QUANTIFICATION OF LONGSHORE SEDIMENT TRANSPORT AND COMPARTMENTS IN URBAN AREAS: A CASE STUDY OF SHORES OF TALLINN

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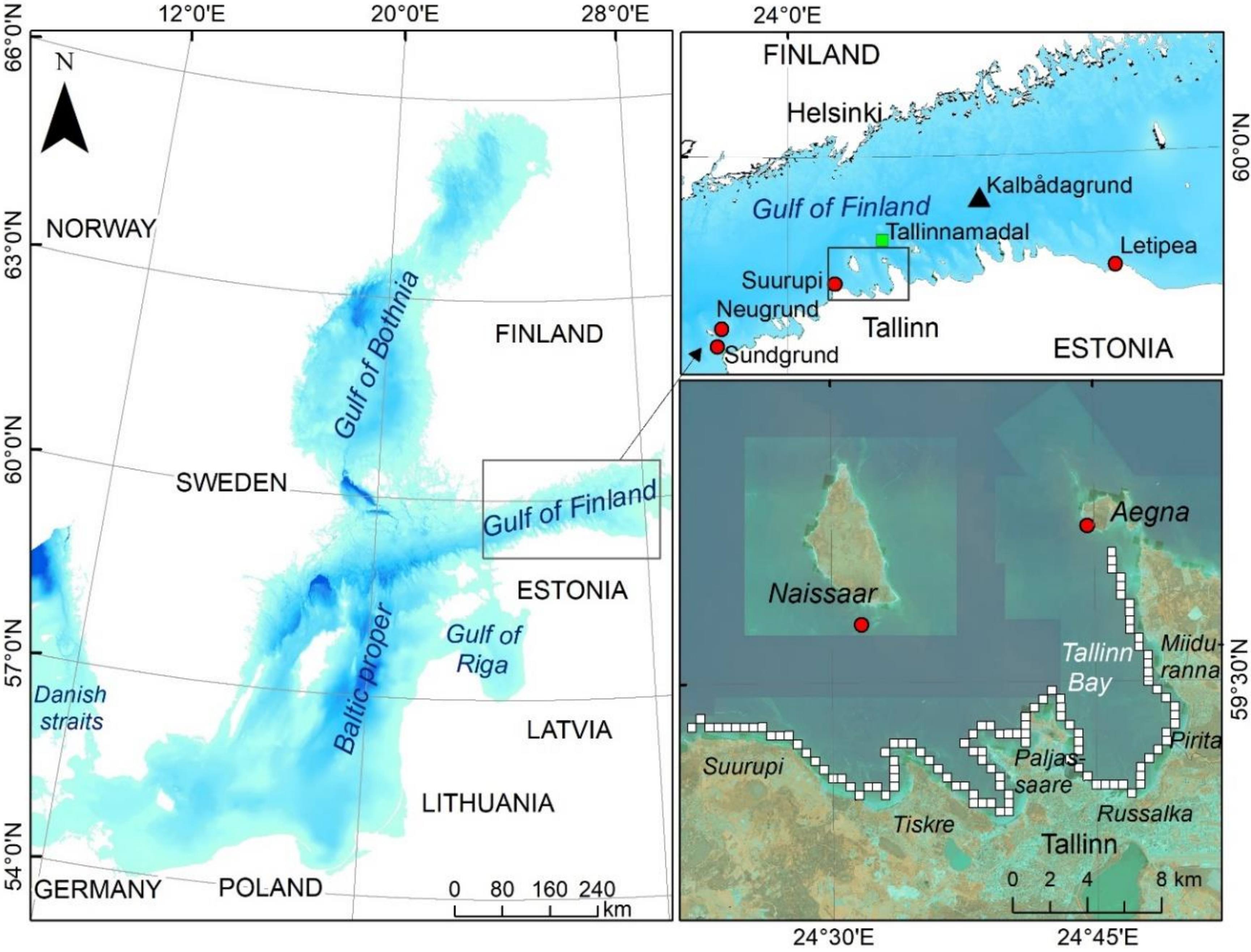
MOTIVATION

- Hard anthropogenic structures: generally disrupting or altering the nearshore natural seascape.
- The impact of anthropogenic interventions on the coastal system is highly variable.
- The impact of such structures becomes dramatic when a source or a major pathway of sediment is affected.
- We focus on the possibilities to systematically identify single littoral drift cells in sedimentary compartments in urbanised areas of complicated shape.
- Outcome: important tool in coastal engineering and management decisions.

TAL TECH

STUDY AREA

- The vicinity of Tallinn Bay: located at the southern coast of the Gulf of Finland, Baltic Sea.
- Region hosts a specific bi-directional wind and wave climate.
- Coastline orientation varies considerably.



Wave-driven longshore sediment transport

CERC method *(Coastal Engineering Research Council)*

$$Q_t = K \frac{\rho}{16(\rho_s - \rho)(1-p)} \frac{\sqrt{g}}{\sqrt{\kappa}} H_b^2 \sqrt{H_b} \sin 2\alpha_b$$

- Q_t – Potential longshore transport
- K – CERC coefficient
- ρ – water density
- ρ_s – sediment density
- p – sediment porosity
- g – acceleration due to gravity
- κ – breaking index/depth $\kappa = H_b / d_b$
- H_b – wave height at breaking
- α_b – **angle between the wave crests and the isobaths** at the breaking (includes information about wave period via refraction)

Slaid: M. Viška

Wave-driven longshore sediment transport is proportional to the wave energy flux (wave power)

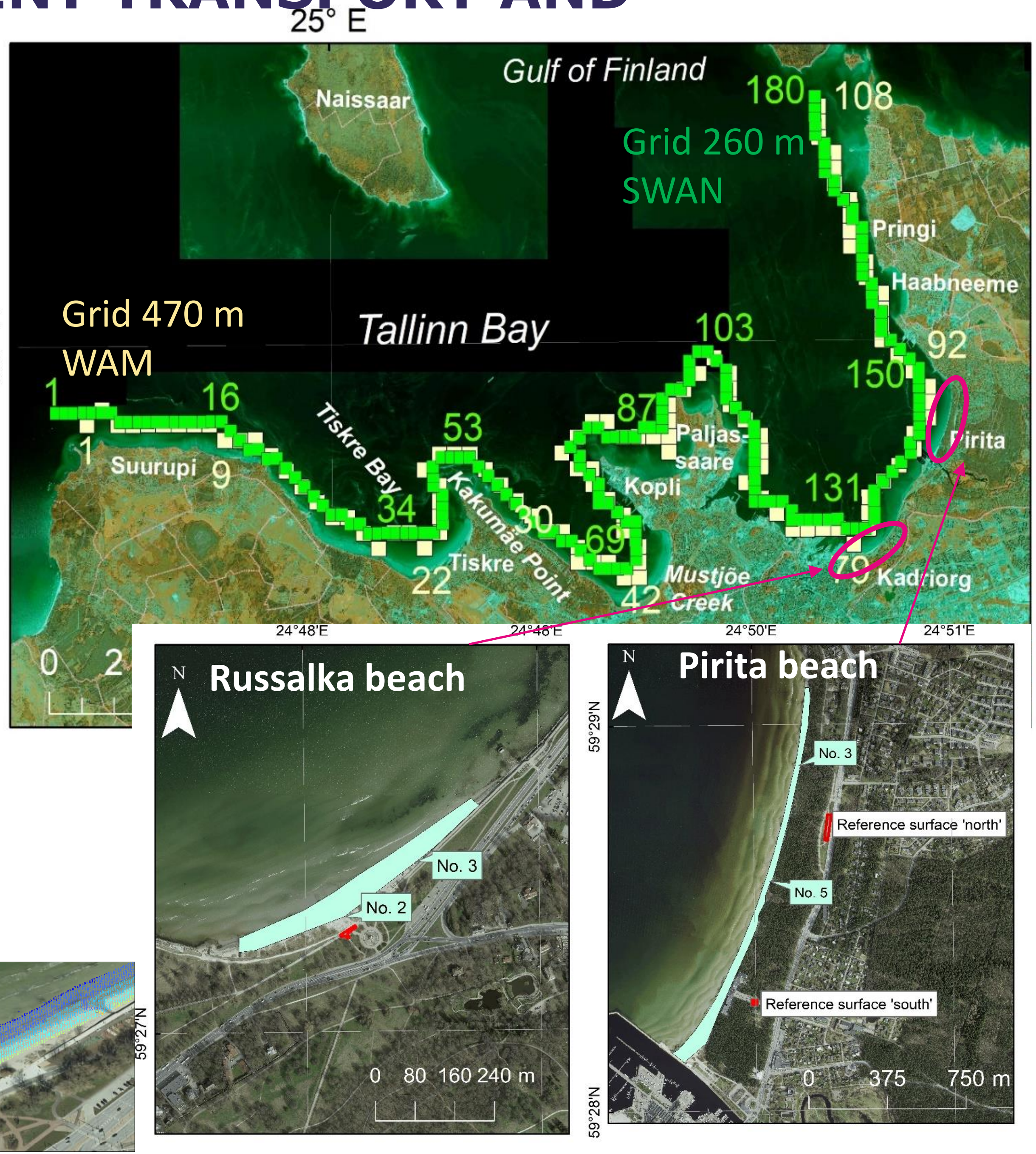
WAVE-DRIVEN POTENTIAL SEDIMENT TRANSPORT AND VOLUME CHANGES

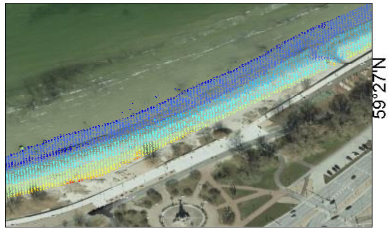
Sediment compartments

- wave statistics re-evaluated:
  - Spatial resolution of 260 and 470 m: triple-nested high-resolution WAM and SWAN models.
  - Forced with three wind data sets:
    - 32 years of high-quality one-point marine winds
    - ERA5 winds for 1990–2021
    - BaltAn65+ winds for 1986–2005.
  - Constructed coastline

Volume changes: major accumulation areas, Pirita and Russalka beaches.

- Detailed survey of the changes on dry beach.
- Lidar measurement: 2008-2020.





ALONGSHORE SEDIMENT TRANSPORT PATTERNS AND LITTORAL DRIFT CELLS

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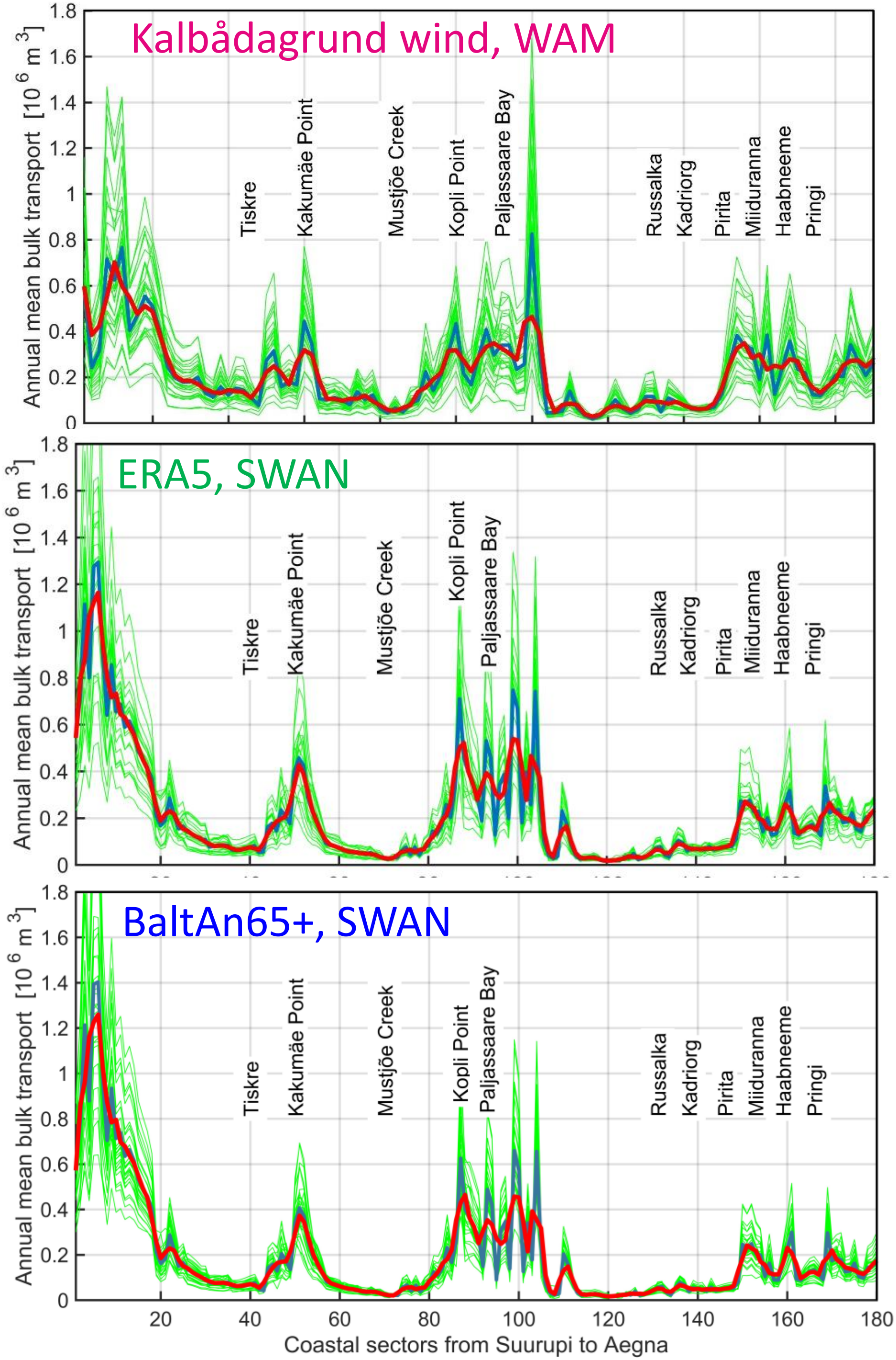
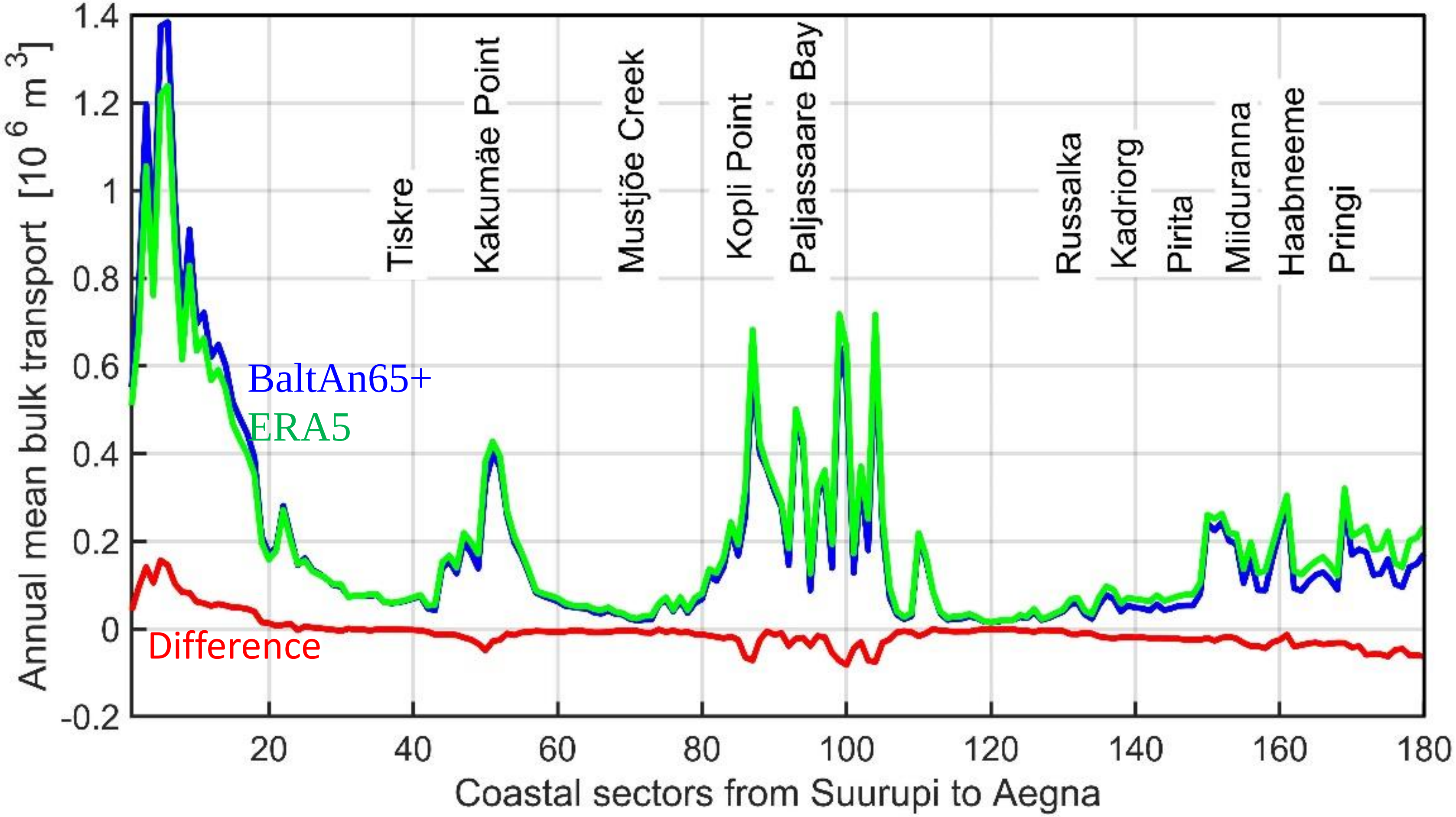
POTENTIAL BULK ALONGSHORE SEDIMENT TRANSPORT

- The largest long-term average annual potential bulk transport rates occur near headlands.
- In the interior of Tallinn Bay: sediment transport rates are by an order of magnitude smaller compared to coastal segments to the west of Tallinn.
- Estimates produced using a simplified scheme for evaluation of wave properties and the WAM model: reasonably follow the alongshore variations in the sediment transport.
  - Similar long-term transport rate in the interior of Tallinn Bay as simulations using modelled winds by ERA5 and BaltAn65+.



DIFFERENCE IN THE ANNUAL AVERAGE MAGNITUDE OF POTENTIAL BULK TRANSPORT ESTIMATED USING BALTAN65+ AND ERA5

- Coastal segment from Suurupi to Aegna for overlapping years 1991–2005.
- Pattern of differences: likely stems from different wave directions represented by these two wind patterns rather than from different wave heights.
- The maximum difference reaches about 15%.
- The two projections of bulk transport almost coincide in the rest of study area.



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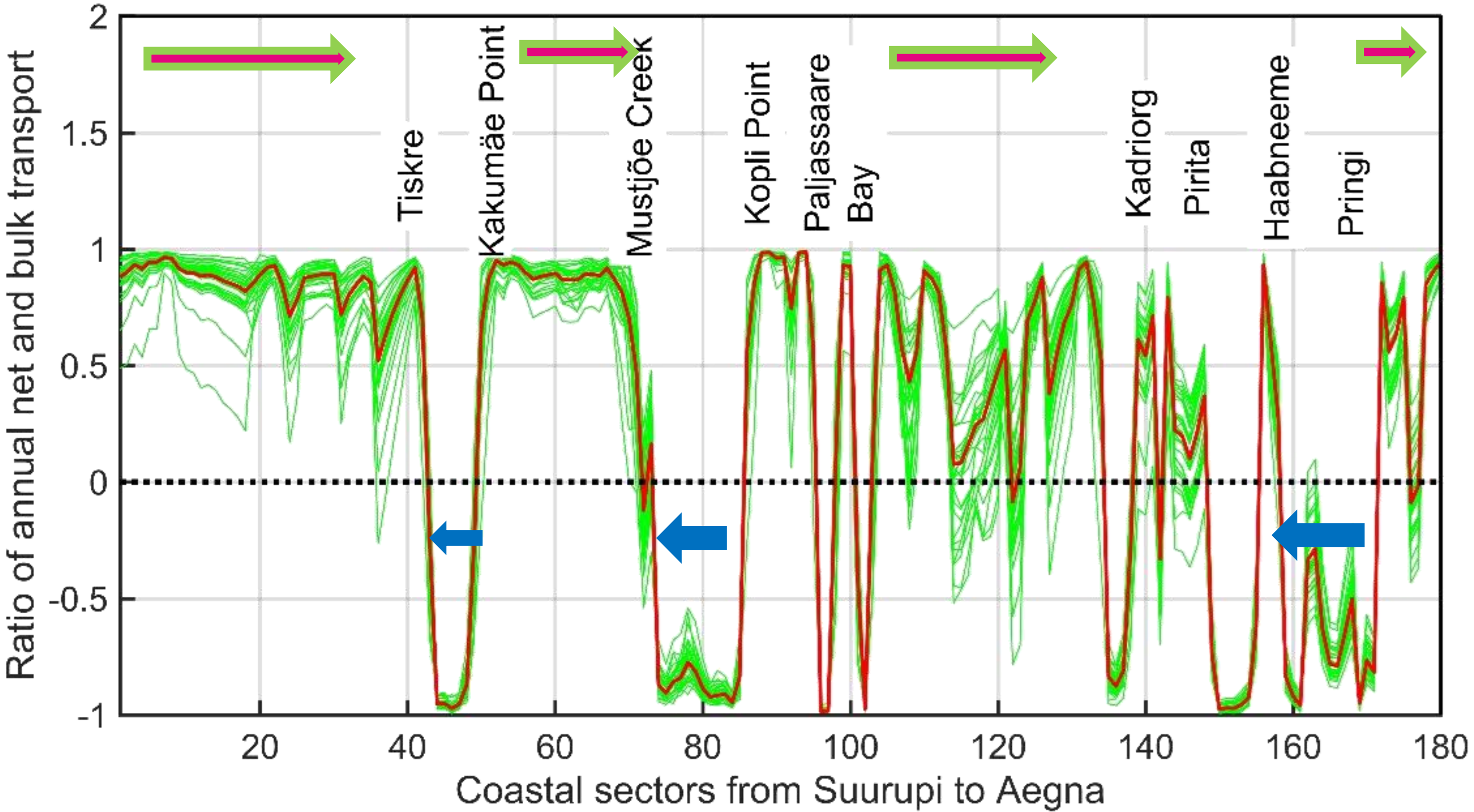
HIGHLY UNIDIRECTIONAL ALONGSHORE SEDIMENT TRANSPORT

- The littoral drift in the study area is predominantly counterclockwise.
- Follows the anisotropy of wind and wave fields in the region.
  - A few exceptions occur to the west of Kakumäe Point and Kopli Point, and in the south-eastern part of the interior of Tallinn Bay from Kadriorg to Pirita.
- The southern part of Tallinn Bay host littoral drift with a varying direction.
  - Caused by a different orientation of the coastal segments.



(The positive direction is from the left to the right for a person who looks from the coast towards the sea)

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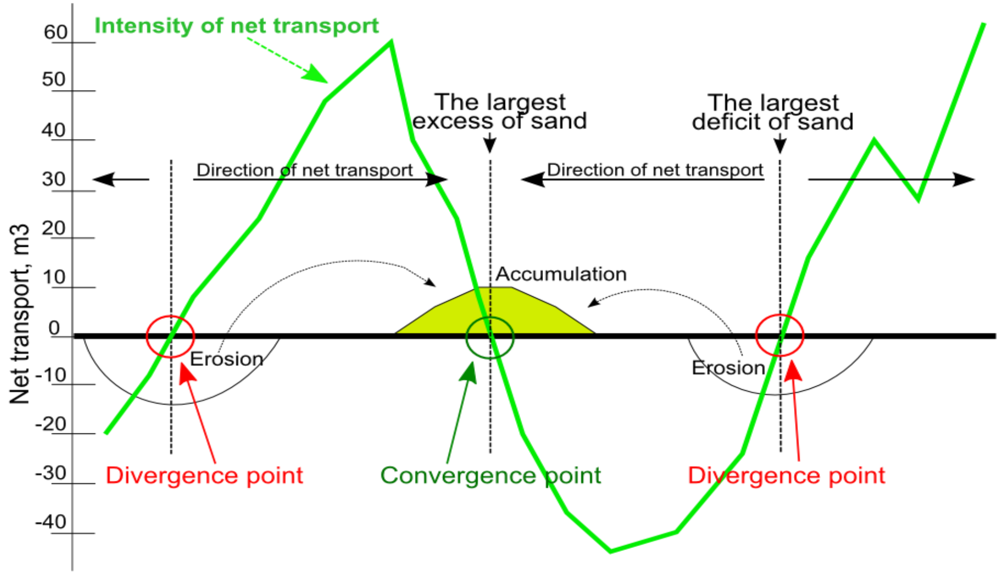
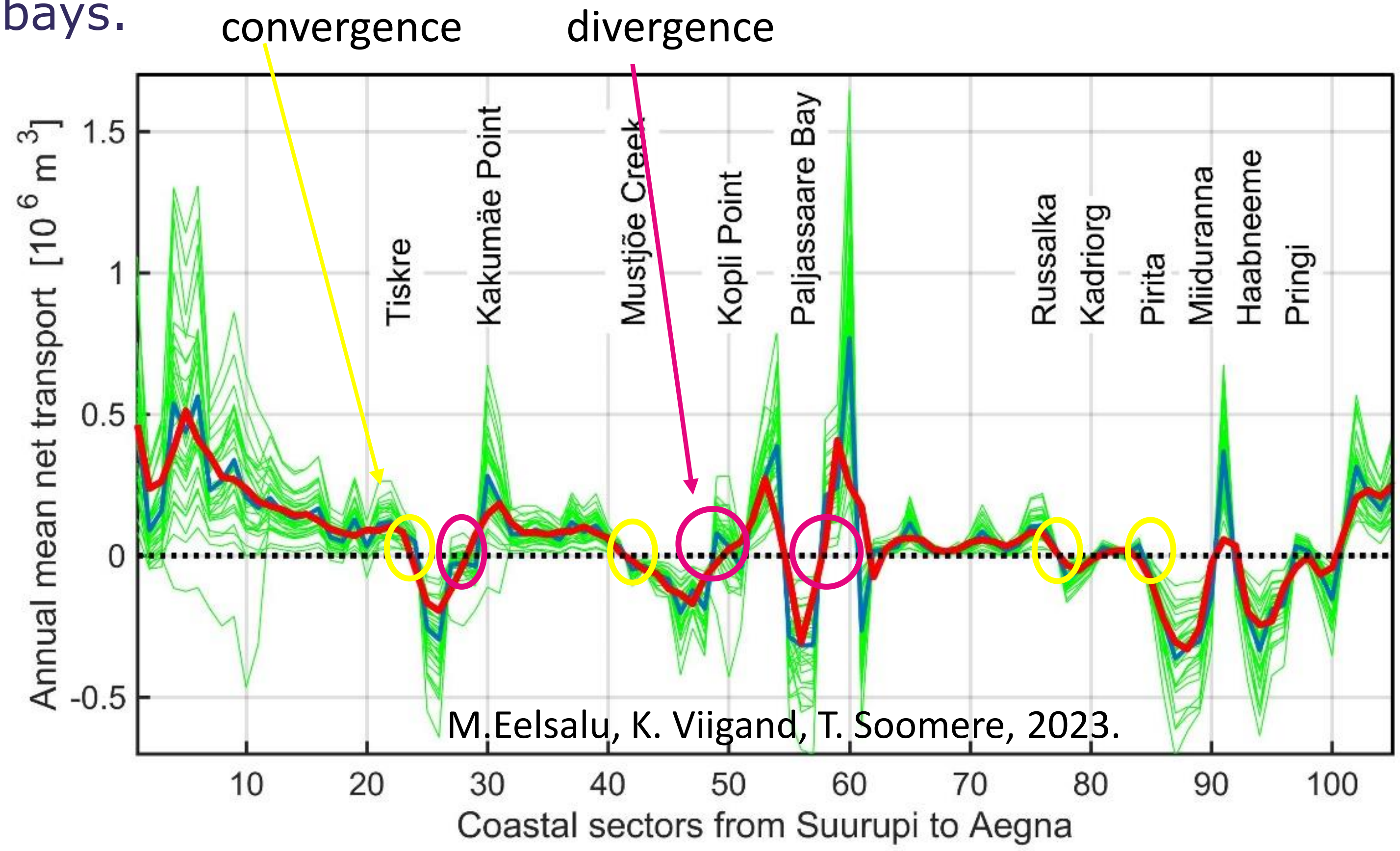
ALONGSHORE VARIATIONS IN THE POTENTIAL NET SEDIMENT TRANSPORT: IDENTIFICATION OF LITTORAL CELLS

- Zero-downcrossings of the alongshore course of net sediment transport indicate convergence areas of sediment flux (rapid accumulation areas).
- Zero-upcrossings show the divergence regions.
  - Considered as borders between neighbouring sediment compartments.
- Stable divergence and convergence points.
- Match major headlands and interiors of bays.



Illustrative scheme: M. Viška



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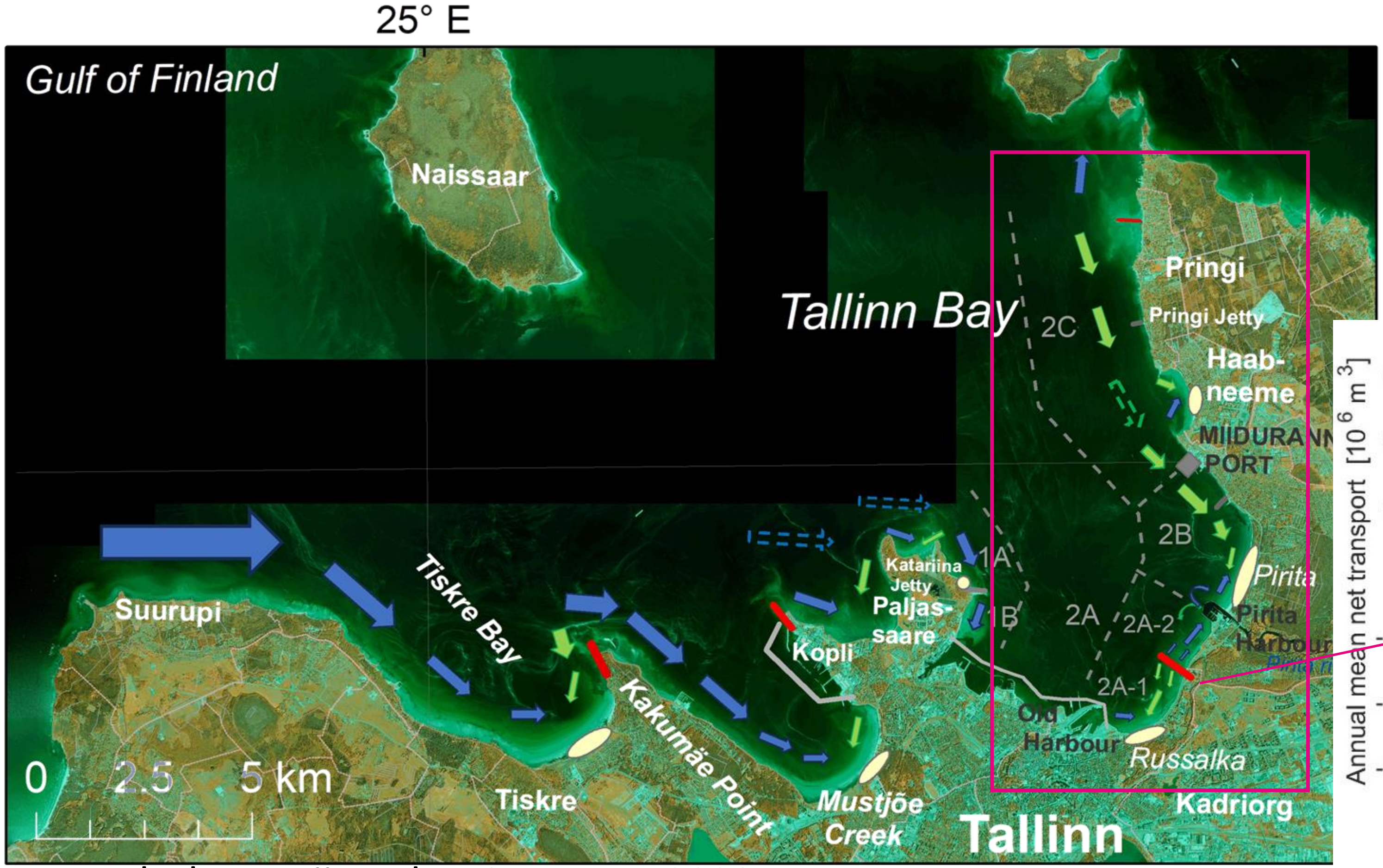
SEDIMENTARY COMPARTMENTS AND CELLS IN THE STUDY AREA

- The major headlands, Kakumäe, Kopli and Paljassaare Peninsula divide the sedimentary system into practically isolated littoral cells
  - typical size of less than 10 km.



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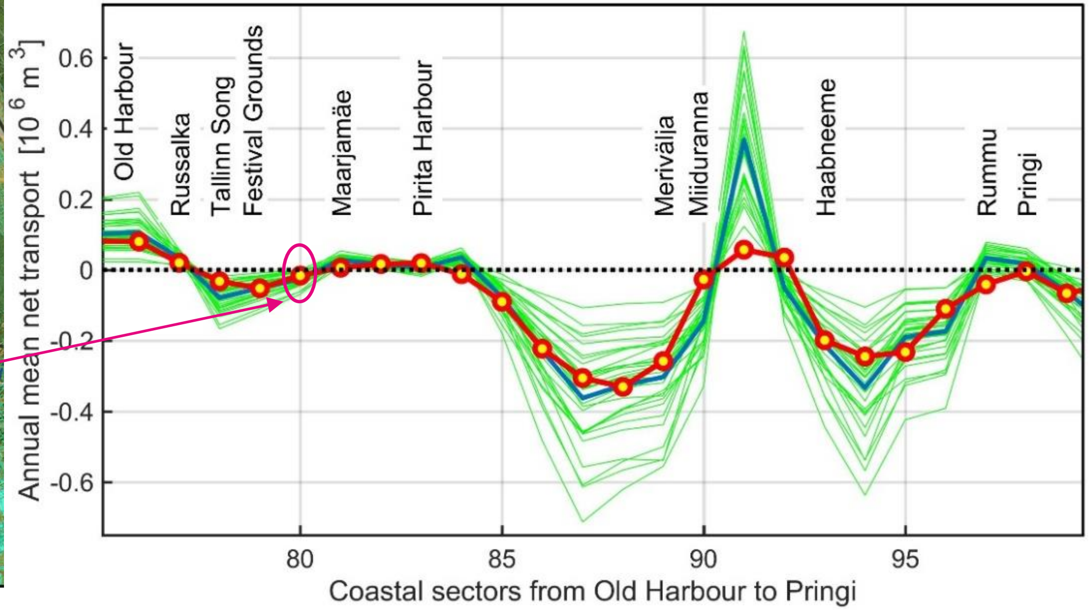
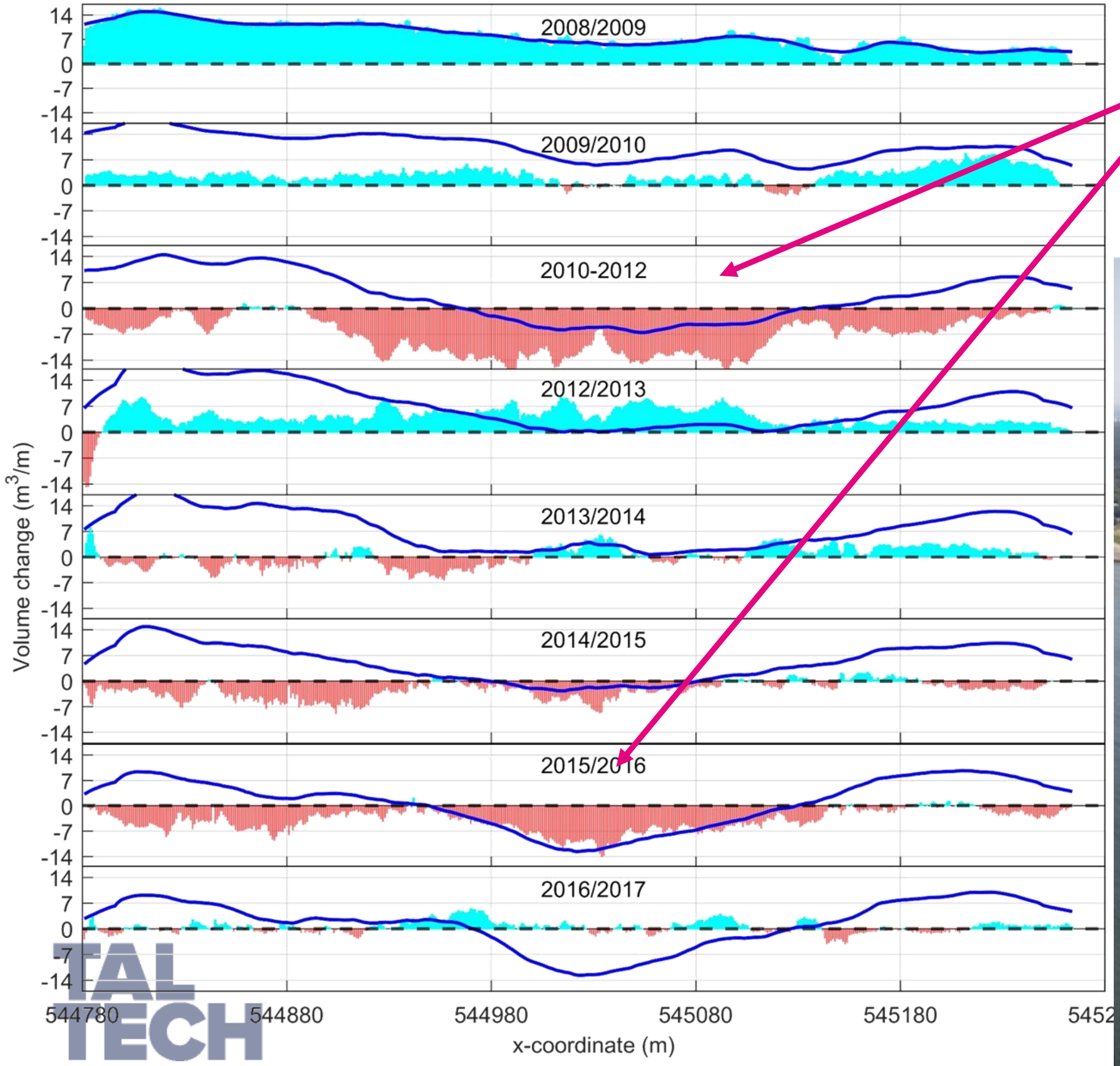
- The southern and eastern shores of Tallinn Bay host a complicated pattern of net transport: interrupted by several engineering structures.
- An unexpected invisible divergence point near Maarjamäe.
  - Persistent divergence area of littoral drift that subdivides the almost isolated compartment into two distinct sedimentary cells.



THE RESULTS VALIDATED AGAINST MEASUREMENTS: RUSSALKA BEACH



- Middle section: most affected by sand removal.
- Attributed with the occurence of wave set-up
- Long-term: stable or increasing

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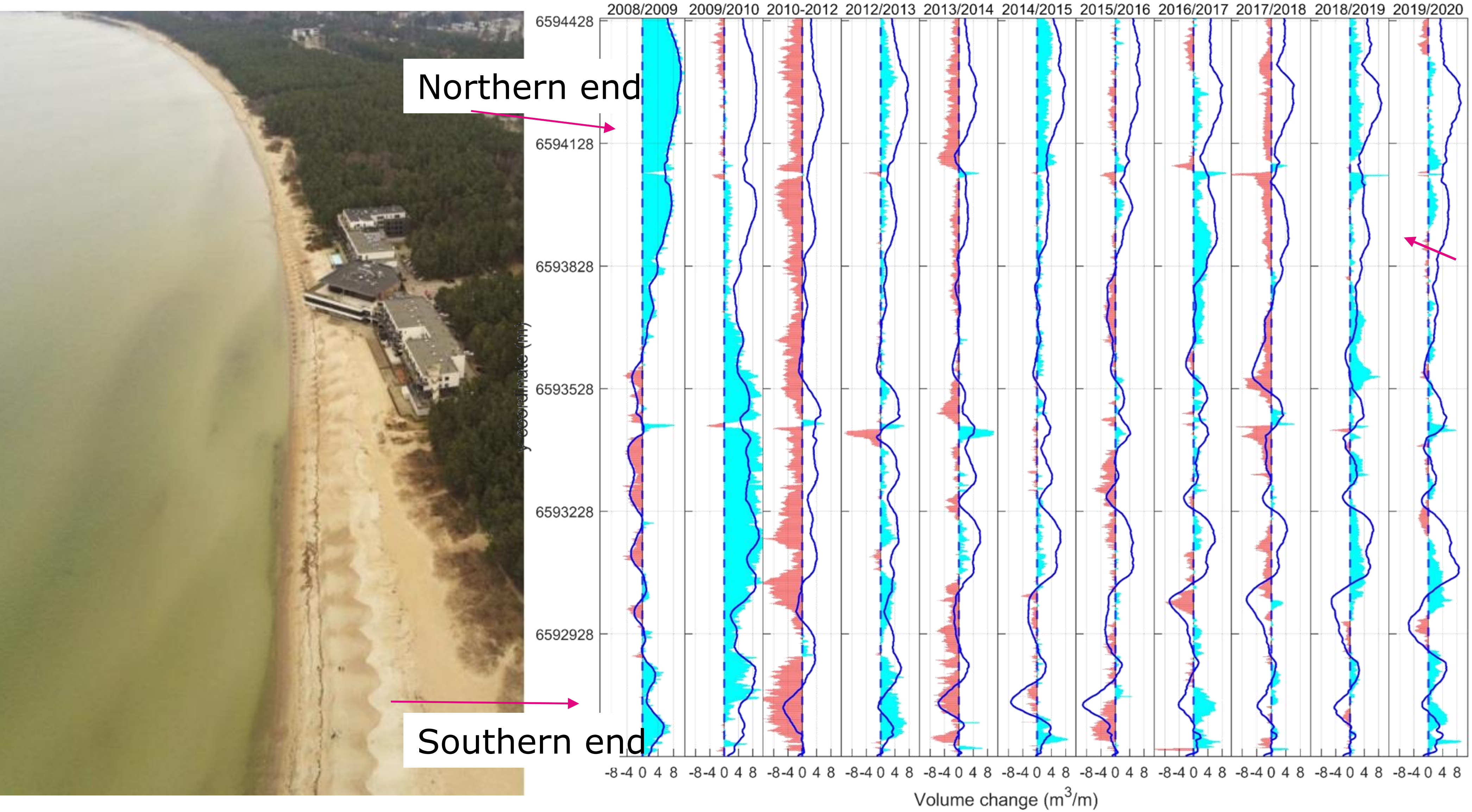
THE RESULTS VALIDATED AGAINST MEASUREMENTS: PIRITA BEACH



Northern end: sand returns

Pirita beach by 2020: cumulative changes to entire beach are fairly small (average gain about 2 m^3/m)

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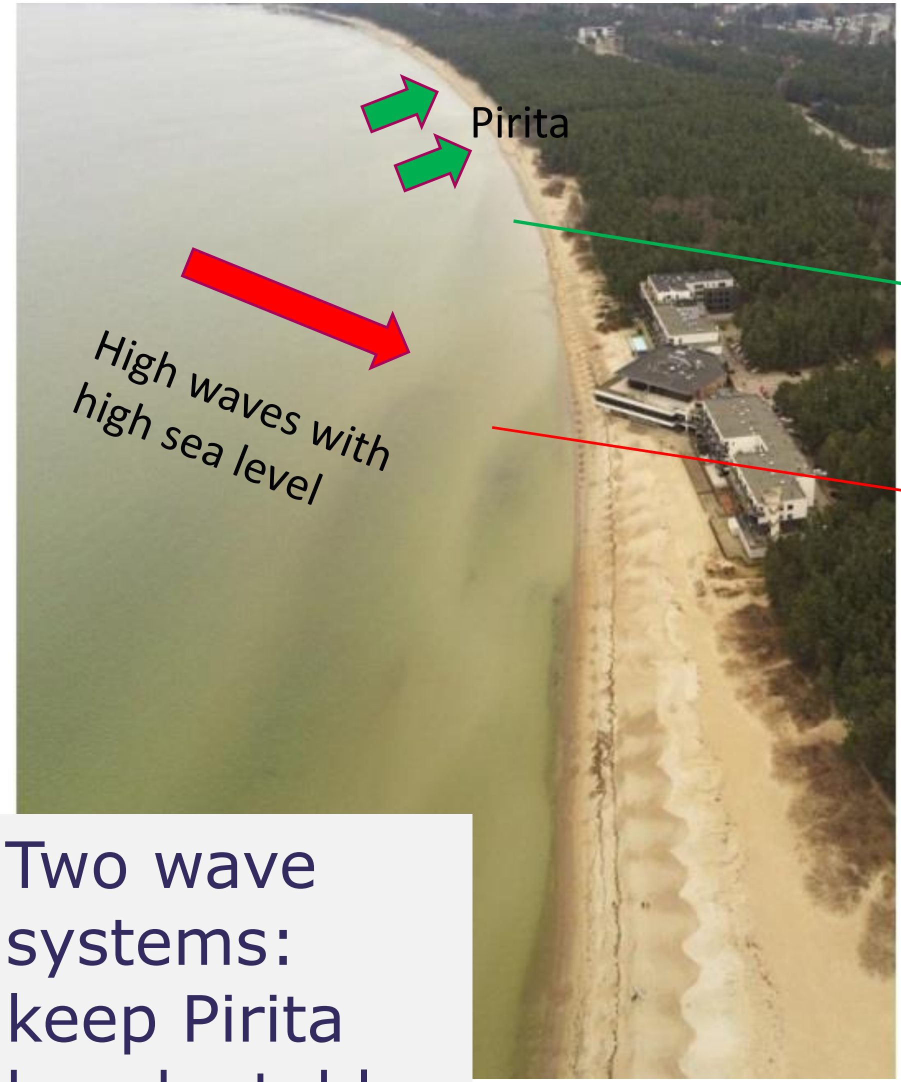
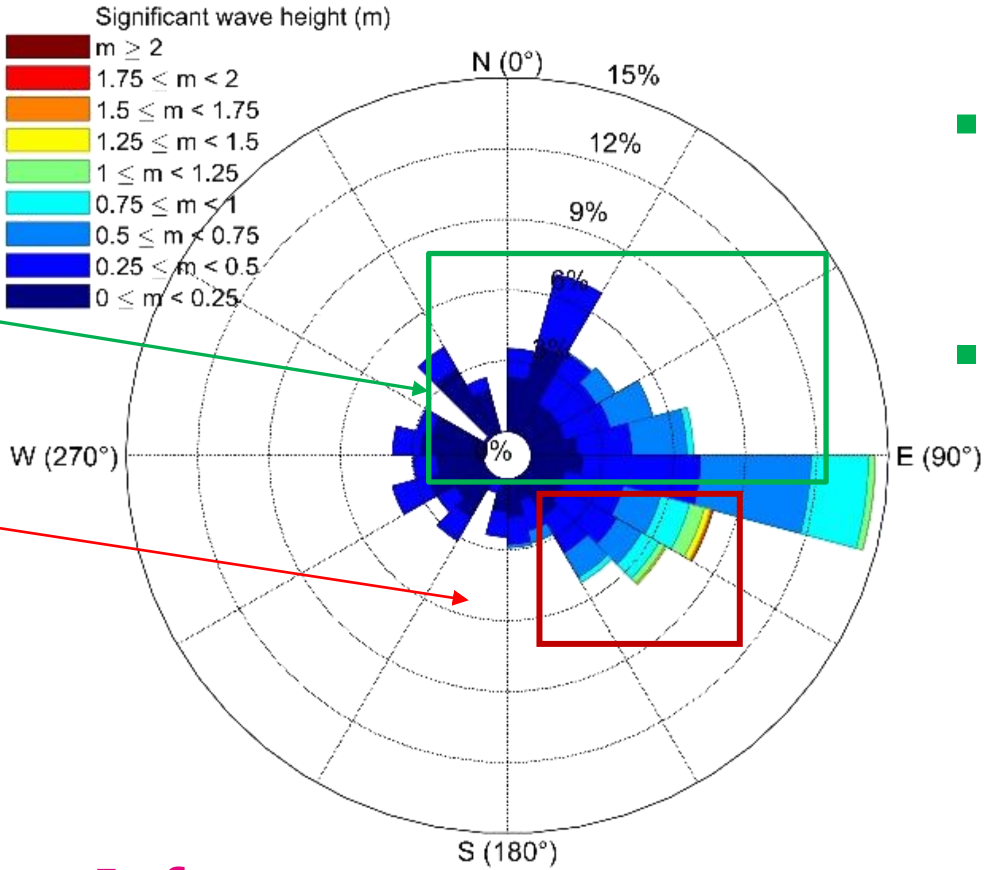
Directionality of wave systems: frequent low wave conditions





- Low waves but frequenty occurring.
- Transport sand to north stabilizes effectively the northern section of Pirita.

- Infrequent strong storm waves with high water level: transport sand to the south.

Two wave systems: keep Pirita beach stable

Conclusions

- The sedimentary system on the northern shore of Estonia, including the vicinity of Tallinn: naturally divided into many almost isolated littoral drift cells.
- These cells often represent one bay that is deeply cut into mainland.
  - Usually separated by major points or headlands.
- The set of man-made structures generates an additional division of the system into subcells.
- A stable point of divergence of wave-driven net sediment transport exists in an almost straight section of the southern coast of Tallinn Bay.
  - Its impact becomes evident as a localised area of accumulation near Tallinn Old Harbour, at Russalka beach.

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THANK YOU!

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