BalticWay: Towards the use of ocean dynamics for pollution control

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Outline

- The site: Baltic Sea – a major highway & particularly sensitive sea area
- The problem: pollution hitting vulnerable areas
- The idea: quantification of offshore areas
- The tool: Lagrangian trajectory simulations

- The outcome: concealed transport patterns

  optimum fairways & locations for potentially dangerous activities

  areas of reduced risk

  dynamically different sea areas

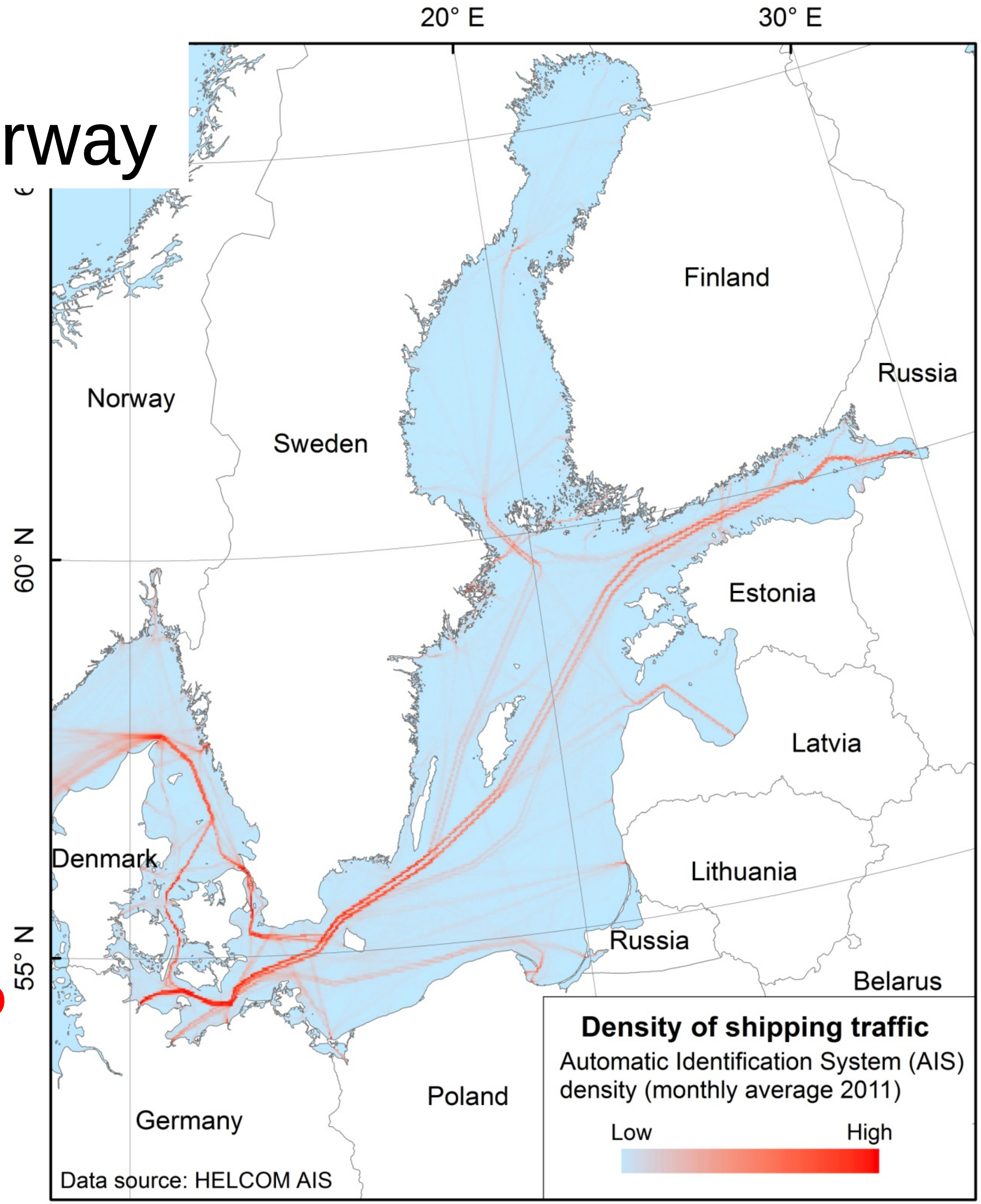
The Baltic Sea – a major marine motorway

Ship traffic:

- 80% of international cargo volume

Baltic Sea:

- 150,000 voyages per year
- 2,000 per day
- 200 tankers per day
- **15 % of world cargo**



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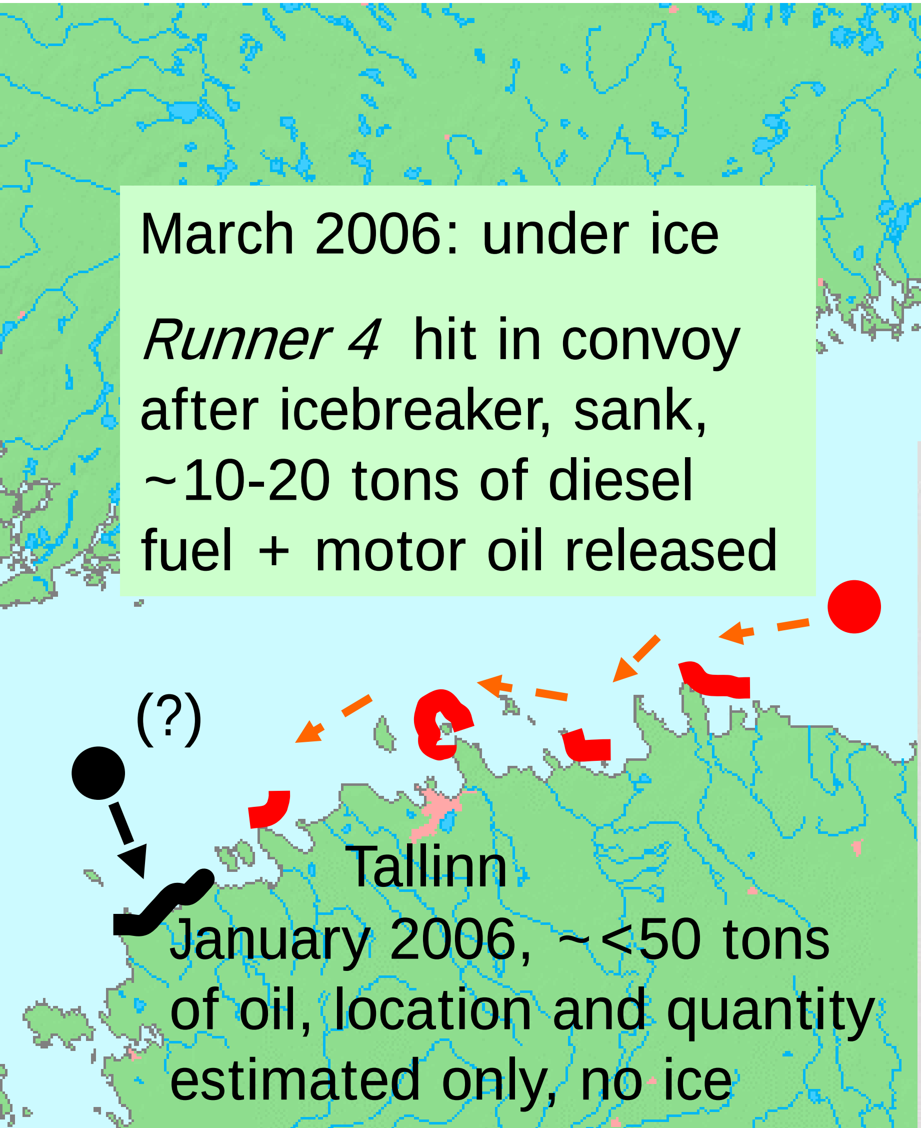
Two major (in local scale) oil pollutions in Estonia in 2006



March 2006: under ice

Runner 4 hit in convoy after icebreaker, sank, ~10-20 tons of diesel fuel + motor oil released

January 2006, ~<50 tons of oil, location and quantity estimated only, no ice

The pollution fortunately hit small sections

The question:

Can we do something to “handle” oil pollution?

Risk=probability × cost (van Dantzig)

(i) Reducing of probability of pollution (double hulls, warning systems, navigation devices etc.)

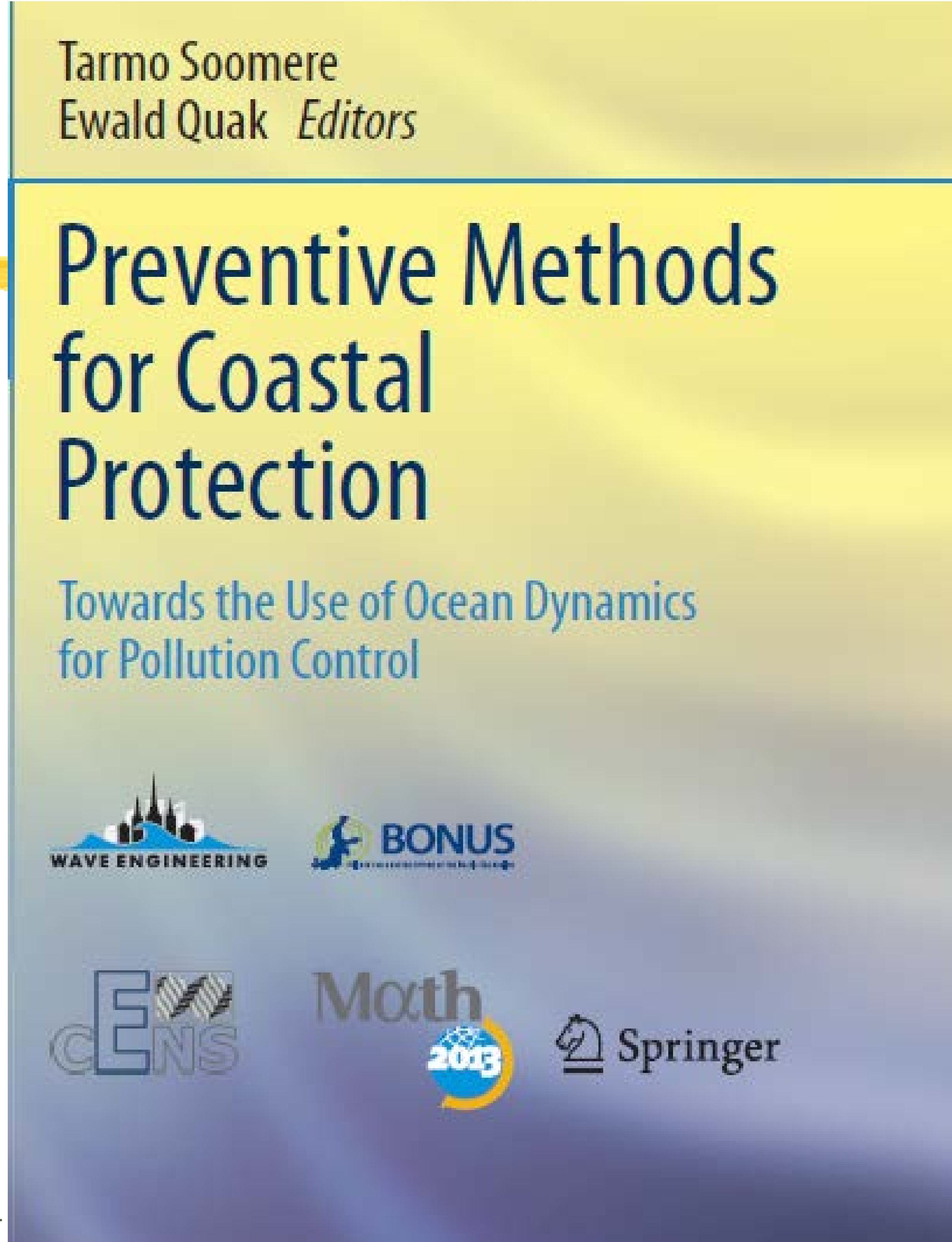
(ii) **Reducing the consequences** of disasters

If we could adjust human activities so:

that the probability of transport of the (potential) oil pollution to the high-value regions (e.g. coasts) will be smaller (than today),

the consequences of (potential) disasters would be smaller.

458 pages
01 July 2013



A short description of an approximate solution

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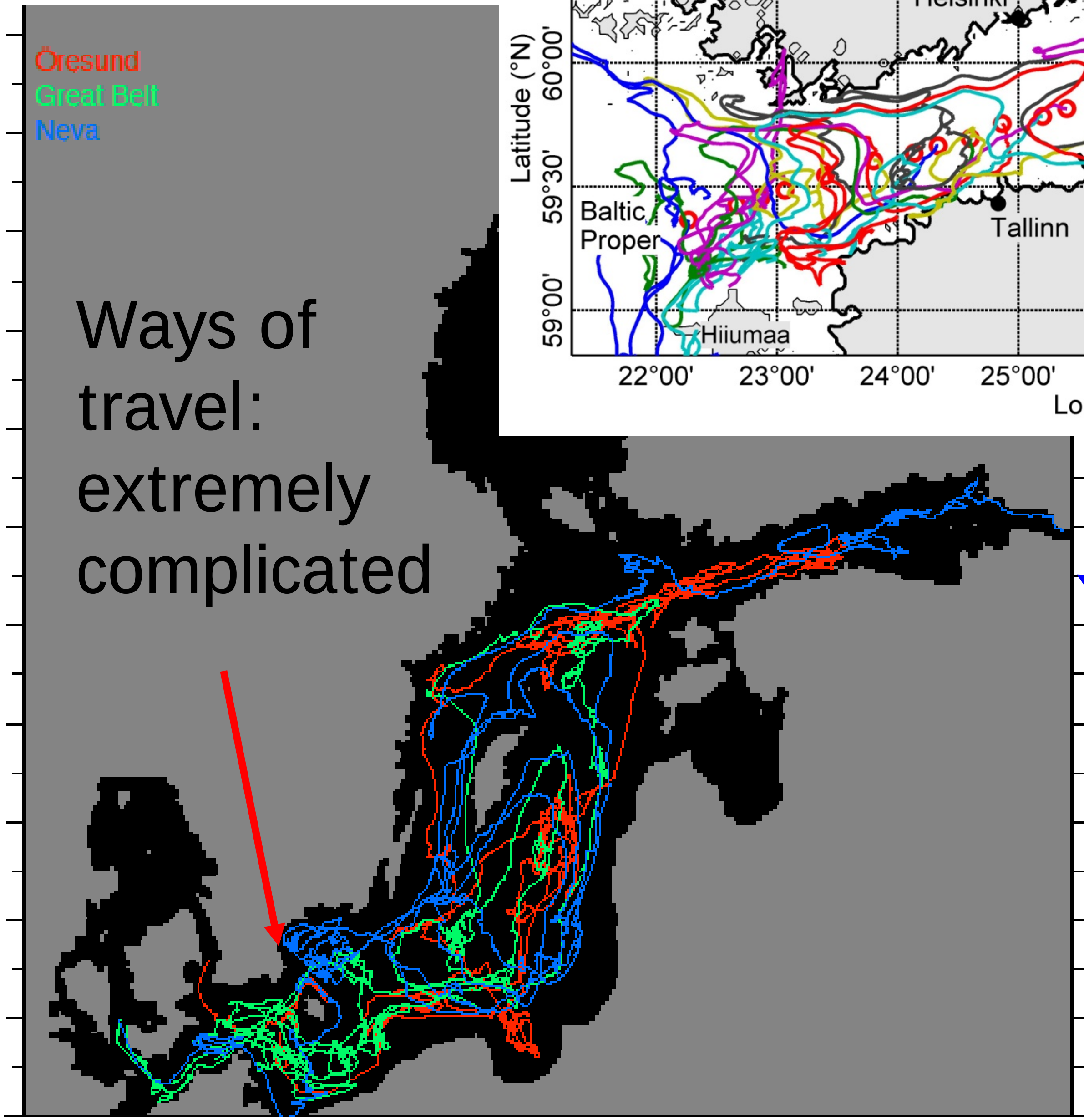
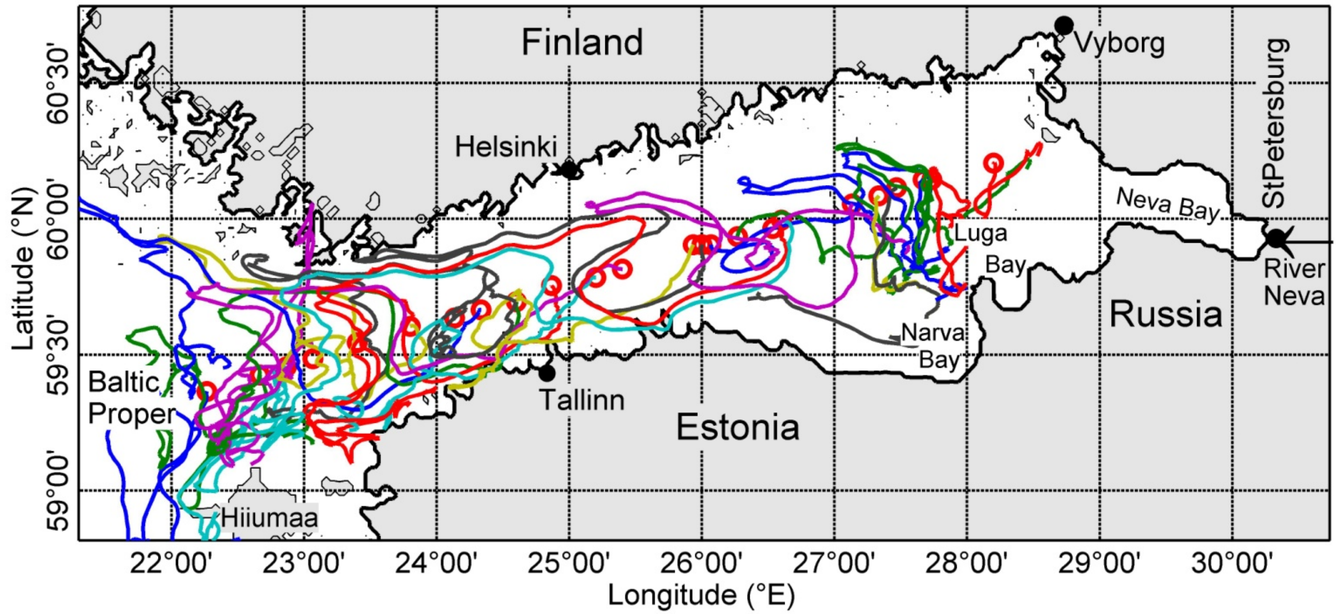
Two ways to proceed:

- WAY1: Given the properties of pollution (location, time, size)
  - Find where it will go and when it will beach
  - (a direct problem of pollution propagation)
  - (not much could be done to protect the high-cost areas)



Ways of travel: extremely complicated



Blue: River Neva

Image: Kristofer Döös, MISU

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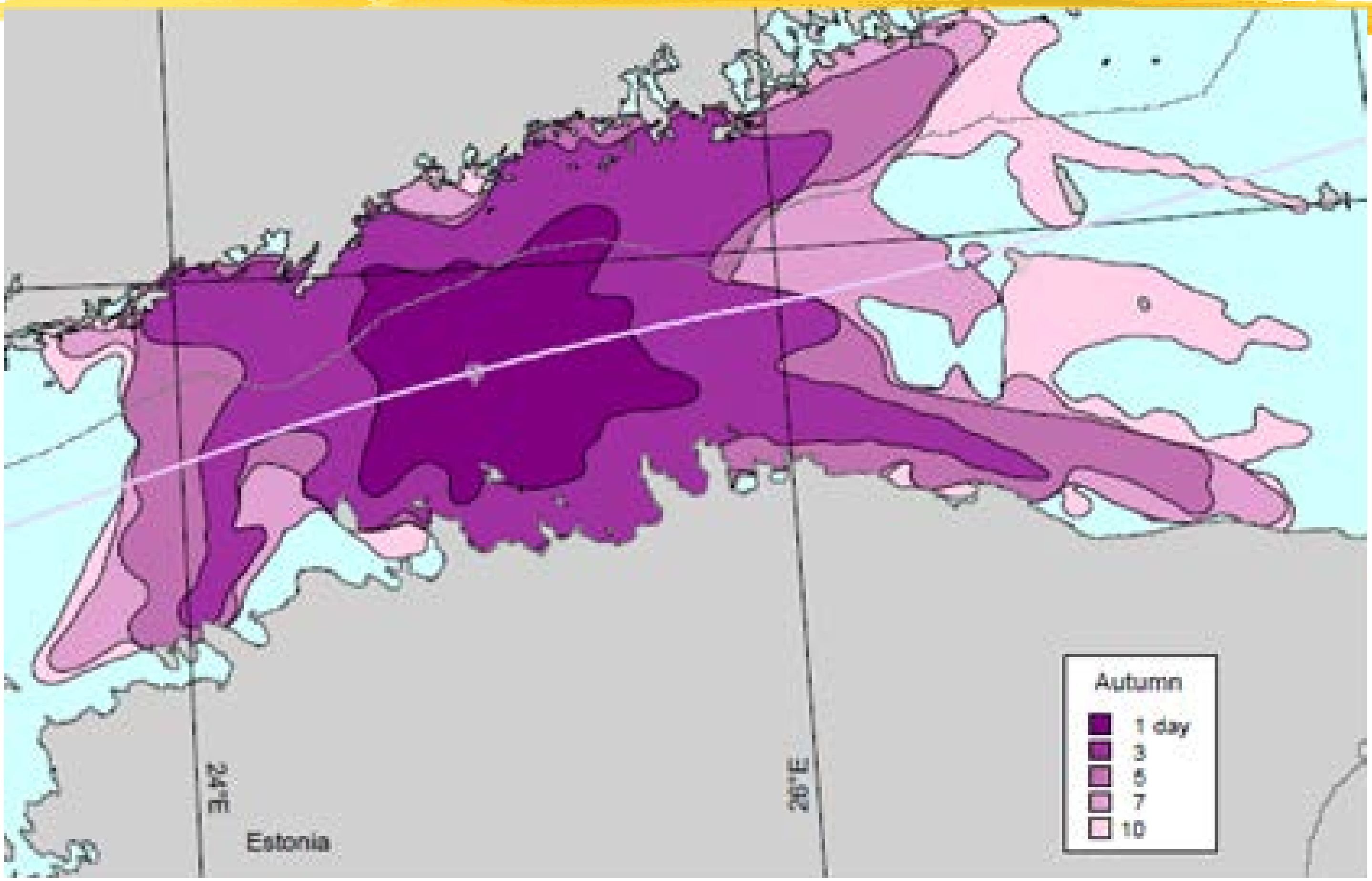
Modelled oil spreading: Gulf of Finland, autumn



Simulations by Dr. S.Ovsienko

There is some order in the chaos

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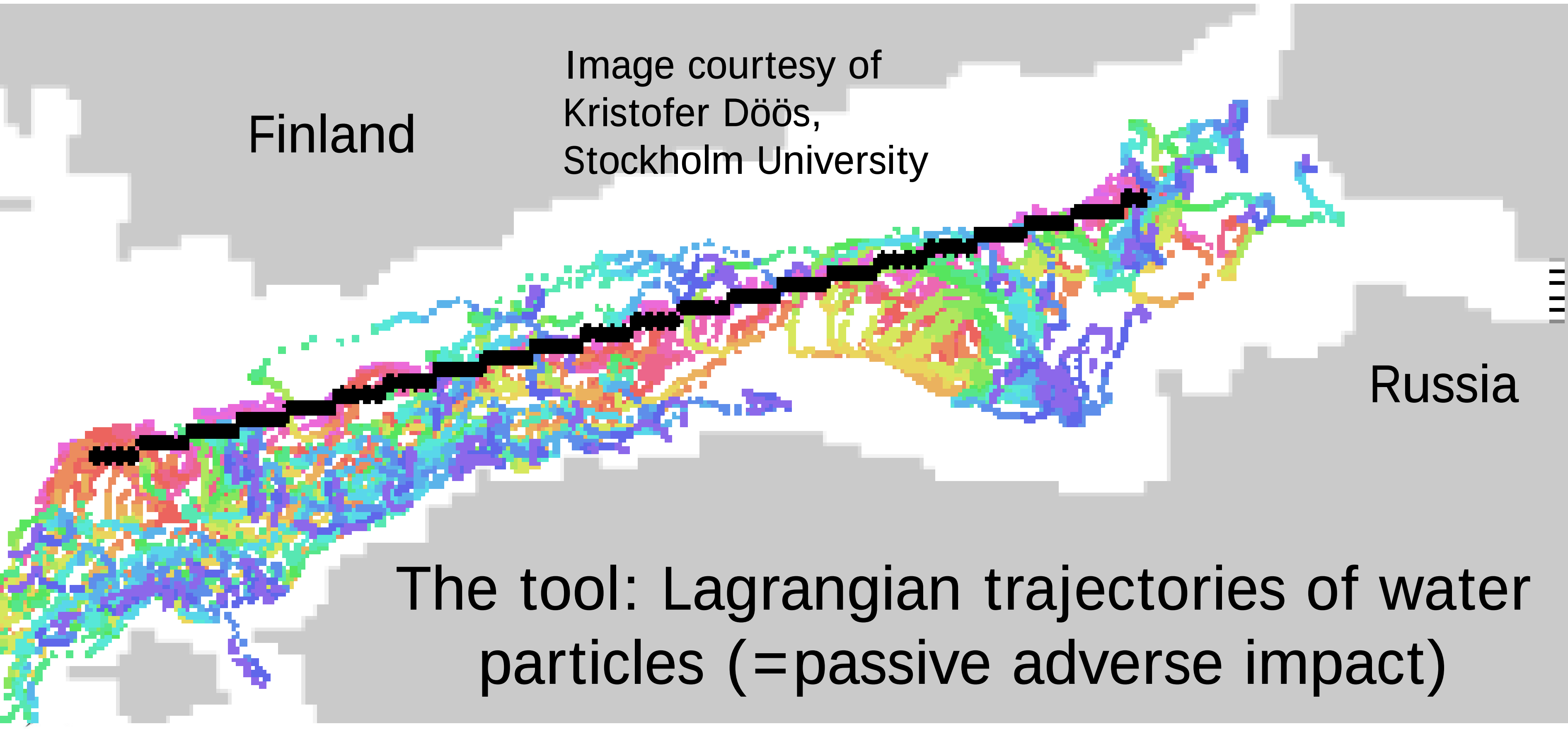
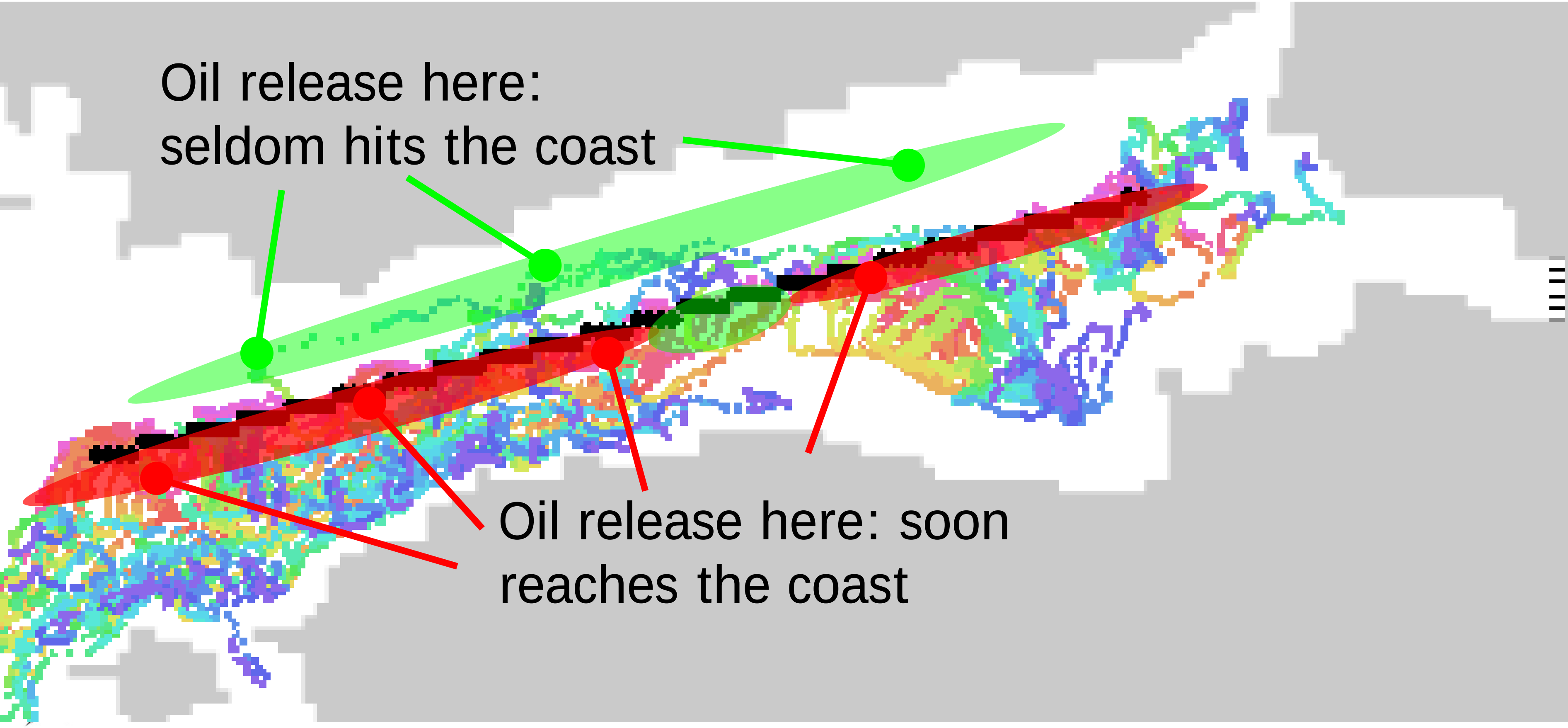
Though this be madness, yet there is method in't:

Anisotropic transport patterns in the GoF



The tool: Lagrangian trajectories of water particles (=passive adverse impact)

Anisotropic transport patterns in the GoF → different cost of the same disaster in different area



Two ways to proceed:

- WAY 1: Given the properties of pollution (location, time, size)
  - Find where it will go and when it will beach
  - (a direct problem of pollution propagation)
  - (not much could be done to protect the high-cost areas)
- WAY 2: Given the vulnerable /high-cost area
  - FROM WHERE pollution may come to this area
  - Are there some areas from which pollution transport to the high-cost area is improbable?

New look to The question:

Can we do something to "handle" pollution?

Risk=probability × cost (van Dantzig)

The goal: Reducing the consequences of disasters

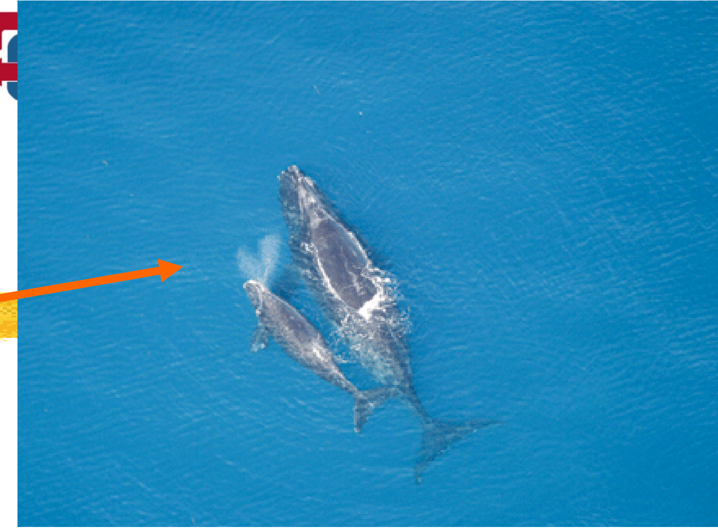
- by smart adjusting the location of human activities
- so that the pollution will not reach the coasts

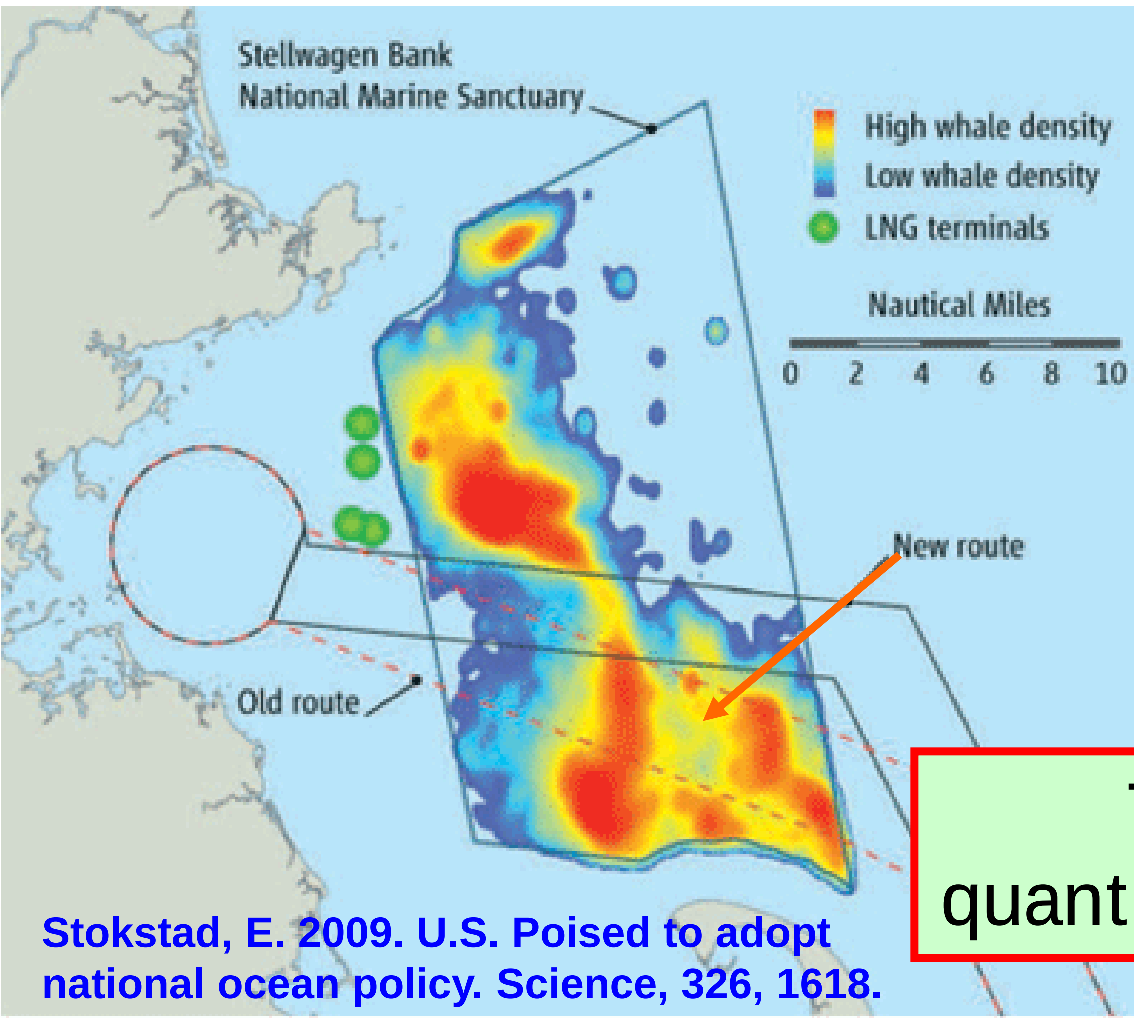
The method: solving the inverse problem:

- quantification of offshore areas
- in terms of their 'ability' to supply coastal pollution
- through current-driven transport

Example of shifting a fairway

Highly endangered North Atlantic right whale





- Cargo ships traveling to Boston may hit highly endangered whales
- Shift of fairway reduced the risk of collision by **56 %**
- The trip is only **15** minutes longer

The key problem: quantification of the offshore

Stokstad, E. 2009. U.S. Poised to adopt national ocean policy. Science, 326, 1618.

Steps of technology I+II

1918 TALLINNA TEHNIKAÜLIKOOL
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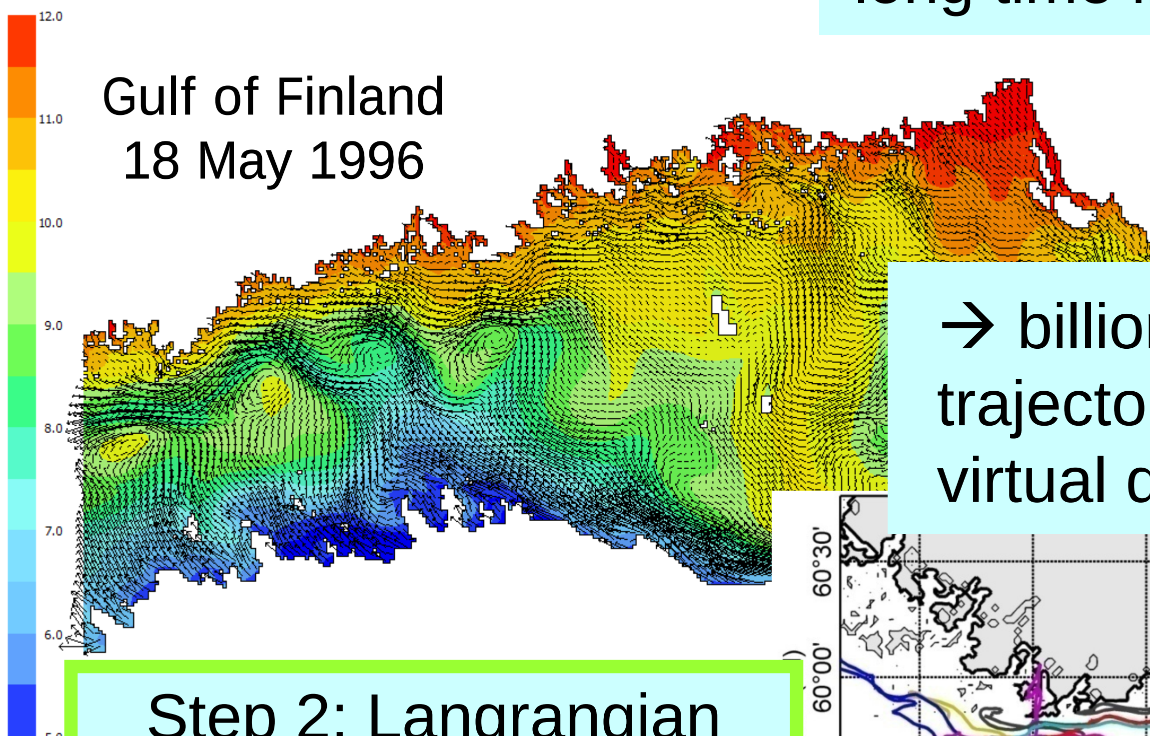
Step 1: eddy-resolving ocean model

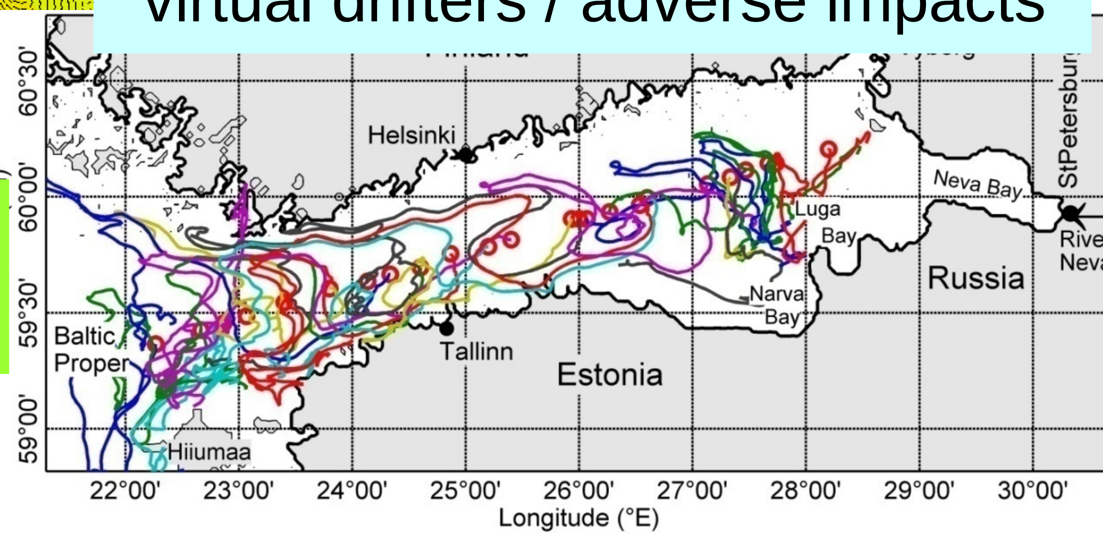
→ simulated 3D velocity fields in the sea area in question over a long time interval



Oleg Andrejev 2010
Grid step 0.25 miles

→ billions of simulated trajectories of water particles / virtual drifters / adverse impacts

Step 2: Langrangian trajectory model



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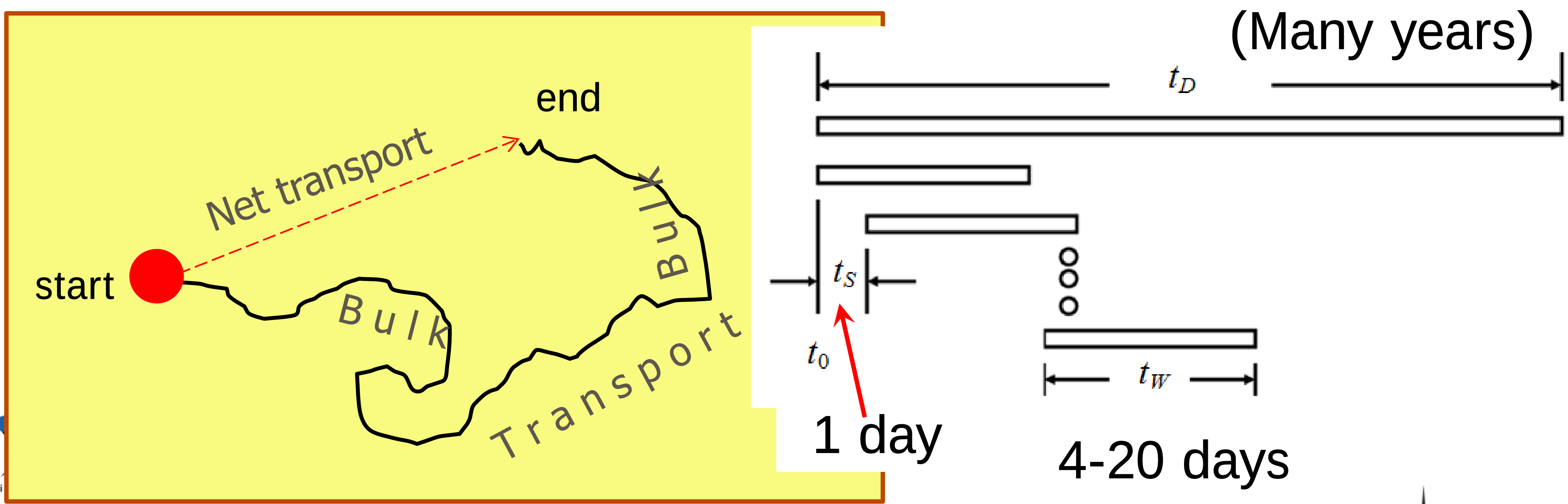
Trajectory simulations

- Net Transport: Distance between start and end

  ← Fast and slow moving trajectories

- Ratio of Net and Bulk Transport

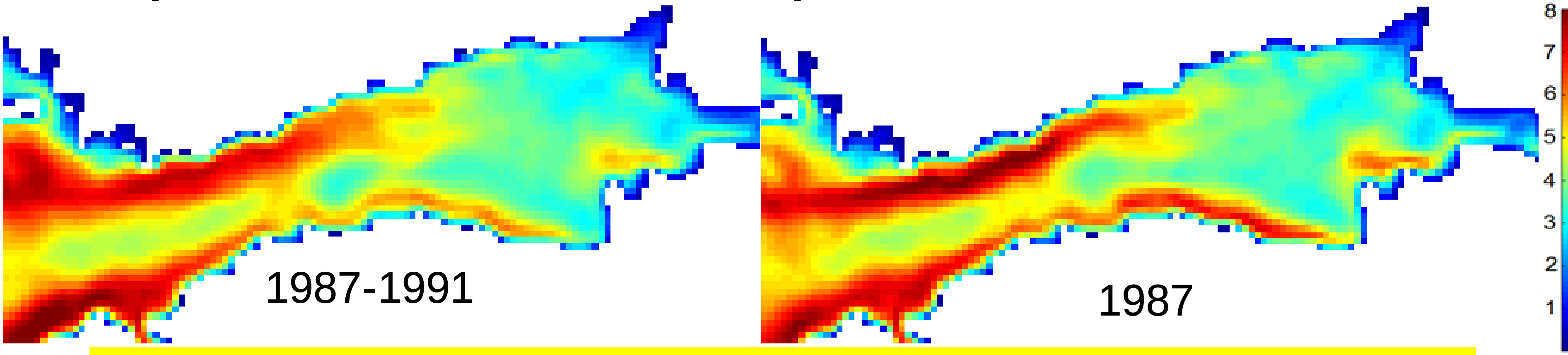
  ← High: Unidirectional flow; Low: eddies



Soomere et al. 2011, *Boreal Environment Research*

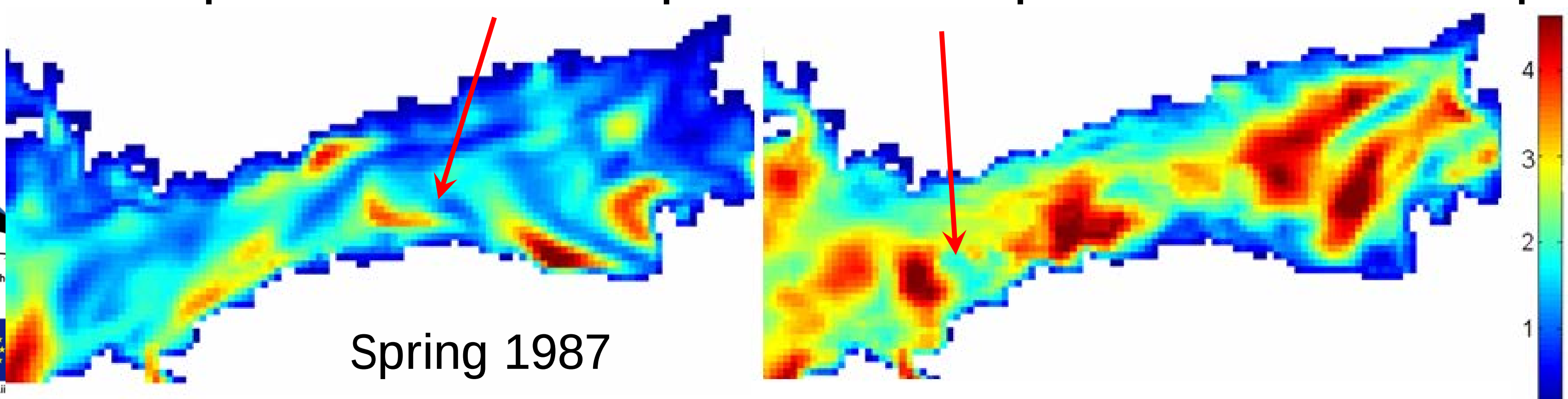
Encouraging side results: patterns of net transport

Soomere et al. 2011, *Boreal Environment Research*



Corollary: although long-term Eulerian mean velocity is very small, there exist clear patterns of intense net (Lagrangian) transport

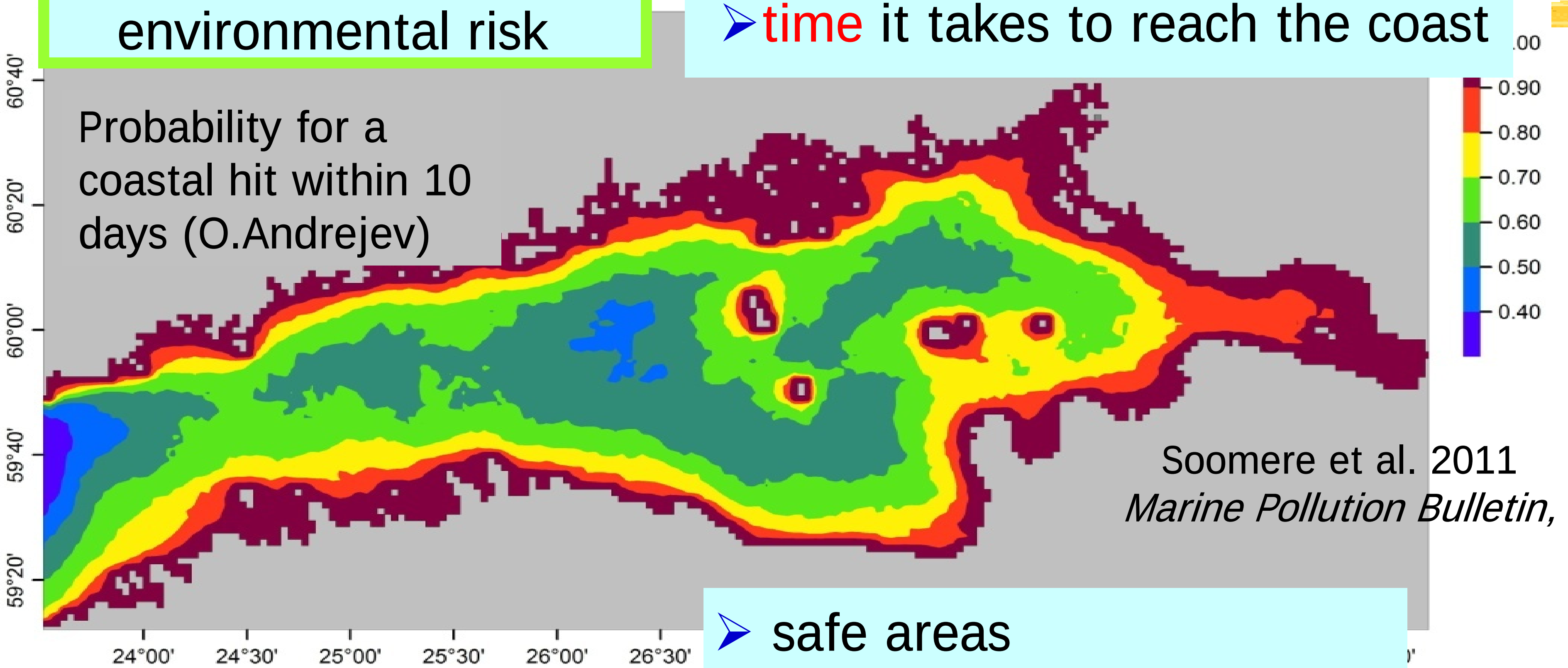
- Expected feature: transport mostly along the gulf axis
- Unexpected: seasonal patterns of rapid cross-axis transport



Steps of technology III+IV

Step 3: measures of the environmental risk

- probability for coastal hits;
- time it takes to reach the coast

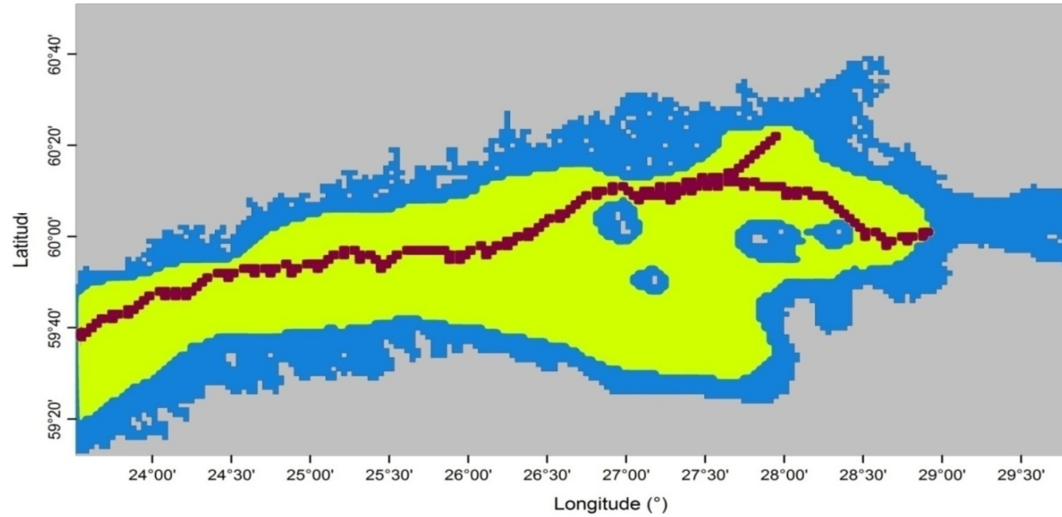


Soomere et al. 2011
Marine Pollution Bulletin,

Step 4: decision-making

- safe areas
- optimal fairways
- maritime spatial planning

Optimum fairway: several solutions

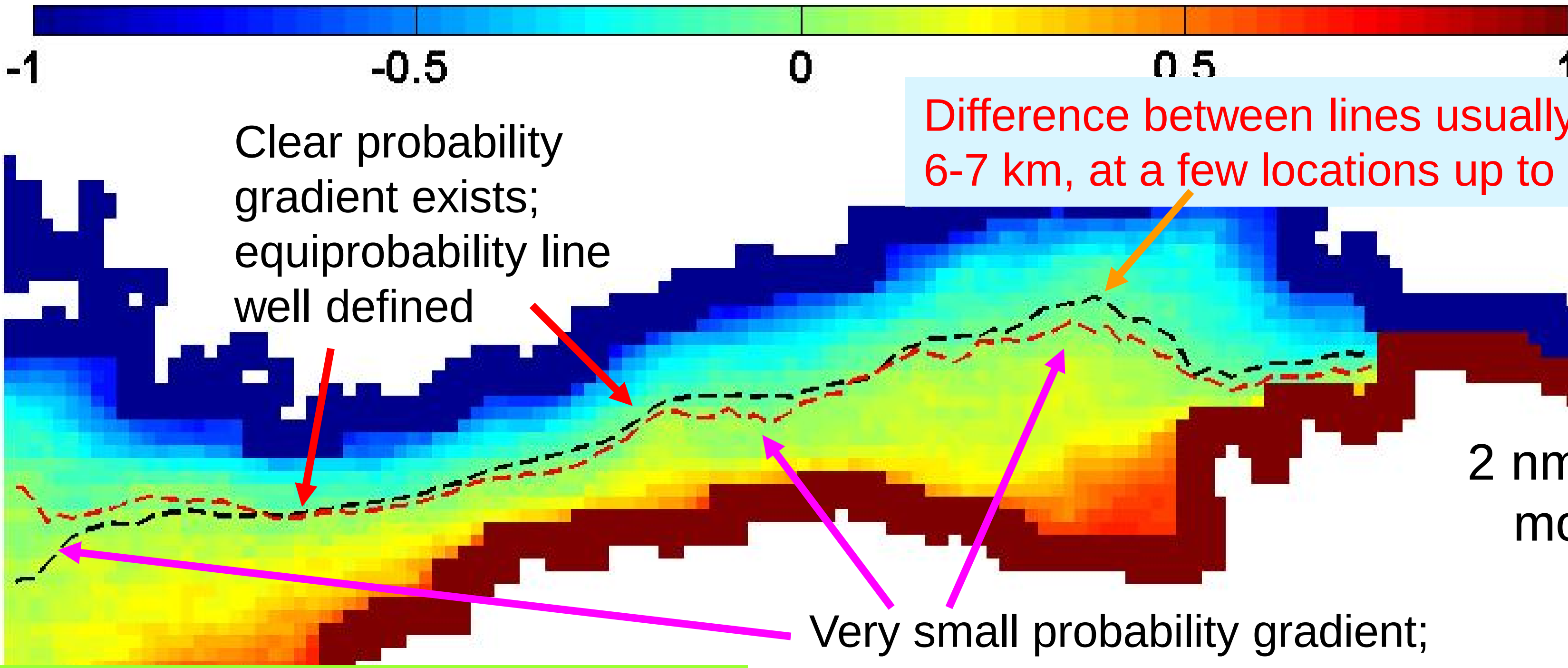


- Equiprobability line
  - Equidivision of costs
  - not perfect from the environmental viewpoint
- Minimum of the probability of coastal hit
  - Not easy to explain to the public etc.
- Maximum of particle age (time until disaster)
  - Clear measure: gain in time until the pollution reaches the coast
- Combined cost functions (Murawski and Nielsen 2013)

Sharing risk
and making use of uncertainty

Hit to the N coast

Hit to the S coast



Difference between lines usually below 6-7 km, at a few locations up to 10 km

Clear probability gradient exists; equiprobability line well defined

2 nm RCO model

Very small probability gradient;

probability of hitting either of the coasts small

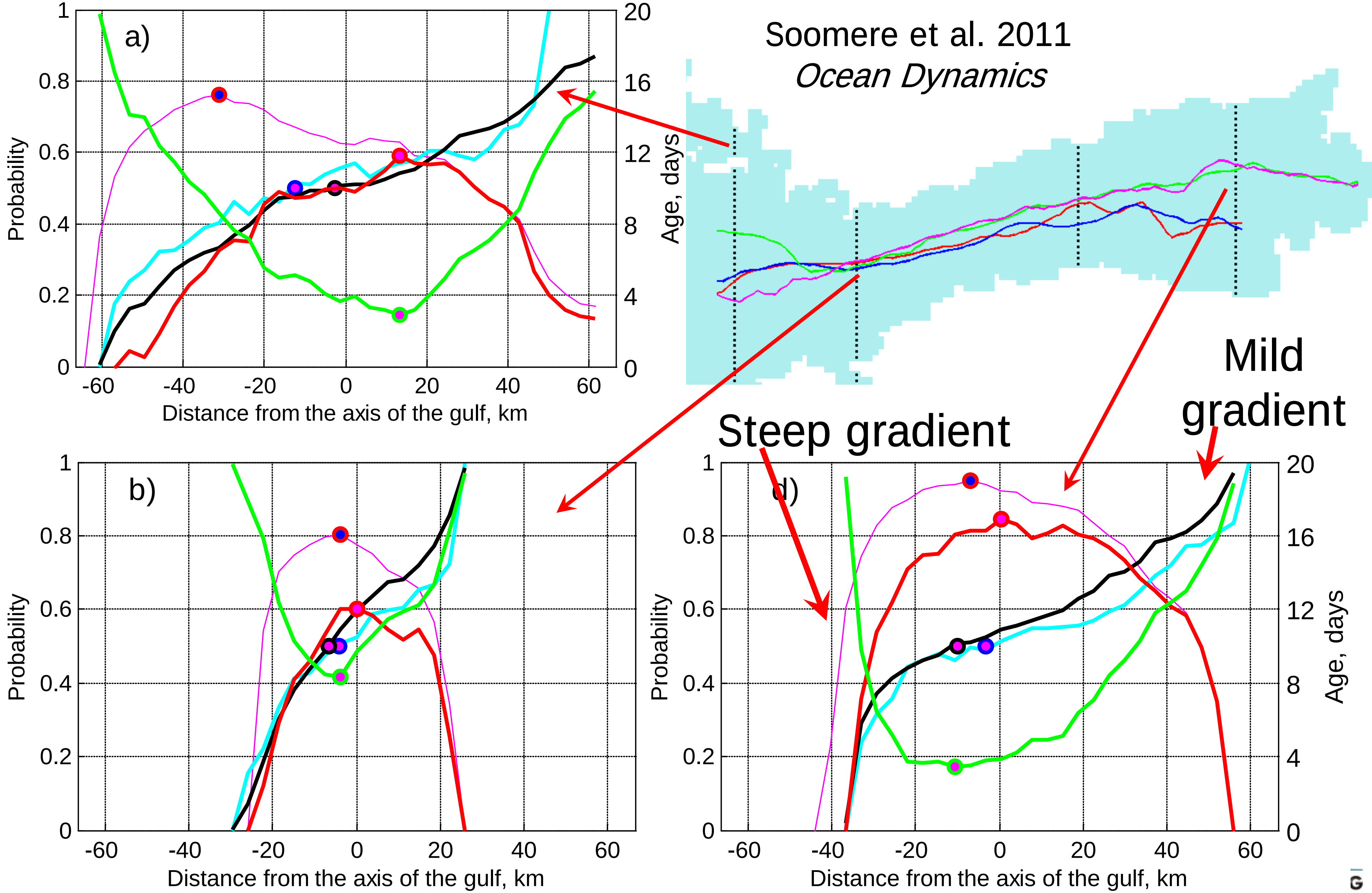
→area of reduced risk,

→equiprobability line not easy to identify

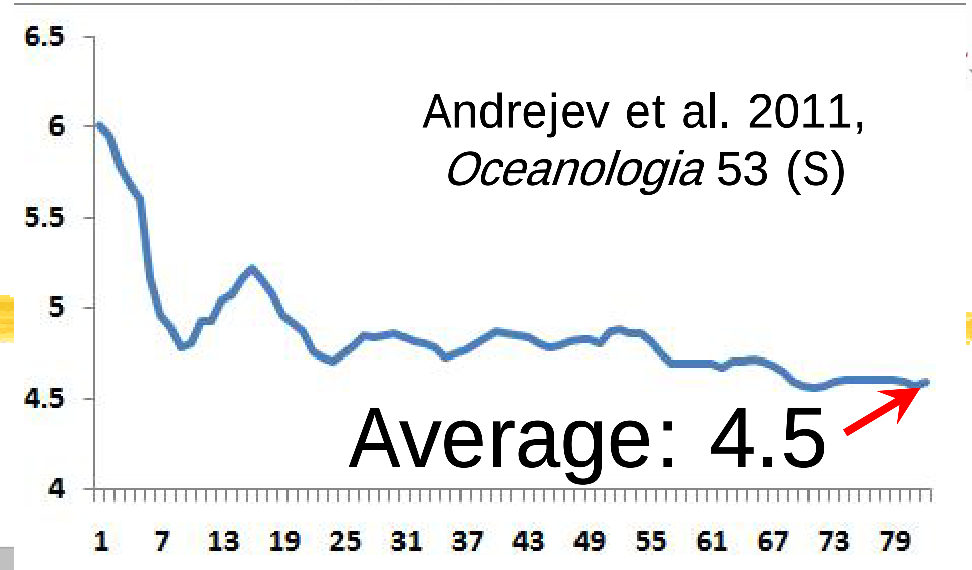
Dynamically different sea areas: a challenge to maritime spatial planning

Soomere et al. 2011, *Ocean Dynamics*

Different solutions – different locations



Average ‘age’ of the particles 1987--1993

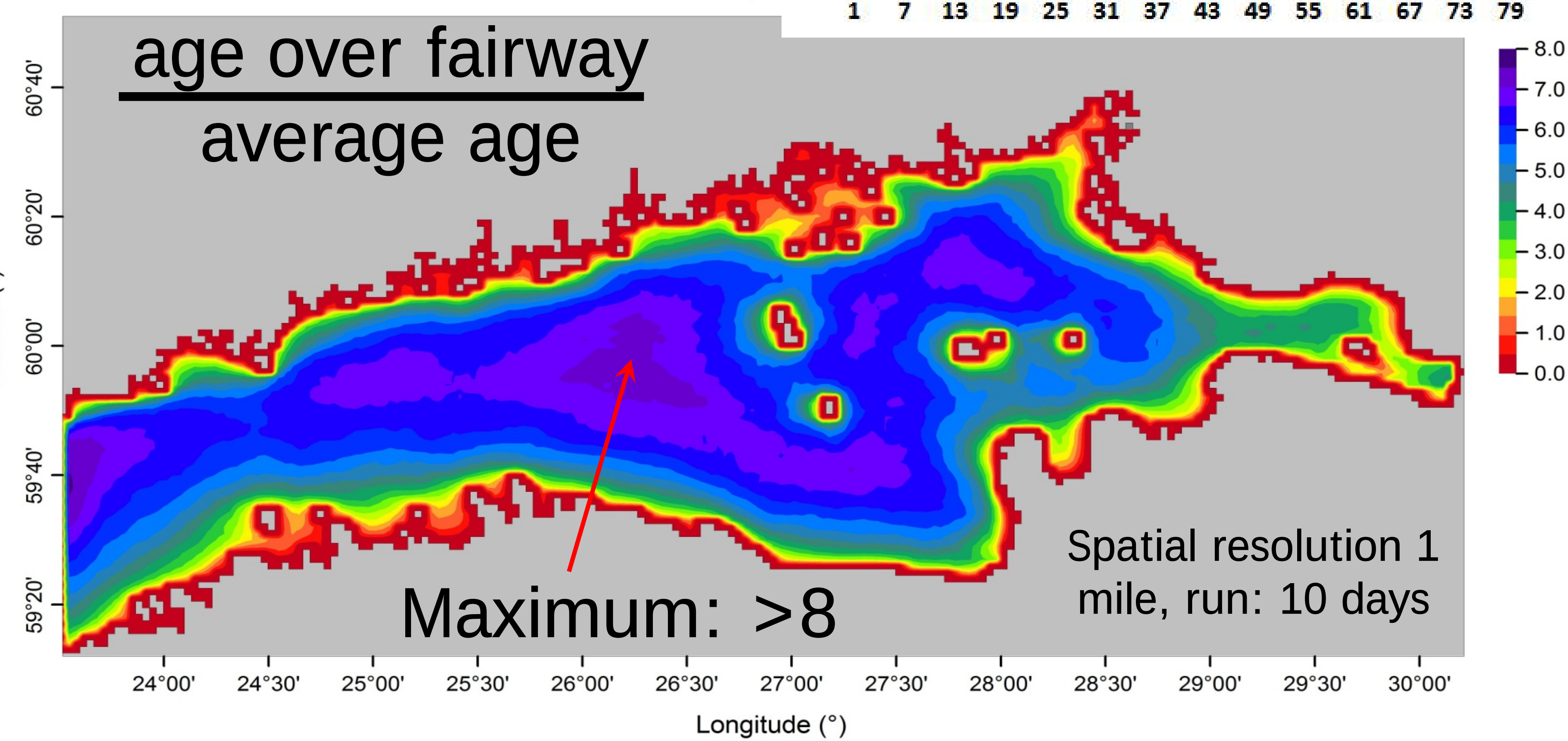


Andrejev et al. 2011, *Oceanologia* 53 (S)

Average: 4.5

The gain – ratio:

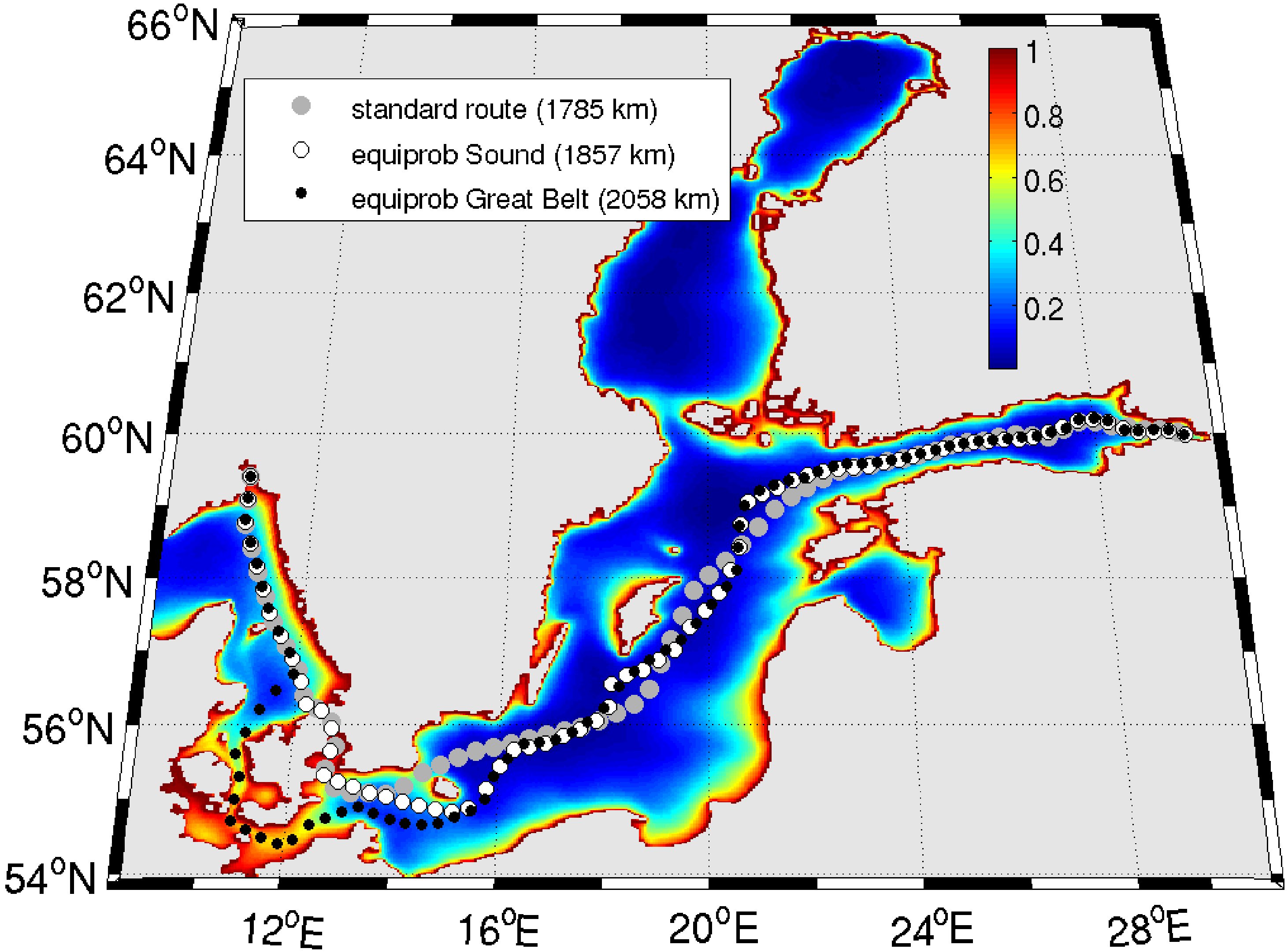
$$\frac{\text{age over fairway}}{\text{average age}}$$



Maximum: >8

Spatial resolution 1 mile, run: 10 days

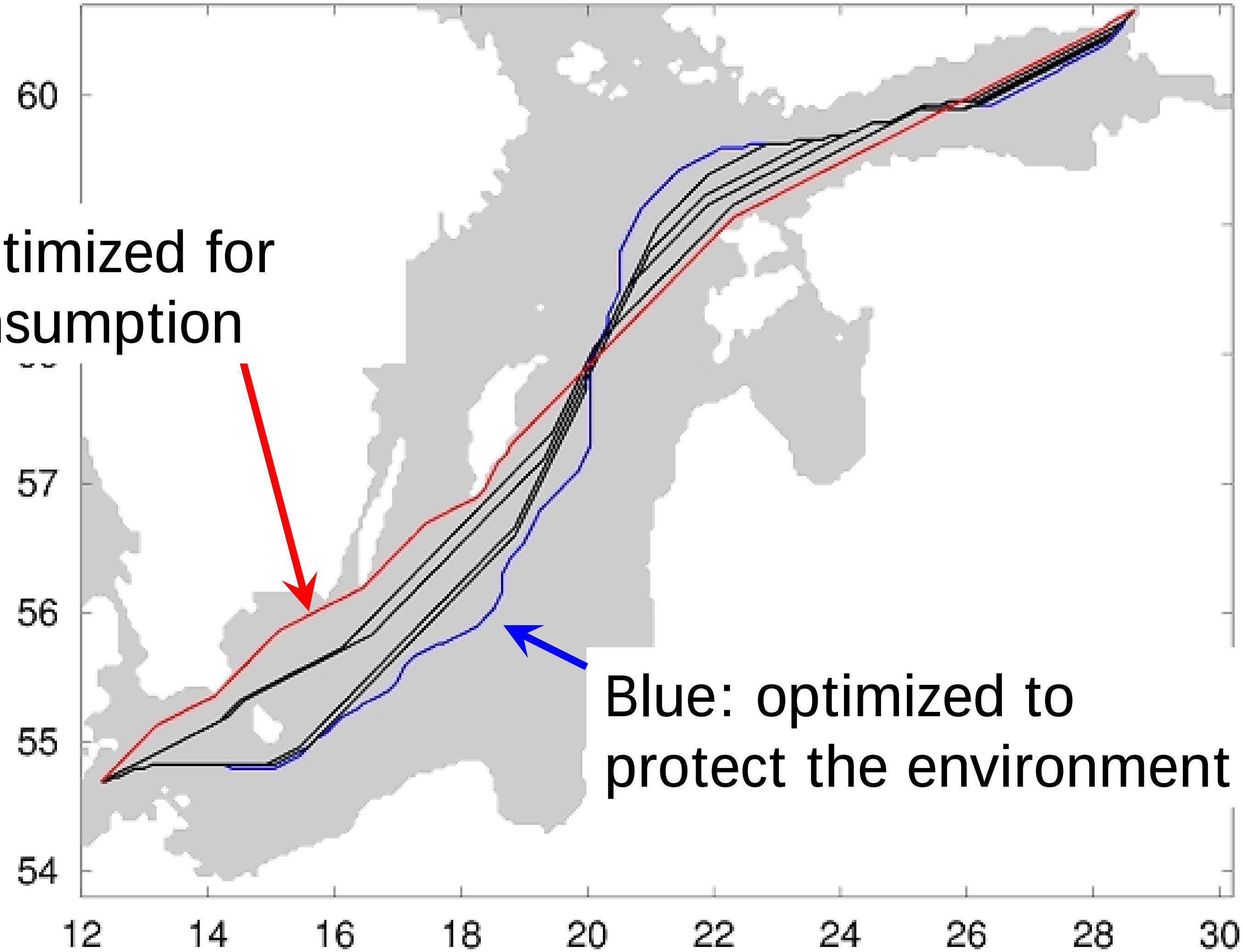
Worked-out exercises



Lehmann et al. 2013 Boreal Environment Research

A fair way for the Baltic Proper using Eulerian tracers

Höglund and Meier 2012

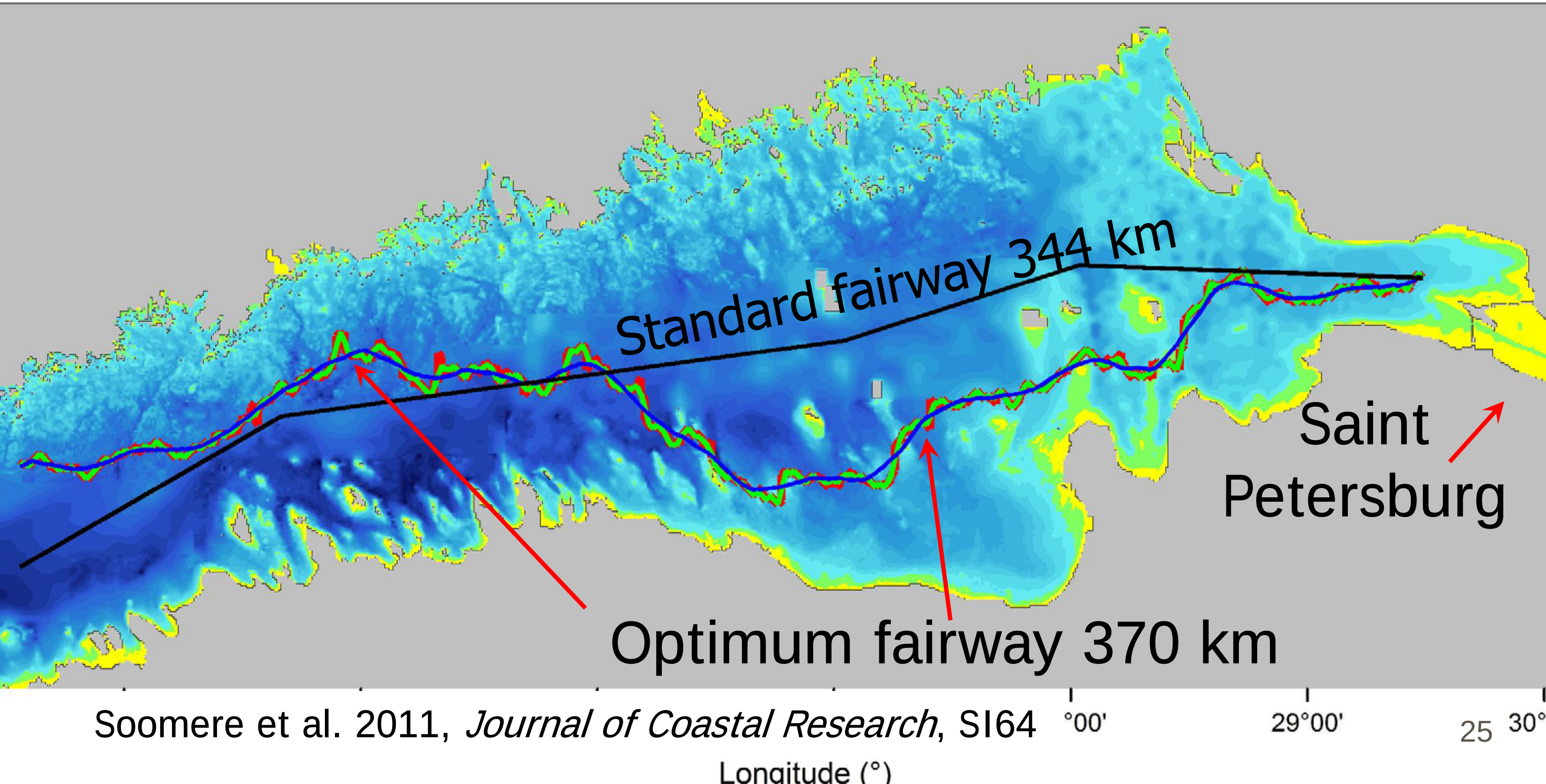


Red: optimized for fuel consumption

Blue: optimized to protect the environment

Winning strategy?

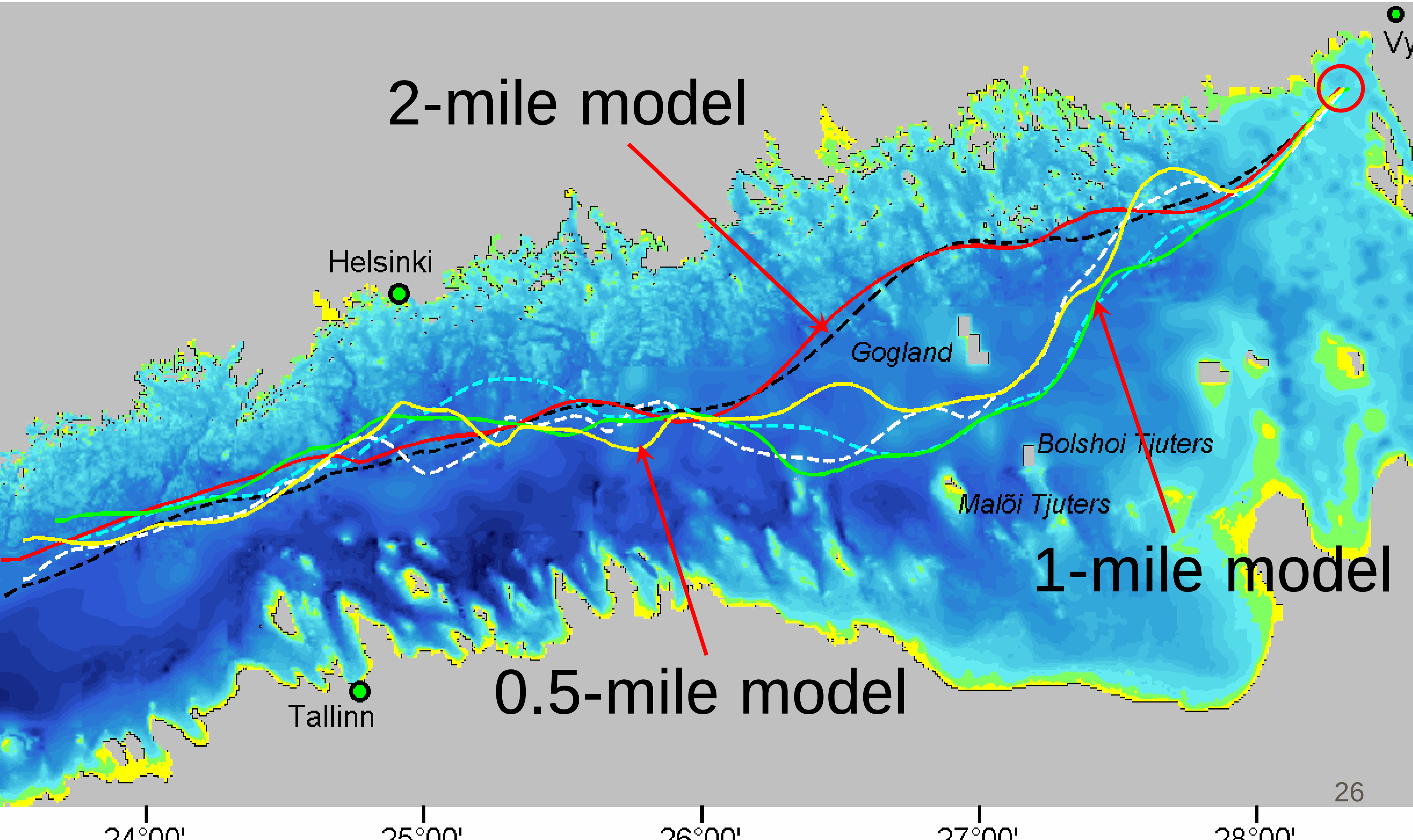
Loss in sailing distance: +5%-10%
Gain in terms of probability: 20%-40%
time to combat the pollution: +2-4 days



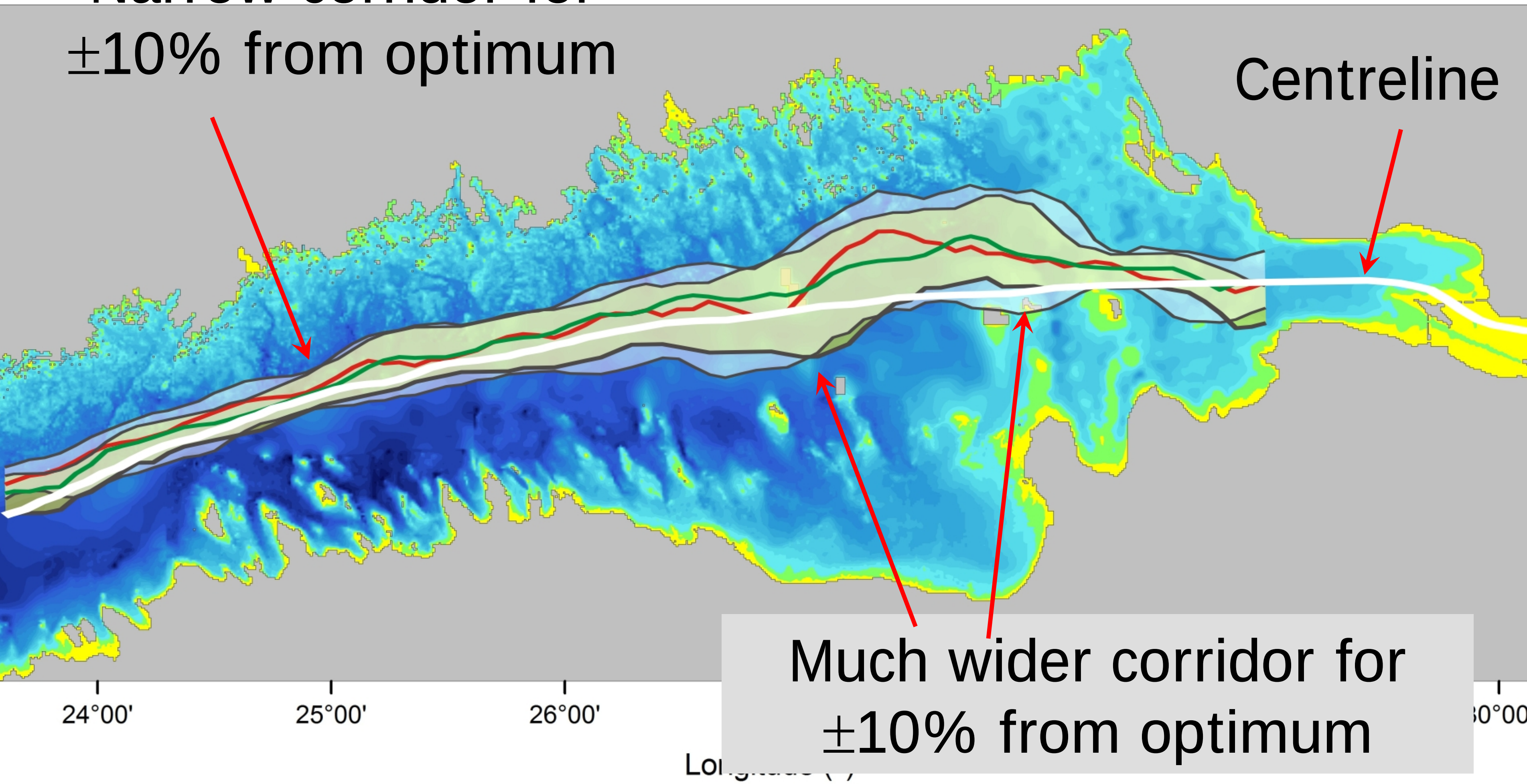
Soomere et al. 2011, *Journal of Coastal Research*, SI64

Inceasing resolution?

Andrejev et al. 2011, *Oceanologia*

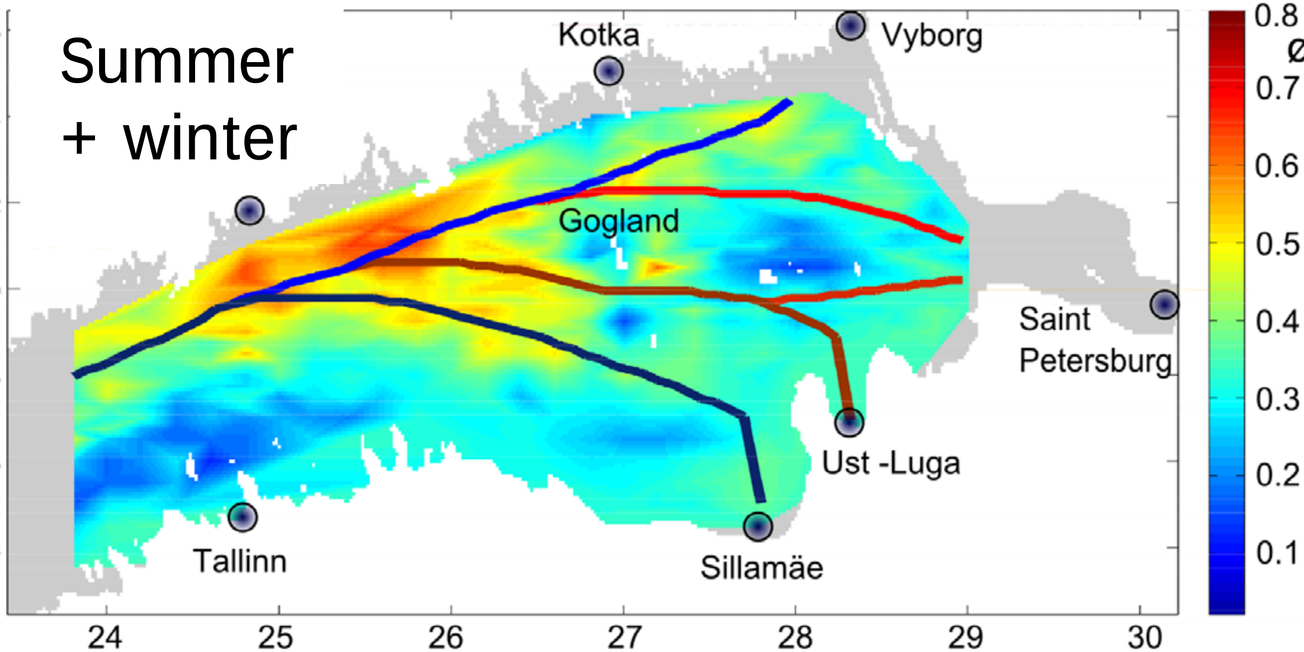


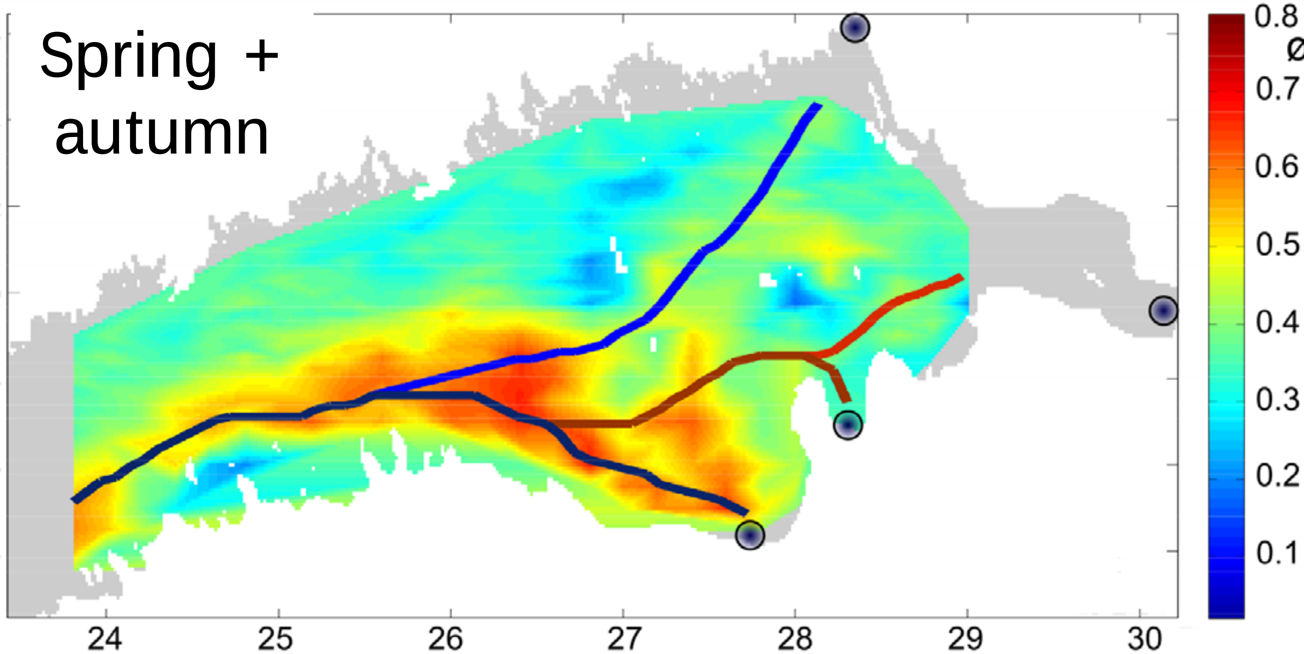
Spatial planning



Soomere et al. 2011 *Ocean Dynamics*

Oil spill model: seasonal design





Murawski and Nielsen 2013, in press

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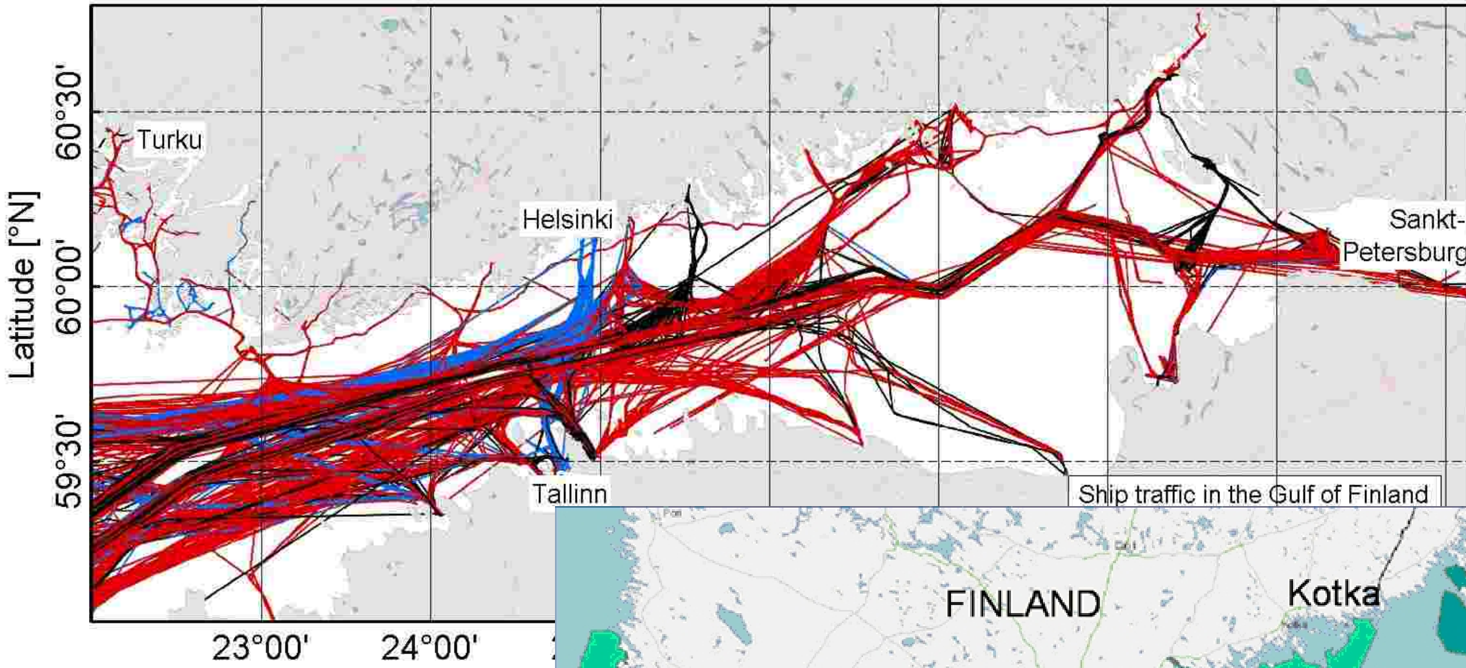
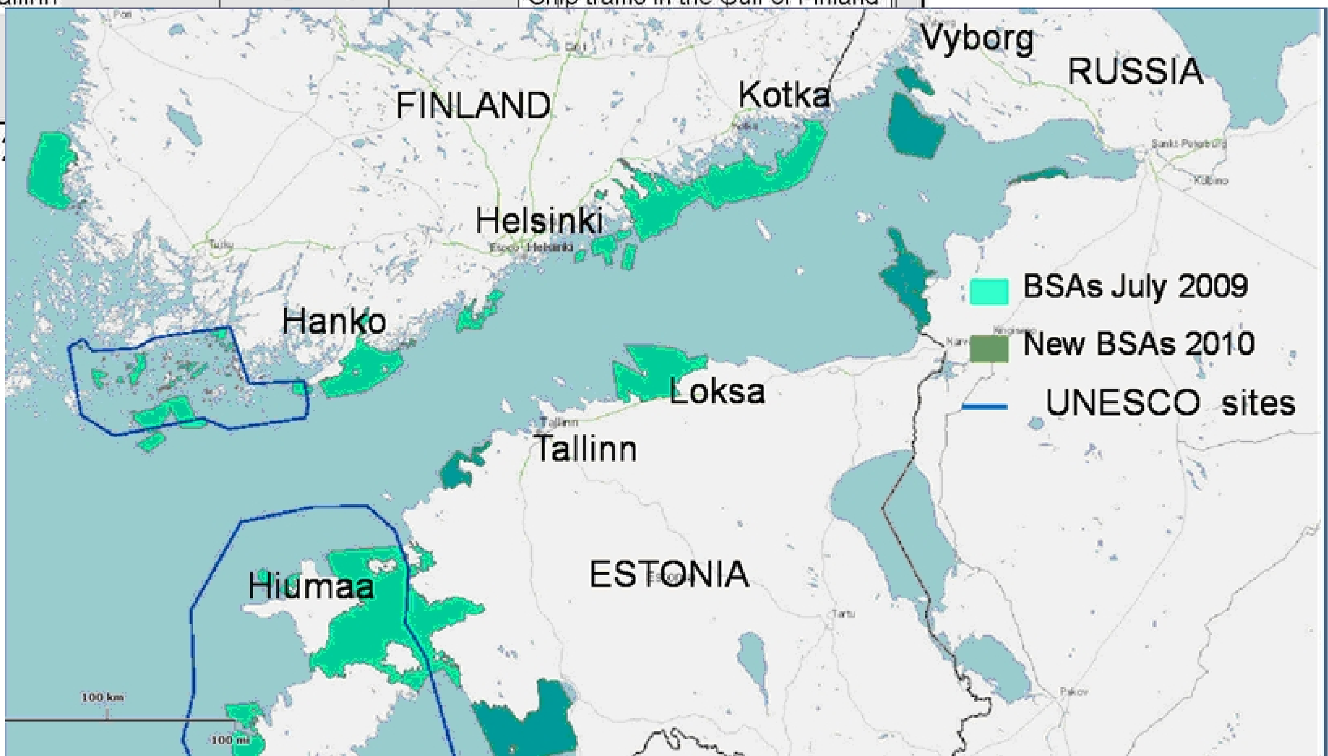
Fairway and marine protected areas (MPA)





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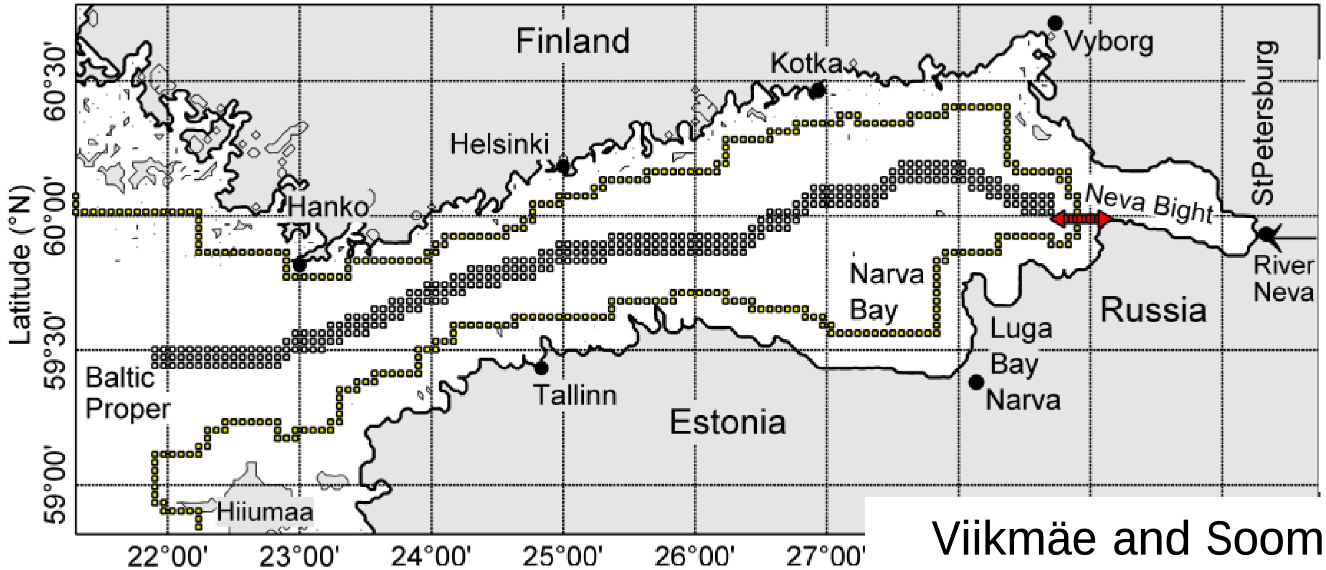
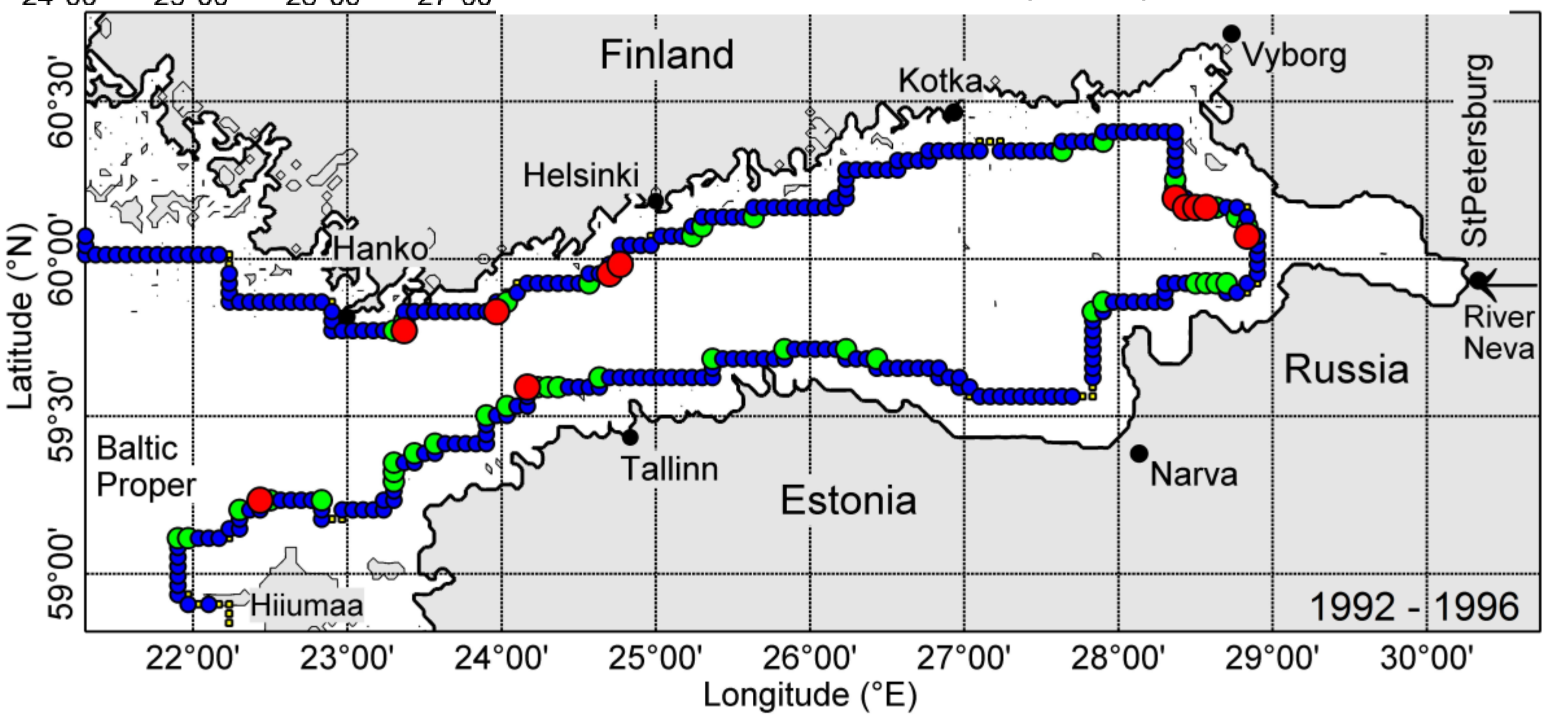
The “links” between MPA and fairway



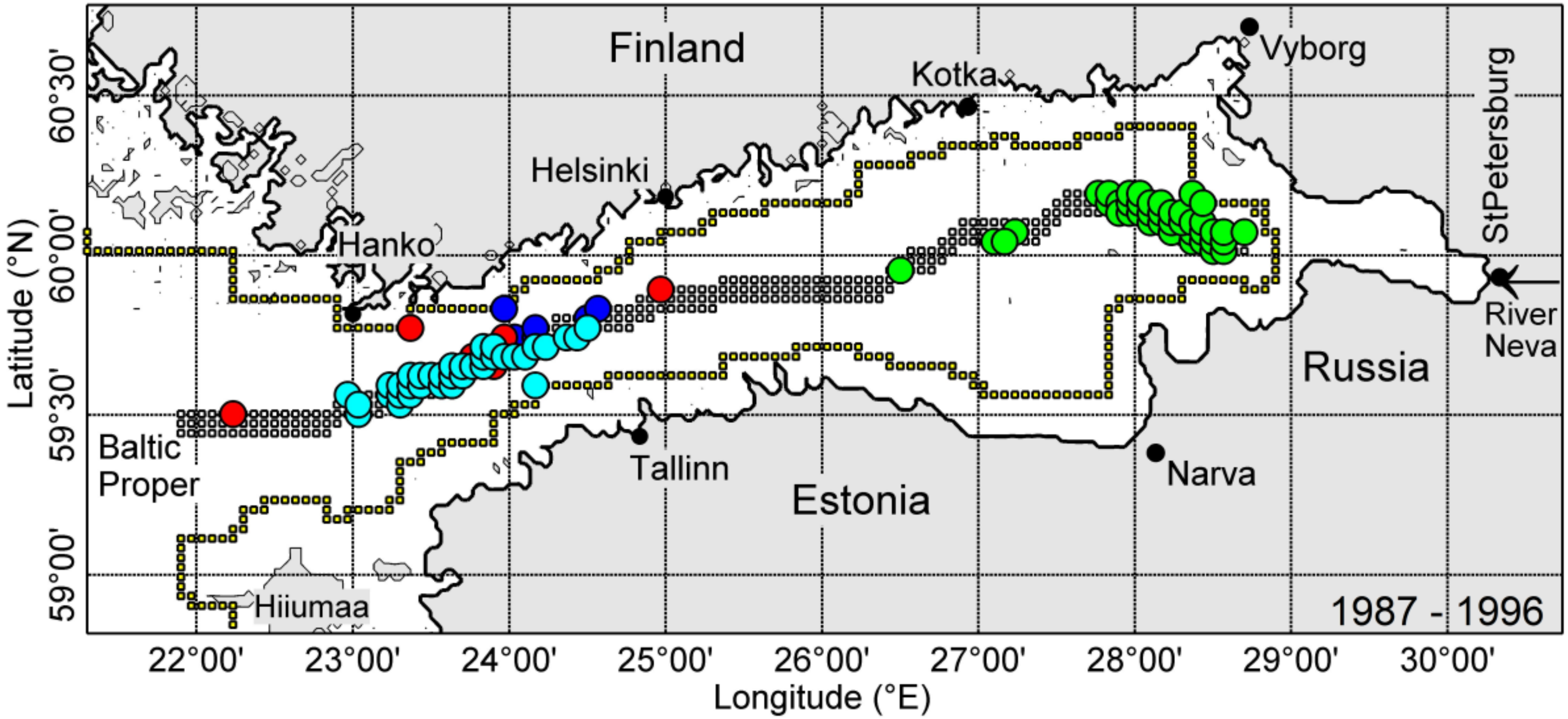
“Seeding” sea surface with pollution parcels

Viikmäe and Soomere, JMS, under review

Usual hitting points

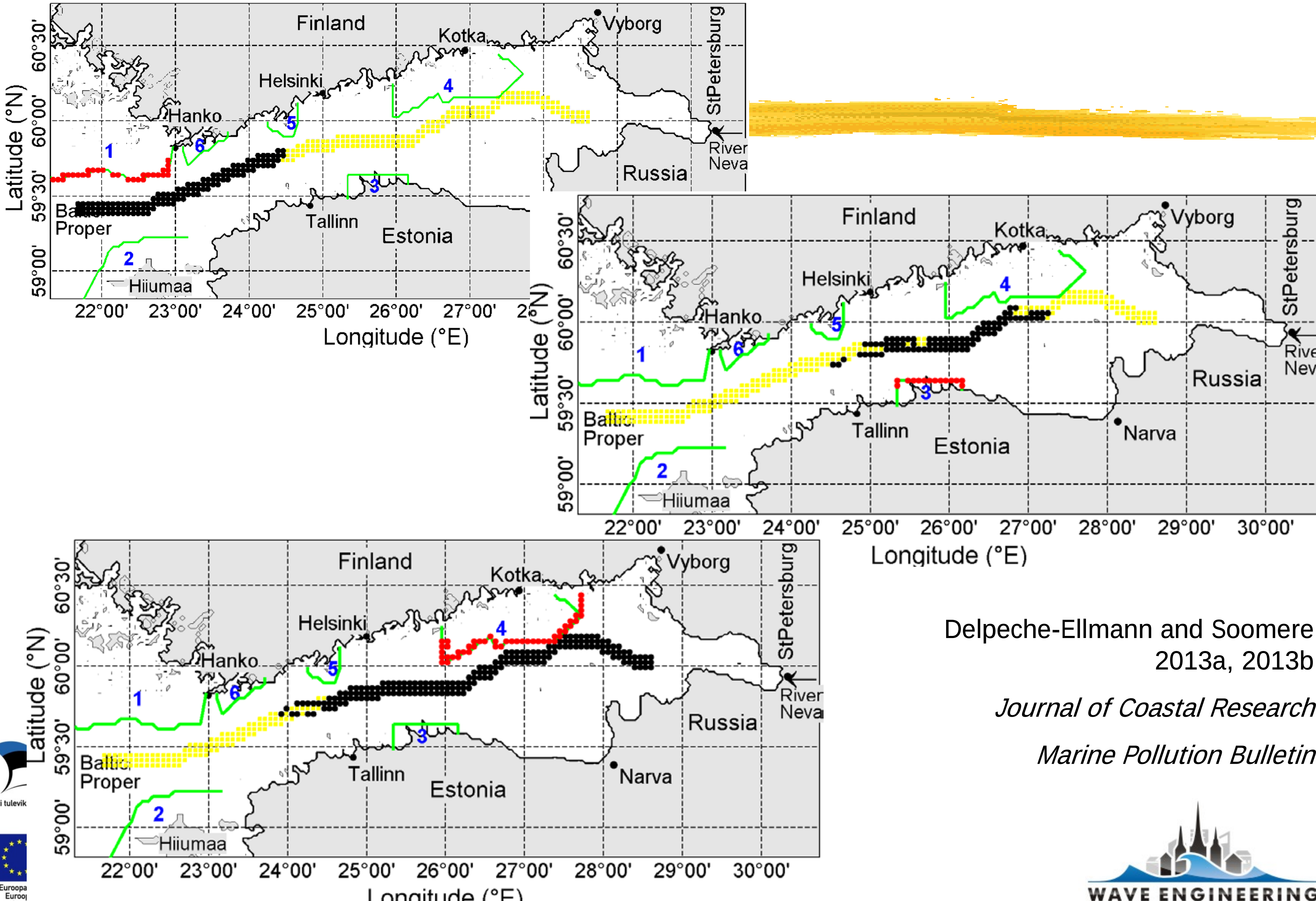


Interconnections



Viikmäe et al. 2013,
JMarSyst, under review

The “impact area”: unexpectedly large

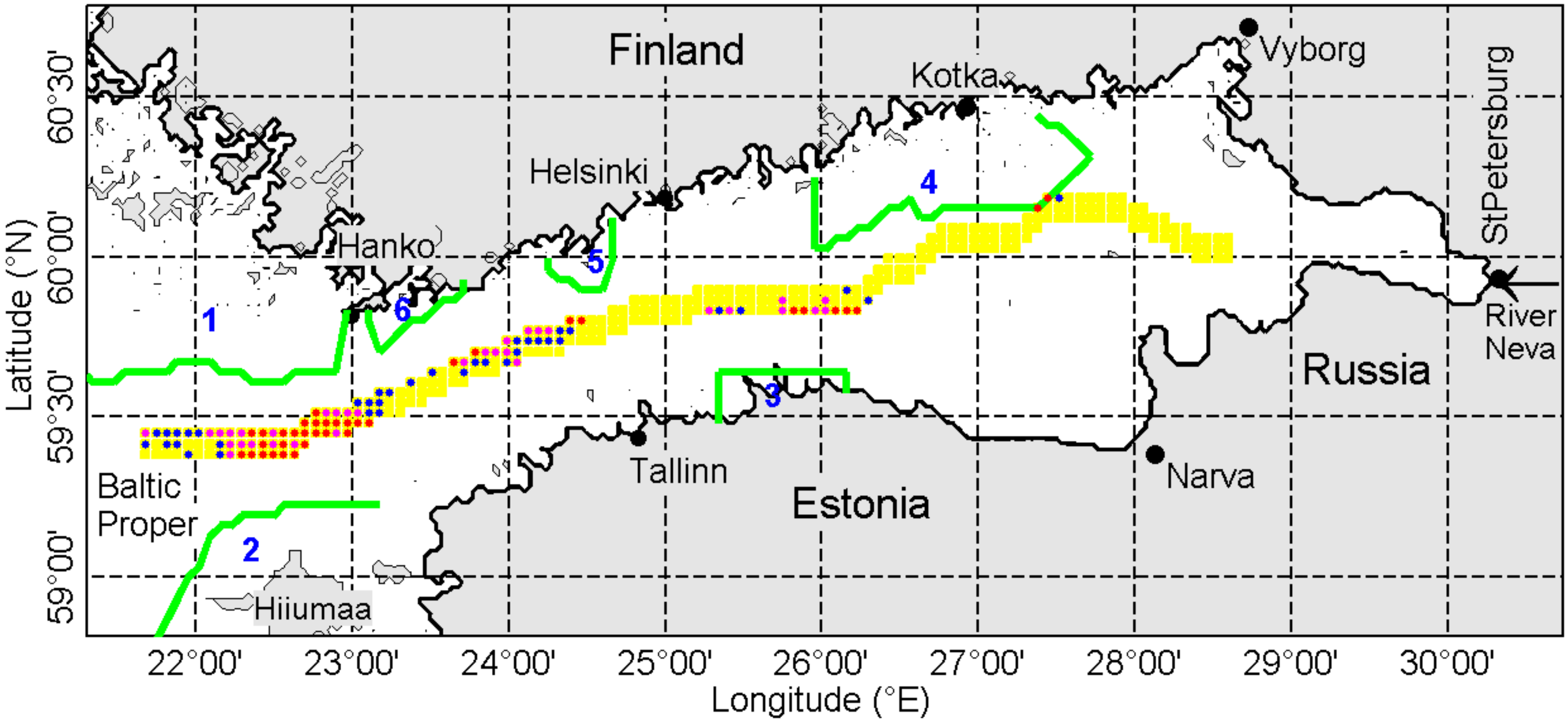


Delpeche-Ellmann and Soomere 2013a, 2013b

Journal of Coastal Research

Marine Pollution Bulletin

There is still system in’t:
Hits arrive from specific sections of the fairway



Locations along the fairway where >70 % of the hits were sourced from for each of the MPA for the period 1987–1991.

Red: >90 %, magenta: 90–80 %, blue: 80–70 %

Delpeche-Ellmann and Soomere 2013 *Marine Pollution Bulletin*

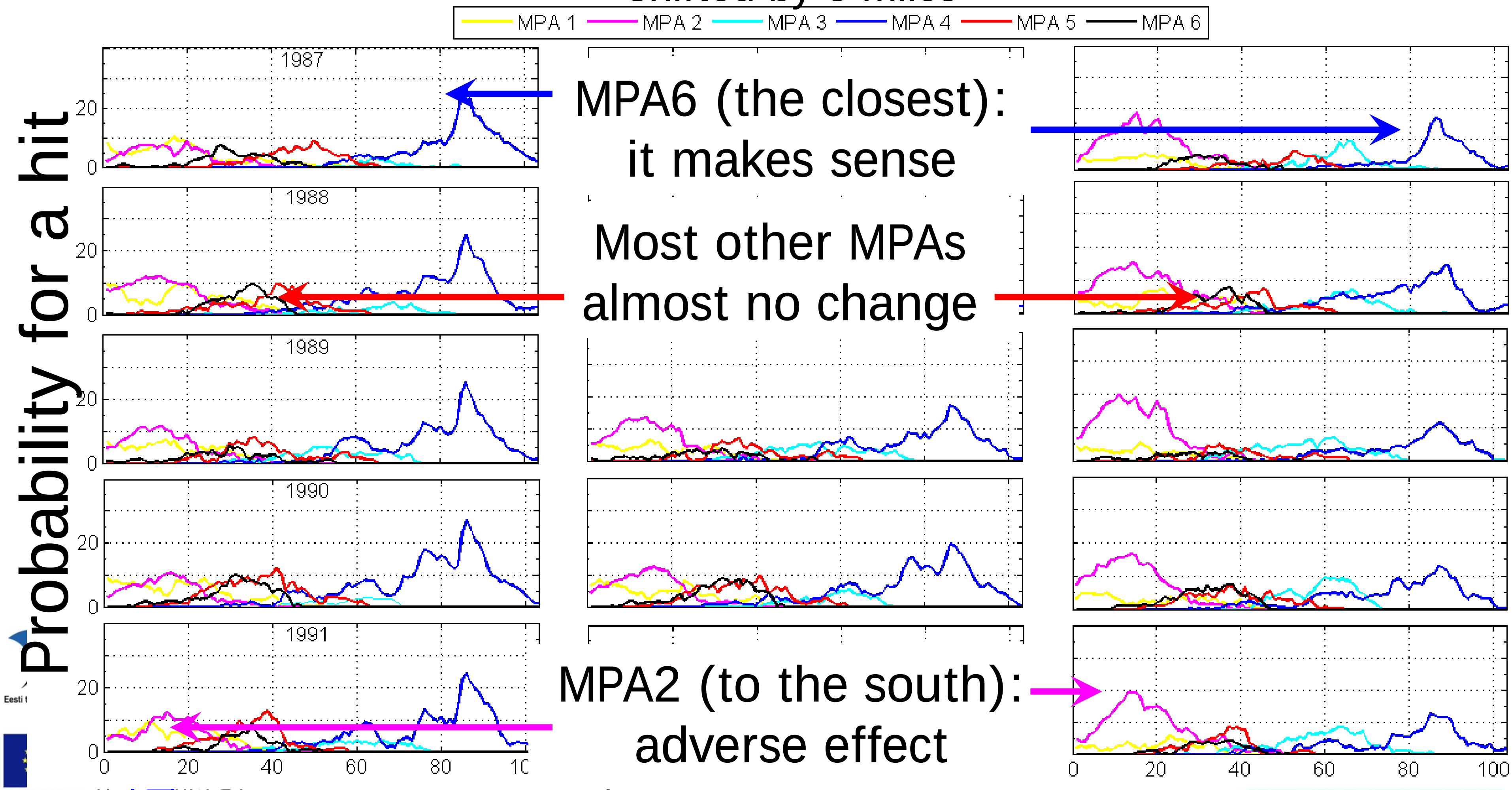
A shift of the fairway?

$$N(x) \approx -1.3x + 36.7$$

Original location

Shifted by 3 miles

Shifted by 6 miles



The essence

- A low-cost environmental management technology
  - based on the use of the internal dynamics of the sea
  - revealing concealed features & making use of them
- Solving the **inverse problem**: statistics over billions of solutions of the direct problem
- Quantification of offshore areas
  - Identification areas that are safer to use
  - and specifying where activities are better avoided
  - because dangerous substances (e.g. oil spills) are likely to be washed from these areas to vulnerable spots of the Baltic Sea
- The gain:
  - additional time to react to the pollution
  - lower probability for polluting vulnerable areas
  - Contribution towards smart maritime spatial planning

Selected publications

TS, B.Viikmäe, N.Delpeche, K.Myrberg 2010. Towards identification of areas of reduced risk in the Gulf of Finland, the Baltic Sea; *Proceedings of the Estonian Academy of Sciences* **59**, 2, 156–165.

B.Viikmäe, TS, M.Viidebaum, A.Berezovski 2010. Temporal scales for transport patterns in the Gulf of Finland, *Estonian Journal of Engineering* 1**6** (3), 211-227.

TS, N.Delpeche, B.Viikmäe, E.Quak, H.E.M.Meier, K.Döös 2011. Patterns of current-induced transport in the surface layer of the Gulf of Finland. *Boreal Environment Research* **16** (Suppl A), 49-63.

O.Andrejev, TS, A.Sokolov, K.Myrberg 2011. The role of spatial resolution of a 3D hydrodynamic model for marine transport risk assessment, *Oceanologia* **53**, 335-371.

TS, O.Andrejev, K.Myrberg, A.Sokolov 2011. The use of Lagrangian trajectories for the identification of the environmentally safe fairways, *Marine Pollution Bulletin* **62** (7), 1410–1420.

TS, M.Berezovski, E.Quak, B.Viikmäe 2011. Modeling environmentally friendly fairways using Lagrangian trajectories: a case study for the Gulf of Finland, the Baltic Sea, *Ocean Dynamics* **61** (10), 1669–1680.

X.Lu, TS, E.Stanev, J.Murawski 2012. Identification of the environmentally safe fairway in the South-Western Baltic Sea and Kattegat, *Ocean Dynamics*, **62** (6), 815-829.

A.Höglund, H.E.M.Meier. 2012. Environmentally safe areas and routes in the Baltic Proper using Eulerian tracers. *Marine Pollution Bulletin* **64**, 1375–1385.

A.Lehmann, H.-H.Hinrichsen, K.Getzlaff. 2013. Identifying potentially high risk areas for environmental pollution in the Baltic Sea. *Boreal Environment Research*

N.C.Delpeche-Ellmann, TS. 2013. Investigating the Marine Protected Areas most at risk of current-driven pollution in the Gulf of Finland, the Baltic Sea, using a Lagrangian transport model, *Marine Pollution Bulletin* **67**(1-2): 121–129

B.Viikmäe, T. Torsvik, T. Soomere. 2013. Impact of horizontal eddy-diffusivity on Lagrangian statistics for coastal pollution from a major marine fairway. *Ocean Dynamics*


Thank you!