On spatio-temporal variations of the wave energy potential along the eastern Baltic Sea coast

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Overview

- Motivation
- Study area
- Wave simulations
- Computation of energy flux
- Spatio-temporal variability of the wave power
- Contributions of storms

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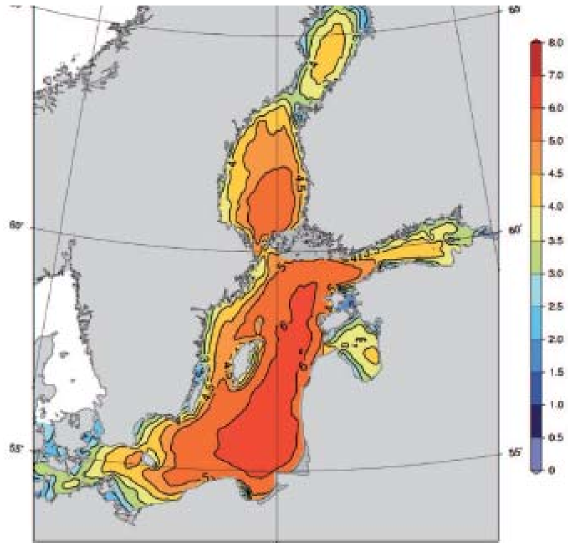
Introduction

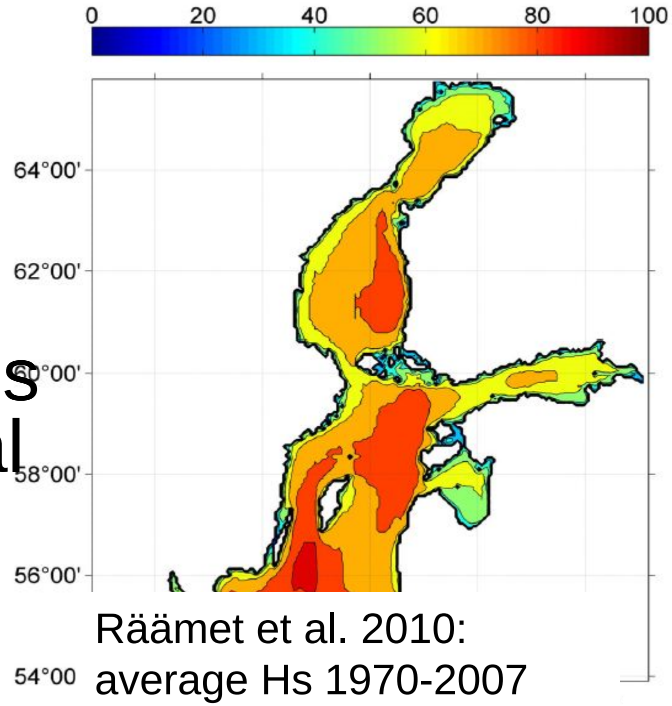
- Energy demand increases
- Need of CO_2- free energy
- Potential energy source: field of ocean waves

Wave energy:

- Renewable energy source with high power density
- Eastern Baltic Sea coast contains the largest wave energy potential in the BS

Tuomi et al. 2011: 99.9%-ile 2001-2007



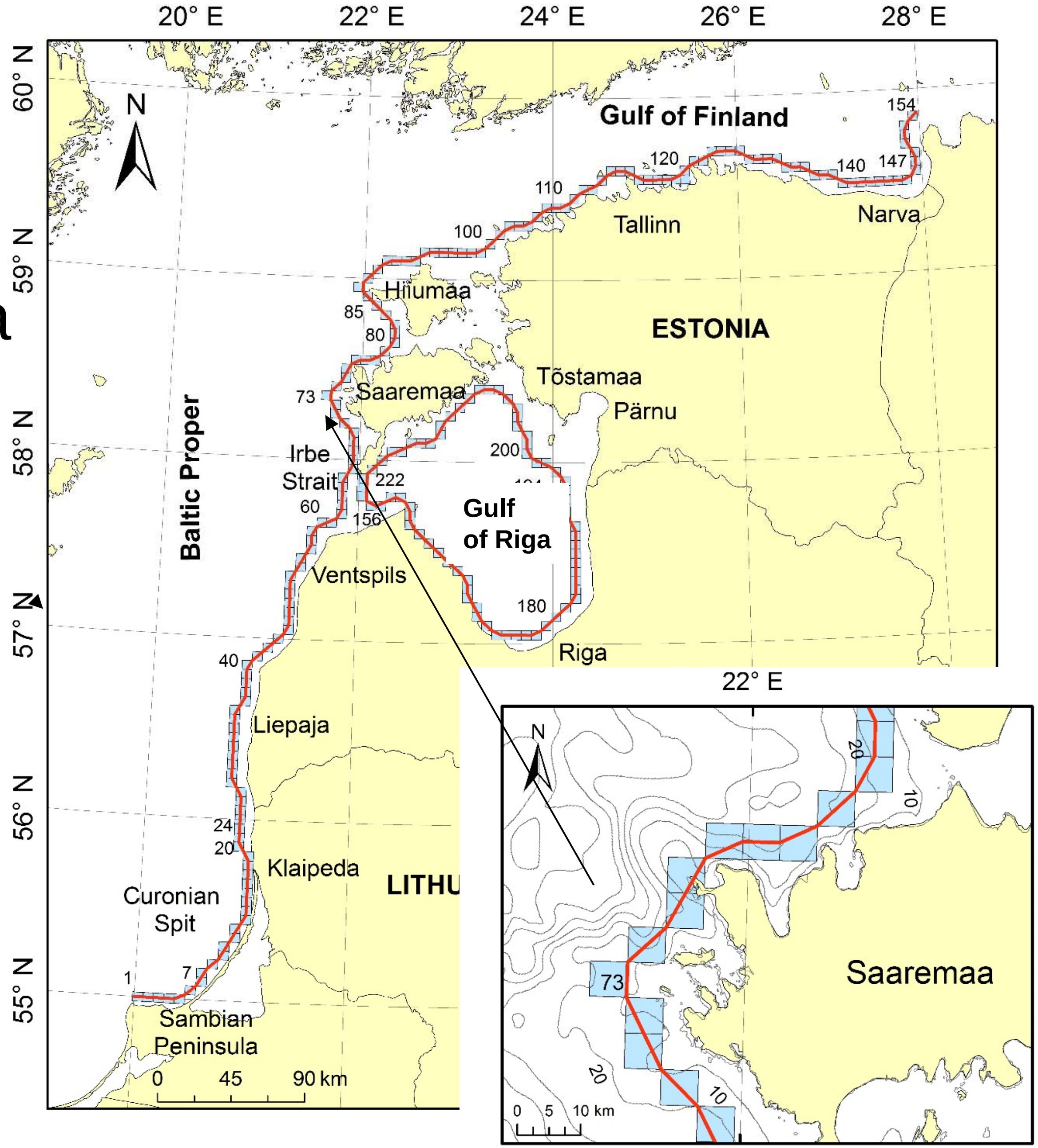


Räämet et al. 2010: average Hs 1970-2007

Fig. 9. Numerically simulated average significant wave height

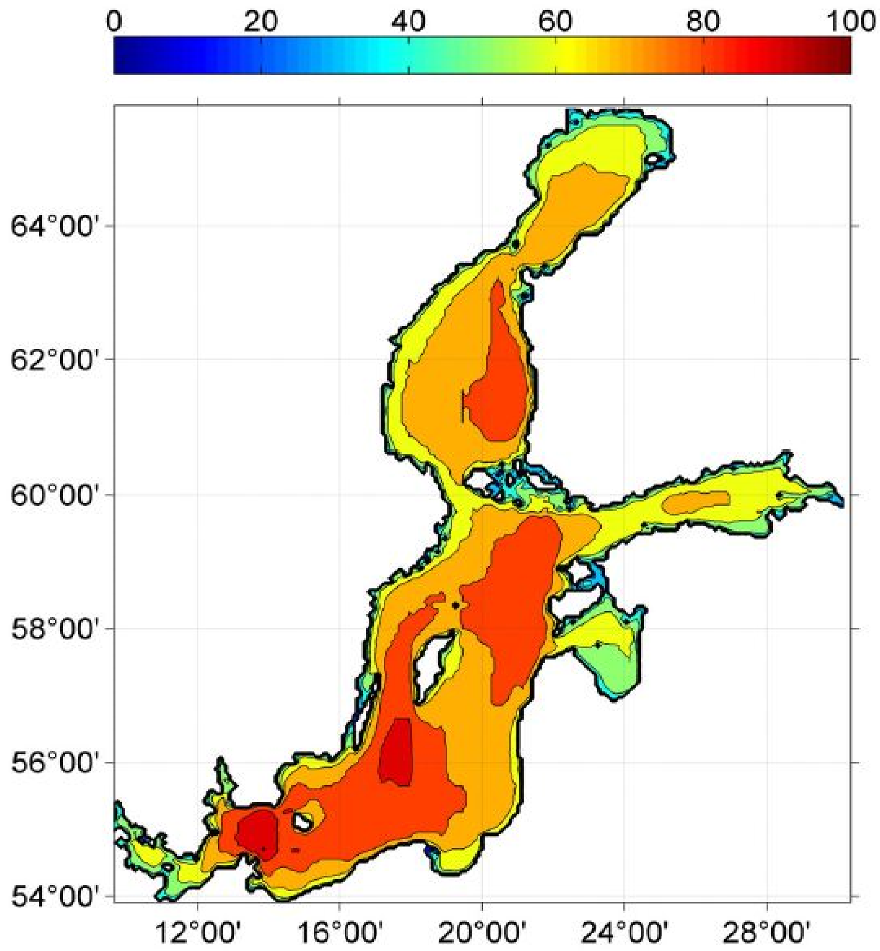
Study area

- ~ 950 km from Sambian peninsula until Kurgolova (Russia)
- Gulf of Riga ~450 km
- Model grid points: at a depth of ~10–20 m



Wave simulations (A.Räämet)

- Third-generation spectral wave model WAM
- Spatial resolution about 3×3 nautical miles
- Temporal resolution 1 hour
- 38 years (1970–2007)
- Forced by adjusted geostrophic winds (Swedish Meteorological and Hydrological Institute)
- Idealised ice-free conditions
- Entire Baltic Sea



Average Hs 1970-2007
(Räämet and Soomere, 2010)

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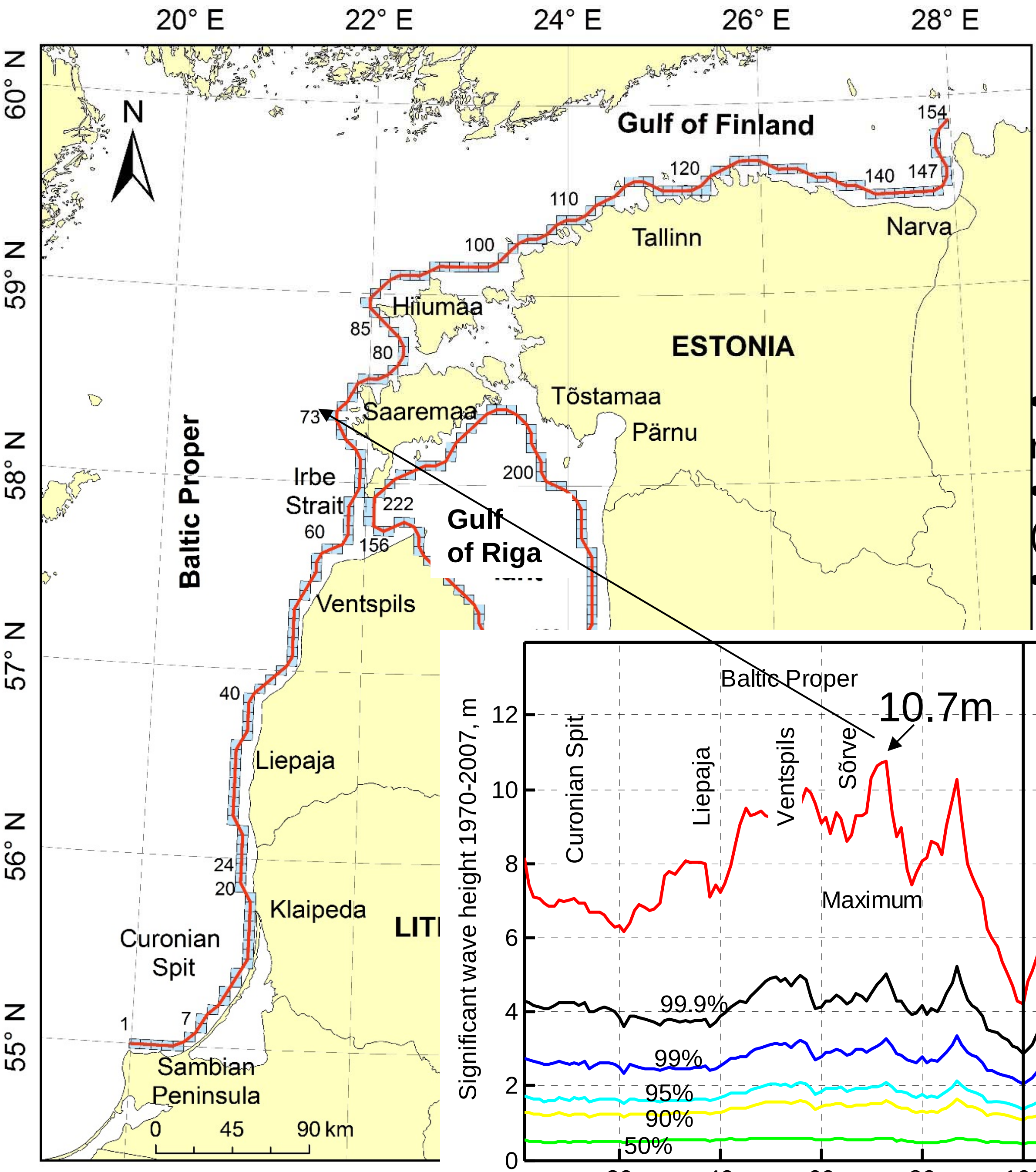
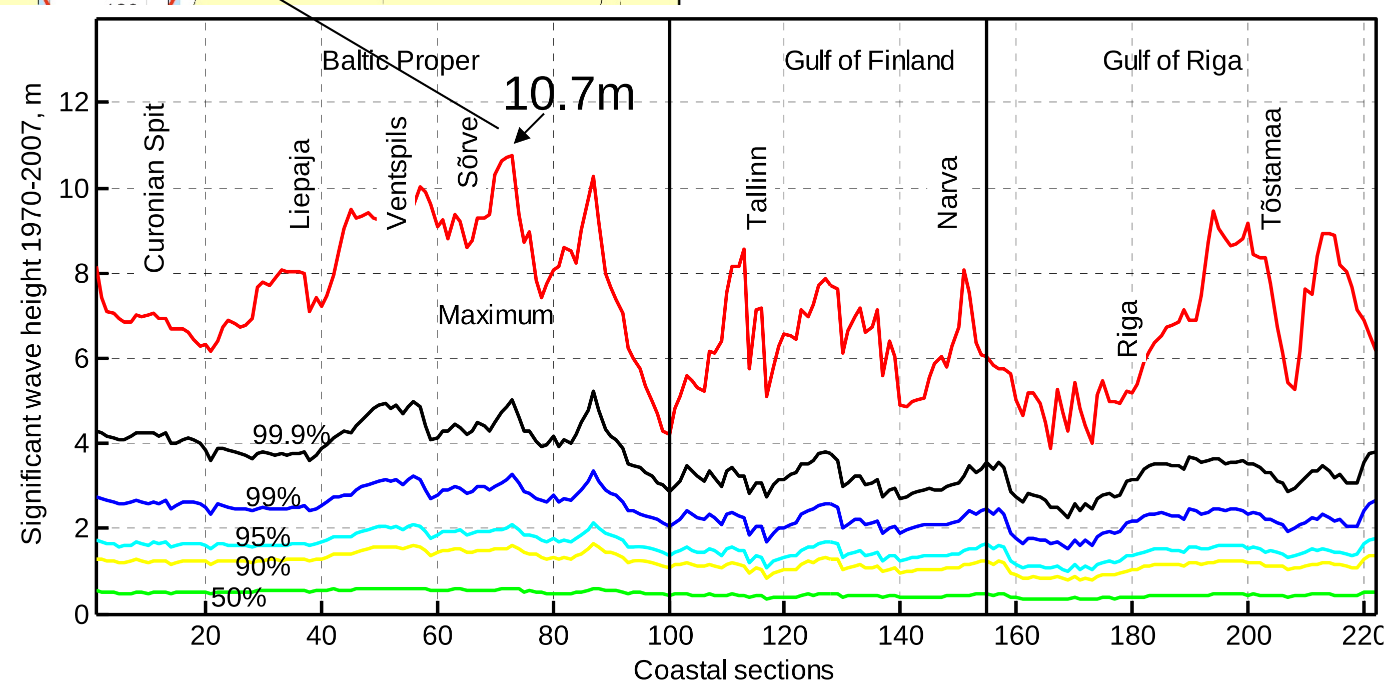
Wave heights along the coastline

38 years, 330960 values





- Baltic Proper: recorded max. 8.2 m, reconstructed 9.01.2005: 9.5-9.7 m
- Gulf of Finland: recorded max. 5.2m (Tuomi et al. 2011)
- Gulf of Riga: estimated max. 5 m

For computing the energy flux:

- Significant wave height
- Peak period
- Direction of wave propagation

From model, once in hour for each coastal section (5.5km)

- Orientation of the modelled coastline
- Seawater density

constant

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Computation of energy flux

Energy flux:
Product of power density and group velocity

$$P = E\,\vec{c}_g \left[\frac{W}{m}\right]$$

Significant wave height

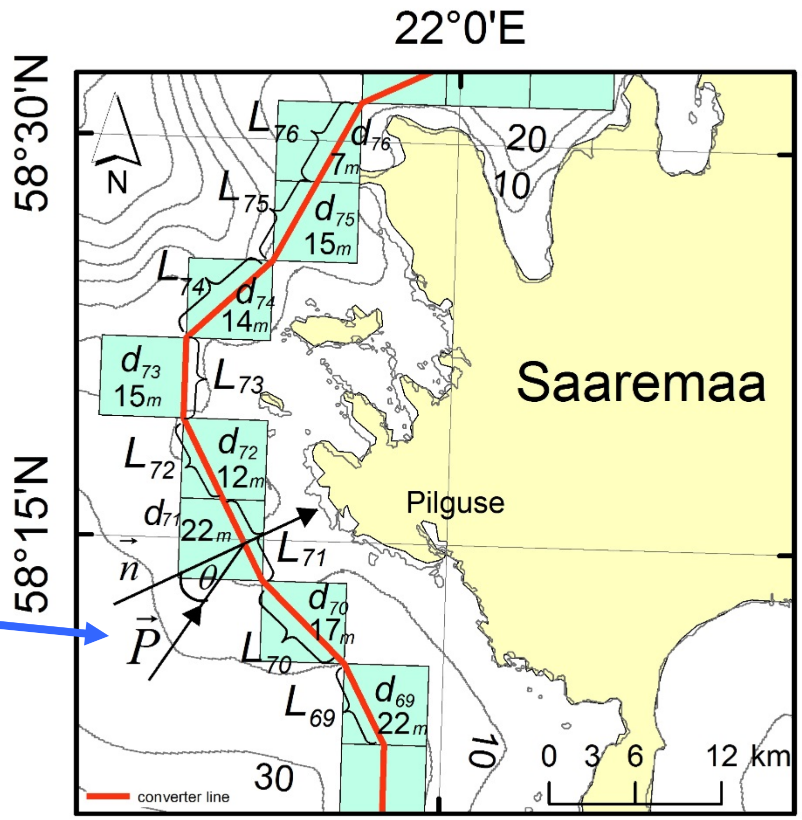
$$E = \frac{H_s^{\,2}\rho g}{16}\left[\frac{J}{m^2}\right]$$

Angular frequency, Wave number, Water depth

$$c_g = \frac{\partial}{\partial k}\omega = \frac{\omega}{2k}\left(1 + \frac{2kh}{\sinh 2kh}\right) \quad \left[\frac{m}{s}\right]$$

$$\vec{P} = \frac{H_s^{\,2}\rho g}{16}\vec{c}_g \cos\theta$$

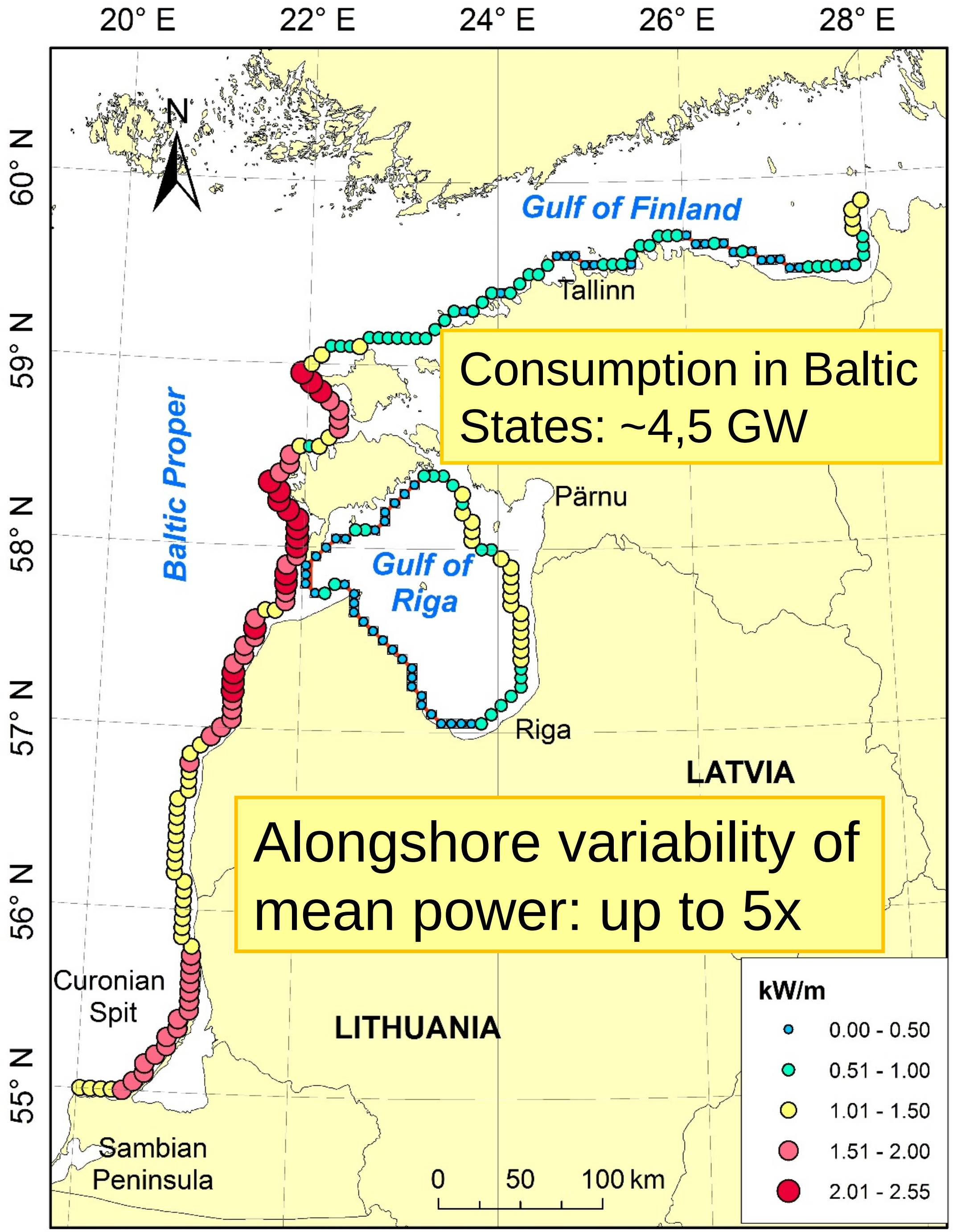
Only onshore component of the energy flux



Theoretical total power: 1,5 GW

(on average, over 38 years)

- Gulf of Finland: ~220 MW
- Western coast of Estonia: ~390 MW
- Lithuania, Latvia, Kaliningrad: ~600 MW
- Gulf of Riga: ~280 MW



Temporal variability of energy flux

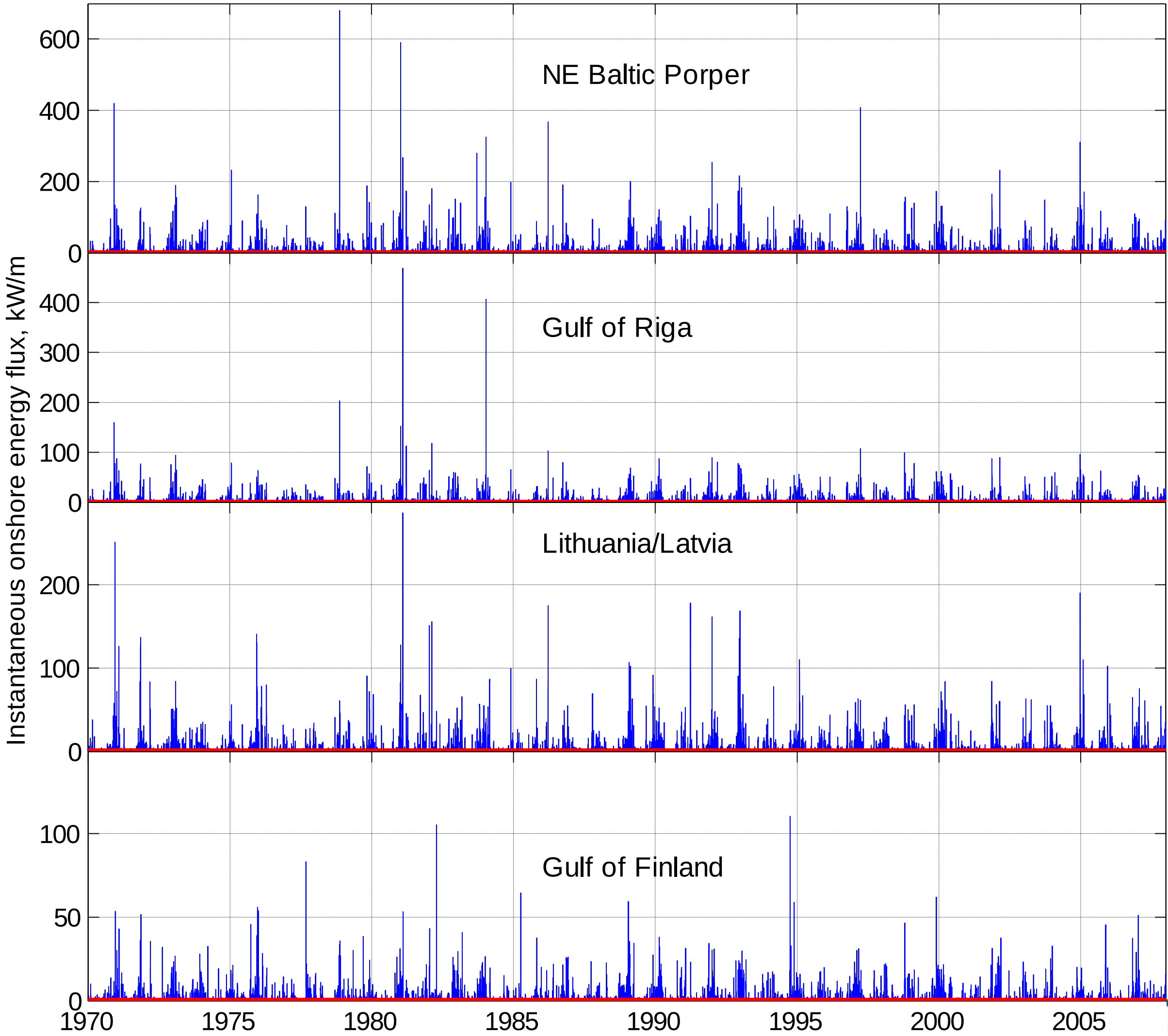
Single values: exceed average values by two orders of magnitude (>**100x**)

Maximum 680 kW/m
Average of grid point 2,5
kW/m

Max. 470 kW/m
average 1,2 kW/m

Max. 286 kW/m
average 1,5 kW/m

Max. 110 kW/m
average 0,7 kW/m



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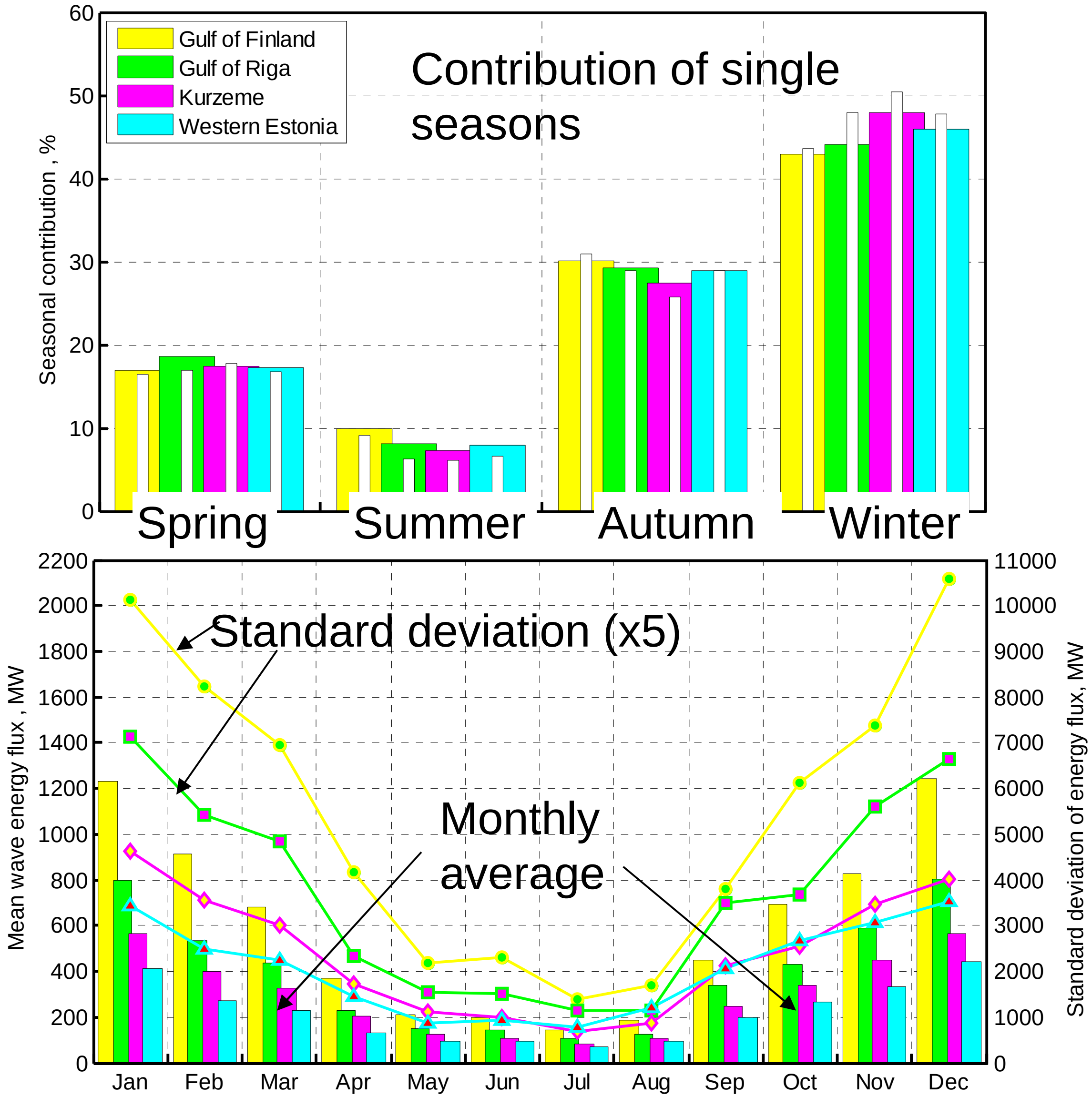
Seasonality of the wave resource

- Spring (M-A-M): ~20 %
- Summer (J-J-A): ~10 %
- Autumn (S-O-N): ~30 %
- Winter (D-J-F): ~40-50%

- Largest total power of the monthly mean: in January and December
- Smallest: in May, June, July and Aug
- Difference between monthly means: 5-6x
- Standard deviation of the single values: exceeds monthly mean by ~10x



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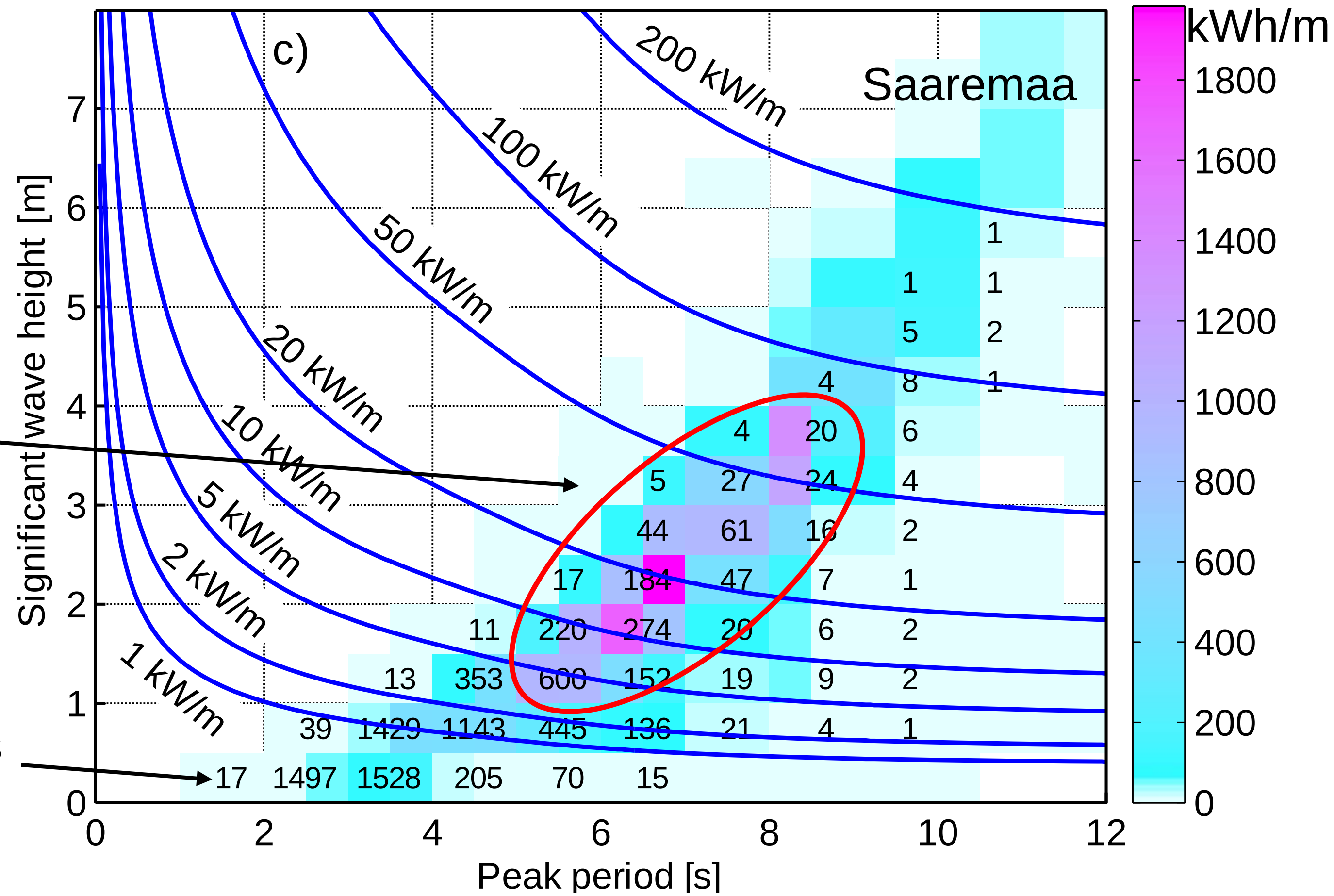
Best energy resource?



No. of occasions per year

Sea states with the greatest contribution to the annual energy:

- Baltic Proper: significant wave height ~2-4 m, peak period ~6-9 s

Semi-sheltered sub-basins

- Significant wave height 1-3 m, period 4-8 s

Limited in time

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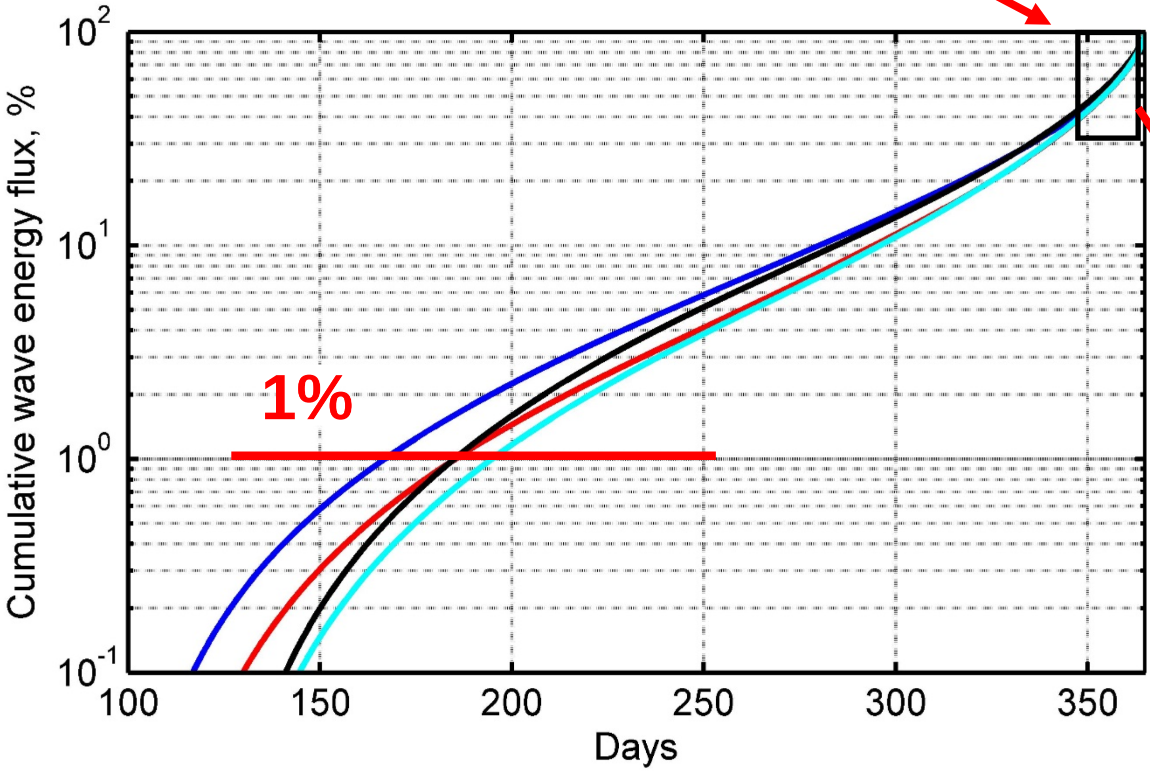
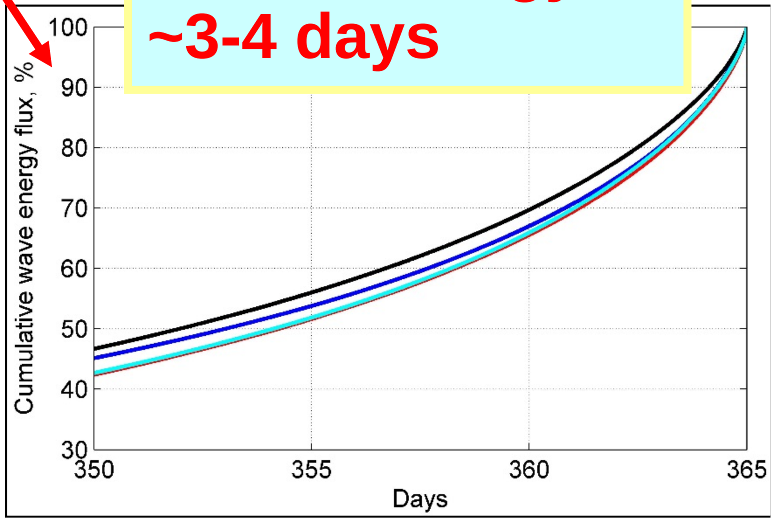
The role of storms

- ~ 1% of the total annual energy arrives within 170-200 days
- **~ 60% of the annual energy arrives within 20 days**



~30% of the annual energy: ~3-4 days



Major limiter for the industrial use

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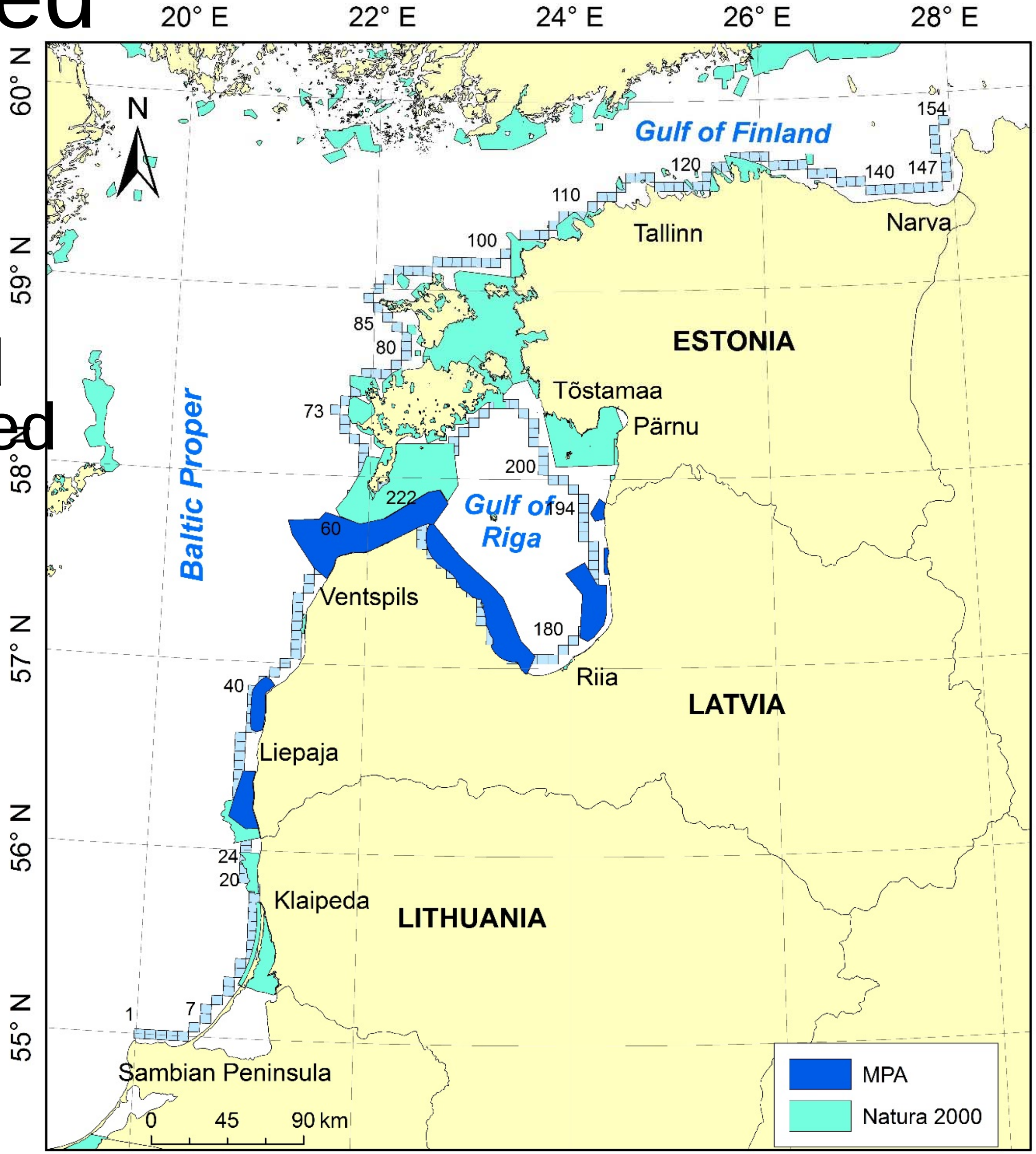
Marine protected areas

- ~46% of the entire study area: covered with marine protected areas (MPA)
- Realistic resource: 840 MW
- Extraction from adjacent to MPA areas: impact to ecosystem unclear



Summary

- Total theoretical wave energy ~1500MW
  - Estonia (western coast) 400 MW
  - Gulf of Finland 200 MW
  - Lithuania and Latvia 600 MW
- Reasonable variation along the coast
- Considerable amount of energy arrives within few storms
  - 30% within 3-4 days
  - 60% within ~20 days
  - Practical utilization is complicated
- Optimal wave energy resource & converters' choice:
  - Wave height ~2-4 m, period 6-8 s
- Largest limitation: Natura 2000 / Marine Protected Areas:
  - Total realistic resource 840 MW