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Exceptional weather and sea level events in changing climate: experiences on providing user-relevant information to support nuclear power plant safety in Finland

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Background and motivation

- Energy technologies not resulting in direct greenhouse gas emissions include renewable energy sources and nuclear energy (NE).
- In Finland in 2018, ~ 1/3 of electricity was produced with NE, and its portion of total energy consumption was 17% [1] (Fig. 1).
- An issue in using NE is its safety: the release of radioactive substances from a nuclear power plant (NPP) to the environment must be prevented with high reliability.

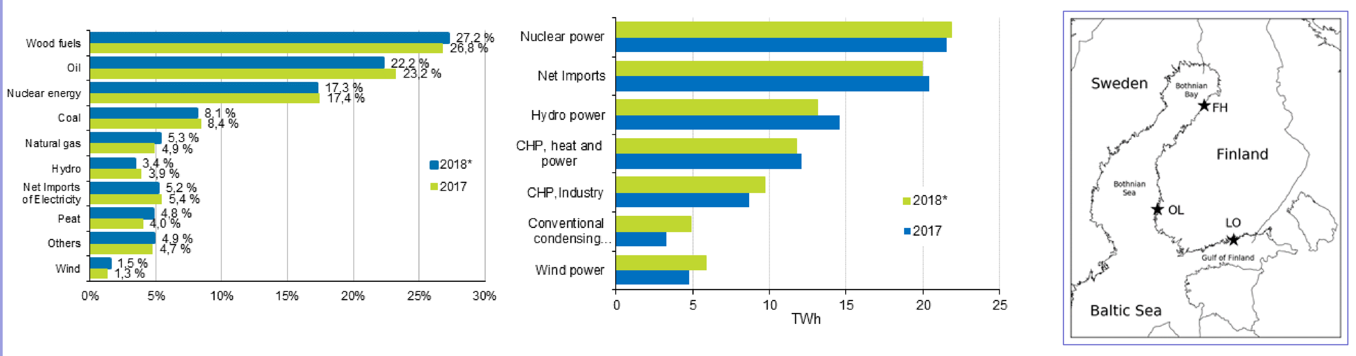

Fig. 1. Left: Share of total energy consumption in Finland in 2017–2018.
Middle: Electricity supply in Finland in 2017–2018.
Right: Sites of the Finnish NPPs in operation (LO, OL) or in licensing phase (FH).

- ➢ Extreme weather and sea level events affect the design principles of NPPs, may hamper normal NPP operation, or endanger a safe shutdown.
- ➢ Probability estimates of exceptional weather and sea level conditions in the current and future climate are needed for:
  - the determination of the design basis for new power plant units
  - the Probabilistic Risk Assessment of new and existing NPPs
  - periodic safety reviews of existing NPPs

Weather-related risks for nuclear power plants

- **Ice, frazil ice, organic material in sea water**
  ⟹ *blockage of intakes of cooling sea water*
- **Snow, frost, freezing rain**
  ⟹ *blockage of intakes of i) ventilation air and ii) emergency diesel generator combustion air*
- **Lightning** ⟹ *power supply, control systems, external power transmission grid*
- **Floods due to high seawater or heavy rain**
  ⟹ *safety equipment, especially electric power supply and control systems*
- **High atmospheric temperature, high air enthalpy**
  ⟹ *ventilation and room cooling systems*
- **High wind speed** (also a factor in high sea water level):
  ⟹ *external power transmission grid connection, air intakes*

Main challenges in providing user-relevant information to support nuclear safety in Finland

- Major nuclear accidents are typically **low-probability–high-consequence events**

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- Probabilities of occurrence of extremely rare events, unseen in the past 100 years of observations and corresponding to return periods of thousands or even millions of years, are needed.
- The ongoing **climate change alters the frequencies and severity of the events** in the future.
- Weather forecasts and warnings issued to the public, or to authorities, are not designed with the needs of nuclear power production in mind.

Research to support nuclear safety in Finland

- FMI has examined extreme weather, climate and sea level events potentially posing risks to NPPs since 2007 [2], currently in the PREDICT project within the SAFIR2022 program [3].
- **Aim**: to develop and maintain research expertise and methods needed for assessing probabilities of occurrence of safety-relevant single and compound extreme events.
- **Research topics** ⬅ Feedback and enquires from the power companies designing and running the Finnish NPPs, and the Radiation and Nuclear Safety Authority in Finland (STUK).

Acknowledgements

We acknowledge the funding from the State Nuclear Waste Management Fund through SAFIR2018 and SAFIR2022, the Finnish Nuclear Power Plant Safety Research Programmes 2015-2018 and 2019-2022, respectively, and from the Finnish Meteorological Institute (FMI). All researchers at FMI contributing to PREDICT at FMI are acknowledged.

Extreme weather in changing climate

Examples of recent and current research topics include sea-effect snowfall (Fig. 2), freezing rain (Fig. 3), compounding heavy precipitation and high sea level (Fig. 4), and thunderstorm occurrence(Fig. 5).

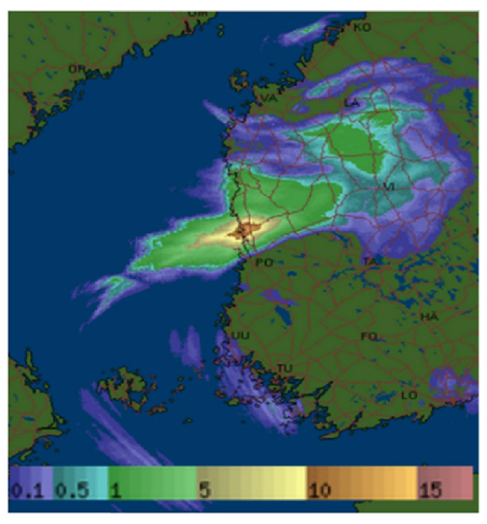


Fig. 2. 3-hour accumulated precipitation (mm/h) as observed by weather radar during a national record-breaking snowdrift of 73 cm on 8 Jan 2016. [4]

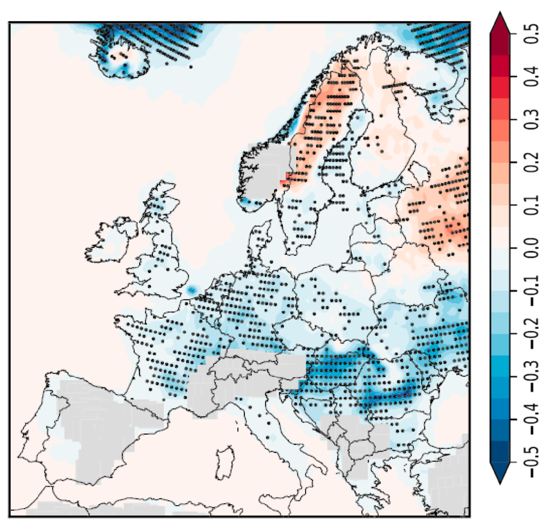


Fig. 3. Change in the annual mean number of elementary freezing rain events exceeding 5 mm/6 hr by 2071–2100 under RCP8.5. [5]

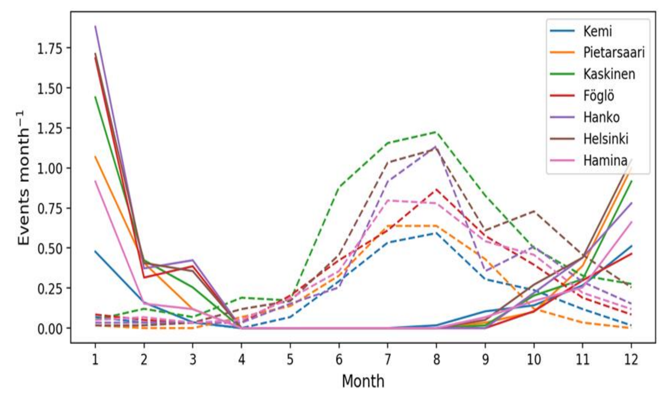
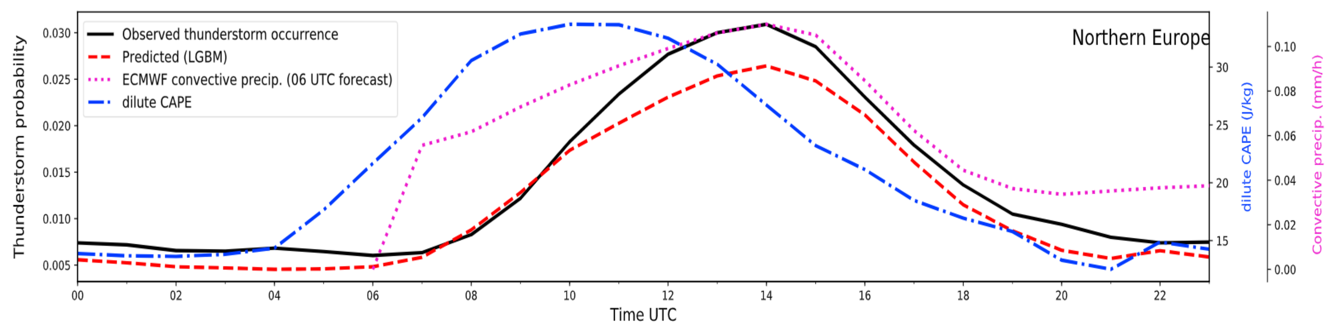


Fig. 4. Number of days when the maximum sea level is at least at the warning level (solid lines) and precipitation is at least 20 mm (dashed lines) at seven Finnish mareographs in 1960-2018. [6]

Fig. 5. The diurnal cycle of observed thunderstorm occurrence in Northern Europe (black), together with three predictors.[7]



Extreme sea level

Research topics during recent years

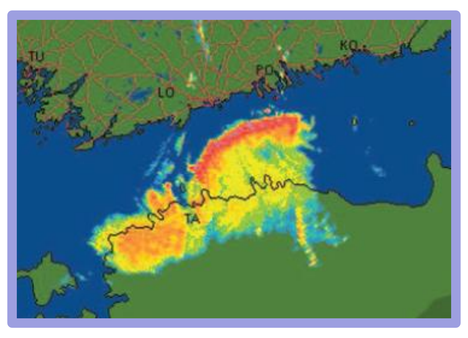


Fig. 6. Meteotsunamis, long tsunami-like waves generated by meteorological processes and resonance effects. [8]

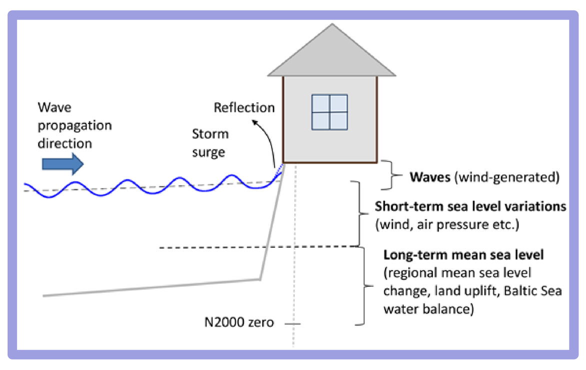


Fig. 7. Joint effect of sea level and wind waves on a shore. [9]

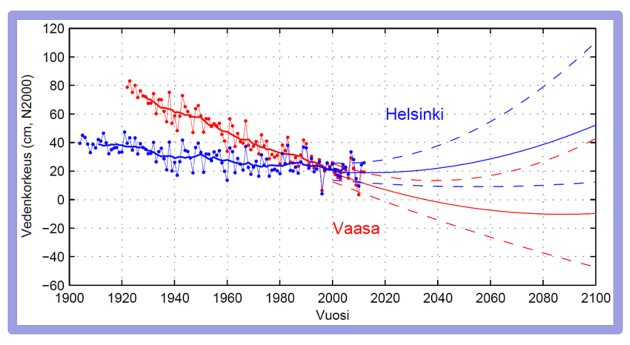


Fig. 8. Regional mean sea level scenarios. [10]

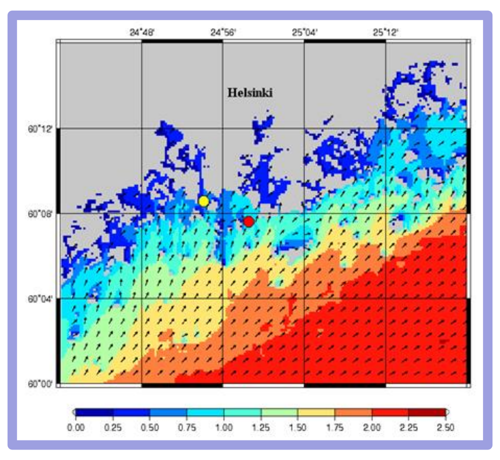


Fig. 9. Validating a high-resolution wave model for the Finnish coast. [11]

New research topics (2019)

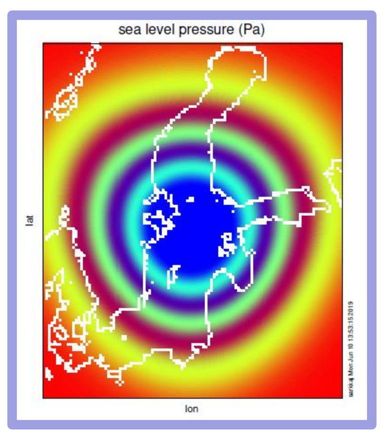
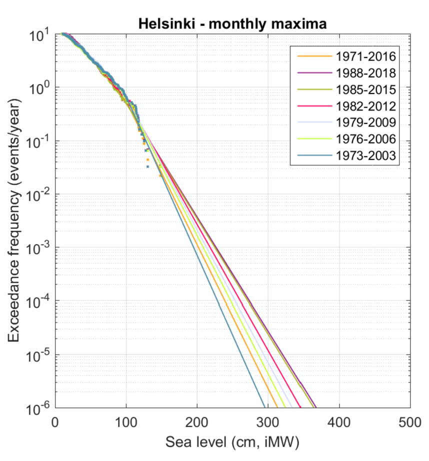


Fig. 10. Simulated low-pressure systems to identify extreme sea levels on the Baltic Sea coast.

Fig. 11. Shedding more light on the uncertainties of the coastal flood risk estimates.



Improving forecasts of extreme weather and sea level events

- Short-term forecasts of extreme weather and sea level events and conditions may allow NPP operators to take appropriate action, provided that they can be issued in time.
- A workshop between experts in nuclear power production and in weather prediction on 9 Oct 2019

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  - to decide upon a set of relevant events to be predicted and
  - to deliver recommendations for weather services in support of safe and economic nuclear power production

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