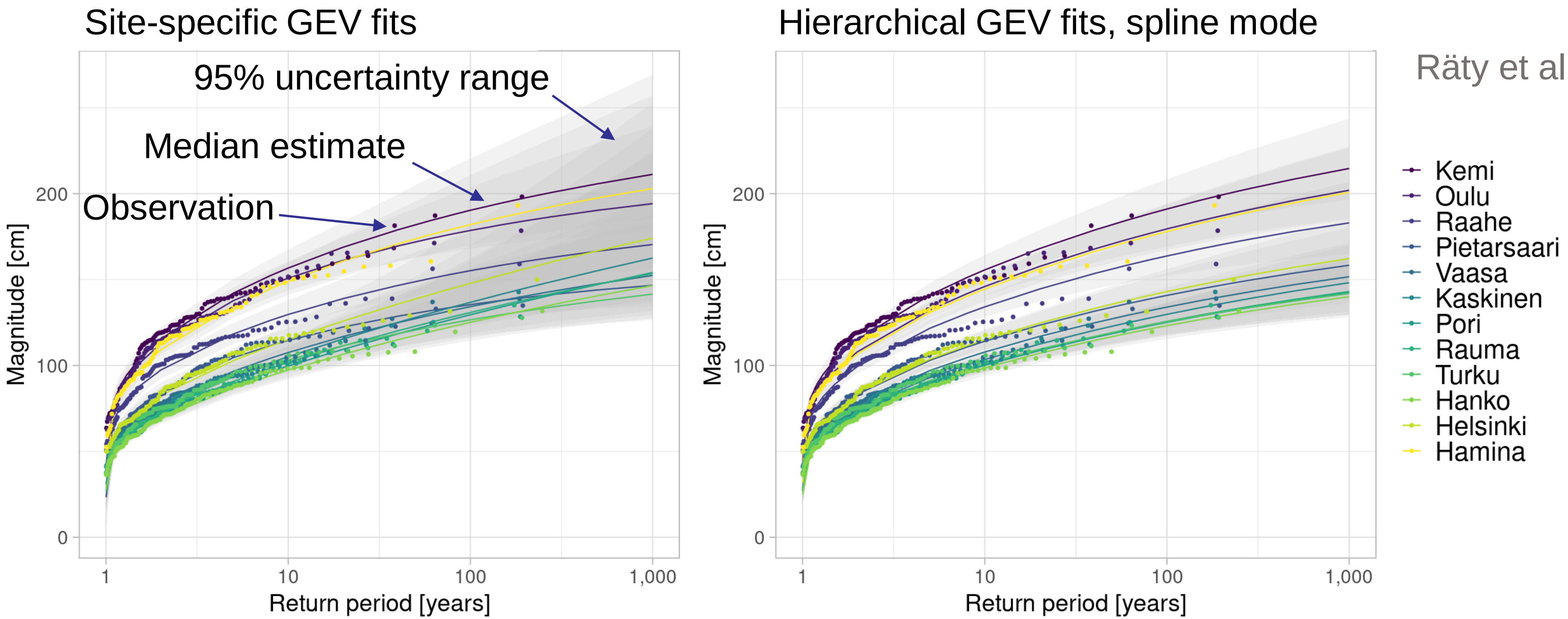
Location parameter of the GEV distribution, spline model:





Räty et al., 2022 (in review)

Return level examples



Räty et al., 2022 (in review)

Conclusions similar for the other two hierarchical models

- Hierarchical modeling approach reduces uncertainty in the return level estimates compared to tide gauge specific fits
- Work ongoing to develop a non-stationary version of a hierarchical GEV model

Evaluation, communication and expert education

Evaluation of the deliverables 2019-2022:

within 0-2 years (16) later (7) no use ( ) cannot say ( )

by nuclear safety authorities (14) NPP power companies (18) in research (14)

Communication with the stakeholder groups:

- Altogether 5 ad-hoc meetings: June 2019, Sep 2019, Sep 2020, June 2021 and June 2022
- PREDICT workshop on probabilistic forecasting in Oct 2019

Education of experts:

Altogether 6 academic dissertations during the project lifetime 

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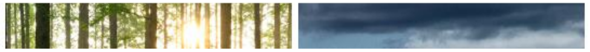

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Thank you for your attention!

More information at:
https://en.ilmatieteenlaitos.fi/predict

ulpu.leijala@fmi.fi

Photo: Ulpu Leijala