→ BALTIC FROM SPACE WORKSHOP

29–31 March 2017 | Helsinki, Finland

Baltic Ocean Dynamics

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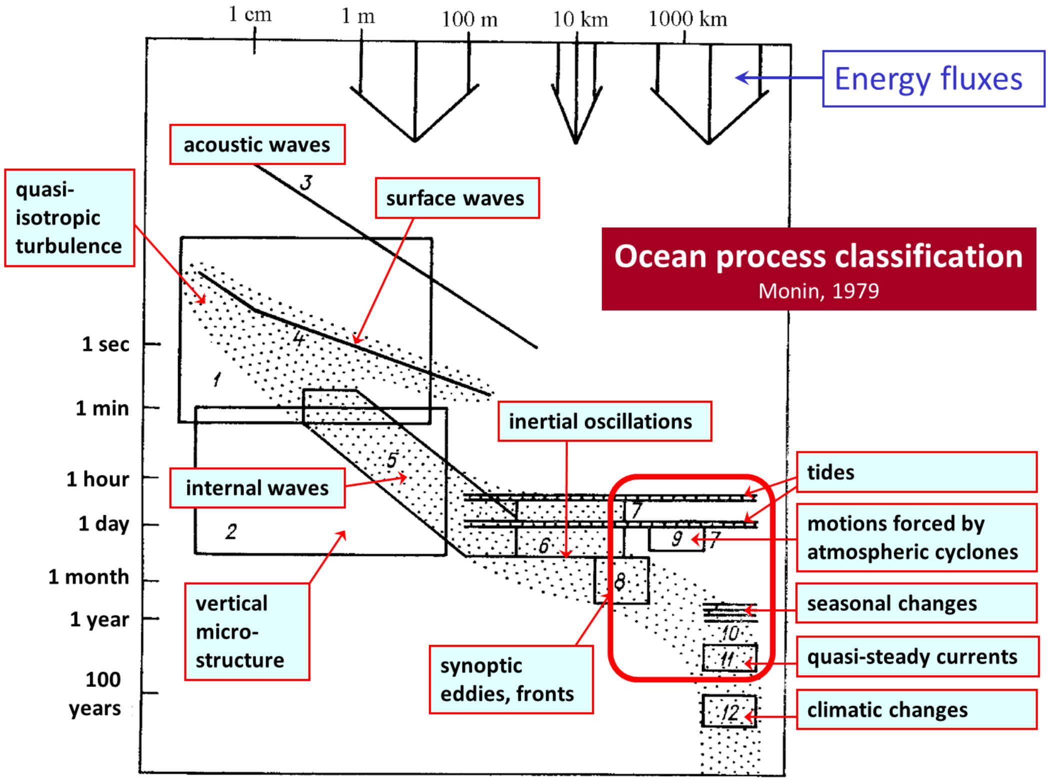


Important scales

	Ocean	Baltic
Depth H	5 km	100 m
Stratification, depth-mean Väisälä frequency N	0.003 s^{-1}	0,015 s^{-1}
Rossby deformation radius $R_d = NH/\pi f$	50 km	5 km

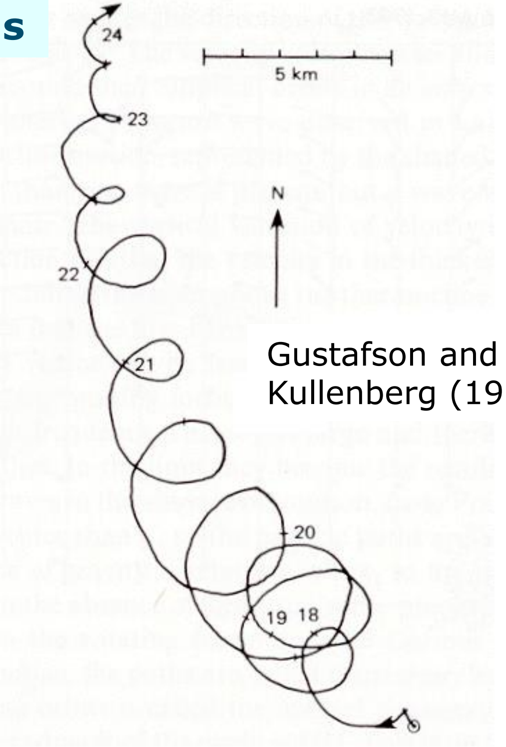
Example how basic knowledge is useful: inertial oscillations

- Theory developed in 1800s
  rotations of water particles with frequency of Coriolis parameter; in our latitude period about 14 h, circle 2-3 km

- First observations in the sea made in the Baltic by Gustafson and Kullenberg (1936)

- „Consumed" formerly mainly by PhysOcean, as generators of mixing
  (e.g. Krauss, 1981, erosion of thermocline)

- Now important for „right" advection-mixing balances in ecosystem, sediment dynamics, ice dynamics etc models



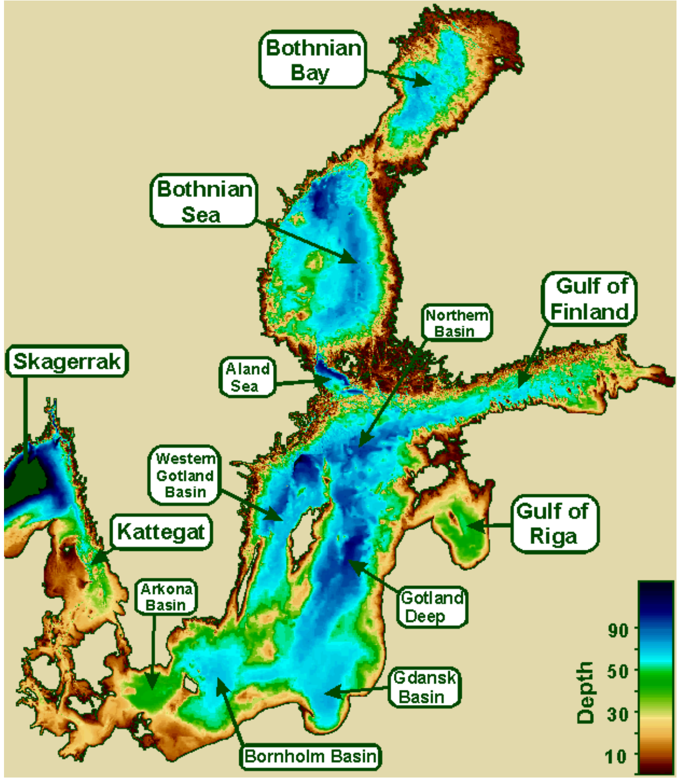
Gustafson and Kullenberg (1936)

We learned from the scales:

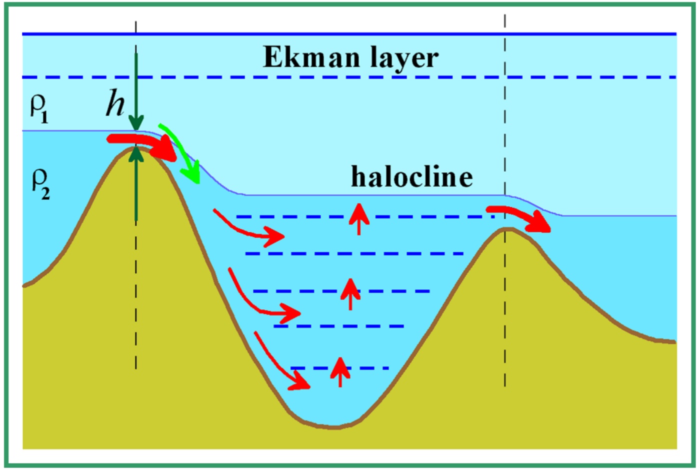
- Baltic R_d about 10 times smaller than in the ocean
- several ocean-type features present in the Baltic

Next:

Flows in deep channels and straits



Water exchange and mixing in connected rotational basins



Volume transport over rotating sill
(Whitehead et al., 1974)

$$Q = \frac{g'h^2}{2f}$$

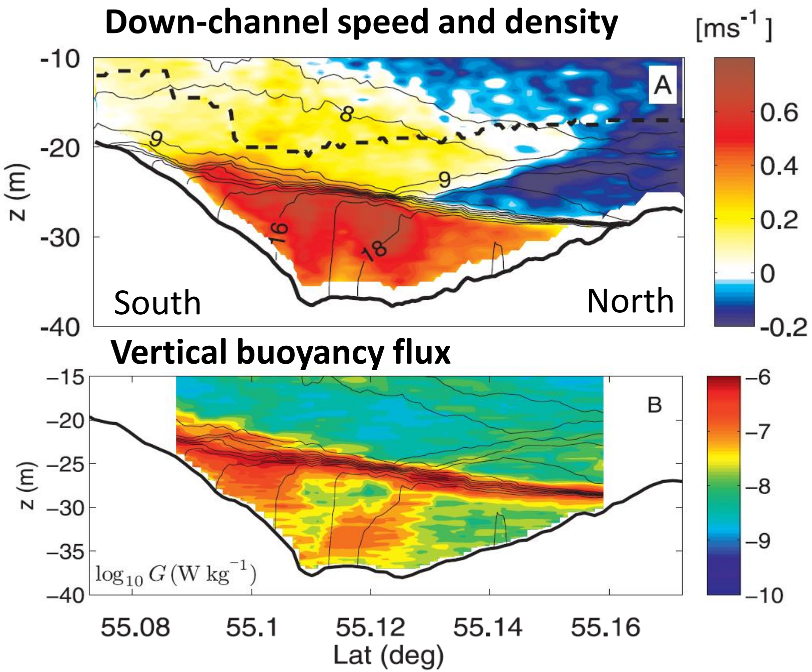
where $g' = g\frac{\rho_2 - \rho_1}{\rho_2}$

rotational control, if

$$W > R_d = \frac{c}{f} = \frac{\sqrt{g'h}}{f}$$

- wind transport in Ekman layer $\Rightarrow$ compensation flow below
- vertical transport due to continuity $w_i(z,t) = \frac{1}{A_i}\int_z^{H_i}(q^-_{i+1/2} - q^+_{i-1/2})dz$ has to be balanced by halocline erosion
- mixing in the halocline is mainly due to internal waves, $K_i^V = \frac{\alpha}{N_i}$

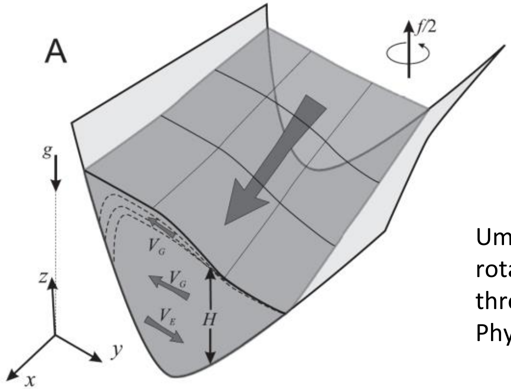
Flow dynamics in the channels: north from Kriegers Flak



Rotational sub-critical gravity current

Frictional effects (Ekman number ≈ 1):

- ❑ transverse Ekman circulation and interfacial jet
- ❑ downward bending of isopycnals on the right-hand slope
  - ➢ asymmetric density pattern
- ❑ strong entrainment on the right-hand slope

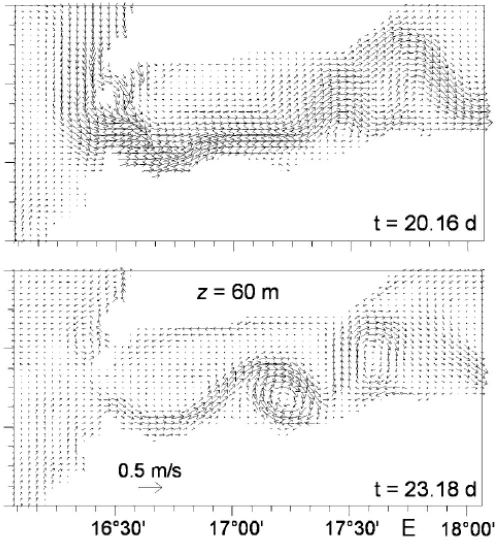


Umlauf, L., & Arneborg, L. (2009). Dynamics of rotating shallow gravity currents passing through a channel. Part I & II. Journal of Physical Oceanography

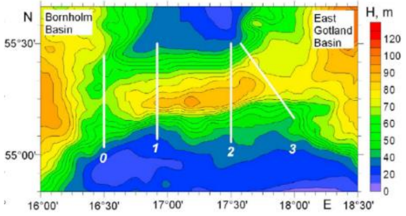
Flow dynamics in the channels: Stolpe / Słupsk

Sub-critical eddy-producing gravity current in a wide channel, including friction effects

Current maps at 60 m

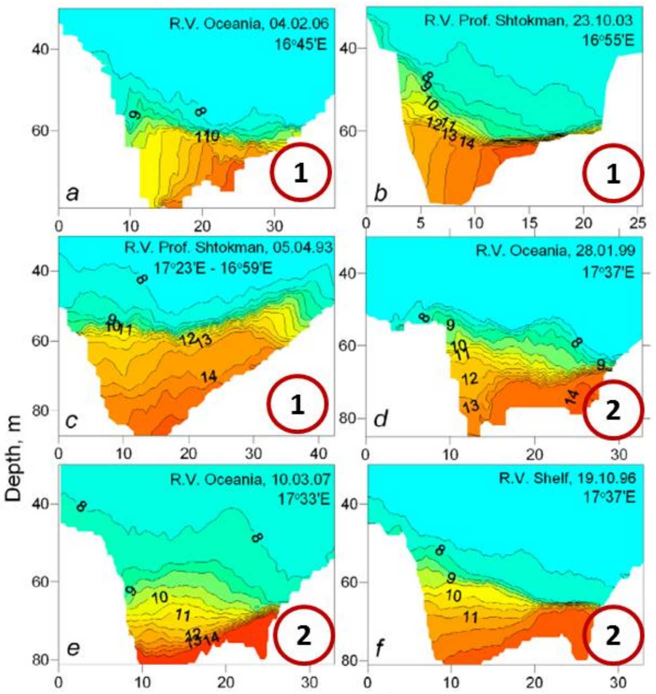


Topography and transects



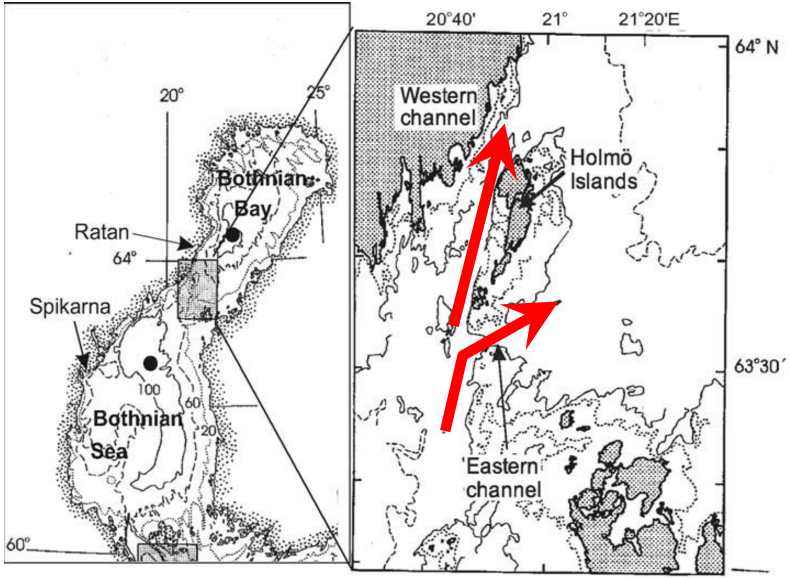
Variety of cross-channel density patterns (pinching and downward bending of isopycnals) is caused by **meandering of the gravity current and mesoscale eddies** – mostly above-halocline cyclones and intrahalocline anticyclones

ZHURBAS ET AL.: UNSTEADY OVERFLOW IN THE SŁUPSK FURROW



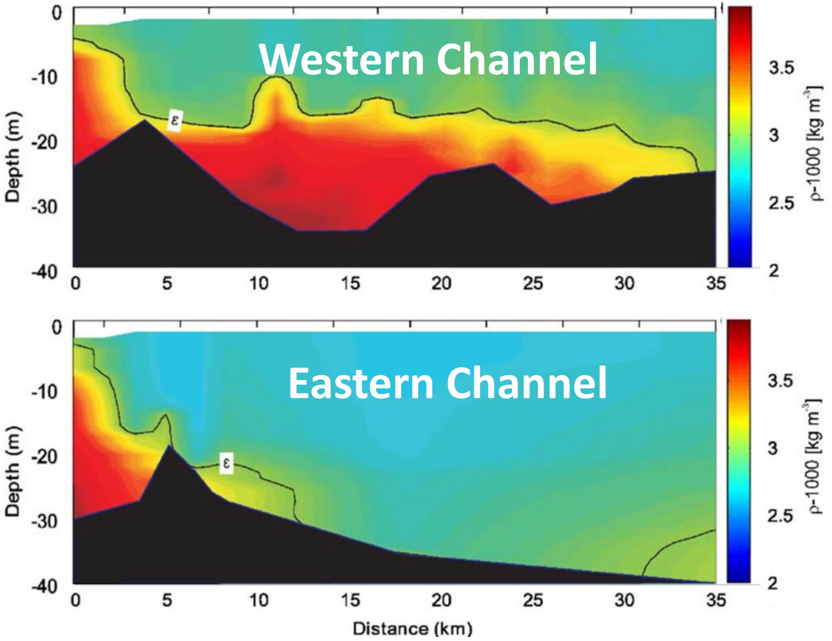
Flow dynamics in the channels: Northern Kvark Strait (1)

Two channels between the Bothnian Sea and the Bothnian Bay



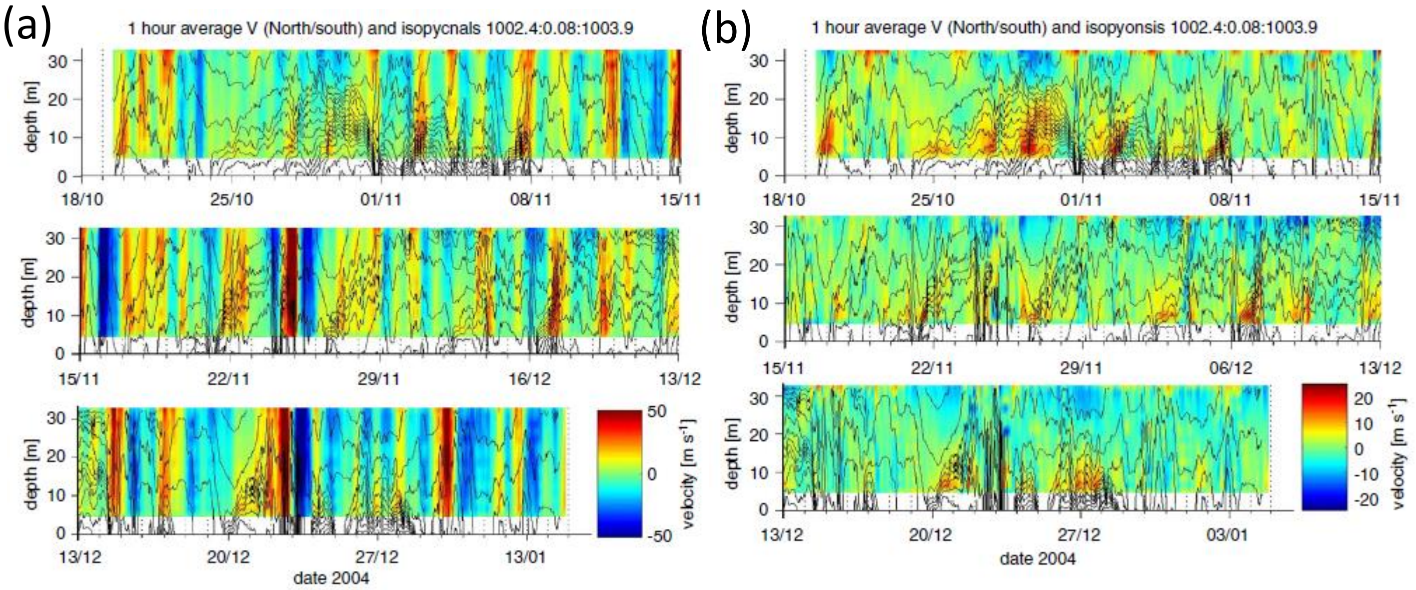
Green, M.J. A., Liljebladh, B., & Omstedt, A. (2006). CSR

Transects of density from S to N



Flow dynamics in the channels: Northern Kvark Strait (2)

Along-channel currents (positive north) (a) and with first EOF mode subtracted (b)



Intermittency of flow regimes

(1) barotropically blocked regime

45% of time

(2) two-layer regime
(3) continuously stratified regime

55% of time, mainly hydraulically controled (Fr ≈ 1)

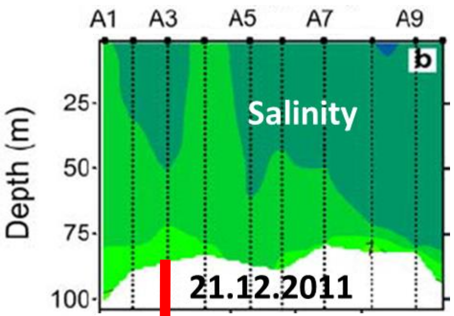
Green, M.J. A., Liljebladh, B., & Omstedt, A. (2006). CSR

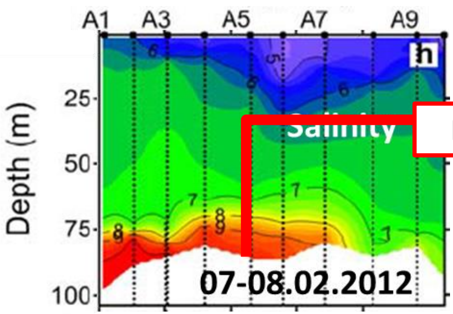
Flow dynamics in the western Gulf of Finland

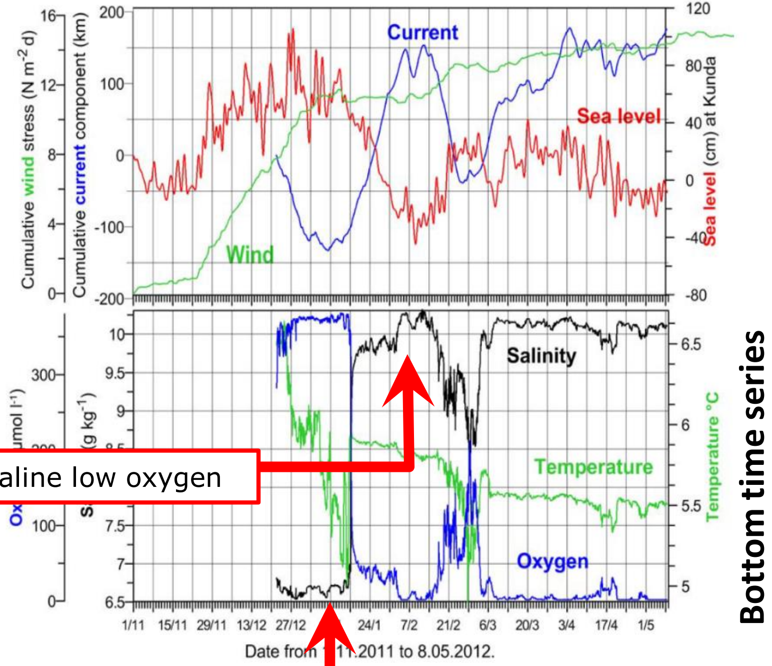
Persistent strong SW winds create during the winter
- anti-estuarine transport
- stratification collapse
- oxygenation of bottom layers

By ceasing the SW winds, stratification and hypoxia are rapidly restored

Liblik et al (2013)







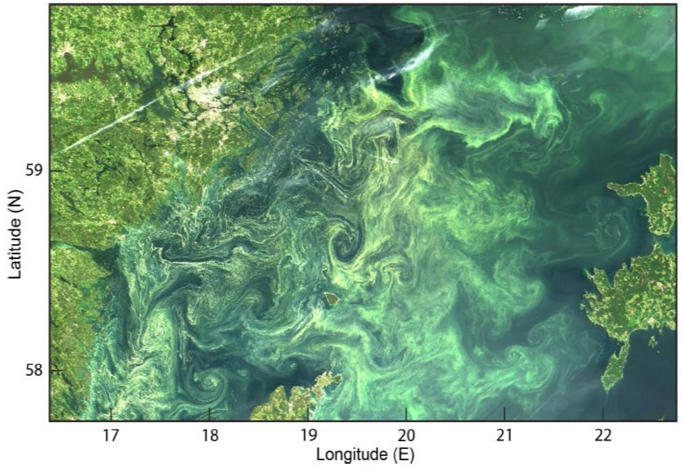
We learned from the flows in deep channels and straits:

- high variability of flow patterns and dynamical regimes
- flow control by rotational hydraulics, but also by eddies and fronts

Next:
Eddies, fronts, upwelling etc

Examples of eddy manifestations in remote sensing

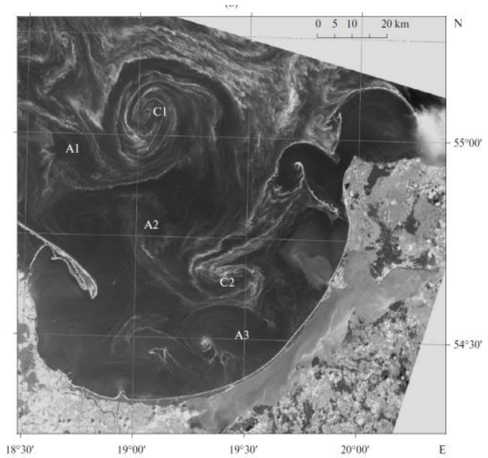
11 July 2005



MODIS Terra quasi true color image at 250m resolution using bands 1 (red), 4 (green), and 3 (blue).

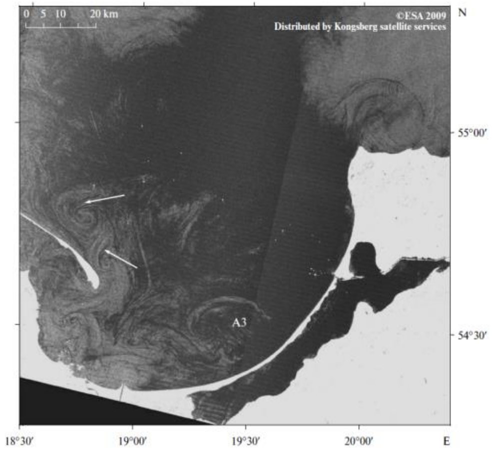
Kahru & Elmgren (2014)

17 July 2009



optical image from radiometer ETM+ Landsat-7

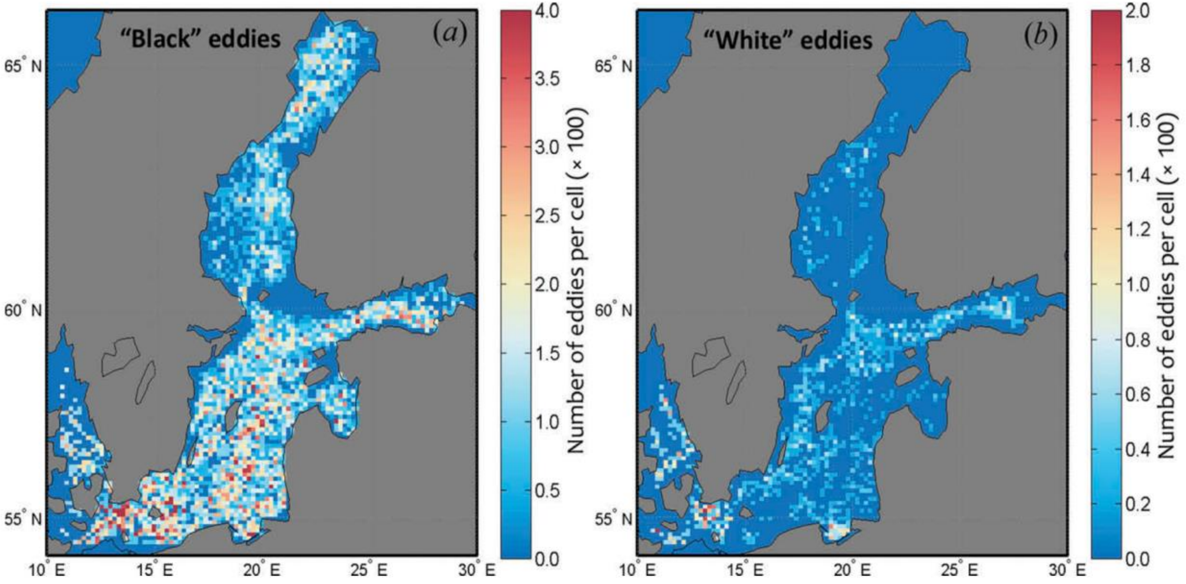
Ginzburg et al (2015)



RI from ASAR Envisat

Spiral eddies from SAR images

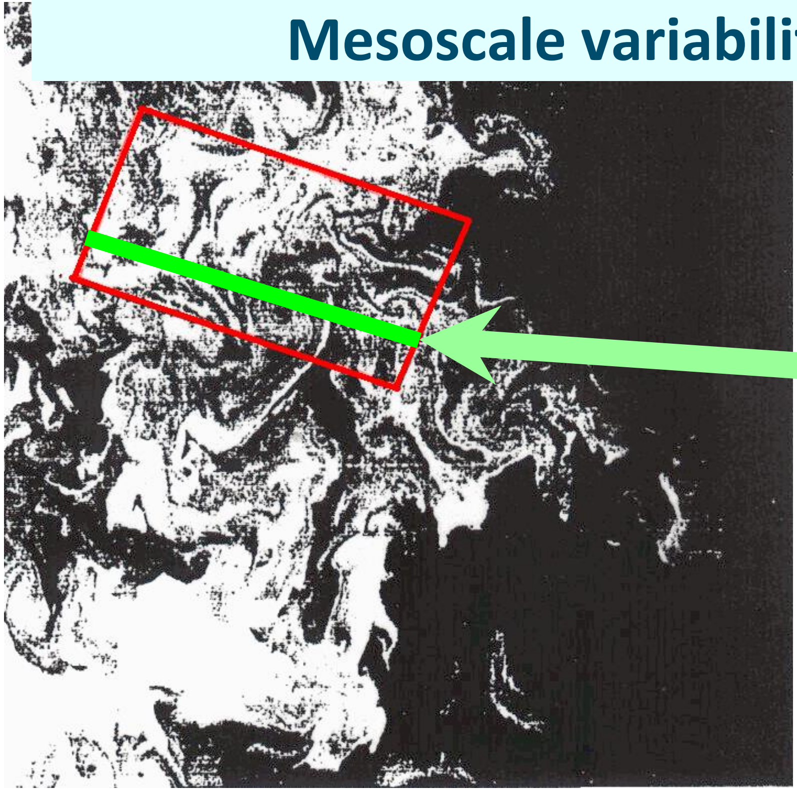
Normalized number of eddies per 6 x 6 mile grid cell 2009 - 2011



- Spiral eddies 5-8 km mainly cyclonic
- Thousands of eddy detections within a year
- „Black eddies" - visualized due to surfactant films
- „White eddies" – visualized due to wave/current interactions

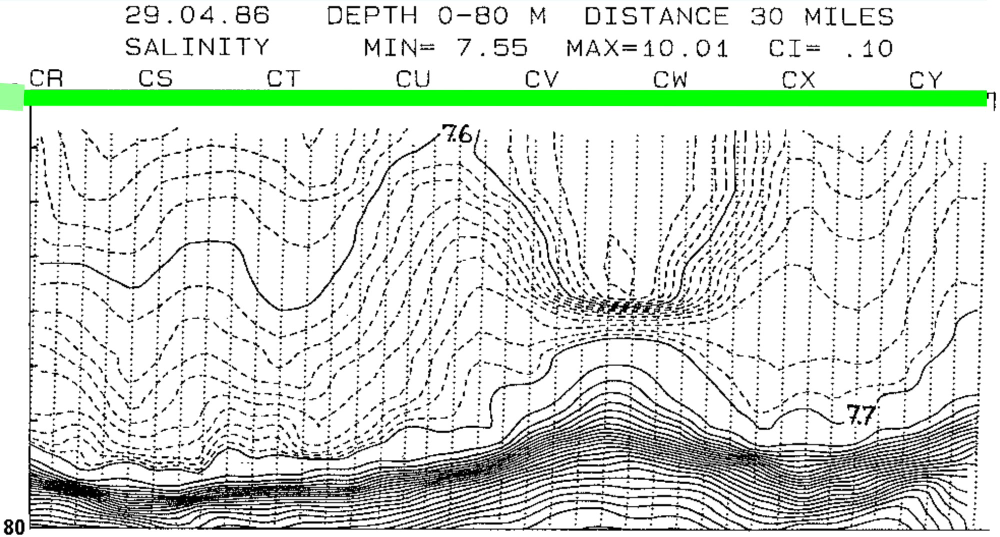
Karimova(2012), Karimova and Gade (2016)

Mesoscale variability: observations from PEX-86



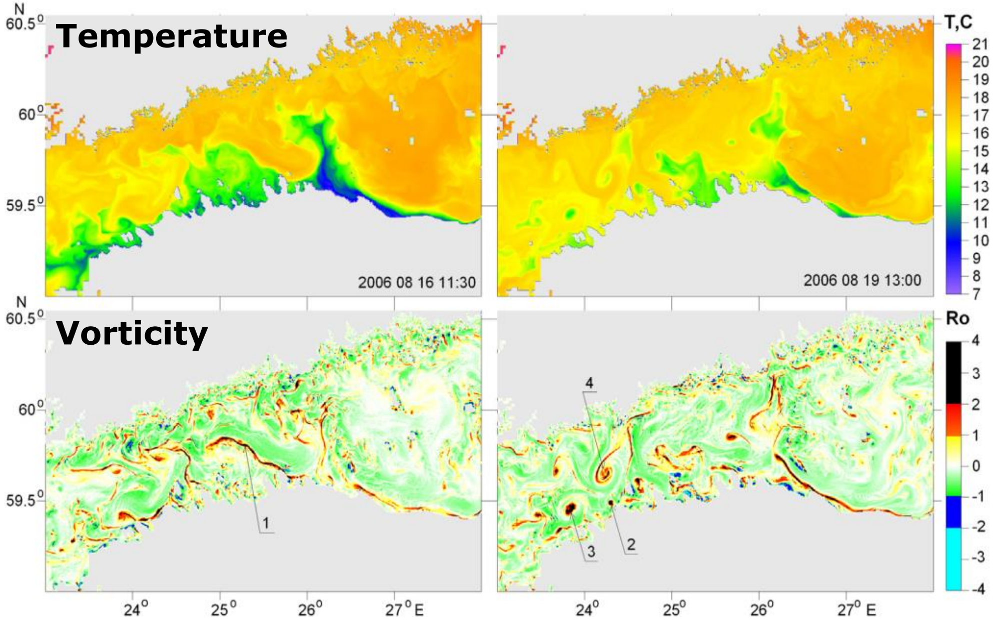
14 ships working 2 weeks in a 20 x 40 mile box

Phytoplankton spring bloom started in the cores of mesoscale eddies



Eddies generated during upwelling relaxation

POM model with 0.125 miles grid step, used for summer 2006



Identified features

1 – cyclonic vorticity thread at upwelling front

2 – submesoscale spot of high cyclonic vorticity

3 – long-living mesoscale cyclonic eddy

4 – spiral submesoscale cyclonic eddy

Väli et al (2017), J Mar Sys

Long-living mesoscale eddy in the Gulf of Finland

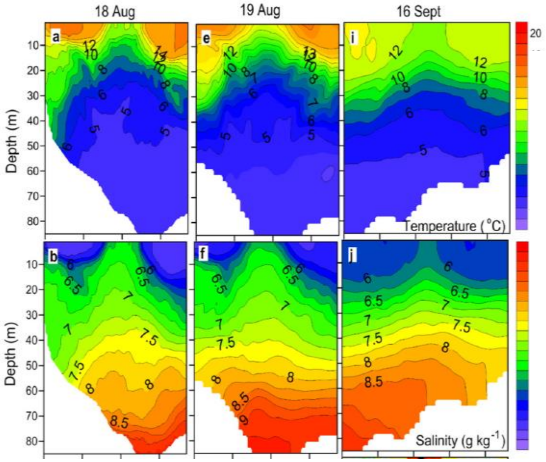
Eddy background is variable, still contrasts in eddy core are distinct over about 1 month.
Diameter about 10 km, travel distance about 80 km over 33 days = translation speed 2-3 cm/s.

Transects of temperature and salinity over 1 month

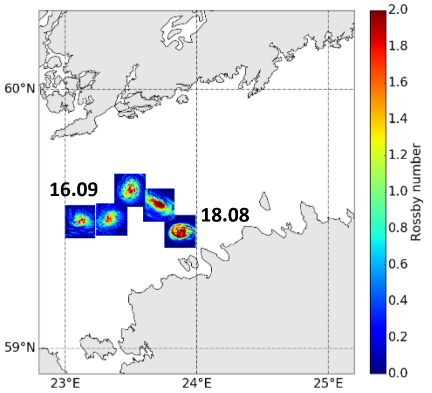
Väli et al (2017)

Decrease of contrast eddy core – periphery

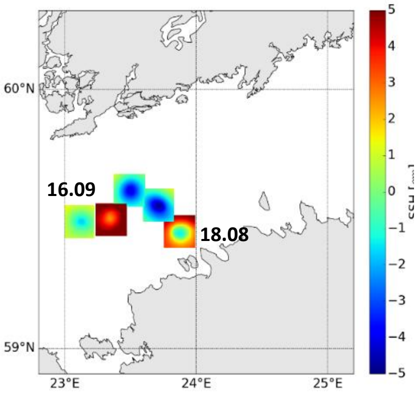
Sea level	**Start -4.7 cm**	**End -2.2 cm**
SST	**Start -4.1 °C**	**End -1.0 °C**



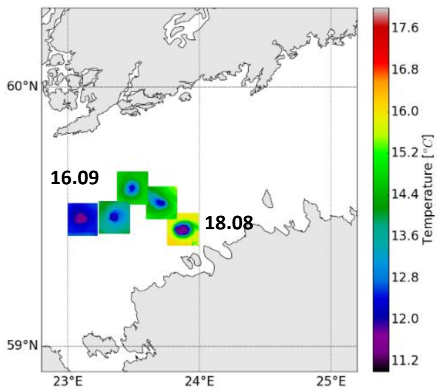
Vorticity



Sea level



SST

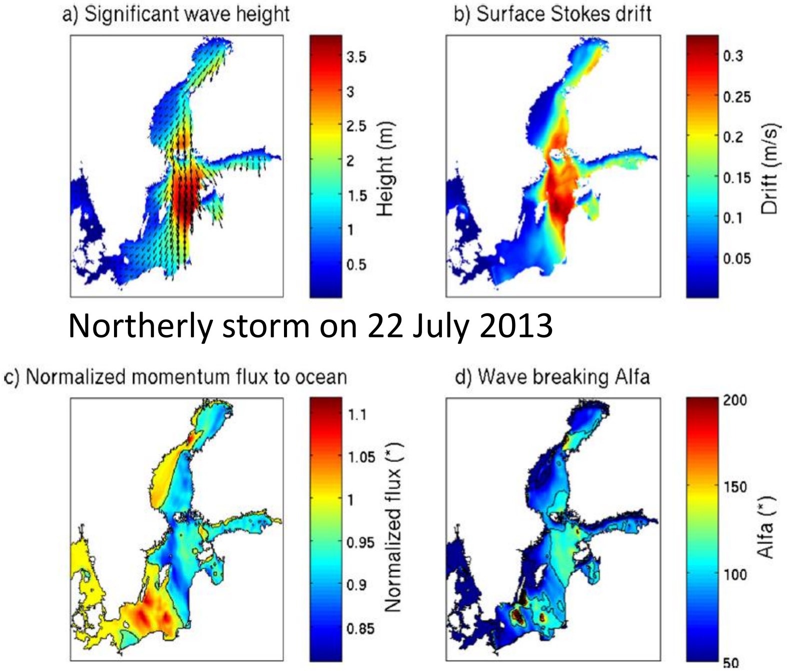


We learned from eddies and fronts:

- variety of eddy types: short-living (< few days) spiral and T-like submesoscale eddies, long-living (> few weeks) mesoscale eddies
- eddies are important for momentum and mass transfer
- knowledge about eddies still fragmentary, good detection methods not yet ready

Next:
Waves and their effects

Effects of waves on ocean dynamics



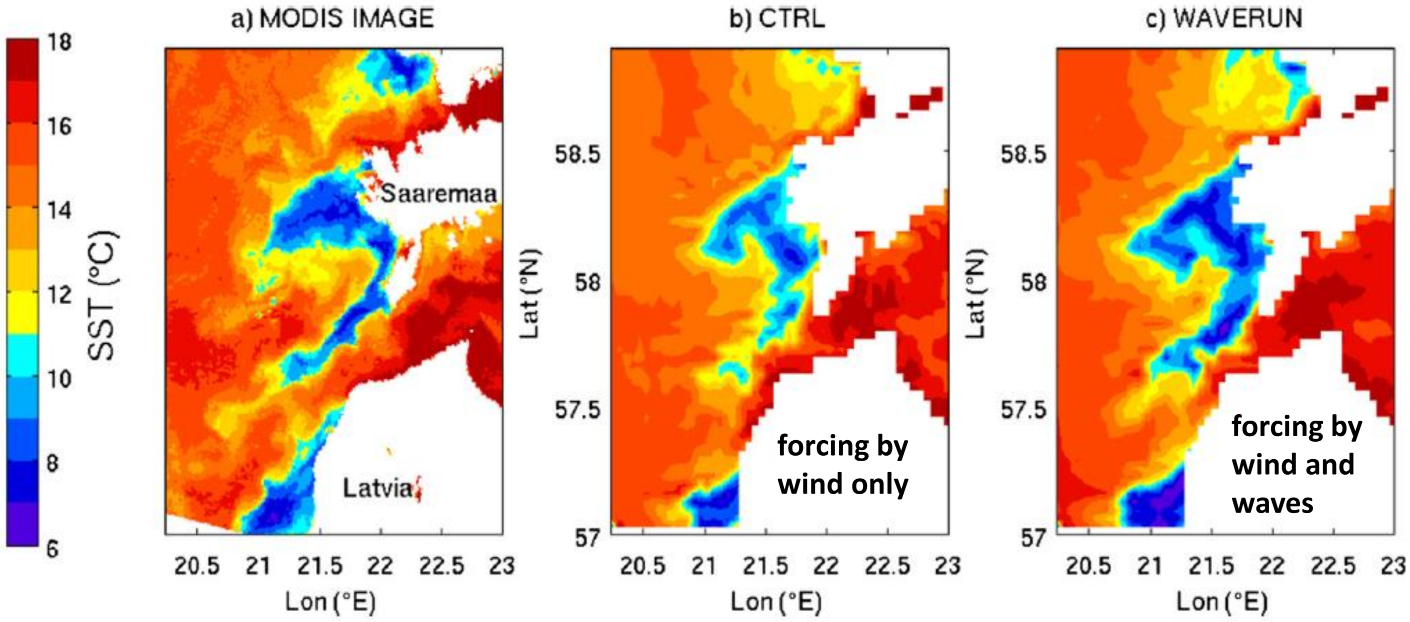
Standard ocean modelling approach prescribes wind and wave effects as a function of wind only.

Specific wave effects on ocean dynamics include:

- Stokes-Coriolis drift in non-linear waves
- wave-dependent momentum flux: surface roughness and drag coefficient for wind stress, release of momentum to ocean by breaking waves
- wave-dependent mixing: induced by breaking waves

Alari et al (2016)

Effect of waves on temperature during upwelling



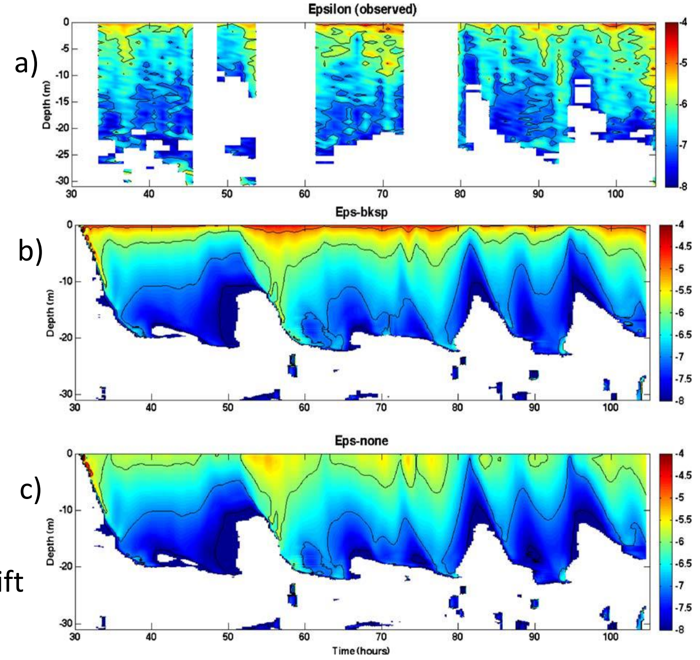
Alari et al (2016)

Turbulence generation by surface waves (Stokes drift)

Stokes production of turbulent kinetic energy in the mixed layer is of the same order of magnitude as the shear production and must therefore be included in mixed layer models.

Presently most of the models count only the shear production (friction velocity) due to wind speed, not the effects of waves.

Microstructure observations in the Bornholm Basin



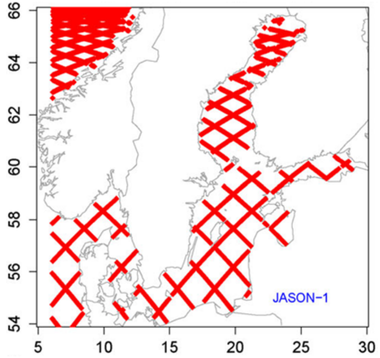
TKE dissipation rate (in W kg^{-1})
a) observed
b) modeled with wave breaking and Stokes drift
c) modeled with wind dependence only

Kantha, L., Lass, H. U., & Prandke, H. (2010).

Wave products for the Baltic Sea

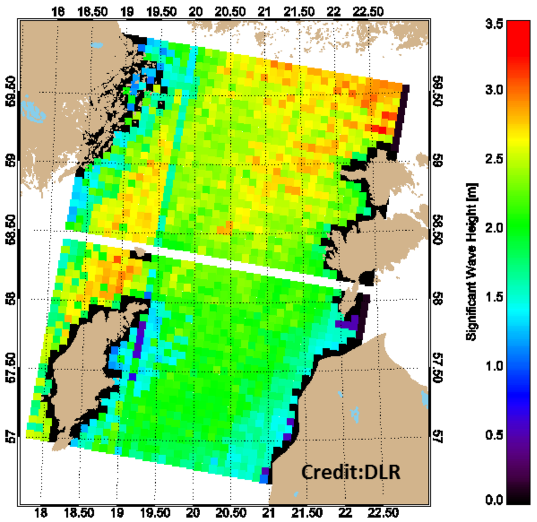
The spatial resolution and coverage of altimetry and SAR wave products

Coverage and resolution of Jason-1 altimeter data

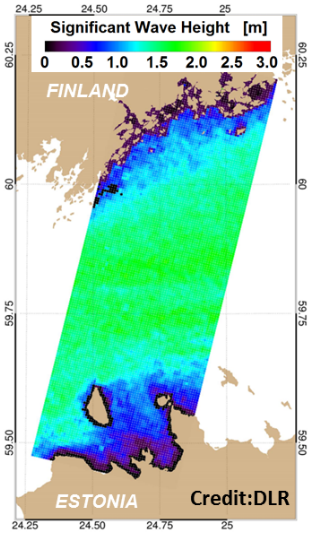


Kudryavtseva and Soomere (2016) "Validation of the multi-mission altimeter wave height data for the Baltic Sea region", *Est.J-Earth.Sci*

Sentinel-1 SAR



TerraSAR-X

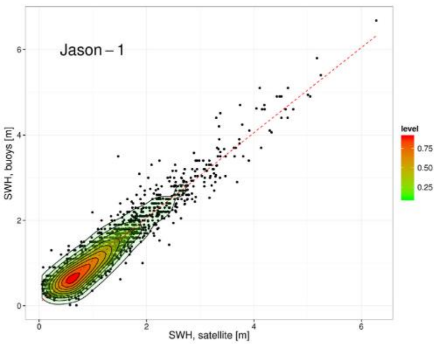


Credit: Rivo Uiboupin and Sander Rikka

- Low-resolution altimetry wave products/algorithms and open ocean SAR wave mode products not good in the Baltic
  - a number of islands and staggered coast line
  - limited fetch resulting in relatively small and short waves
- Sentinel-1 SAR data could be basis for much more detailed „dedicated Baltic" wave information than altimetry products.

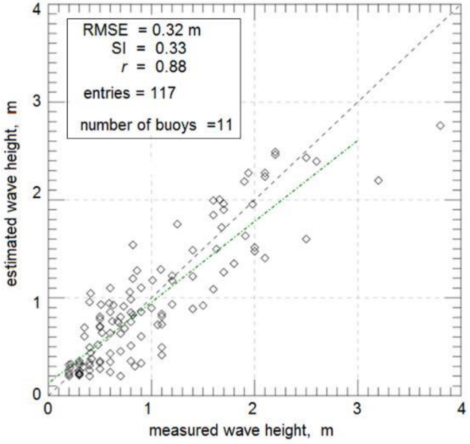
SAR wave product accuracy

Altimetry



Kudryavtseva & Soomere (2016)

SAR



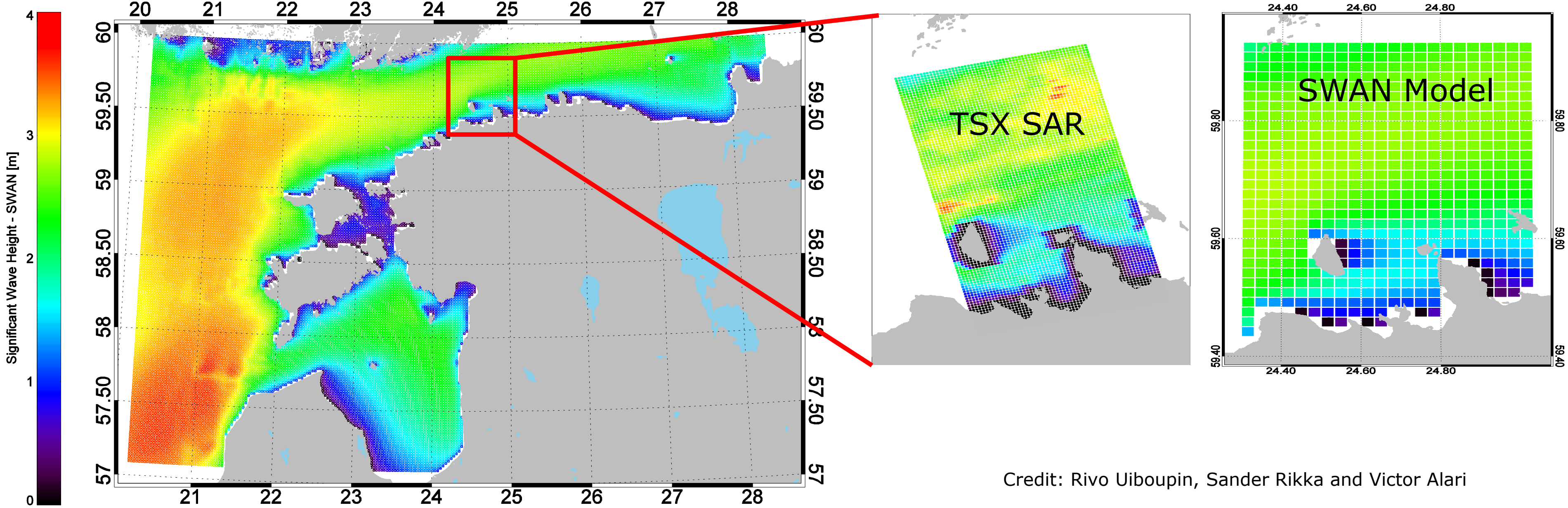
- SAR based wave fields as accurate as from altimetry, but SAR coverage is better
- The value of high-res wave field information retrieved from SAR imagery in the Baltic Sea and in the German Bight has been demonstrated:
  - Pleskachevsky, Rosenthal, Lehner (2016) ISPRS J Photogramm. „Meteo-marine marine oarameters for highly variable environment in coastal regions from satellite radar imagery “
  - Rikka; Uiboupin; Alari. (2017).) Int. J. Remote Sens. „Applicability of SAR based wave retrieval for wind-wave interaction analysis in the fetch-limited Baltic“
  - Rikka, Pleskachevsky, Uiboupin, Jacobsen (2017) IGARSS Proceedings, „Sea state parameters in highly variable environmentof Baltic Sea fro m satellite radar images“

High-res SAR based wave fields need to be assimilated into forecast models

Credit: Rivo Uiboupin and Sander Rikka

esa

Spatial details of SAR wave products in the coastal area



Credit: Rivo Uiboupin, Sander Rikka and Victor Alari

We learned from wave effects:

- waves are important for currents, mixing, TS patterns
- wave models already quite good, still observations needed, e.g. for data assimilation
- wave products from SAR seem to have high value

Baltic ocean dynamics and remote sensing:

a number of new RS products would be highly valuable, for

- better understanding of complex natural processes
- improving quality and reliability of ocean forecasts