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Re-assessing extreme sea level events through interplay of tides and storm surges

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Basic Concepts – Tide Gauge

- Tide gauges provide automatic observations of sea level height at a single given location
- They provide measurements at high temporal resolution (e.g. 10 minutes)
- Observed sea level height is a combination of many different factors, but primarily astronomical tide and storm surge
- Since astronomical tides are predictable with spherical harmonics and knowledge of the bathometry, by subtracting the predicted tide from the observation, we obtain the storm surge, or the component due to meteorological effects

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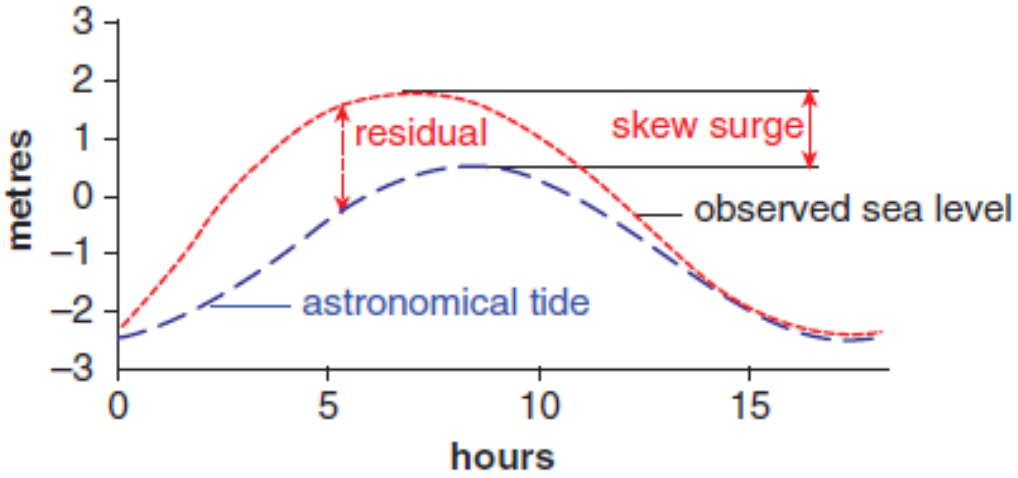
Basic Concepts – Skew surge

- Peak astronomical tides are semi-diurnal on many coastlines, with peaks occurring approximately twice per day
- Since the observed sea level is a combination of factors, the peak observed sea level may not coincide with the peak of the high tide
- This introduces the commonly used metric of ‘skew surge’ – the difference in height between the peak of the astronomical tide and the peak of the observed sea level height within a single tidal cycle, irrelevant of timing
- Since weather effects can both amplify and supress the sea level height, skew surge can be positive or negative



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Motivation

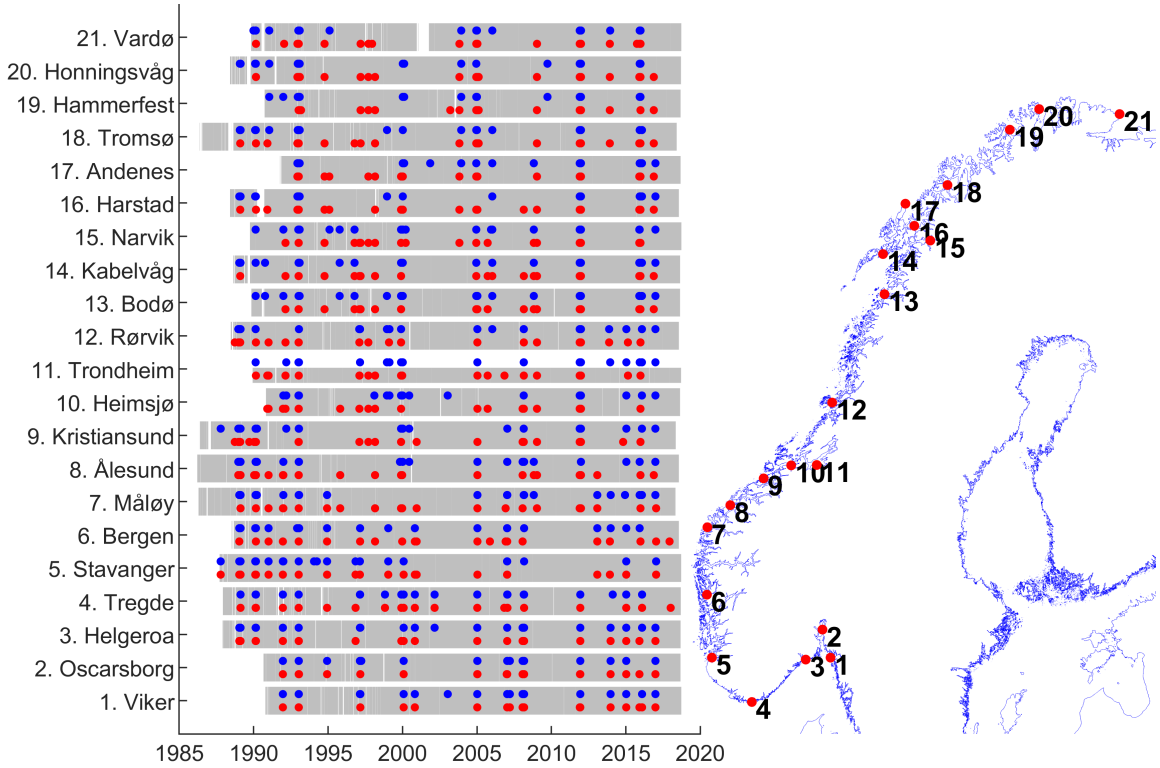
- Extreme sea levels often assessed in terms of Return Levels
  - Return levels – water level that will be exceeded approximately every set number of years
  - Calculated using Extreme Value Analysis
  - Based on few decades of observations
- Return levels usually based on the observed sea level only
  - So-called ‘Direct‘ method
  - Ignores interplay between astronomical tides and storm surges
- Return levels are the basis for national building standards in Norway
  - Sensitive infrastructure must withstand 1000 year return level event

Tide gauge data

- Data from 21 of 23 tide gauges around Norway was examined in this study
  - 10 minute measurement interval
  - Provides observed sea level and predicted tide

- Grey area - Data availability
- Red dots – Extreme sea levels
- Blue dots – Extreme skew surges

(Note: 'Extreme' here is 99.9th percentile)



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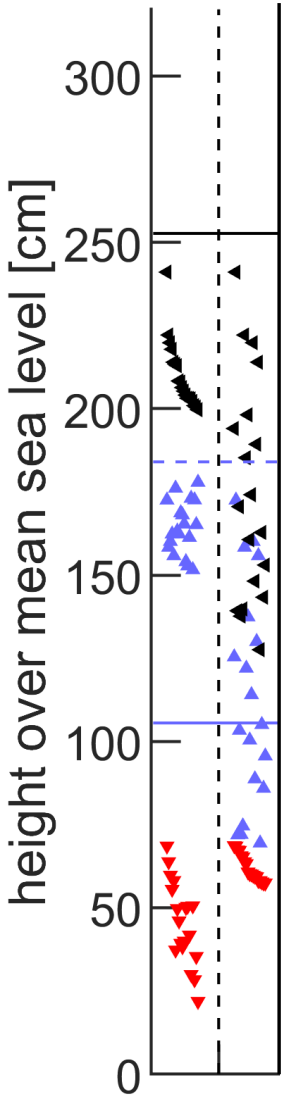
Sea level and skew surge at Vardø

- Data for tide gauge at Vardø separated into
  - Black – Observed sea level
  - Blue – Astronomical tide
  - Red – Skew surge

  i.e. Each observed value (black) is the sum of the accompanying tide (blue) and skew surge (red)

- Data separated into
  - Left column - Top 99.9th percentile of observed sea level (black)
  - Right column – Top 99.9th percentile of skew surges (red)

- Three levels are marked
  - Blue solid line – Mean astronomical tide
  - Blue dashed line – Highest astronomical tide
  - Black solid line – Combined max astronomical tide and max skew surge



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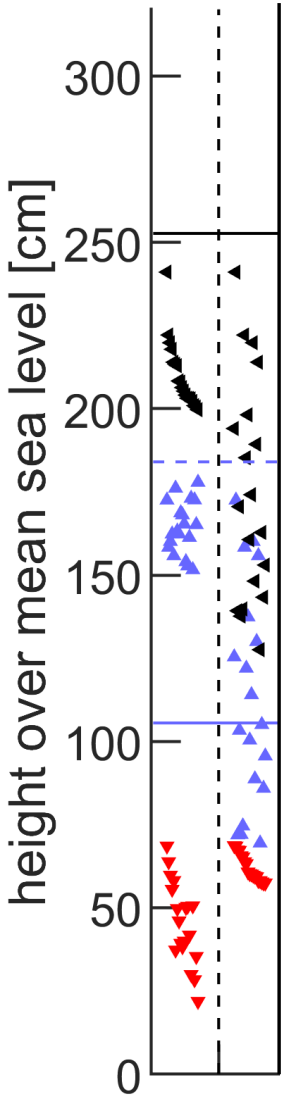
Sea level and skew surge at Vardø

- At Vardø, 99.9th percentile of events results in 19 individual events
- In only 5 of these 19 events are the observed sea level and skew surge both in the 99.9th percentile (i.e. five of the black points in the left column are for the same events as five of the black points in the right column)
- Many of the top 99.9th percentile of observed sea level events occur with high tides but only medium levels of skew surge, and some occur with modest tide and a high skew surge
- While the highest black point is the highest observed sea level in the Vardø data, the solid black line is the height the water level would reach if the highest tide in the record co-occurred with the highest skew surge

i.e. This is the level the water could reach given the right combination of an already observed tide and skew surge



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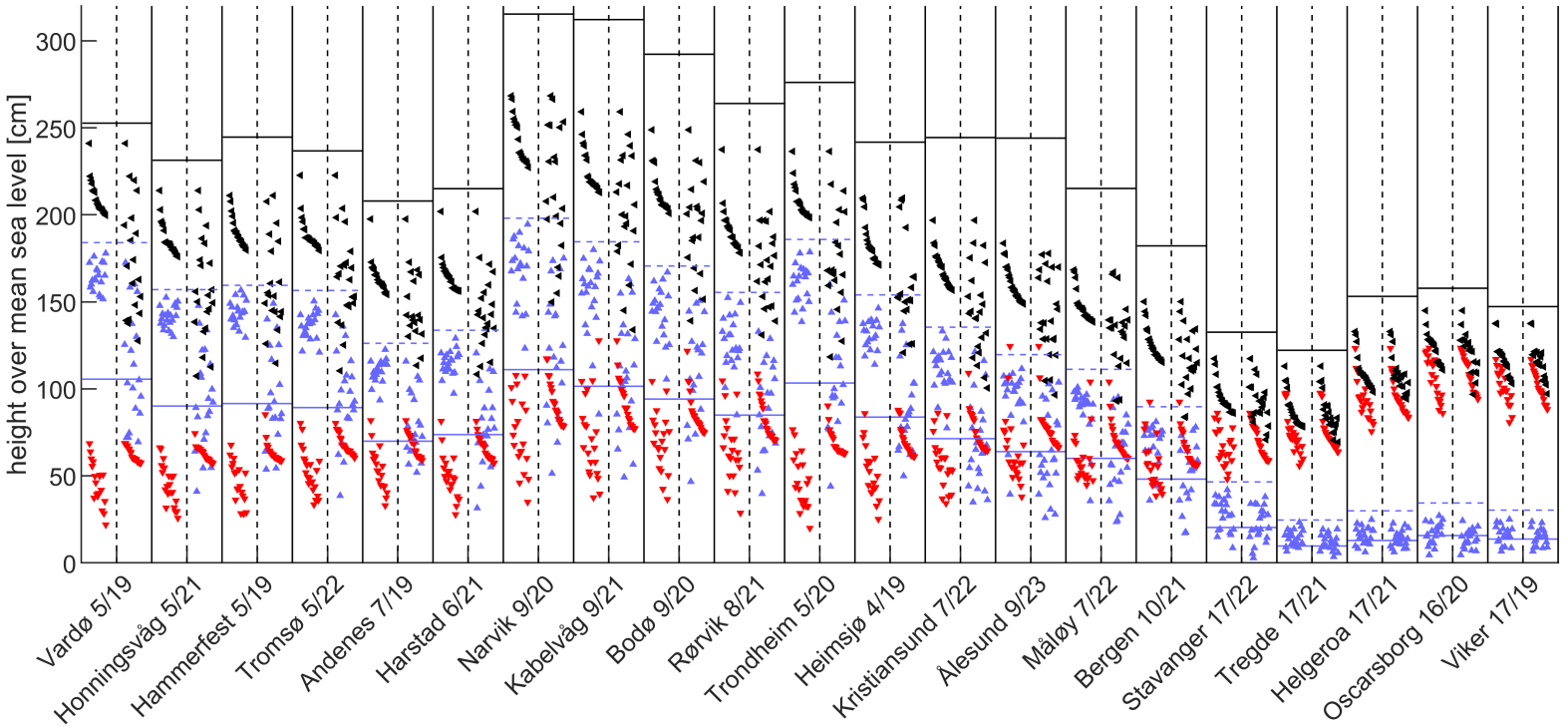
Mismatch of extreme sea level events and skew surges



- Same plot for all 23 tide gauges
- Numbers after station name are number of events with both observed sea level and skew surge in the top 99.9th percentile, and total number of events

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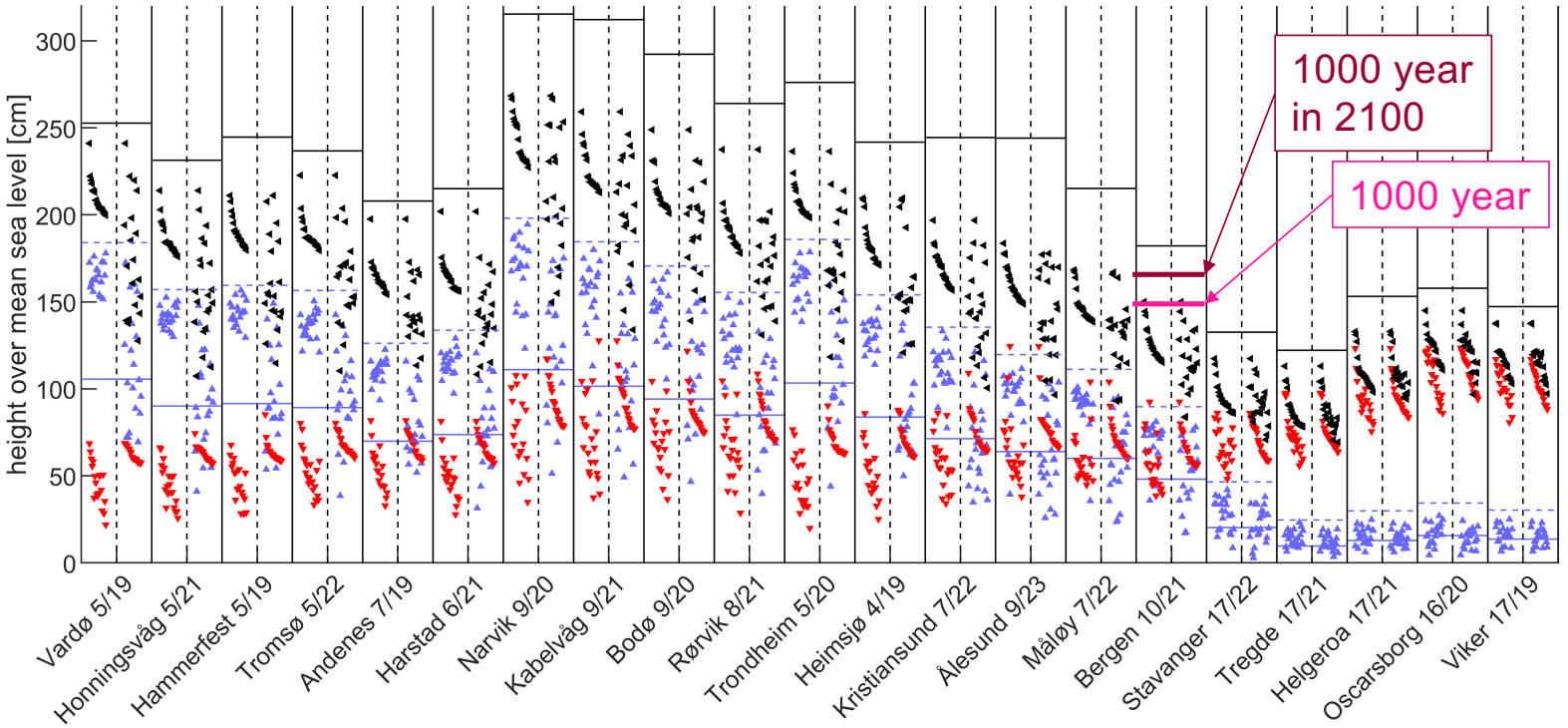
Mismatch of extreme sea level events and skew surges



- For Bergen, 1000 year return level given in pink
- 1000 year return level adjusted for sea level rise given in dark red
- Both are considerably lower than the combination of the highest tide and highest skew surge *already observed* in the data (solid black line)
- This means the right combination of tide an skew surge currently occurring could far exceed the current 1000 year return level, used for the design of sensitive infrastructure

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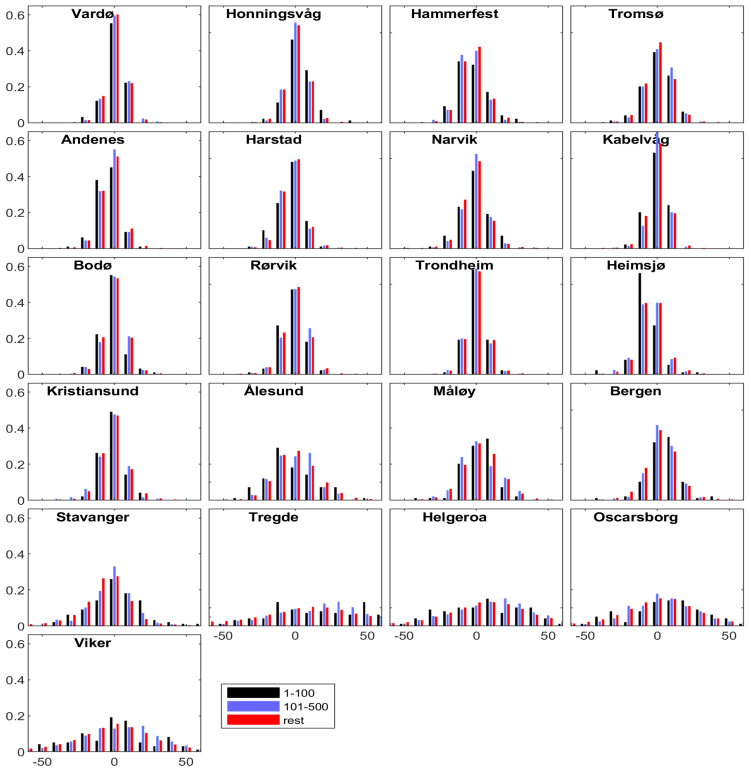
Co-occurrence of extreme tides and storm surges

- Can extreme tides and extreme storm surges occur at the same time?

- Offset between maximum astronomical tide and maximum storm surge per tidal cycle shows approximately zero lag at most stations, supporting the idea that these can co-occur



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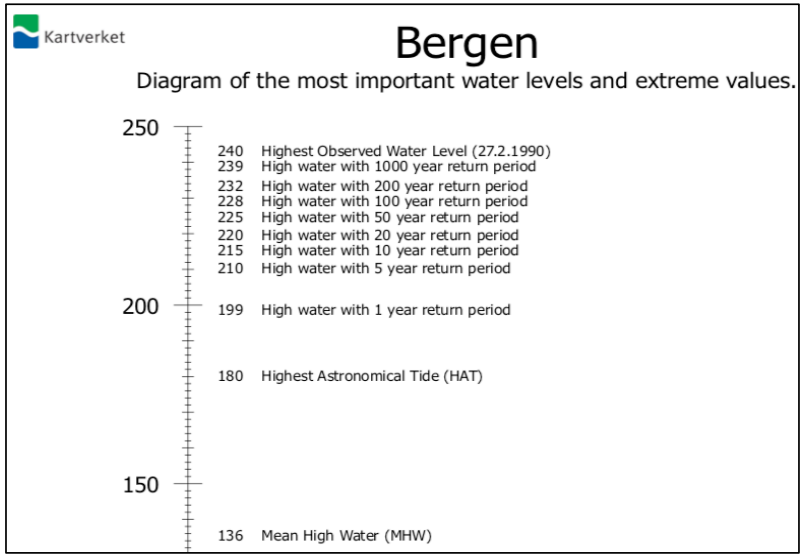
Recent extreme sea level events in City of Bergen

› Recent observations suggest the current return level are not accurate for their apparent frequency, possibly in part due to their estimation being based purely on observed sea level and not tides and storm surges separately



Source: Kartverket

Since 1st January 1990 :	
Return level (years)	**Number of occurrence**
1	40
10	12
50	5
200	4
1000	2

Summary

- Observed sea level at 23 tide gauges around the Norwegian coast have been separated into their components of astronomical tide and skew surge
- Only some of the highest observed sea levels occur from the co-occurrence of a very high tide with a very high storm surge
- Many observed high sea levels occur from a high tide co-occurring with a moderate storm surge, or a moderate tide co-occurring with a high storm surge
- At all stations, the co-occurrence of the highest tide with the highest storm surge in the approximately 30 year long record would exceed any observed sea level, and at many stations, would exceed the 1000 year return level used for designing sensitive buildings and infrastructure


Thank You