The ecological state of Baltic Sea

The Baltic Sea as a complex system: its function, present state and future projections

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Web sources:
http://www.baltex-research.eu/BACC2/index.html
http://www.baltex-research.eu/ecosupport/
http://www.myocean.eu/
http://www.boos.org/

Thanks: MSI colleagues, BACC2, ECOSUPPORT, MyOcean, BOOS-HIROMB

Summer school , August 2014
Sustainable chemistry and process technology

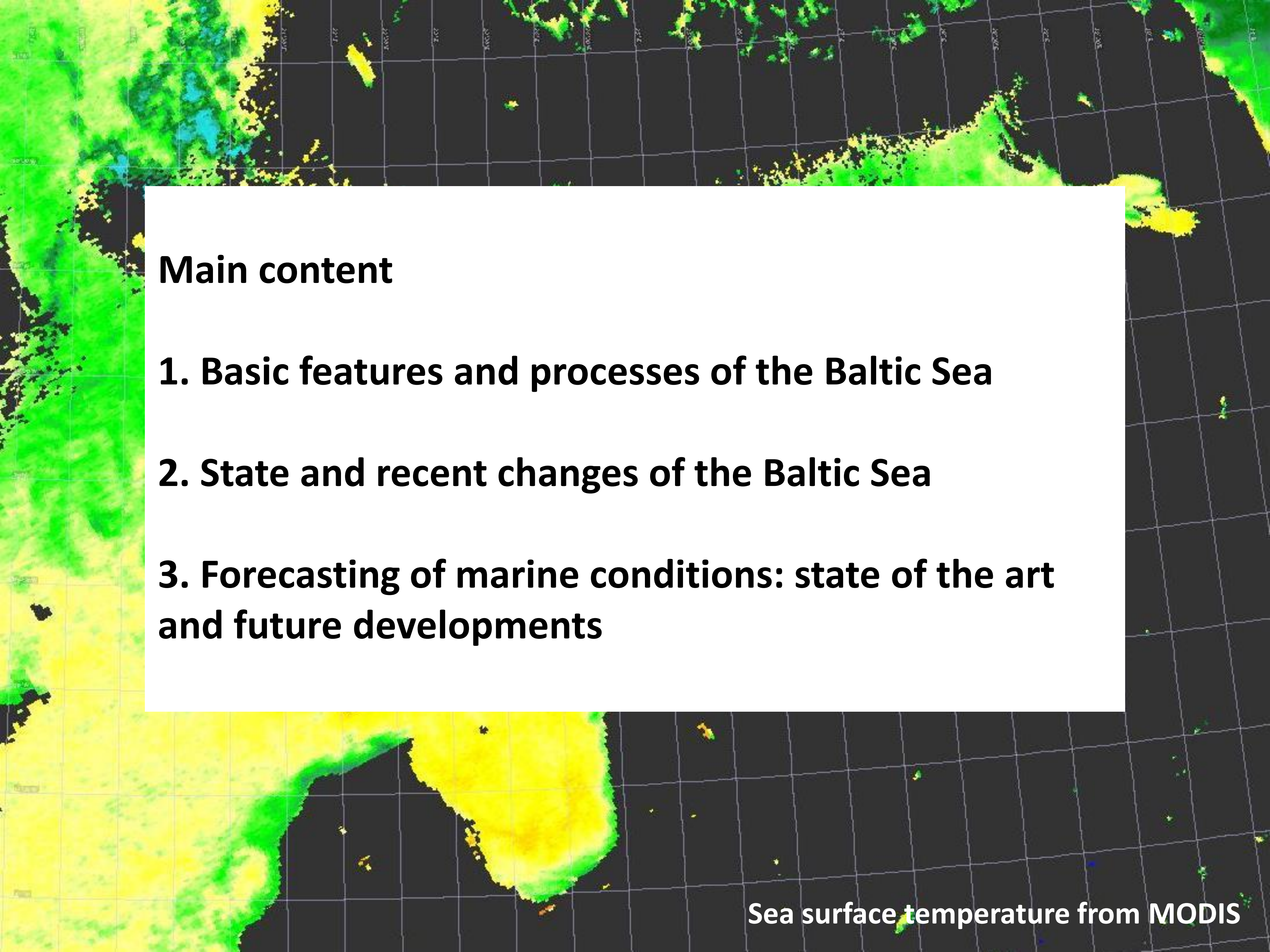
Estonian fractal coastline is ca 3800 km long

Main content

1. Basic features and processes of the Baltic Sea

2. State and recent changes of the Baltic Sea

3. Forecasting of marine conditions: state of the art and future developments



Sea surface temperature from MODIS

1. Basic features and processes of the Baltic Sea

Topics:

- basic aspects of oceanography
- physics of the Baltic Sea
- loads of nutrients and aspects of ecology

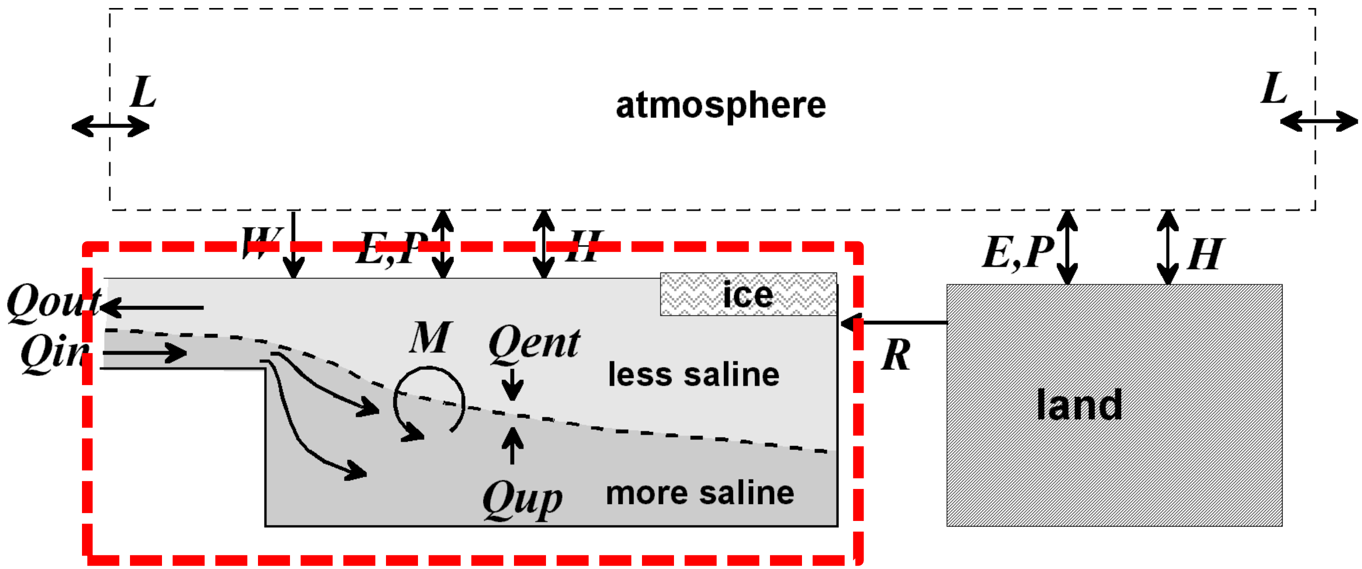
Cyanobacteria from remote sensing

Possible „narrow“ viewpoints in oceanography

- **series of Fourier’ components** (waves and currents researcher)
- **T, S, O_2 etc profile collection** (descriptive oceanographer)
- **ensamble of pulsations** (turbulence researcher)
- **gridded data sets** (modeller)
- **concentrations in water samples** (marine chemist)
- **species in the microscope** (marine biologist)
- **layers in the sediment cores** (marine geologist)

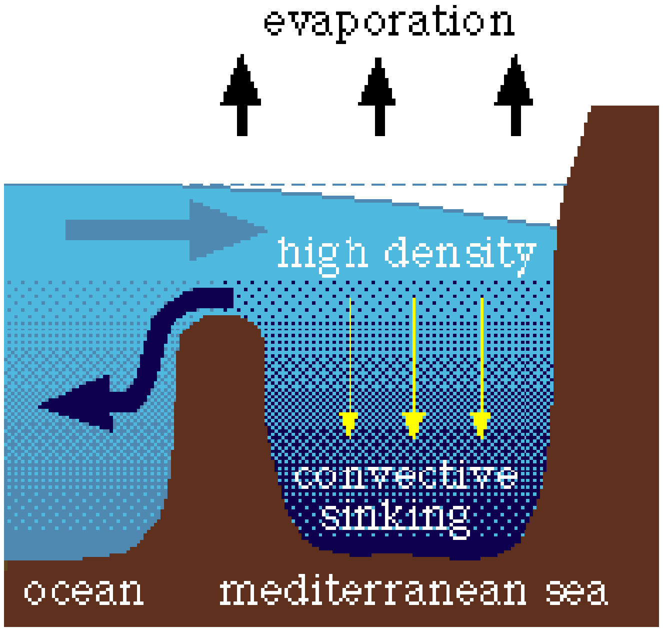
etc

Forcing: atmosphere, land, adjacent sea basins



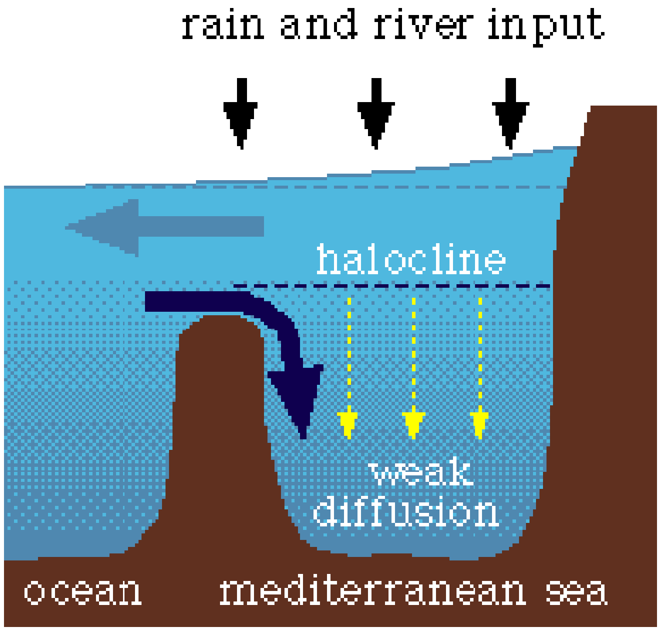
E,P – evaporation and precipitation,
W – wind stress above sea,
H – heat exchange, including radiation,
R – freshwater discharge by rivers,
L – atmospheric exchange with adjacent regions,
Qout – outflow of seawater,
Qin – inflow of oceanic water,
Qup – upward motion of halocline due to inflow (continuity),
Qent - entrainment of less saline surface waters into the saltier layer to compensate upward velocity of halocline
M – vertical diffusion-like mixing.

concentration basin:
evaporation dominates



like Mediterranean

dilution basin:
freswater flux dominates



like Baltic

The Baltic Sea

viewpoints as:

- **huge estuary**

large-scale processes

exchange between sub-basins

- **large lake**

wind-driven circulation

wind-induced waves

thermocline evolution

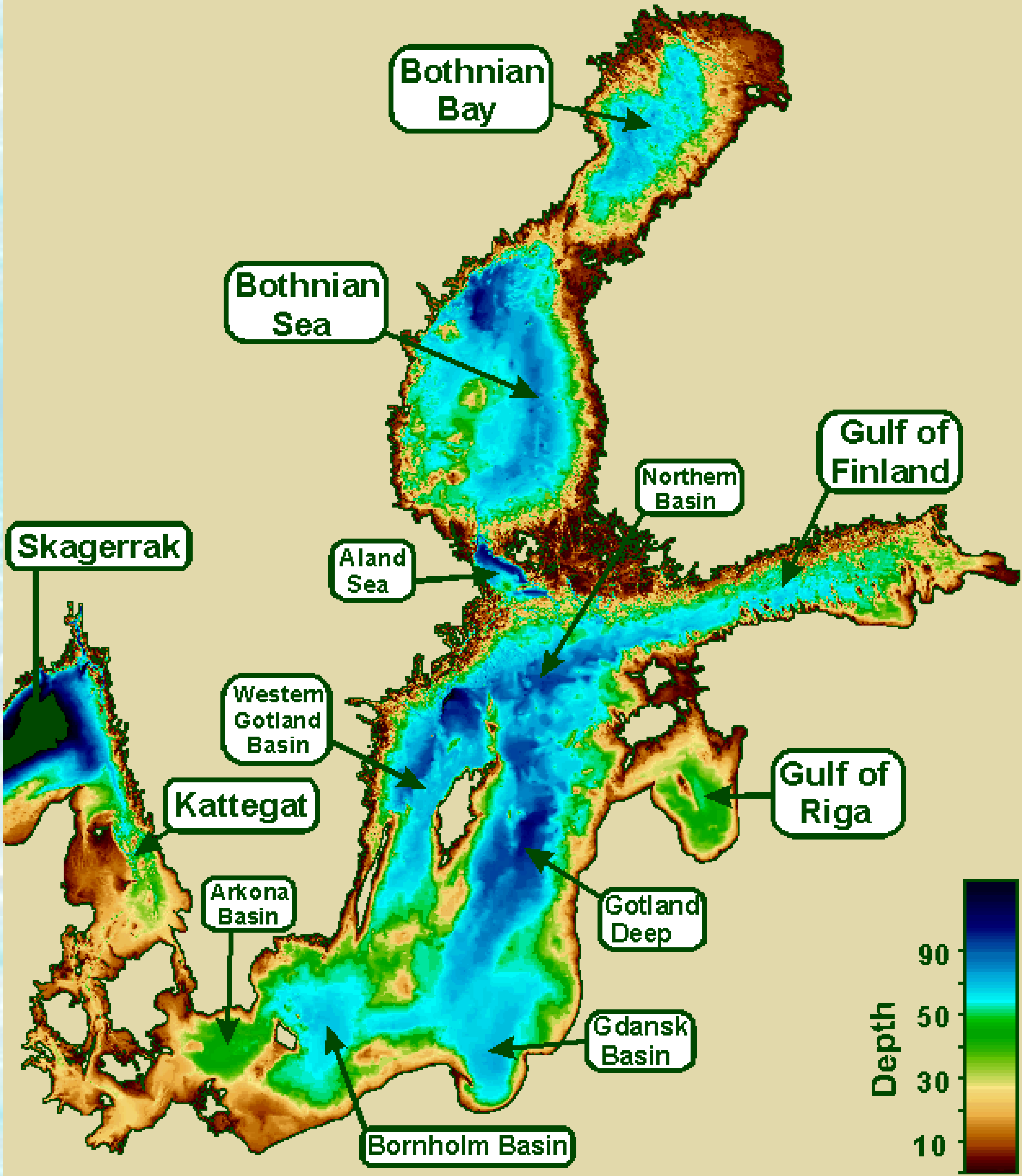
- **small ocean**

fronts

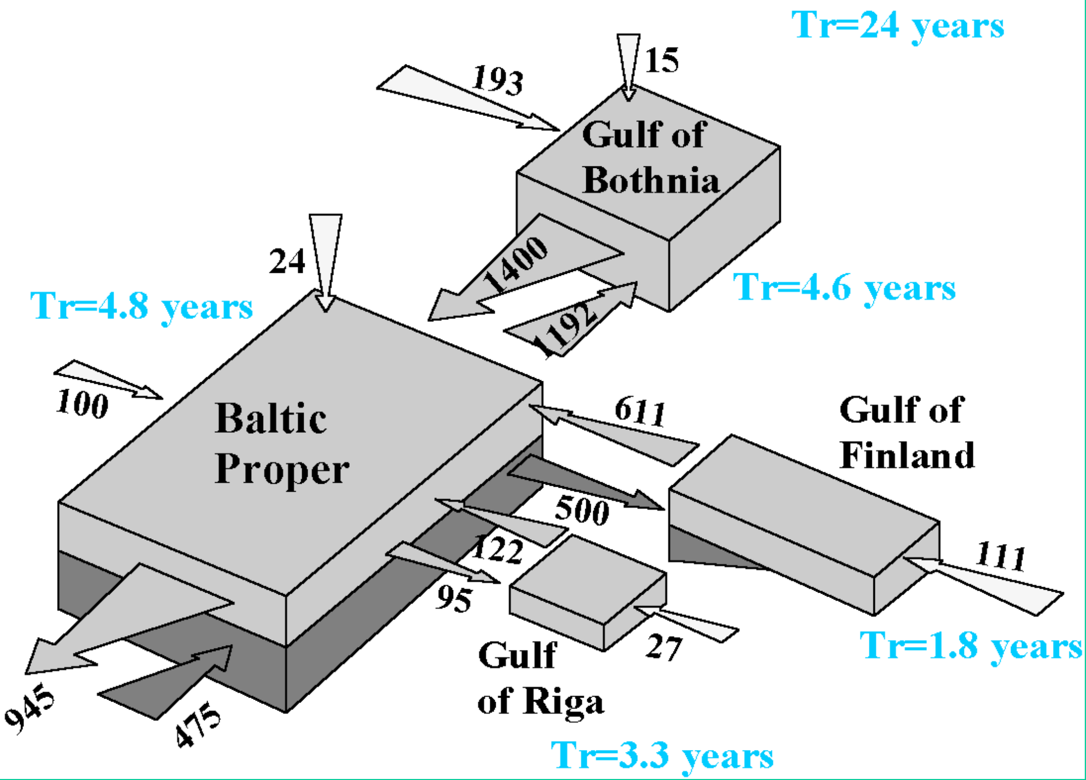
mesoscale eddies

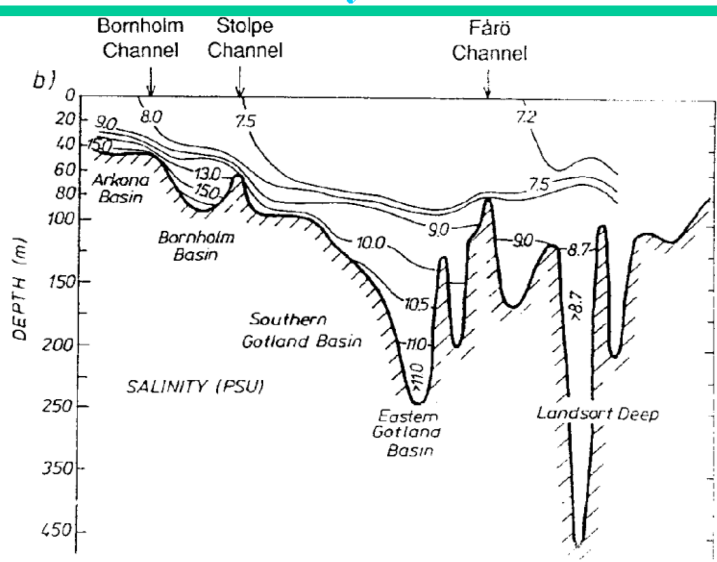
thermohaline effects and

finestructure



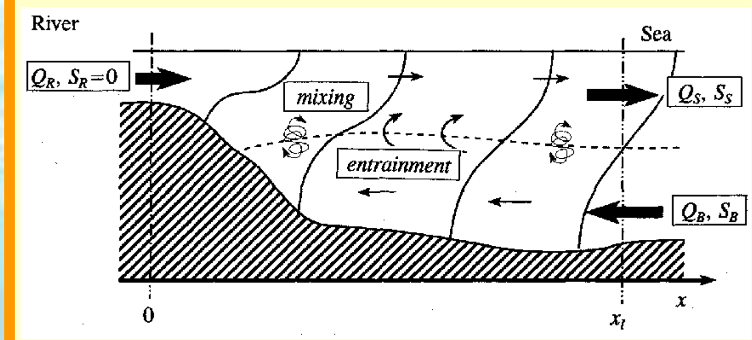
Baltic Sea WATER EXCHANGE km^3/year





typical salinity transect

Steady Knudsen budget



water budget

$$Q_R + Q_B = Q_S$$

salt budget

$$S_R Q_R + S_B Q_B = S_S Q_S$$

$$S_R = 0$$

$$Q_B = \frac{Q_R S_S}{S_B - S_S} \qquad Q_S = \frac{Q_R S_B}{S_B - S_S}$$

residence time

$$T_R = \frac{V}{Q_S}$$

Hydrostatic balance

…holds for motions with time scale > hour

vertical pressure gradient force = gravity force per unit volume

$$\boxed{\frac{\partial p}{\partial z} = -g\rho}$$

Pressure at vertical level z (counted here upwards from undisturbed surface) is calculated by integrating hydrostatic equation from depth h (where $z = -h$) up to sea level elevation ξ (positive upwards)

$$p = p_a - g\int_z^0 \rho(x,y,z,t)dz + g\rho_0\xi(x,y,t)$$

or

$$p = p_a + g\bar{\rho}h + g\rho_0\xi$$

where p_a - atmospheric pressure

$\bar{\rho}$ - mean density of water column

Density range 1000-1025 kg m^{-3}

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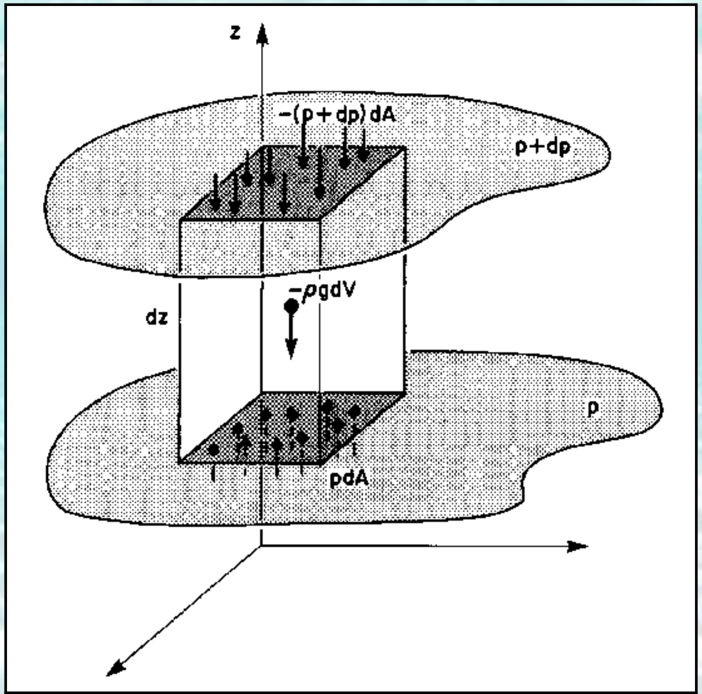
1 m of depth $\approx$ 1 dbar of pressure



Newton III Law

$$p\,dA - (p+dp)dA - \rho g\,dV = 0\ .$$

using $dV = dA\,dz$ we obtain

$$p\,dA - (p+dp)dA - \rho g\,dA\,dz = 0$$

and further

$$\frac{dp}{dz} = -\rho\,g$$

Pressure gradients

Horizontal pressure gradient at a given depth **depends** on the gradients of **water density** ρ and **sea level** ξ.

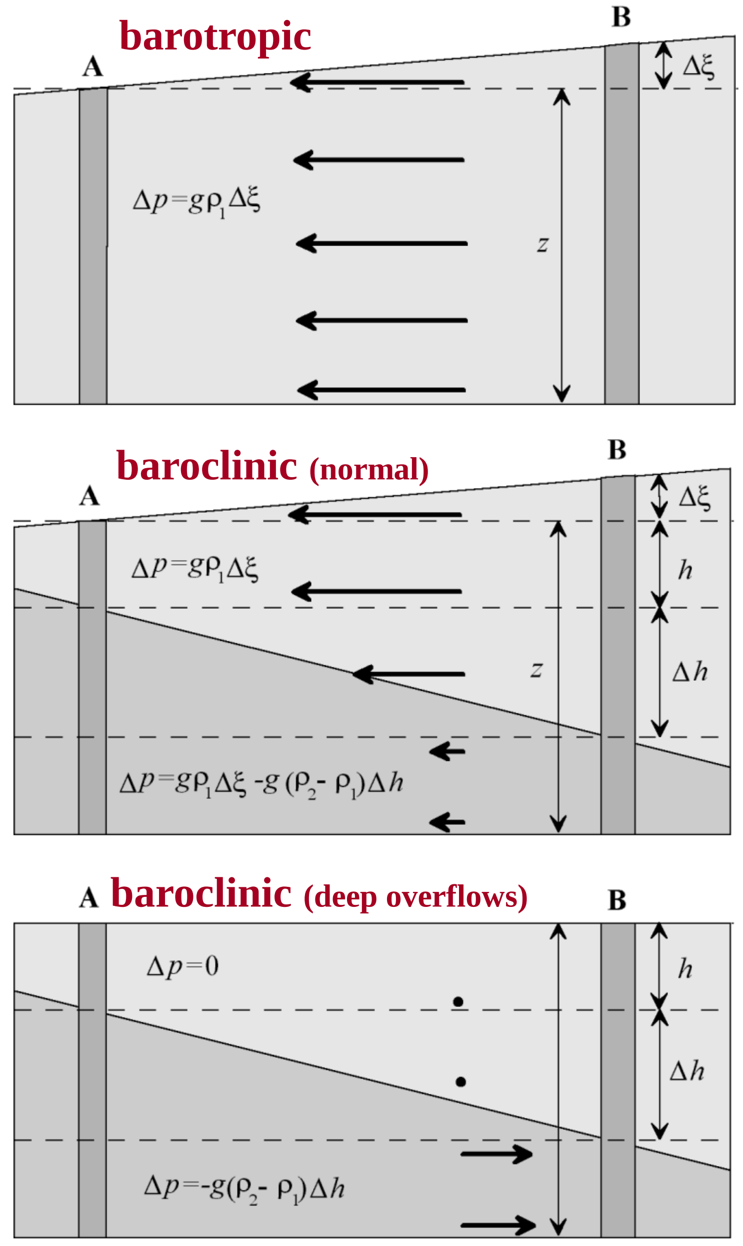
If **density is constant**, then $p = \rho g\left(z + \Delta\xi\right)$ and **pressure gradient is determined by sea level gradient**

$$\frac{\Delta p}{\Delta x} = \rho g \frac{\Delta \xi}{\Delta x} \ .$$

Density variations can be often treated by **two-layer approach**, *ie* density is constant in both layers but pycnocline depth h is variable.

Barotropic motions have no horizontal density gradient (vertical density gradient is allowed) and all the pressure gradient comes from sea level

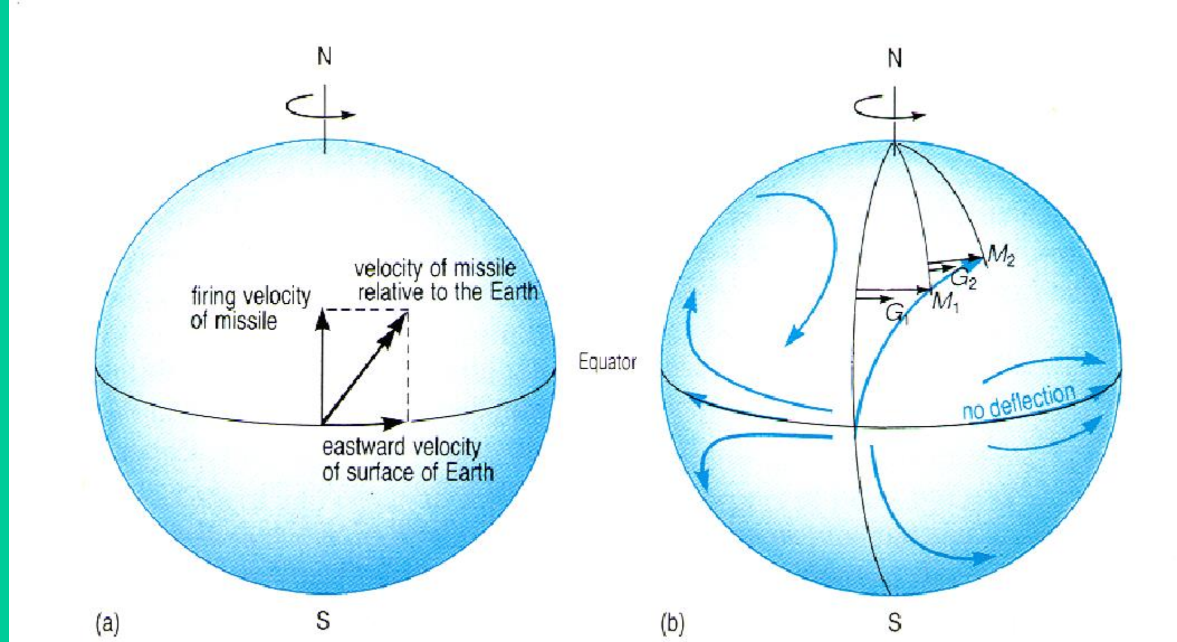
Baroclinic motions have both the density and sea level contribution to the pressure gradient



Coriolis force

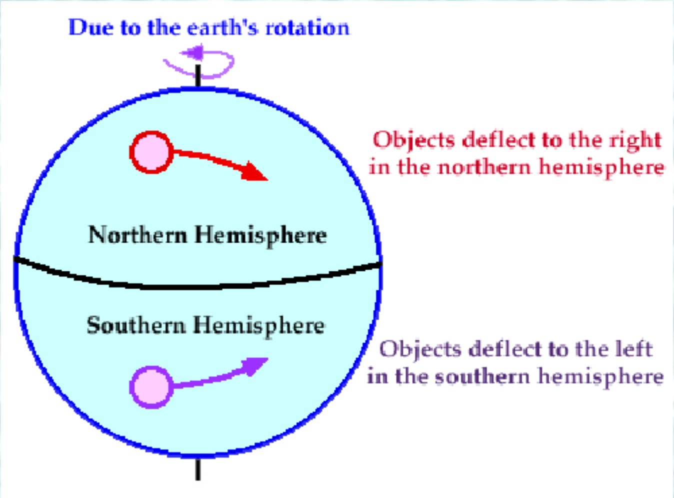
is perpendicular to velocity

$$\frac{\vec{m}_c}{\rho} = (fv, -fu, 0)$$



- becomes evident due to Earth rotation
- deflects motion to the right
  in the Northern Hemisphere
- allows geostrophic balance
- causes inertial oscillations

It is expressed by **Coriolis parameter** $f = 2\Omega \sin\varphi$,
Ω - angular velocity of Earth, φ - geographic latitude



Momentum equations for **inertial oscillations**

$$\frac{\partial u}{\partial t} - fv = 0 \qquad \frac{\partial v}{\partial t} + fu = 0$$

that has solution $u = A\sin ft, \quad v = A\cos ft$

This means that **current vector rotates clockwise** with a period

$$T_f = \frac{2\pi}{f} = 14\,\mathrm{h}$$ at latitude 60^0 N

Inertial period T_f is frequently dominating in current observations in the interior of large basins

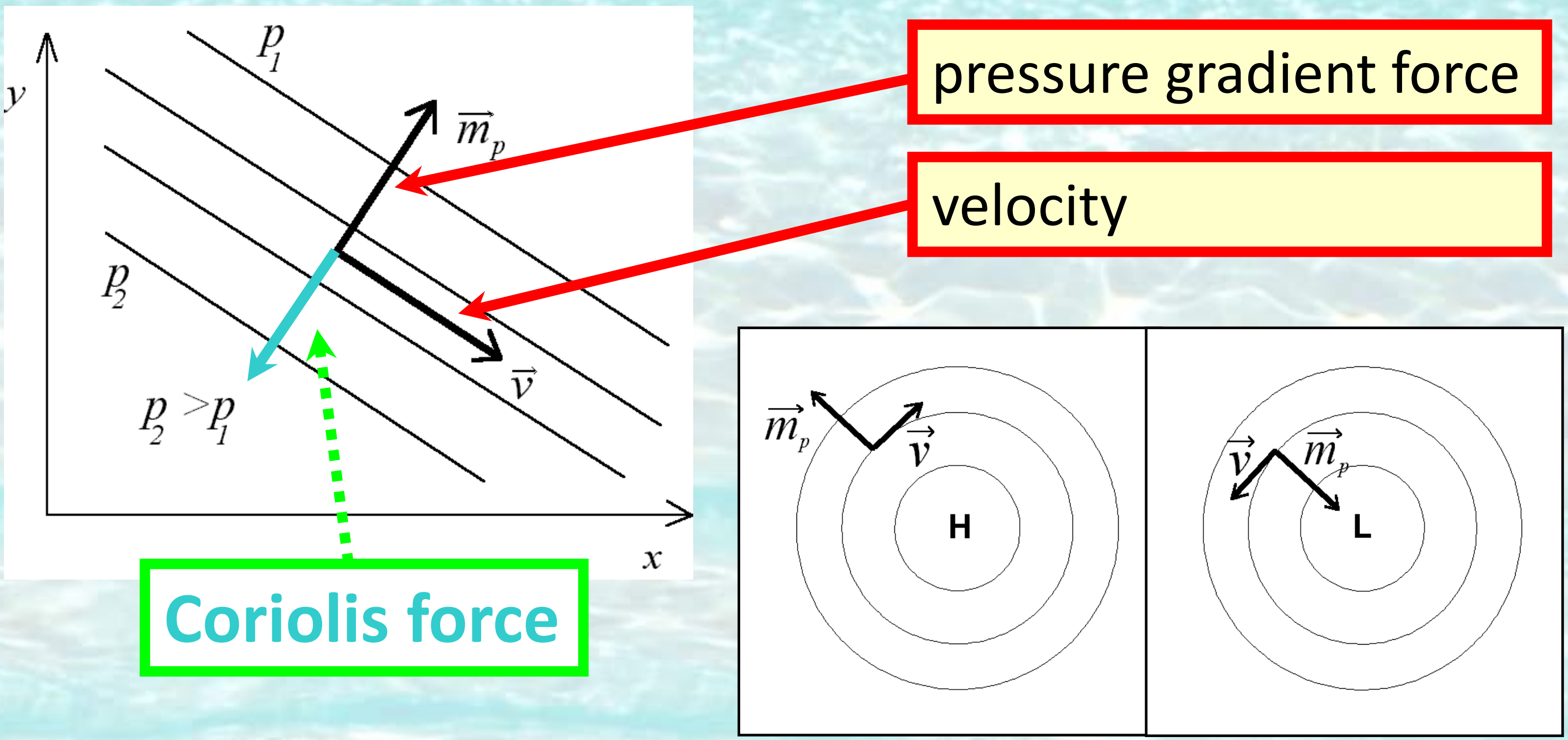
$$2\vec{\Omega} \times \vec{v}$$

Geostrophic balance

In geostrophic motions **horizontal pressure gradient force is balanced by Coriolis force**

$$-fv = -\frac{1}{\rho}\frac{\partial p}{\partial x} \qquad\qquad fu = -\frac{1}{\rho}\frac{\partial p}{\partial y}$$

Geostrophic flow is along the lines of constant pressure. In the Northern Hemisphere the **flow is to the right from the pressure gradient** (from high to low pressure).



Drift currents: Ekman spiral

Nansen noticed in 1890s that surface drift currents deflect 20^0-40^0 to the right from wind. Ekman found explanation: **frictional force is balanced by the Coriolis force:**

$$-fv = \frac{\partial}{\partial z}\nu\frac{\partial u}{\partial z}, \qquad fu = \frac{\partial}{\partial z}\nu\frac{\partial v}{\partial z}$$

where u, v are horizontal velocity components, f - Coriolis parameter, ν - turbulent viscosity. Boundary conditions are

$$\nu\frac{\partial u}{\partial z} = \tau_x, \quad \nu\frac{\partial v}{\partial z} = \tau_y \quad \text{if} \quad z = 0$$

$$u = 0, \quad v = 0 \quad \text{if} \quad z \to -\infty$$

In case of northerly wind $\vec{\tau} = (0, \tau_y)$ the solution is

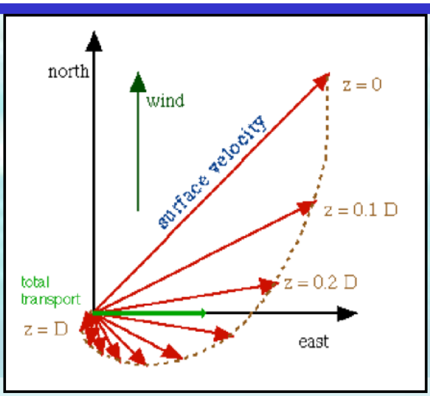
$$u(z) = \frac{\tau_y}{2\nu\gamma}e^{\gamma z}(\cos\gamma z - \sin\gamma z),$$

$$v(z) = \frac{\tau_y}{2\nu\gamma}e^{\gamma z}(\cos\gamma z + \sin\gamma z),$$

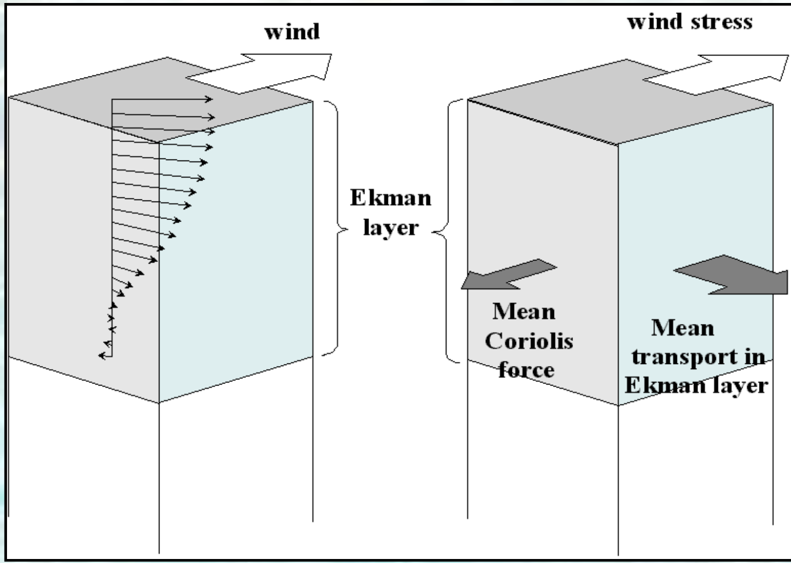
where $\gamma = \sqrt{\frac{f}{2\nu}}$.

Ekman (frictional) **depth** (10-100 m) is $D = h_E = \frac{\pi}{\gamma} = \pi\sqrt{\frac{2\nu}{f}}$

Surface current speed is $u_0 = v_0 = \frac{\pi\tau_y}{h_E f}$.



Surface current vector is deflected by 45^0 to the right from wind. By depth, current speed decreases and vector further deflects to the right. **Mean transport is by 90^0 to the right from wind.**

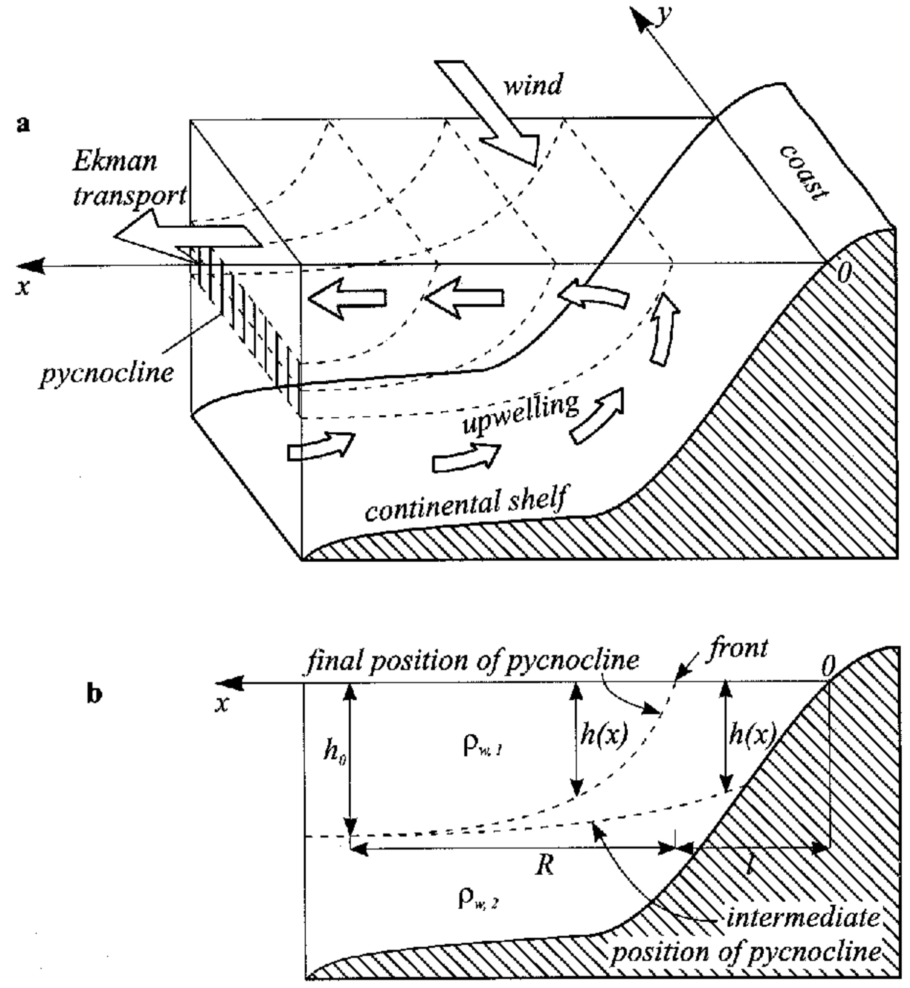


Upwelling

Steady frictional drift currents form in the upper layer **Ekman transport** that **is deflected by 90^0 to the right from wind direction** on the Northern Hemisphere under the **influence of Coriolis force**.

Along-shore wind may blow the surface water offshore. Near the coast deeper waters below the pycnocline (density jump layer) rise to the surface to replace the offshore transported surface waters. This process is called **upwelling**.

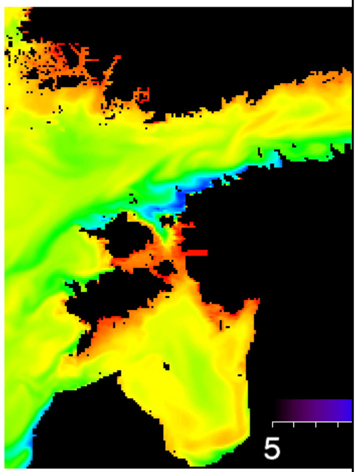
Upwelling is a time-dependent phenomenon. It modifies the temperature, salinity, nutrients and other water properties in the coastal embayments. Largest changes in the near-shore water take place when the pycnocline outcrops to the surface.



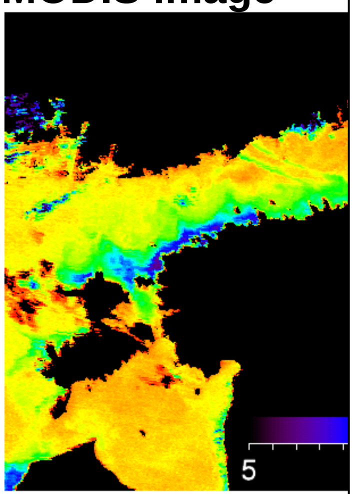
Upwelling effects on the nutrient cycle

example from 2006: combination of 3 research methods

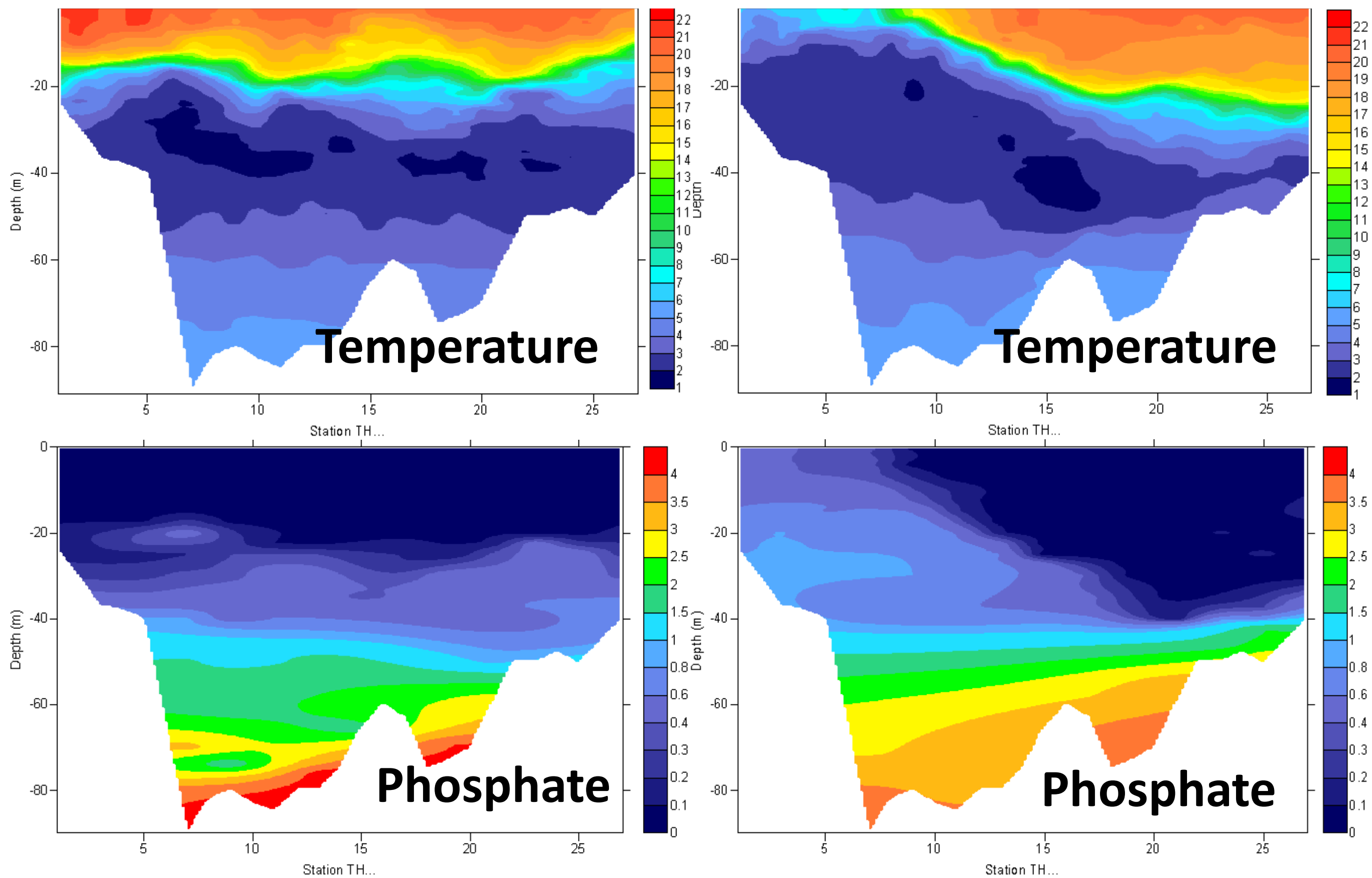
HIROMB model fo



MODIS image



Before upwelling 11.07.2006 **During upwelling 8.08.2006**



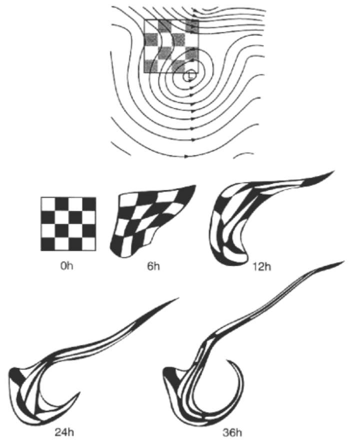
0,3-0,4 µmol/l – 20 m layer – 20 km coastal zone – 100 km long

Vertical flux estimate – 400-600 tons of P, equals to ca 1 month riverine load

Urmas Lips

Fronts: zones of enhanced gradients

Eddy currents distort “chessboard

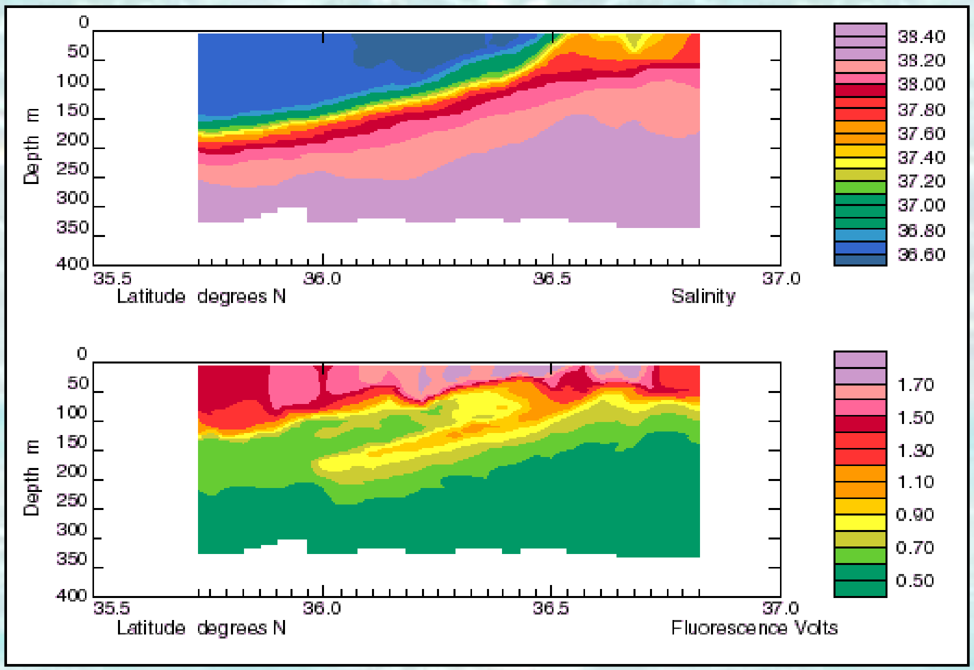


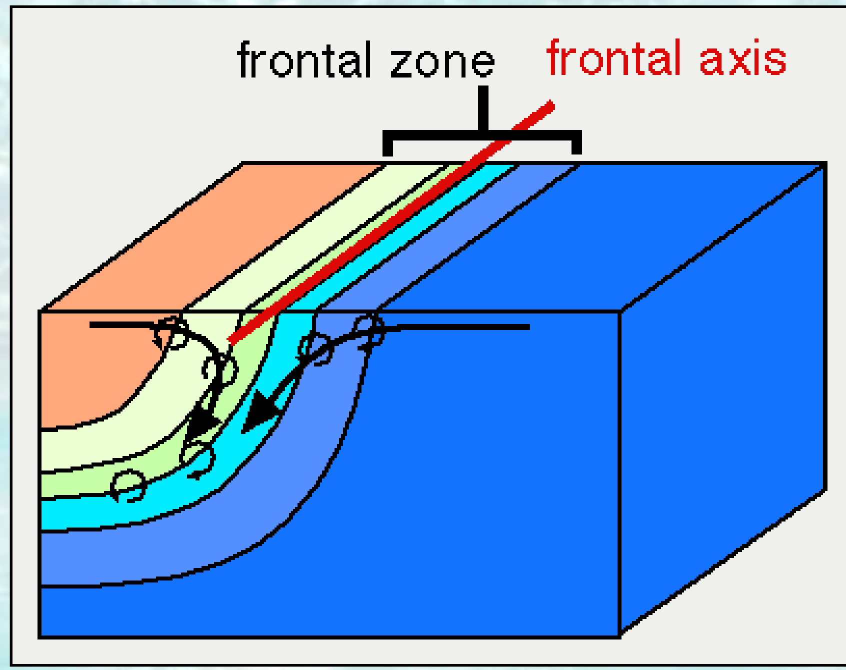
Converging currents - FRONTOGENESIS - maintains front against turbulent mixing.

In the surface, converging water sinks down.

along-front velocity is geostrophic

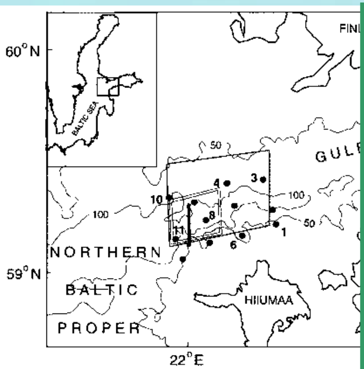
$$v = \frac{1}{f\rho_1}\frac{\Delta p_1}{\Delta x} = \frac{g(\rho_2 - \rho_1)}{f\rho_1}\frac{\Delta h}{\Delta x}$$



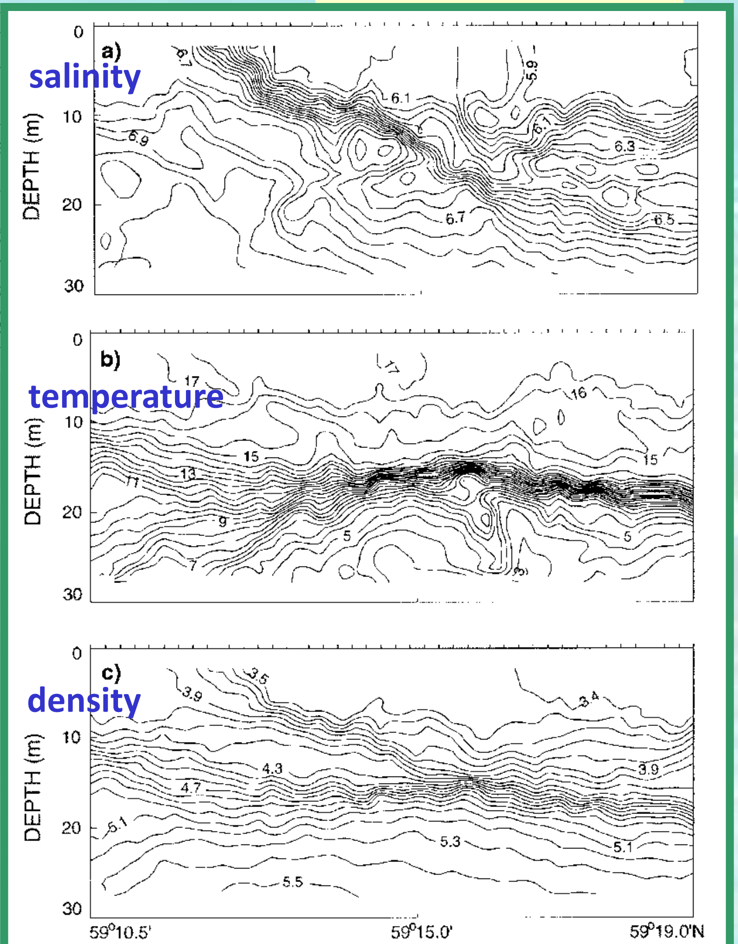


Frontal area at the entrance to the Gulf of Finland

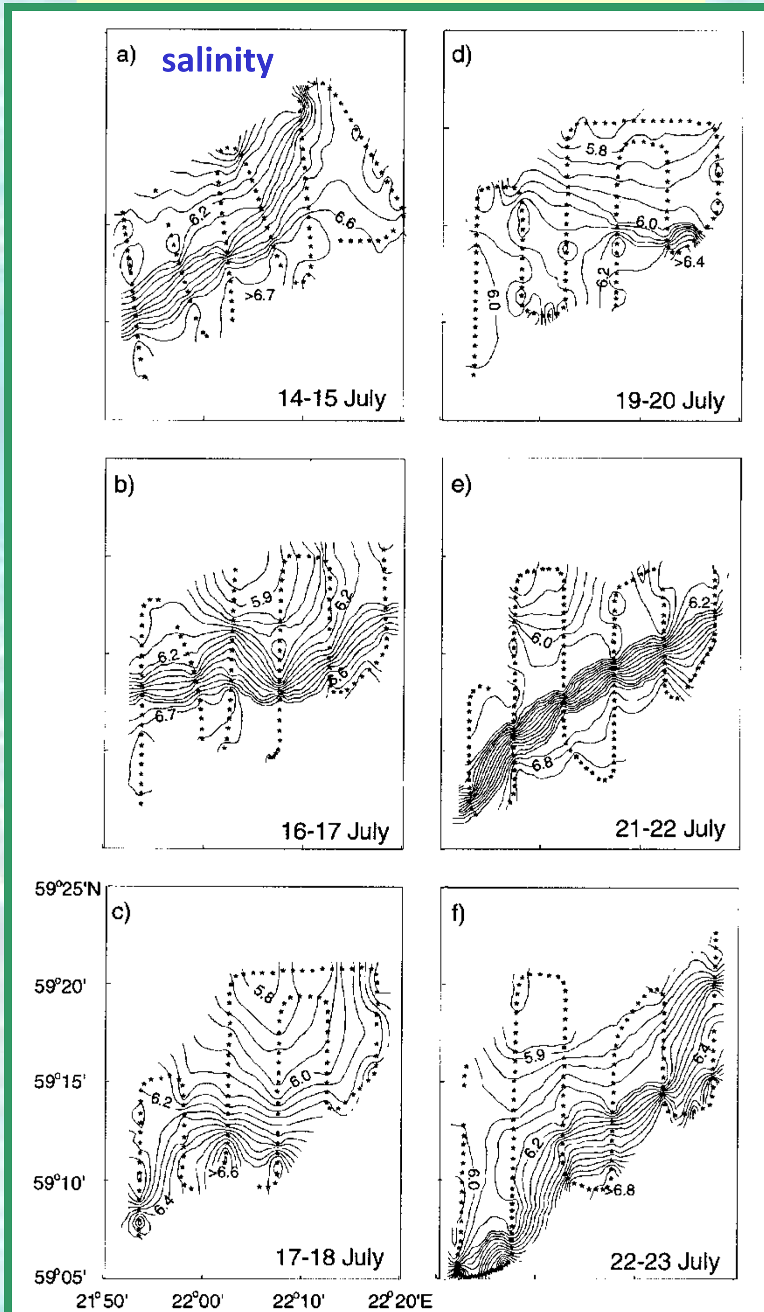
Pavelson, J., J. Laanemets, K. Kononen, S. Nõmmann, Quasi-permanent density front at the entrance to the Gulf of Finland: Response to wind forcing. *Cont. Shelf Res.*, Vol. 17, No. 3, 253-265, 1997.



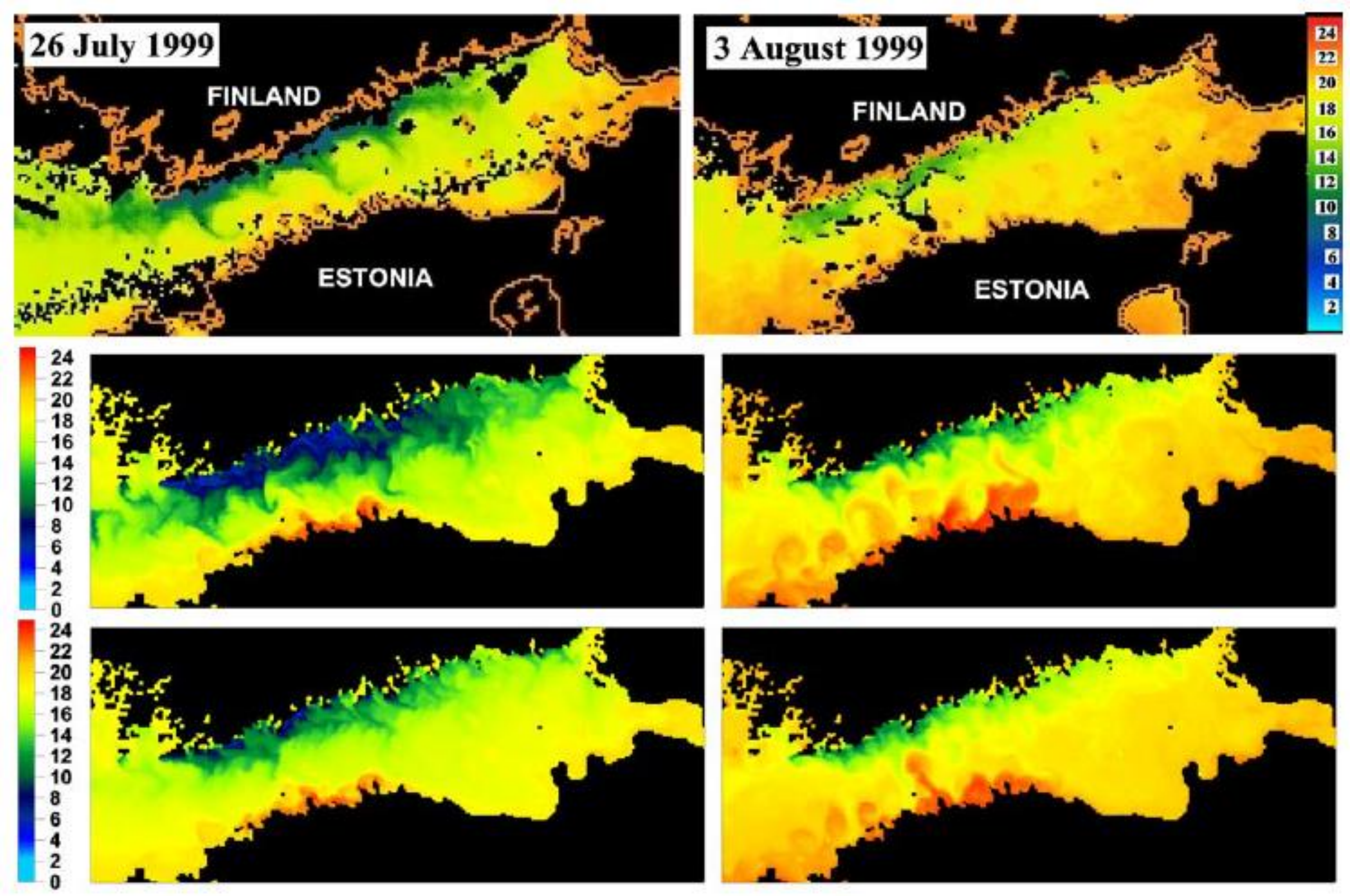
frontal transects



frontal maps (time sequence)



Coastal - offshore exchange: upwelling filaments



Remote Sensing

Model with wind 1.0

Model with wind 0.5

When the strong westerly winds producing the upwelling/downwelling weaken, the long-shore jets become unstable and produce transverse jets, cold/warm water squirts.

Zhurbas et al, 2008

Mesoscale variability: quasigeostrophy

Mesoscale variability is **quasigeostrophic**. Each time instant horizontal currents are along the isobars, but **pressure patterns evolve slowly**.

Slow evolution is due to **conservation of potential vorticity** $\dfrac{\varsigma + f}{H}$ along fluid particle trajectories.

Here ς is absolute vorticity, f is Coriolis parameter and H is depth.

As a result, slow **Rossby waves** (due to variation of f with latitute) and **topographic waves** (due to variable H) appear.

Main types of mesoscale motions are **fronts** and **eddies**. They are generated by baroclinic instability of large-scale flows. Most unstable wave length determines the **lateral scale** of mesoscale motions that is given by **baroclinic Rossby deformatsion radius**

$$\boxed{R_d = \frac{NH}{f}}$$

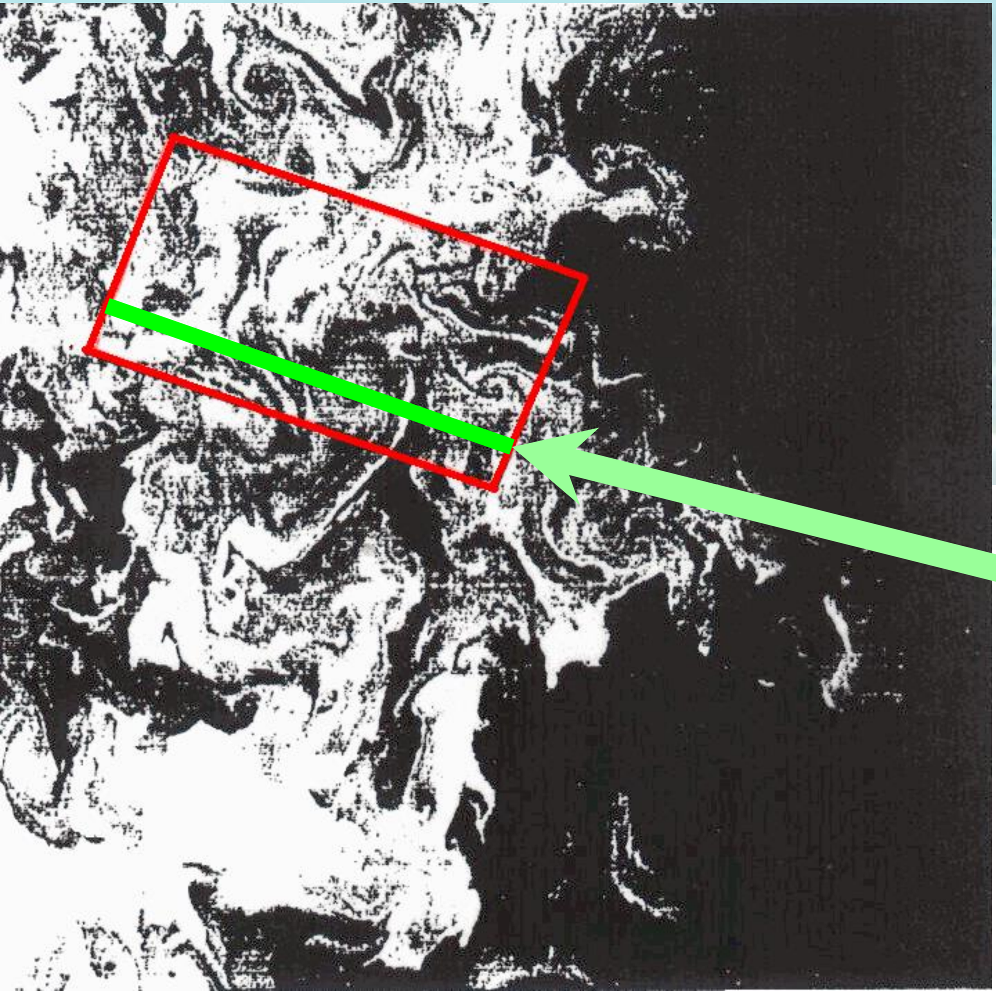
which value is ca **1000 km in the atmosphere, 50 km in the ocean and 10 km in the Baltic**. Here N is buoyancy (Väisälä) frequency.

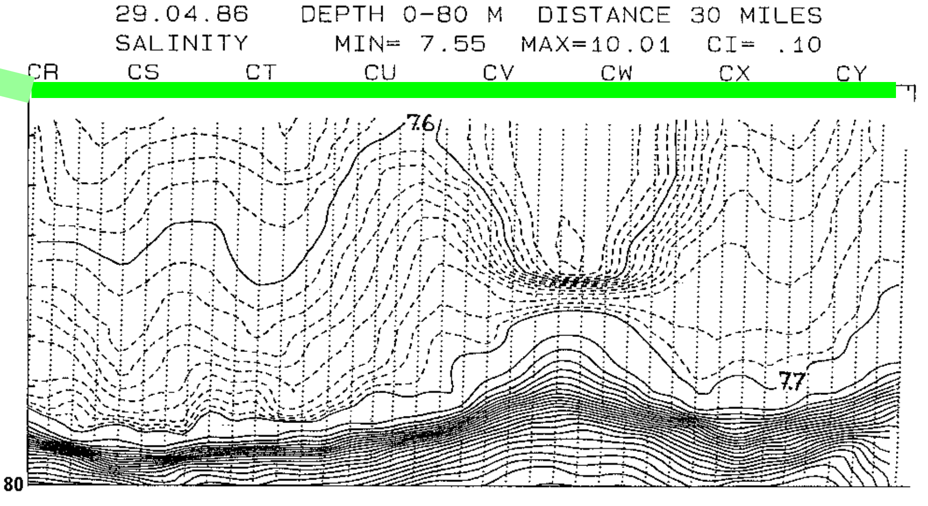
Mesoscale variability: observations from PEX-86

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

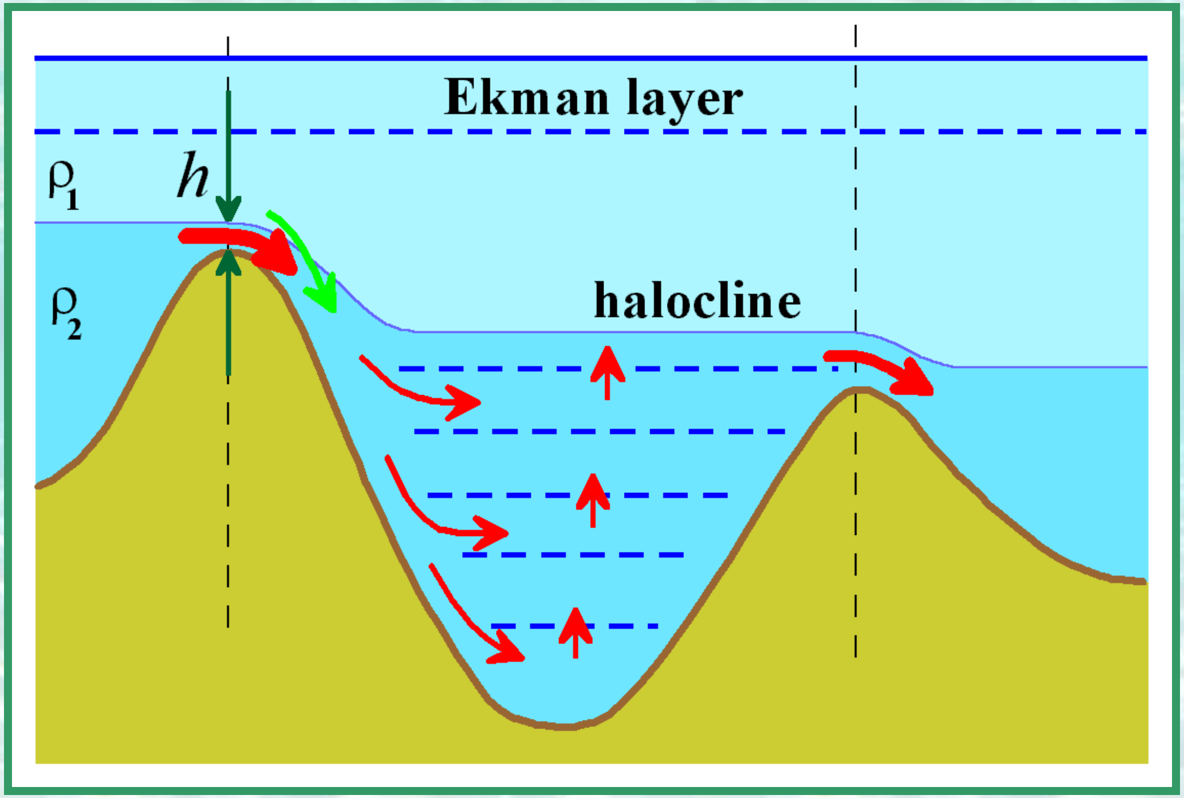
Observation of
mesoscale eddies

phytoplankton spring bloom started in the cores of eddies





Water exchange and mixing in connected rotational basins



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

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

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

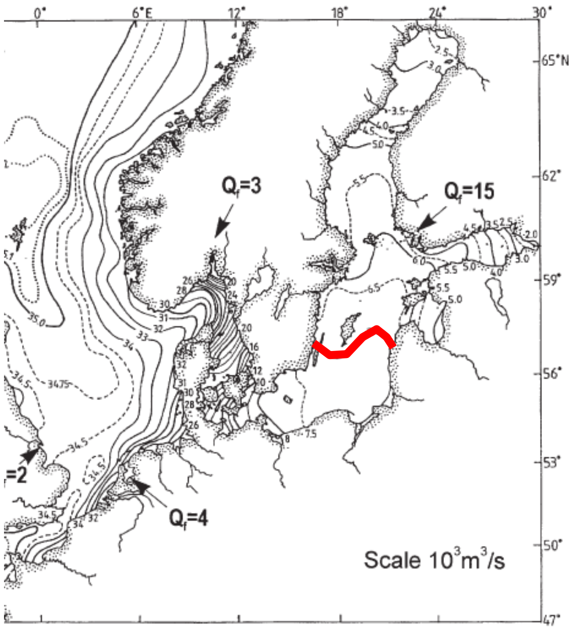
rotational control, if

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

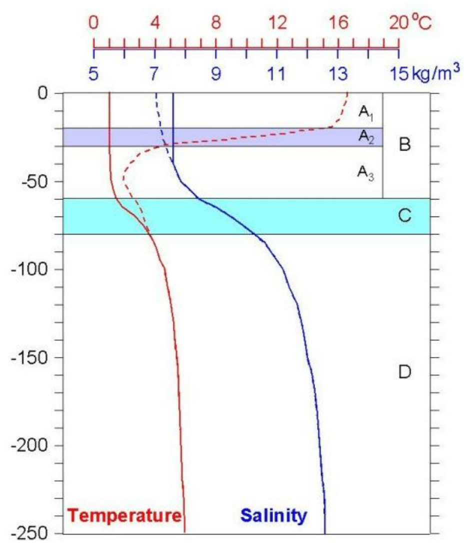
- wind transport in Ekman layer $\Rightarrow$ compensation flow below
- vertical transport due to continuity $w_i(z,t) = \dfrac{1}{A_i}\displaystyle\int_z^{H_i}(q^-_{i+1/2} - q^+_{i-1/2})dz$ has to be balanced by halocline erosion
- mixing in the halocline is mainly due to internal waves, $K_i^V = \dfrac{\alpha}{N_i}$

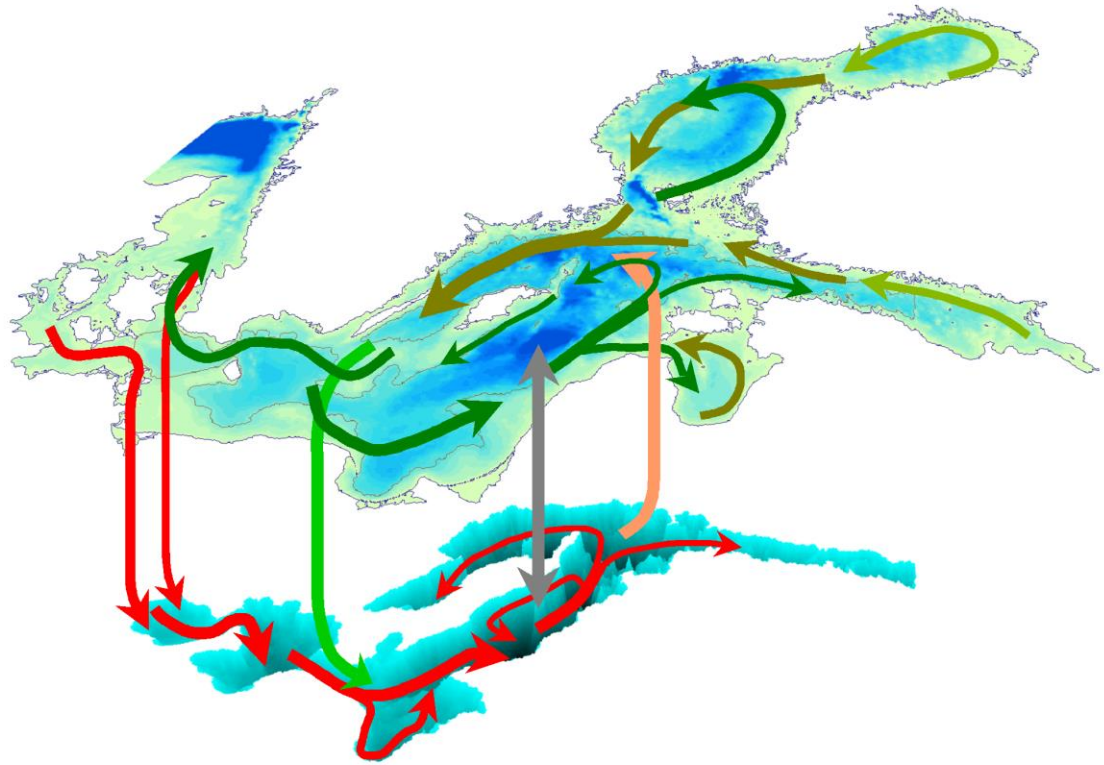
Baltic Sea water cycle

Surface salinity



Stratification





Elken & Matthäus, BACC 2008

Baltic Sea drainage basin (catchment area)

Annual river discharge is 2.1% of the sea volume

80% of freshwater enters into the NE bays

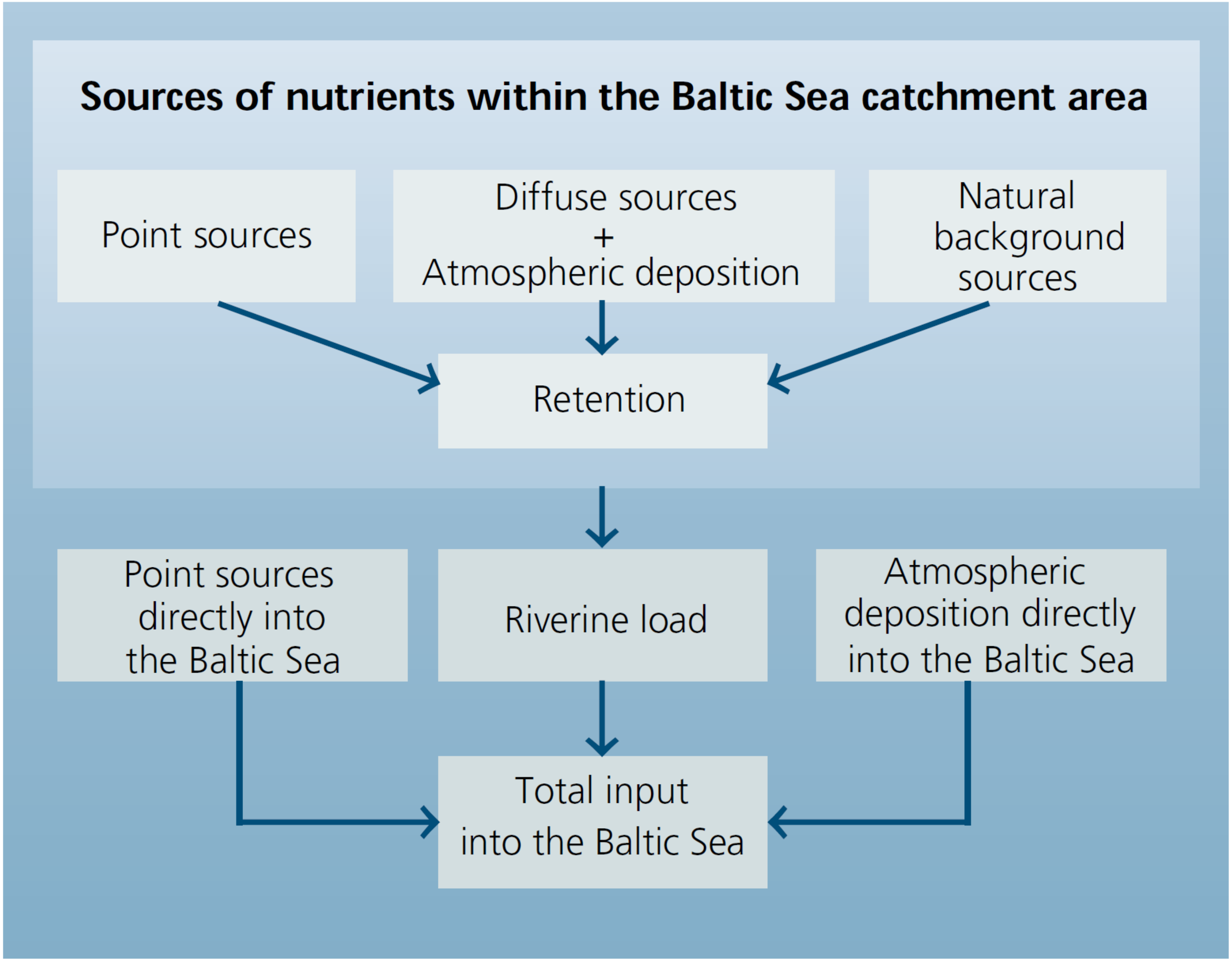


Figure 3.1 Conceptual model of nutrient sources and loads to the Baltic Sea.

HELCOM BSEP115B (2009)

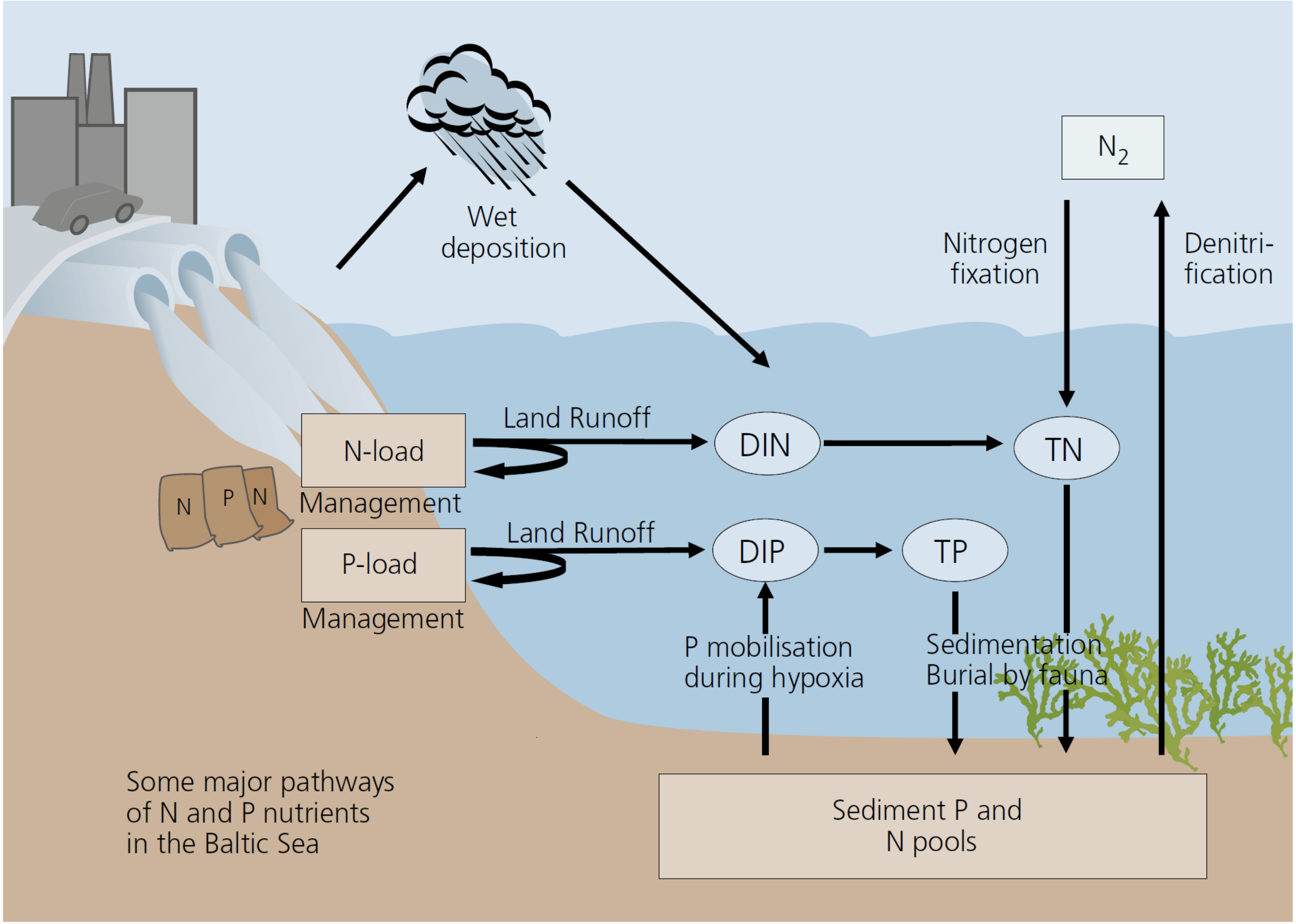


Figure 2.3 Simplified conceptual model for N and P nutrients in the Baltic Sea, where DIN = Dissolved inorganic nitrogen, TN = Total nitrogen, DIP = Dissolved inorganic phosphorus and TP = Total phosphorus. Flows along arrows into the blue sea area tend to increase concentrations, and flows along arrows out from the sea act in the opposite direction. Management refers to nutrient load reductions.

HELCOM BSEP115B (2009)

Nutrient limitation

In the seawater the nutrients N:P are consumed by 16:1 Redfield ratio (molar values). If in „general“ N:P > 16 then the sea area is P limited, otherwise N limited.

With N limitation (most of the Baltic, except Bay of Bothnia), there can be more or less P but it does not affect eutrophication. All additional N input is consumed for eutrophication, since there is enough P.

A special case is cyanobacteria blooming during end of July – August. They can fix N from the atmosphere, therefore they are limited by P while other phytoplankton is limited by N. For cyanobacteria blooms there must be high temperature and enough P in the surface layers, usually formed during the preceding winter.

P is often released from the sediments, when anoxic conditions take place. Nutrients in sediments have been accumulating over longer time scales.

Average nutrient loads to the different parts of the Baltic

Baltic Nutrient Noad (thousand tons/year of N and P)

Basin and Area	Riverine Load, Natural + Anthropogenic	Coastal Point Sources	Atmospheric Load, Natural + Anthropogenic	Sum Total	N:P Ratio (molar)
Gulf of Bothnia* (115,500 km^2)	N: 100 P: 5	N: 10 P: 1	N: 48 P: <1	N: 158 P: 6	58
Baltic proper (211,100 km^2)	N: 363 P: 23	N: 27 P: 4	N: 185 P: 2	N: 575 P: 29	44
Gulf of Finland (29,600 km^2)	N: 126 P: 6	N: 31 P: 4	N: 23 P: <1	N: 180 P: 10	40
Gulf of Riga (16,300 km^2)	N: 113 P: 2	N: 5 P: 1	N: 11 P: <1	N: 129 P: 3	95
Baltic Sea total (373,200 km^2)	N: 702 P: 37	N: 73 P: 9	N: 267 P: 3	N: 1042 P: 48	48

* Gulf of Bothnia = Bothnian Bay + Bothnian Sea. Modified after Elmgren and Larsson[49].

Sources: Riverine load[35], coastal point sources[45], atmospheric N load[53] multiplied by 1.25 to include organic N. Atmospheric P load calculated as 1% of N load.

All the loads are P limited, while most of the sea areas are N limited due to the internal processes

Elmgren and Larsson, 2001

Evolution of eutrophication concepts

Table 3. Changes over time in our views of Baltic proper nutrient pollution.

Early view, ca 1968	Mid-way view, ca 1985	Present or emerging view
Is there open-sea eutrophication? P increase in water shown, N increase not documented	Open-sea eutrophication major problem, both N and P increase continuously	Open-Baltic eutrophication still a major problem, but nutrients no longer increasing
Sediments could be source of increased P concentration	Sediment sink for both N and P, increases must come from land/air and be anthropogenic, continuous increase of N and P loads suspected	Same, except loads have changed little since 1970, internal dynamics important for nutrient changes, decreased N and P fertilizer use, but recovery time long
Only P removal needed	Both N and P removal needed	Same for coastal zones, renewed debate over need for N removal for open sea
Nitrogen unimportant	N presently main limiting nutrient, N removal costly (6–8 USD kg^{-1} N)	N main limiting nutrient since ~7000 years, N removal now cheaper (2–4 USD kg^{-1} N)

Do we need to remove P or N or both

N removal costly

Elmgren, 2001 (AMBIO)

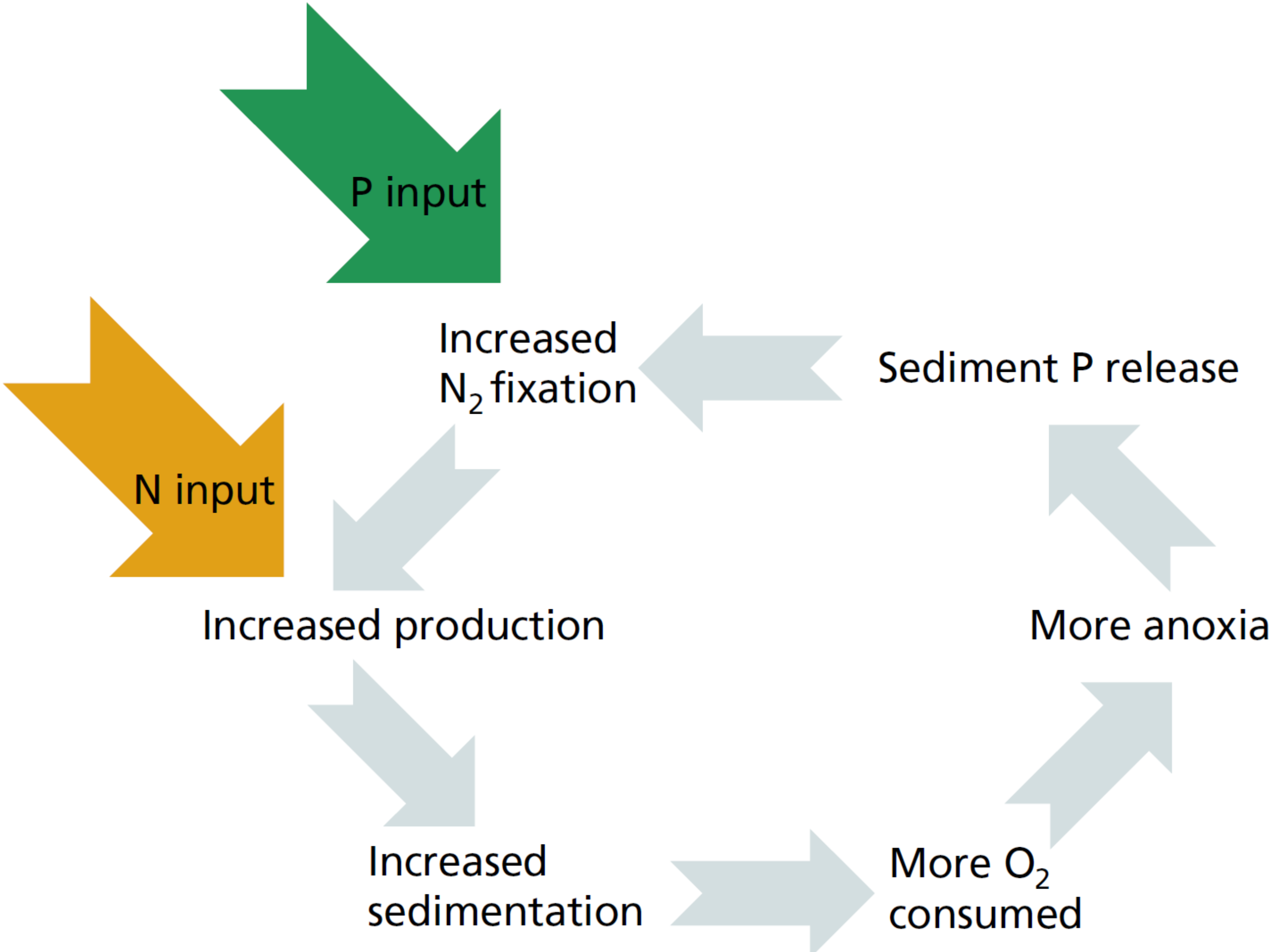
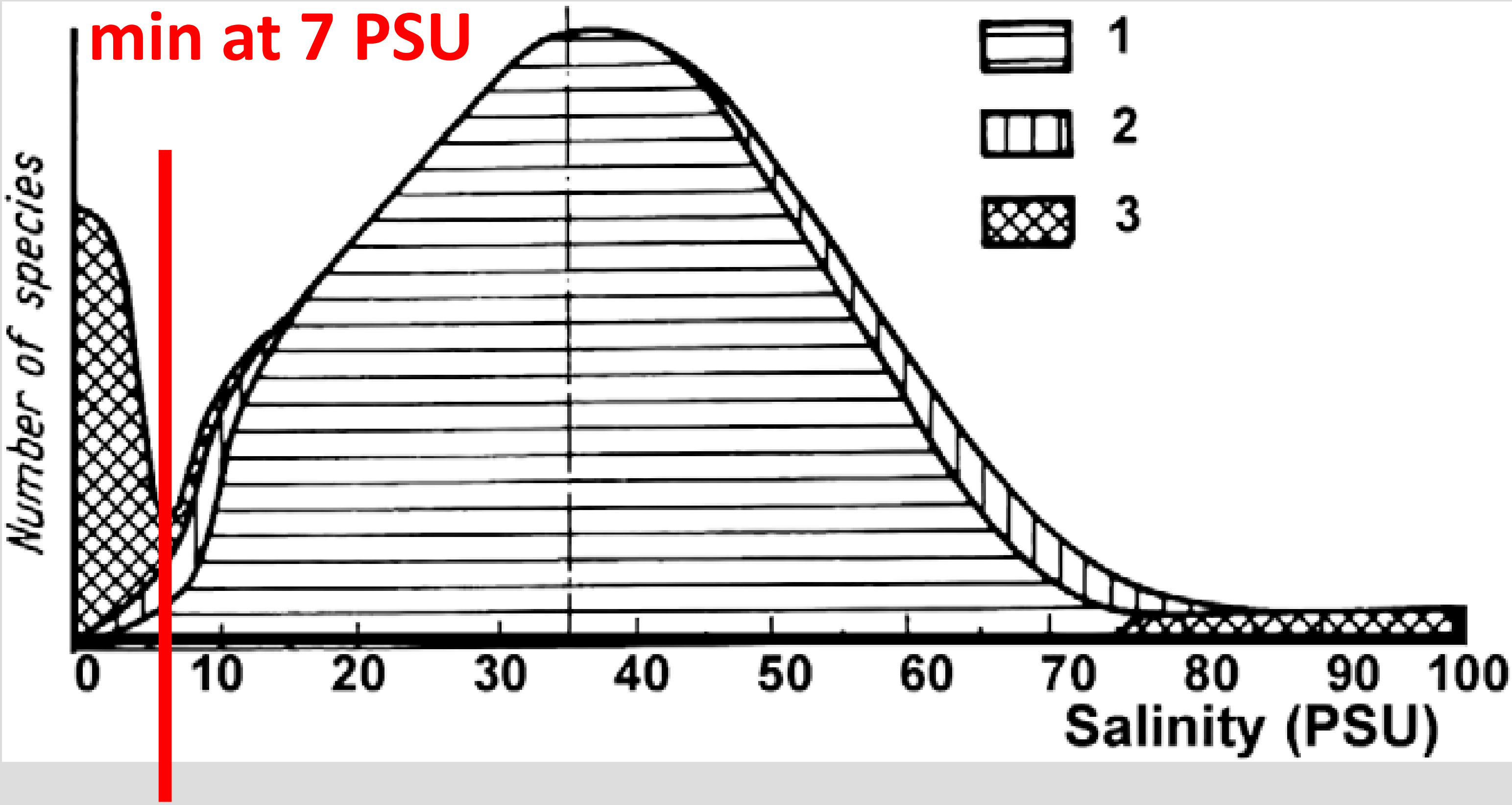
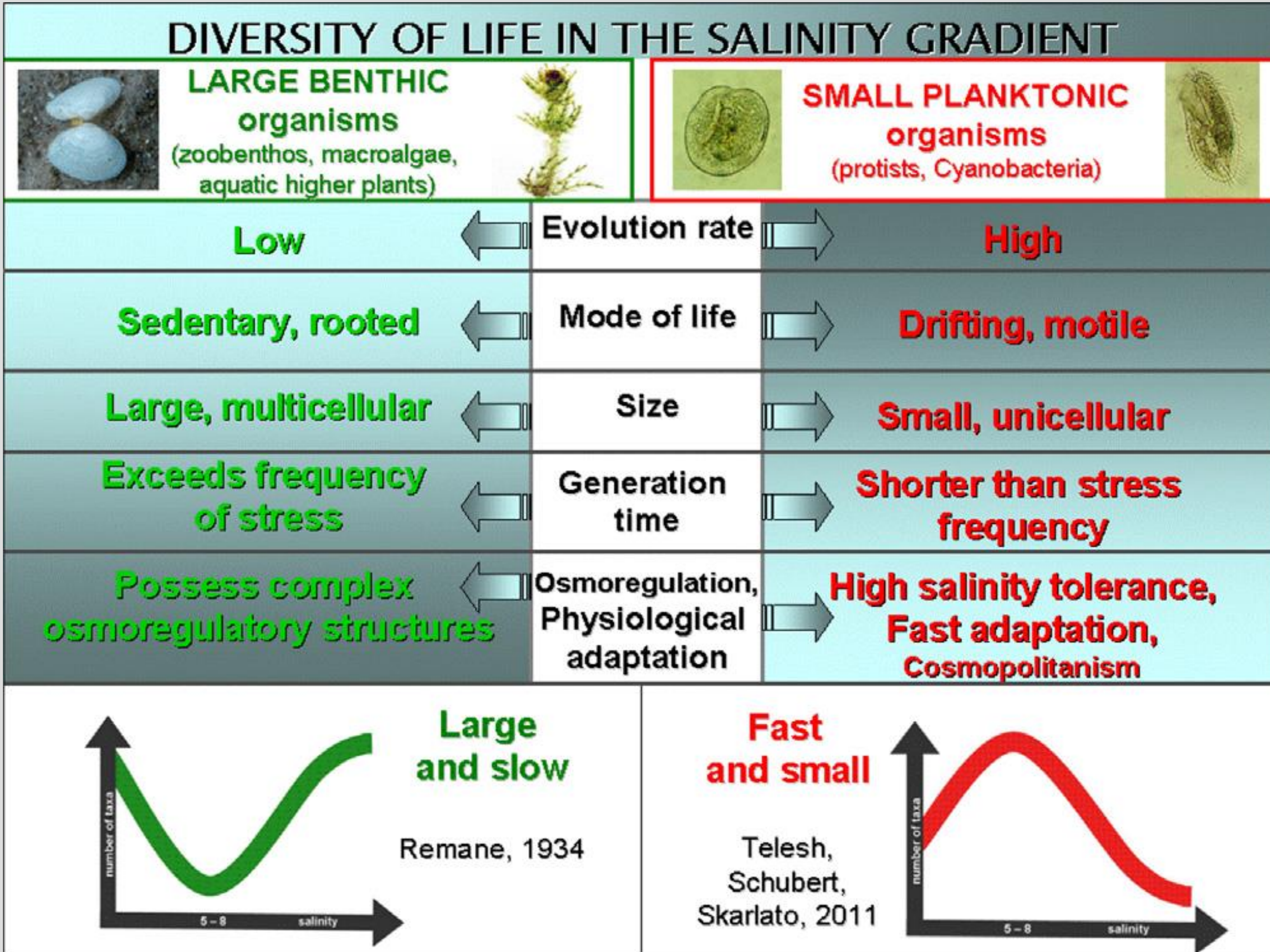


Figure 1.4 **A simple conceptual model of the positive feedbacks between nitrogen and phosphorus in the Baltic Sea. Based on Elmgren (2006).**

HELCOM BSEP115B (2009)



Number of marine animal species (1), brackish water and euryhaline animal species of marine origin (2), and freshwater species (of freshwater origin, 3) (after Khlebovich (1962, 1969)).



Telesh et al, 2013: Life in the salinity gradient

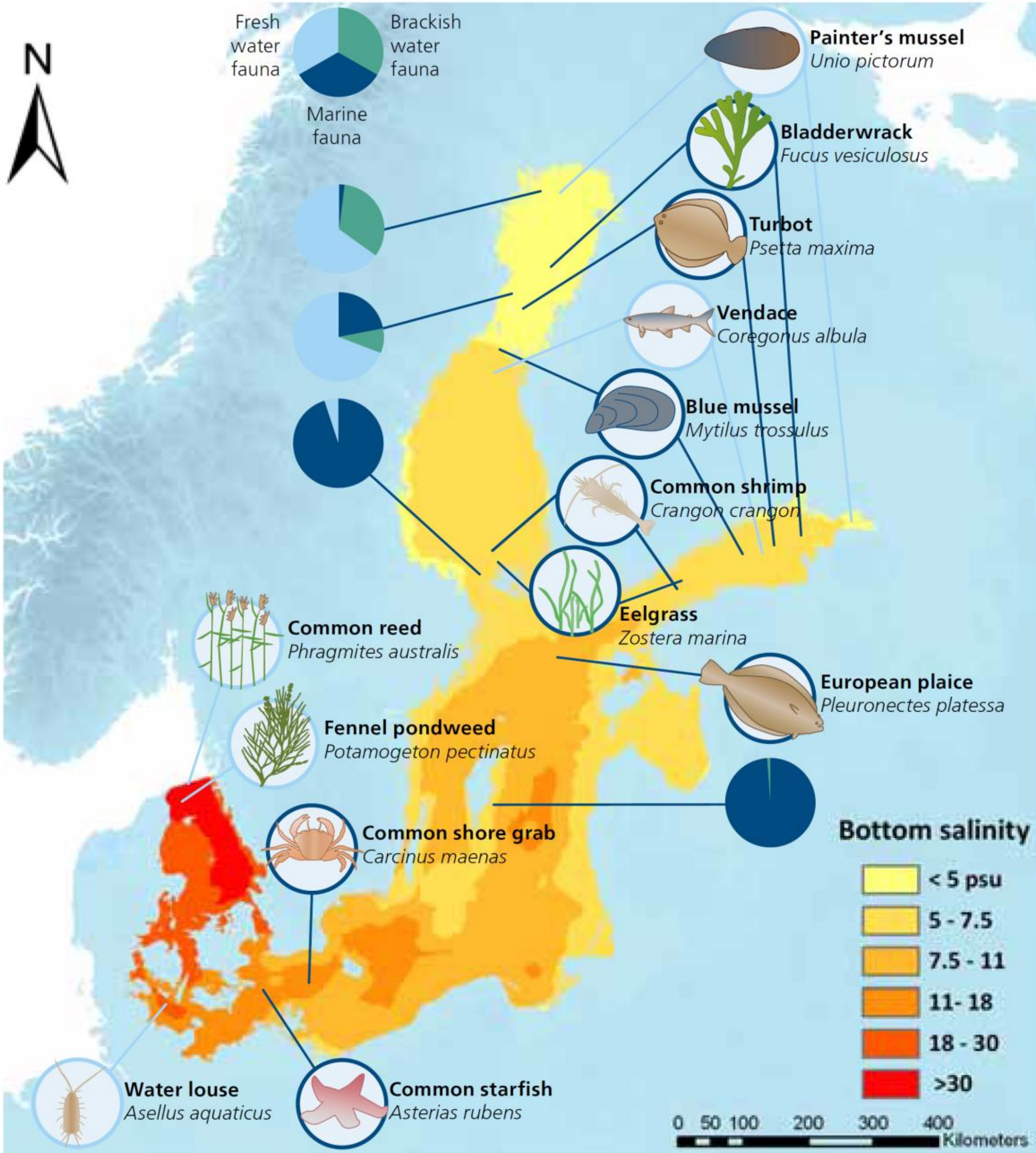


Figure 1.2 Distribution limits of some marine (dark blue) and freshwater (light blue) species due to salinity, as well as bottom salinity (Al-Hamdani and Reker 2007). Based on Fuhrman et al. (2004).

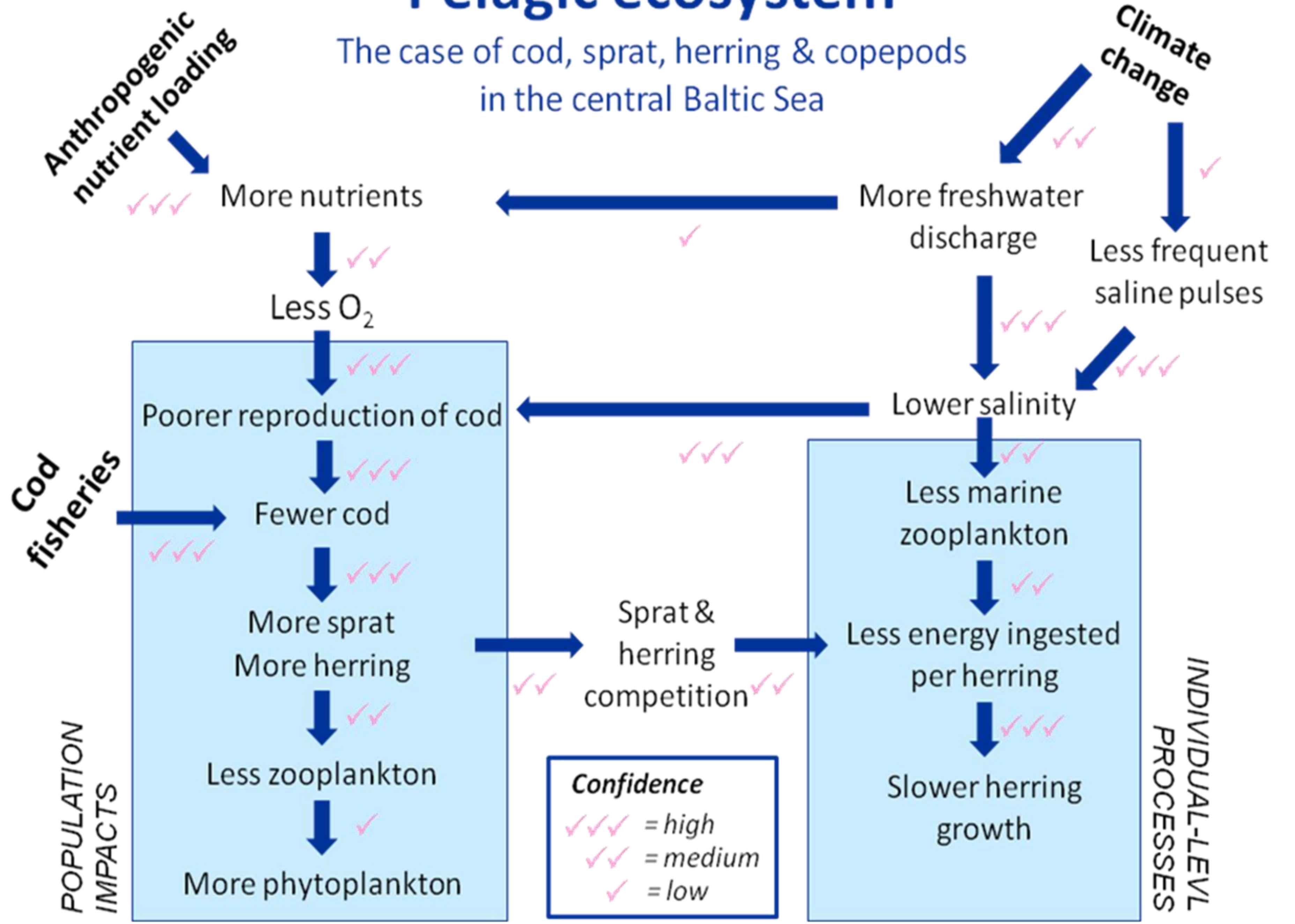
Typical marine (dark blue) and freshwater (light blue) species depending on the mean bottom salinity

HELCOM BSEP122 (2010)

Viitasalo et al, 2014 (BACC2)

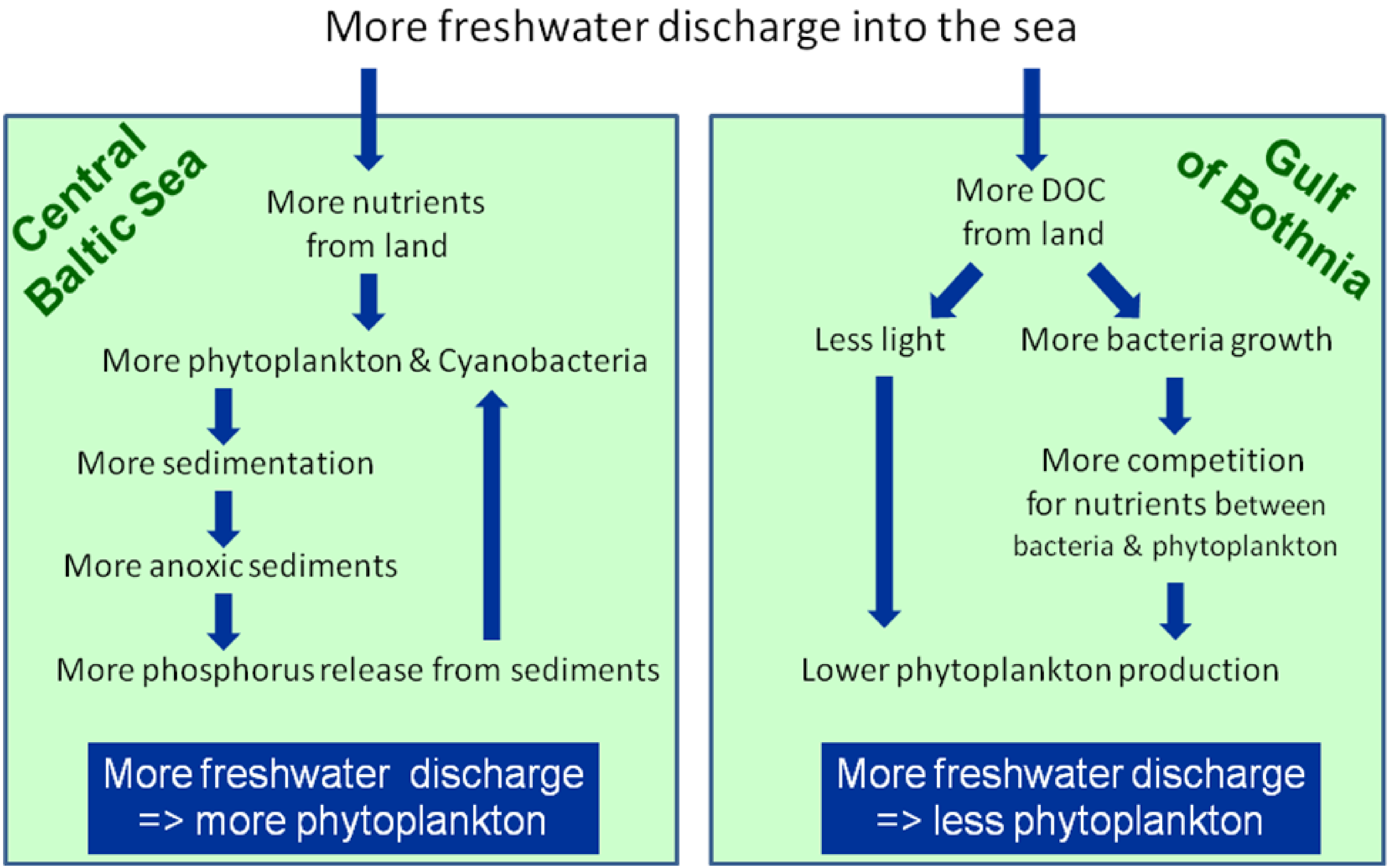
Pelagic ecosystem

The case of cod, sprat, herring & copepods
in the central Baltic Sea



Viitasalo et al, 2014 (BACC2)

Eutrophication

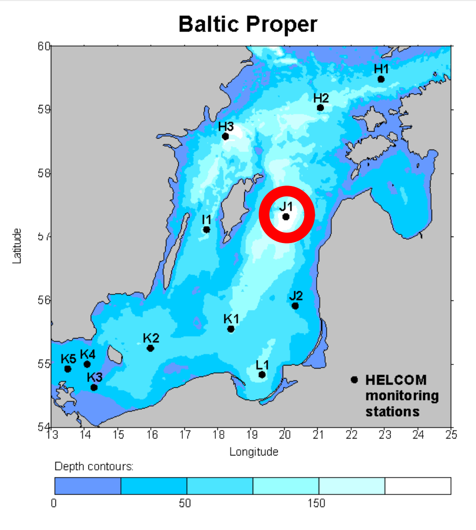


2. State and recent changes of the Baltic Sea

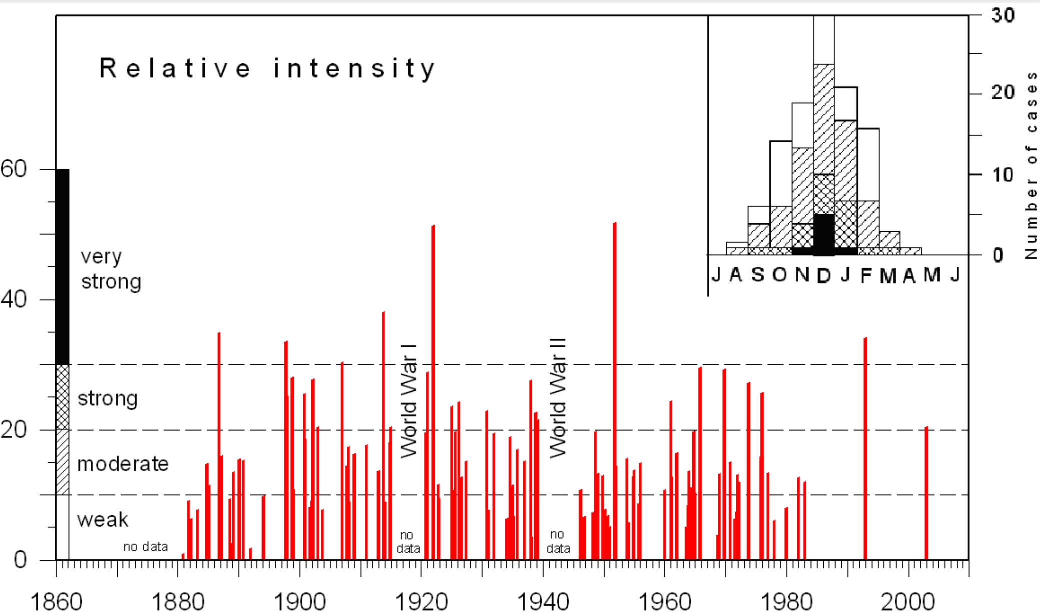
Topics:

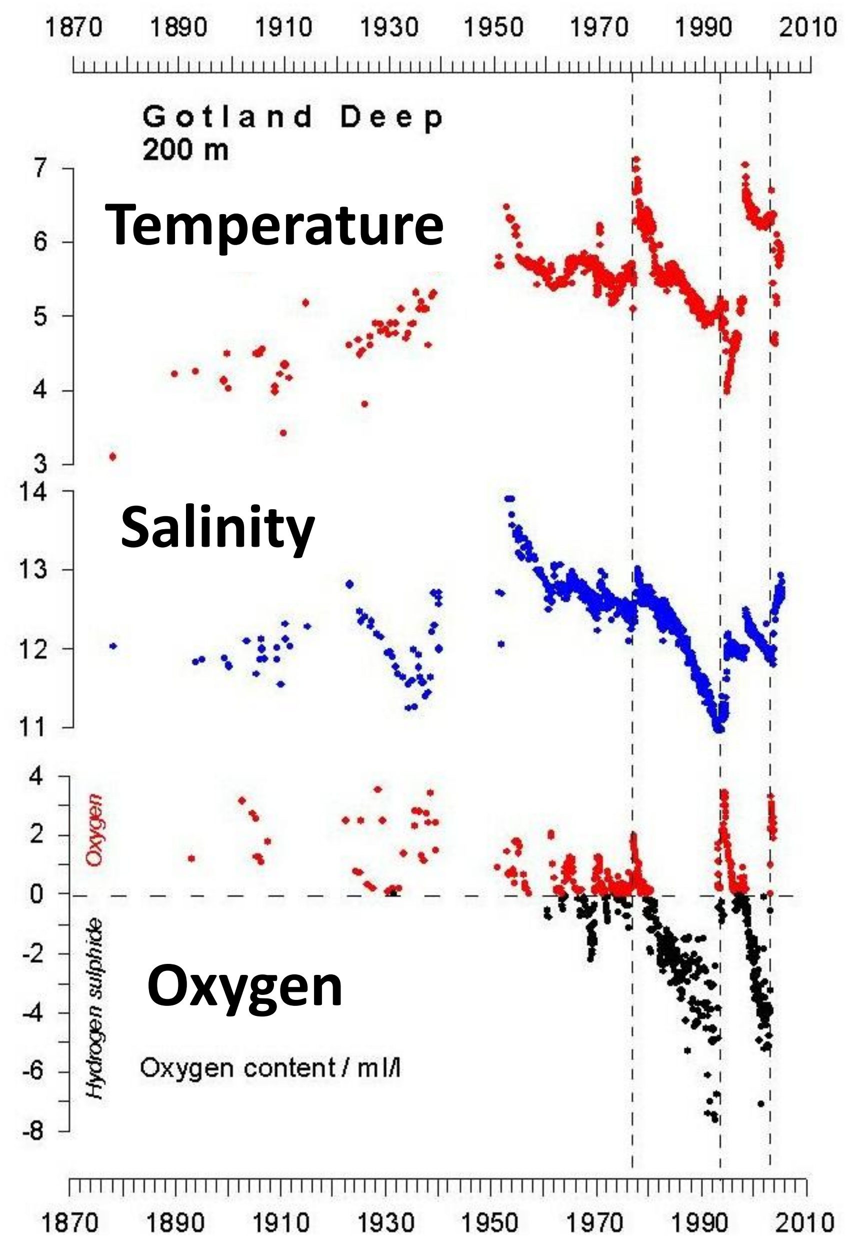
- **physical variables and climate**
- **nutrient loads and responses**
- **quantification of ecological status**

Changes (past 130 years) of physical system



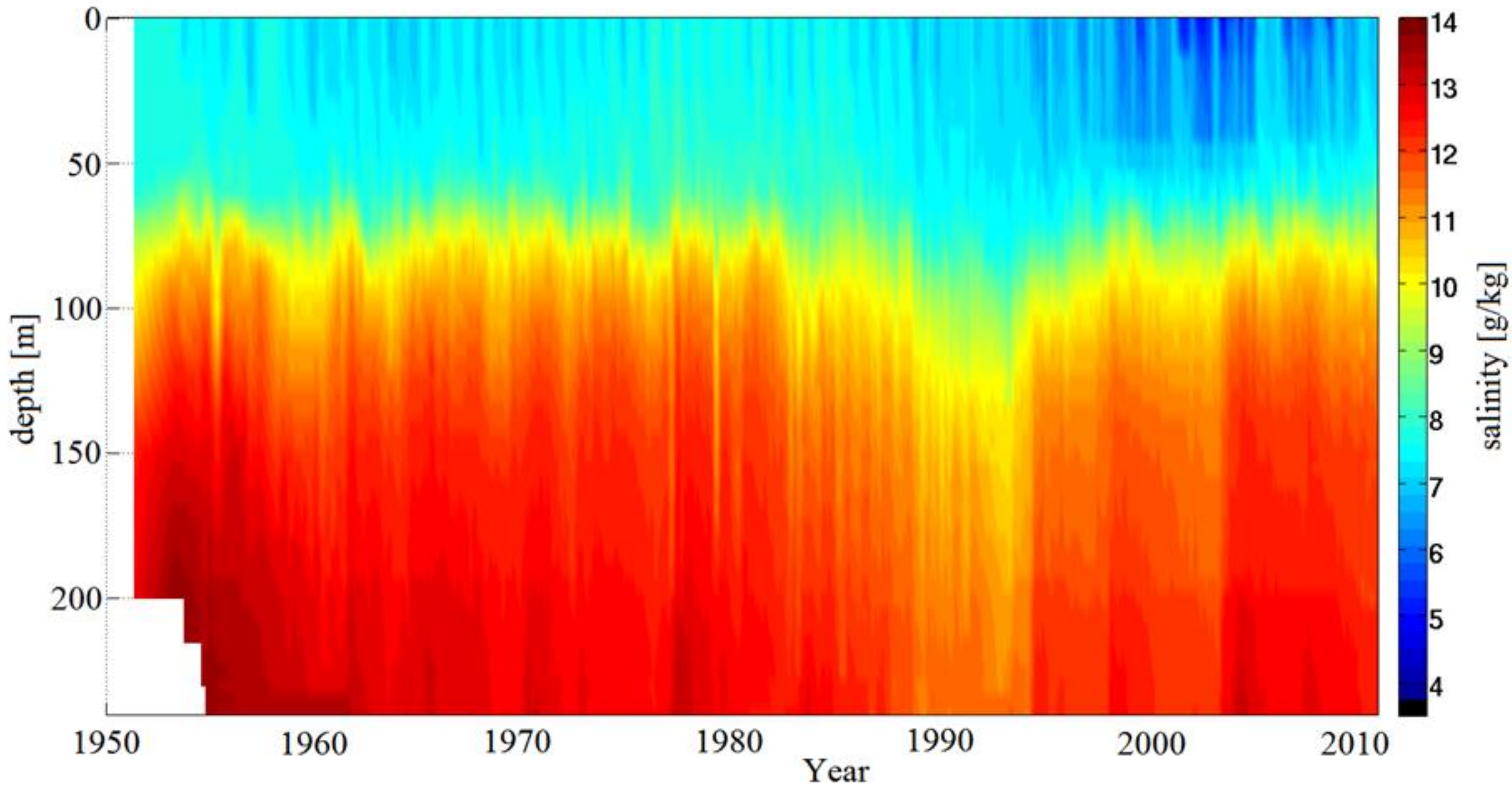
Major Baltic Inflows (MBI) and changes in the deep layers of the sea





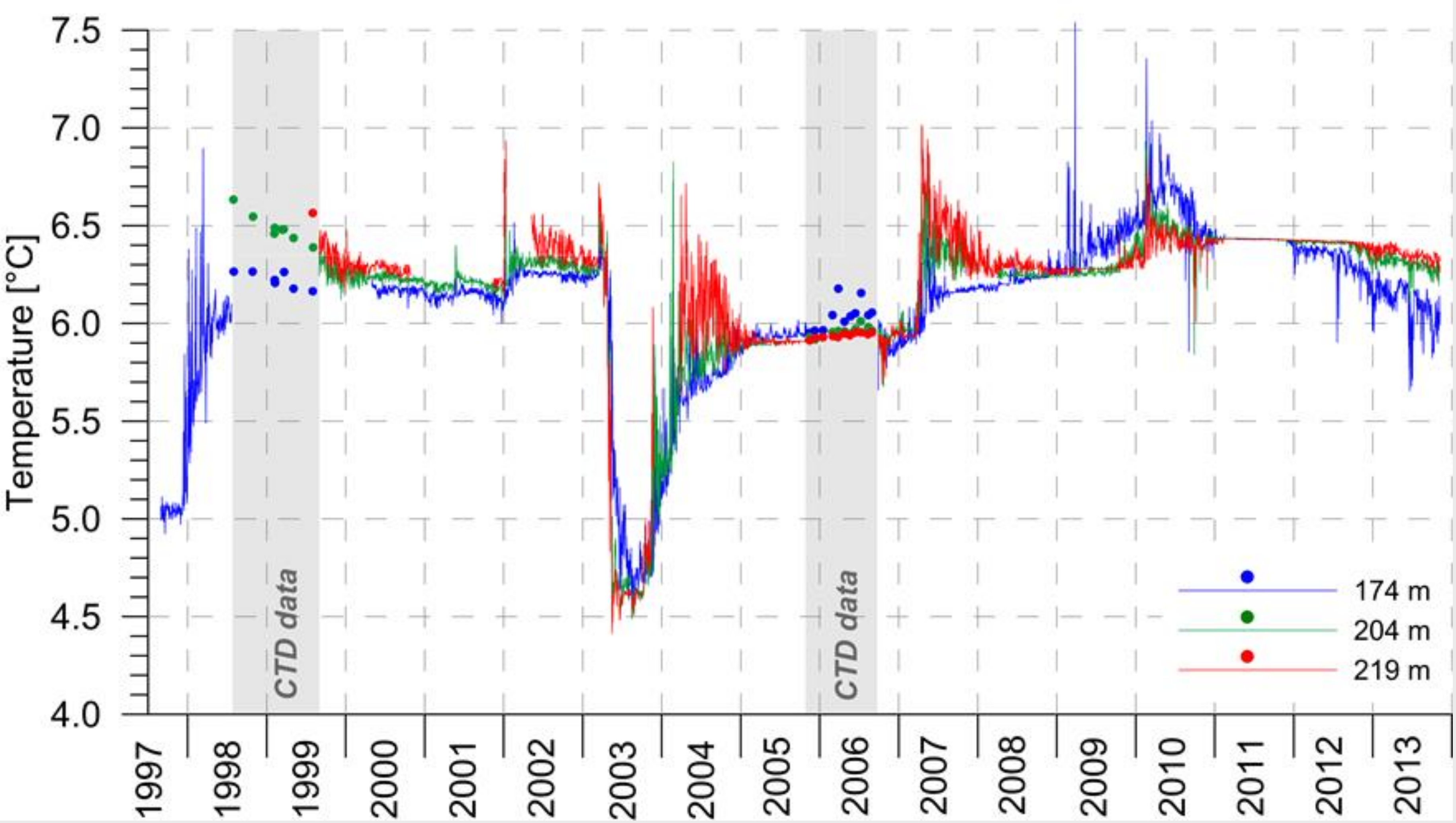
Elken & Matthäus, BACC 2008

Observed salinity in the Gotland Deep



BACC2

Observed deep temperature in the Gotland Deep

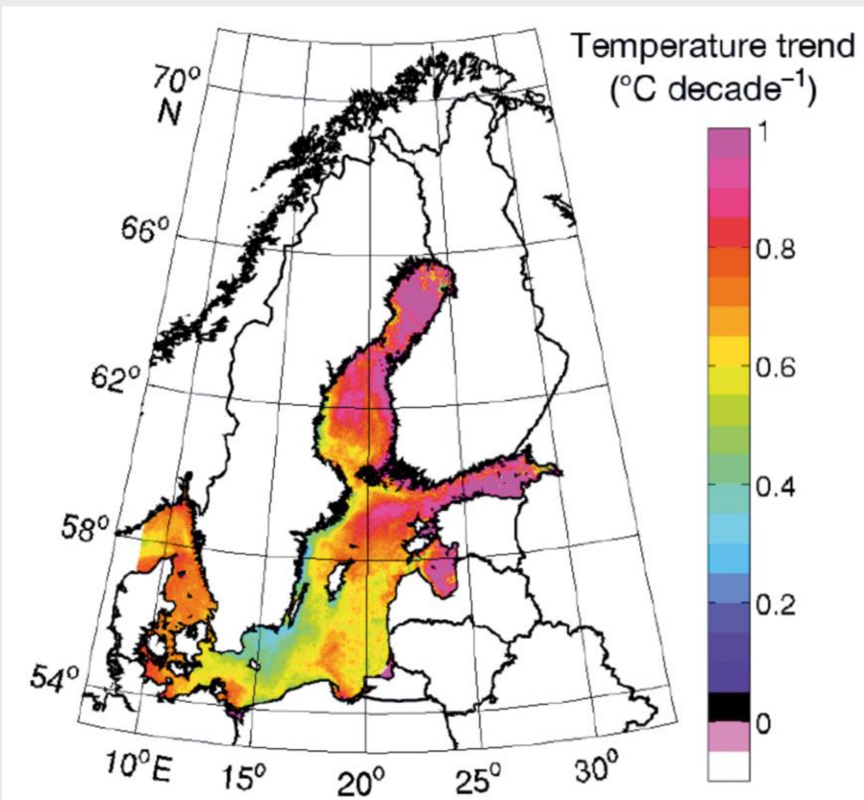


This "Hagen curve" is redrawn from Feistel et al. (2008) by the authors using recent data.

Changes of marine conditions: sea surface temperature and upwelling

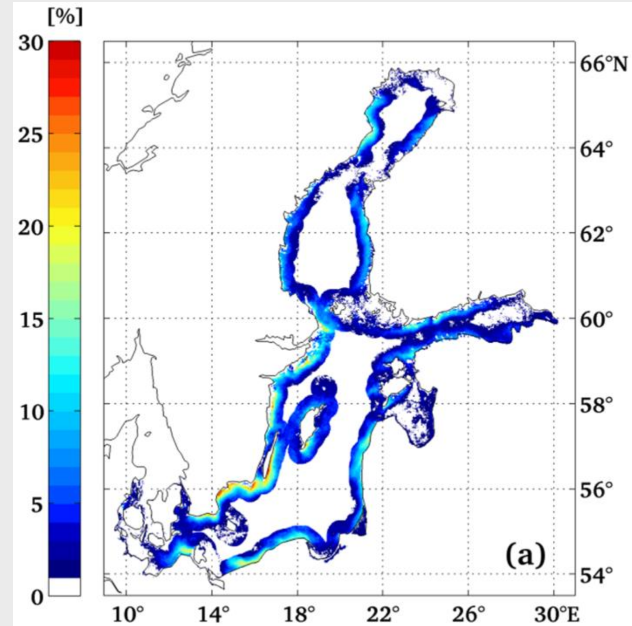
Analysis from remote sensing data 1990-2008

Sea surface temperature has recently increased. Frequency of upwelling on western coasts has increased due to the increased westerly winds.

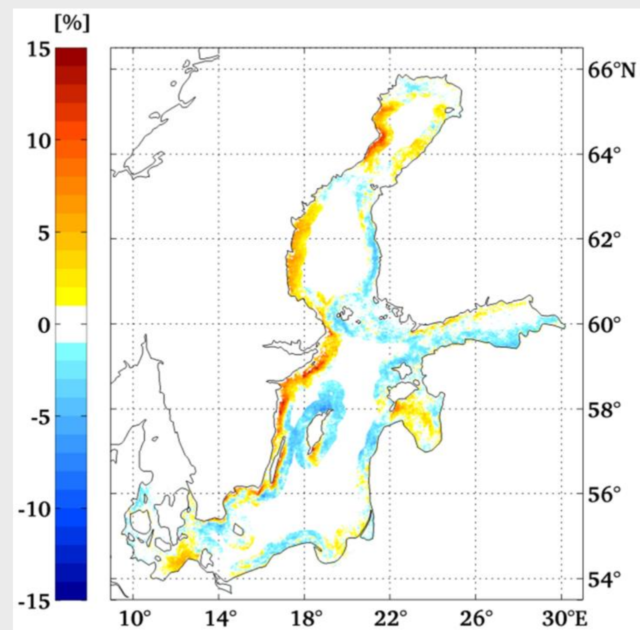


Lehmann et al 2011

Upwelling frequency



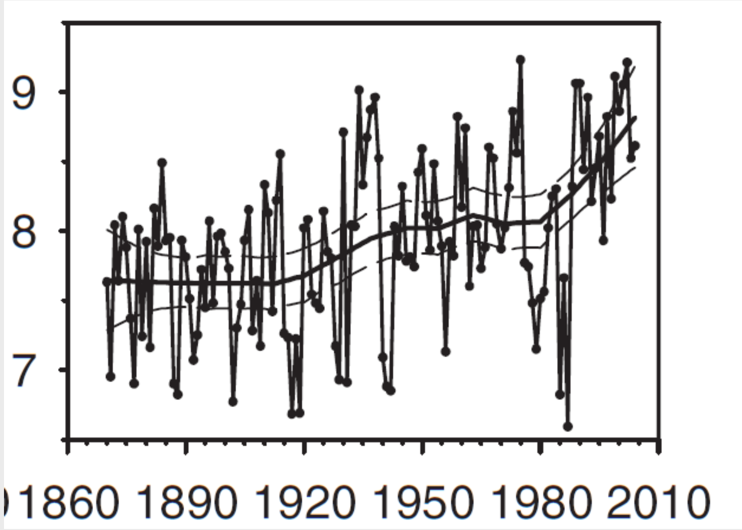
Trend in upwelling frequency



Lehmann et al 2012

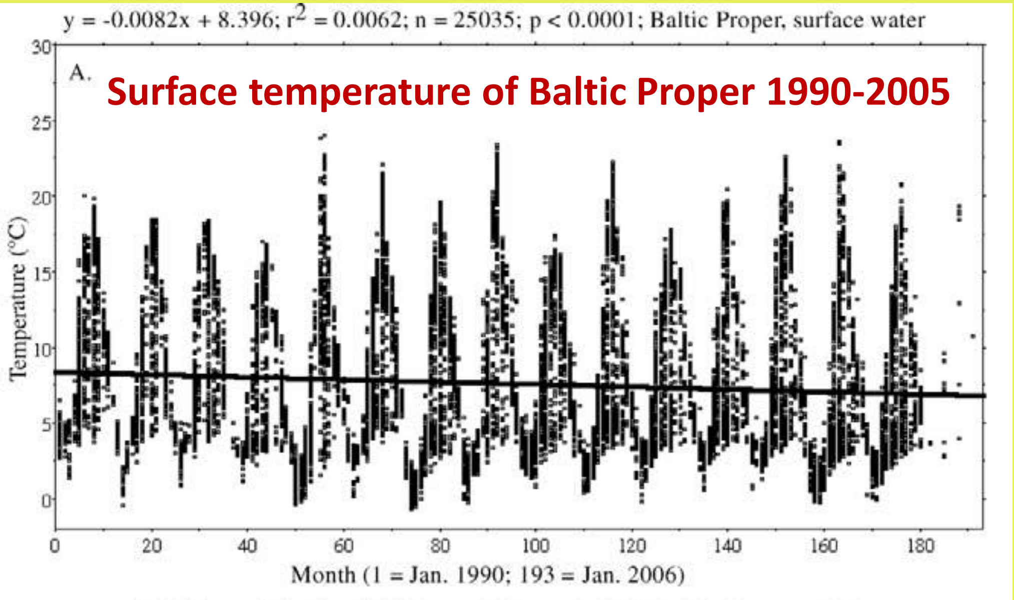
Changes of marine conditions / surface temperature: *in-situ*

Annual mean temperature has recently increased. Highest increase has occurred during summer.



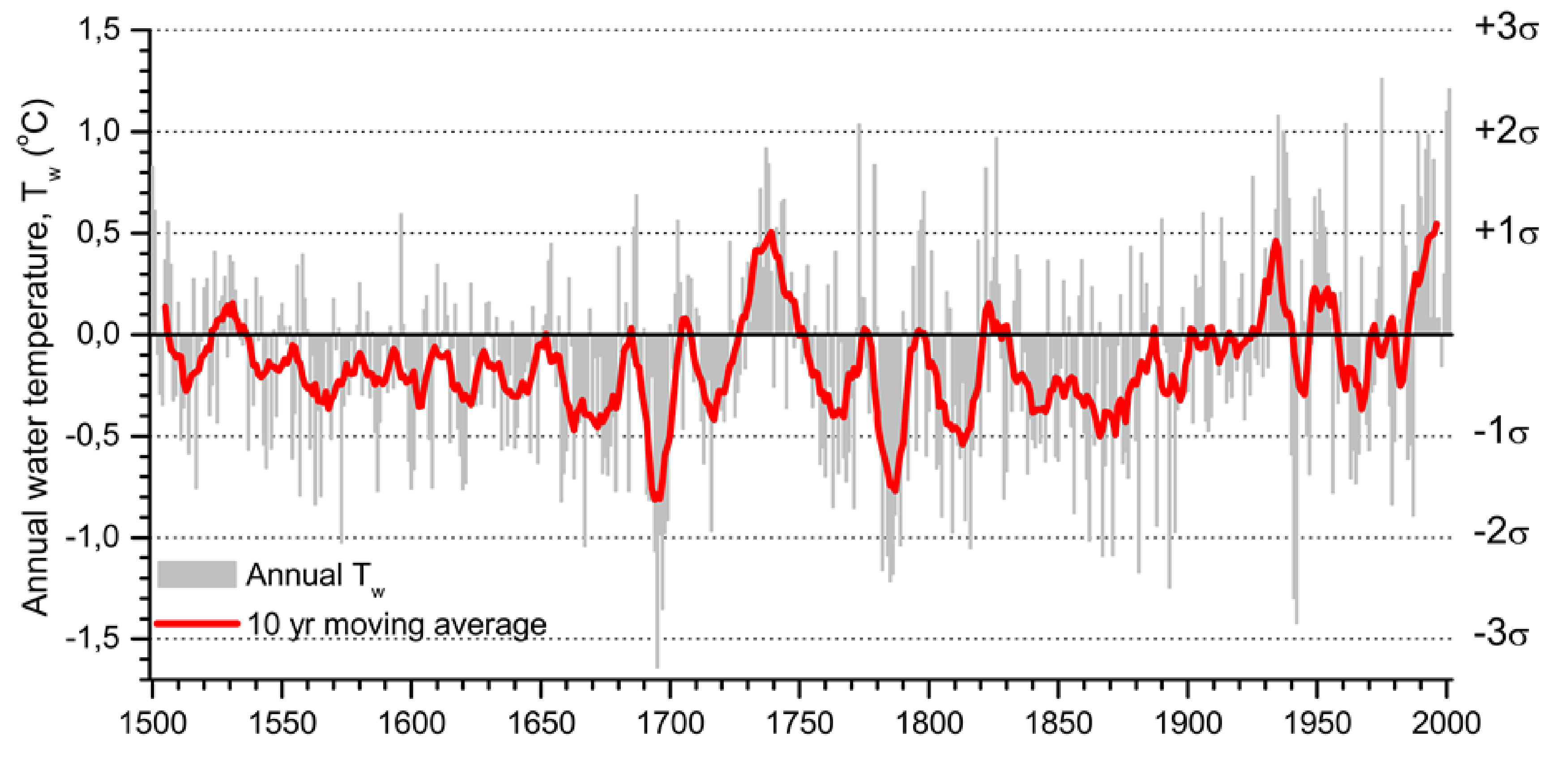
Normalized and homogenized data set, processed by advanced methods.
MacKenzie & Schiedek, 2007

… also faulty assessment may be obtained: surface temperature has decreased ??



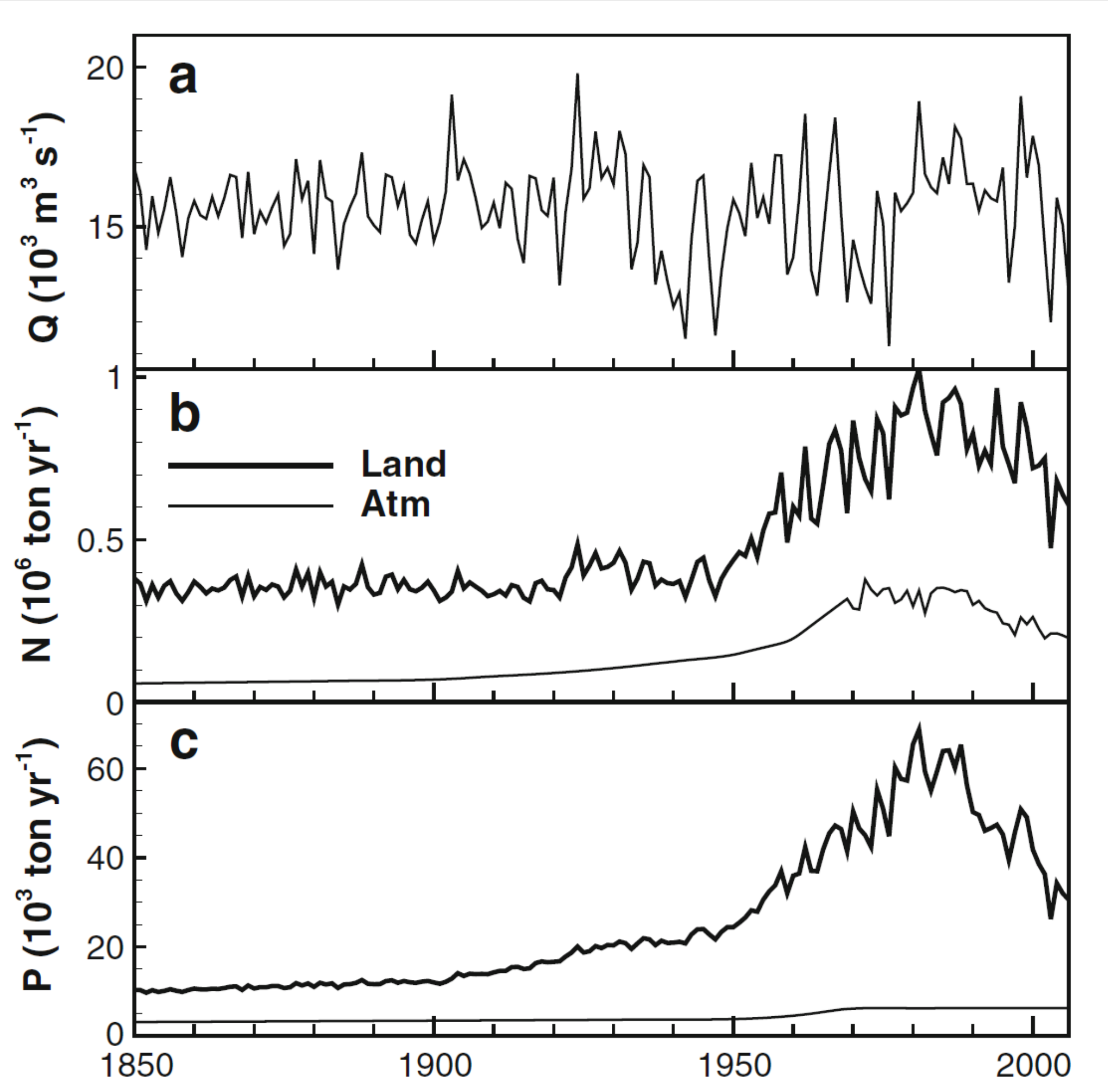
HELCOM/ICES data from irregular monitoring, simple regression. During recent decades with less ice, fraction of wintertime observations has increased causing fictional „cooling".
WoS journal paper, 2008

Annual and spatial mean temperature of the Baltic Sea



Anomalies of the annual and decadal moving average of the modeled Baltic Sea spatially mean water temperature over the period 1500-2001. The dotted horizontal lines are the standard deviations of the water temperature during the standard period 1900-1999 (adopted from Hansson and Omstedt 2008).

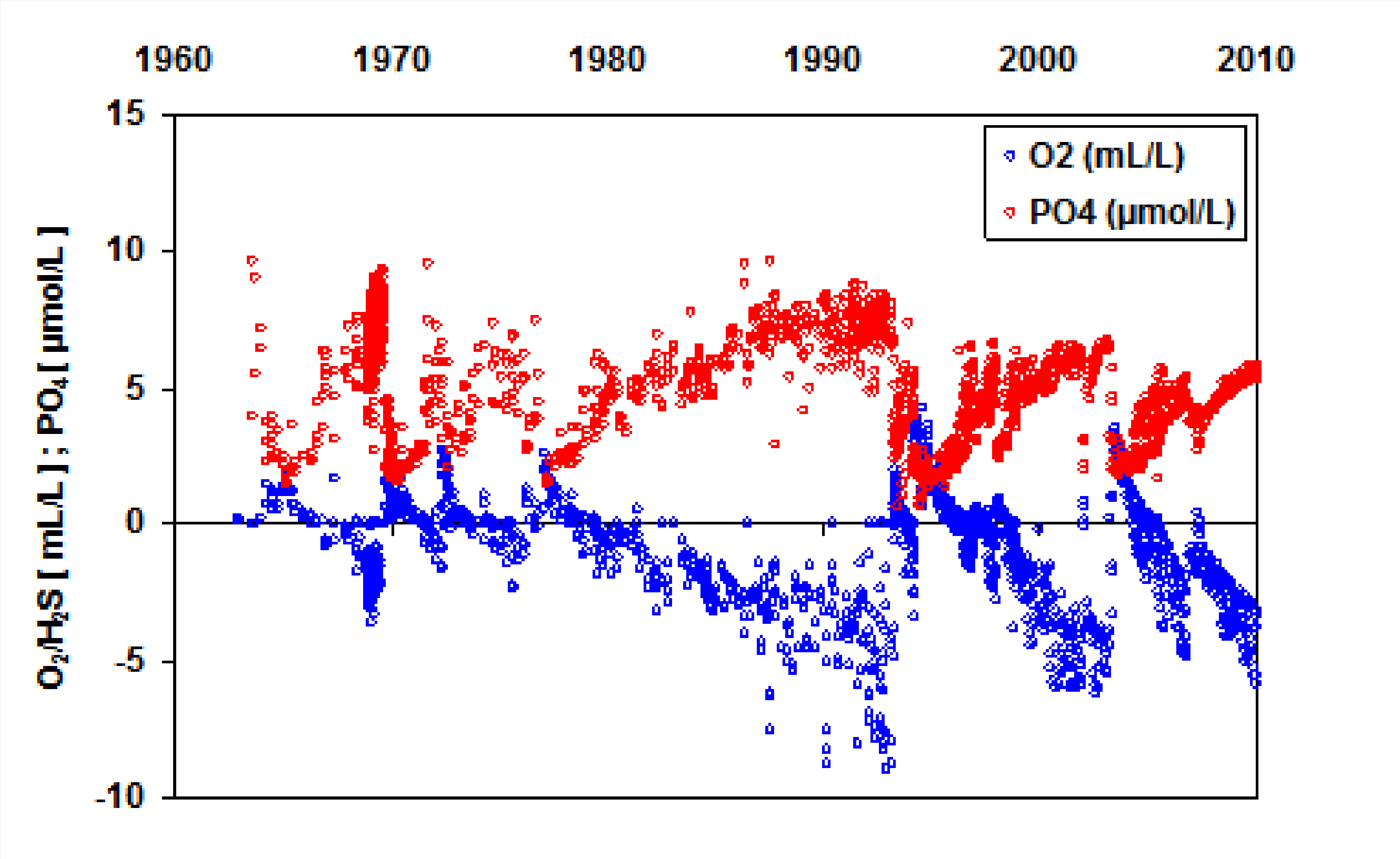
Freshwater discharge and nutrient loads, past 150 years



Time series of annual average total river runoff (Q), nitrogen (N), and phosphorus (P) loads from land and atmosphere to the whole Baltic Sea

Gustafsson et al, 2012

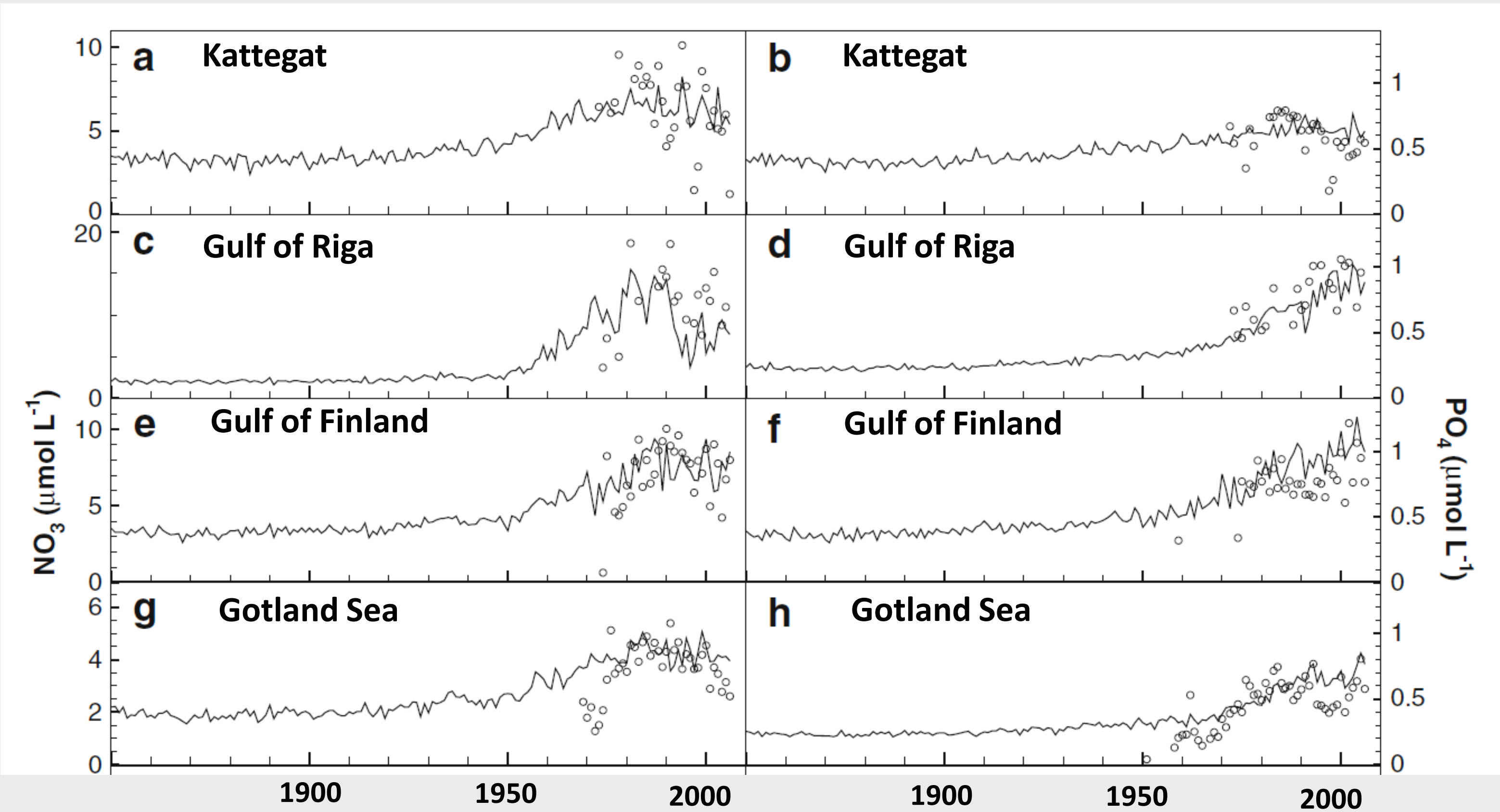
Near-bottom oxygen and phosphate in the Gotland Deep



Time series of PO_4 and O_2 concentrations in the deep water of the central Gotland Sea. Negative O_2 values represent hydrogen sulphide oxidation equivalents (Swedish National Monitoring Programme, SMHI).

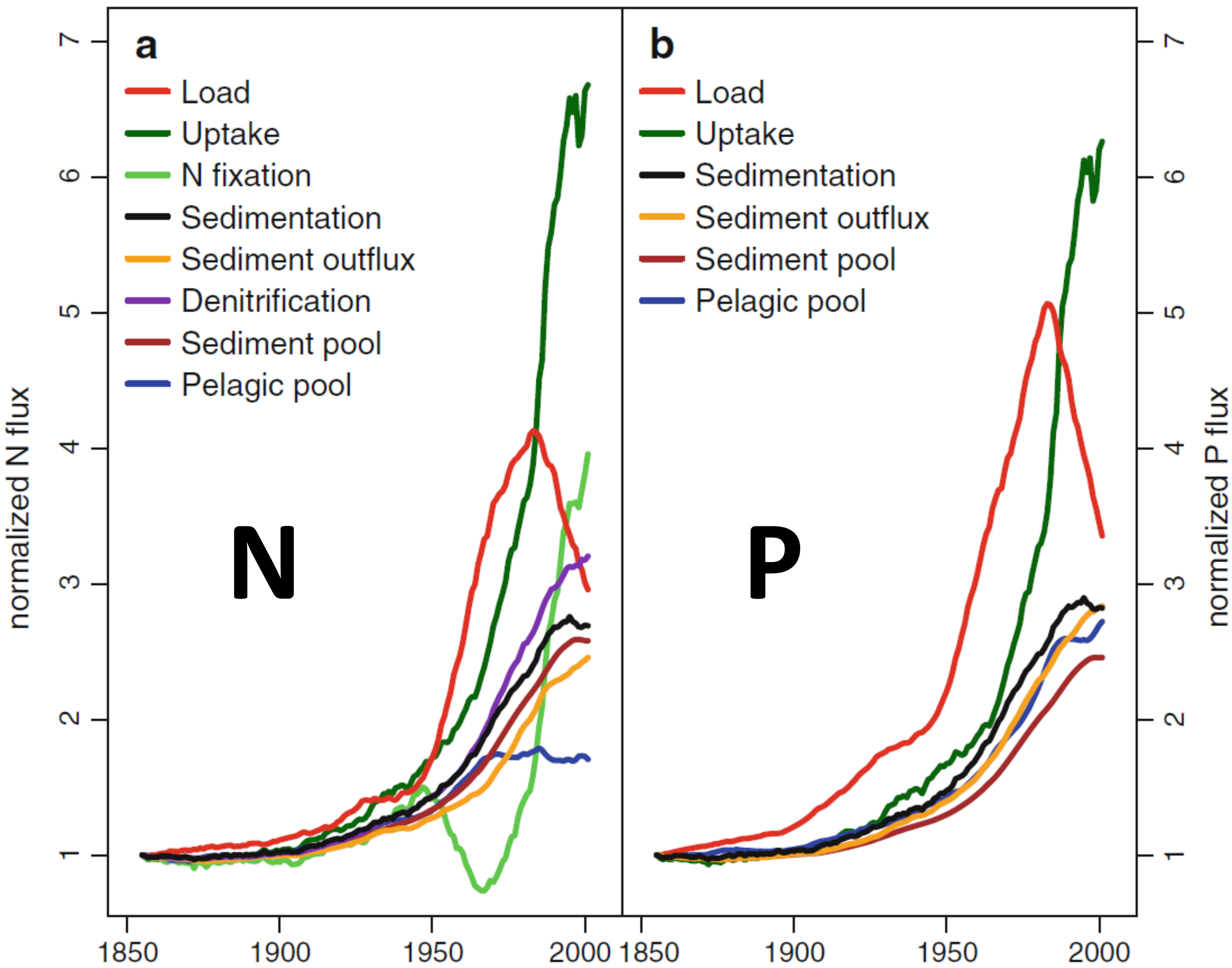
Reconstructed eutrophication indicators

Mean wintertime surface nutrients



Gustafsson et al, 2012

Time series of N and P fluxes and pools



While loads have decreased then nutrient uptake by phytoplankton and macroalgae still increased

Integrated over the whole Baltic Sea and smoothed by decadal (11-year) running mean.
The fluxes and pools are normalized with the 1850–1860 average.

Gustafsson et al, 2012

„Good Environmental Status“: Marine Strategy Framework Directive

Use Ecosystem Approach to management of the marine environment.

- It has a multisectoral focus
- It includes ecosystem services in decision making
- It recognises the tight coupling between social and ecological systems

Good Environmental Status to be defined for each sea region based on 11 descriptors

Descriptors for „Good Environmental Status“: Marine Strategy Framework Directive

1. Biodiversity
2. Non-indigenous species
3. Commercial species
4. Marine food webs
5. Human-induced eutrophication
6. Sea floor integrity
7. Hydrographical conditions
8. Contaminants
9. Contamination of fish and seafoods
10. Marine litter
11. Energy and noise

Nutrient management

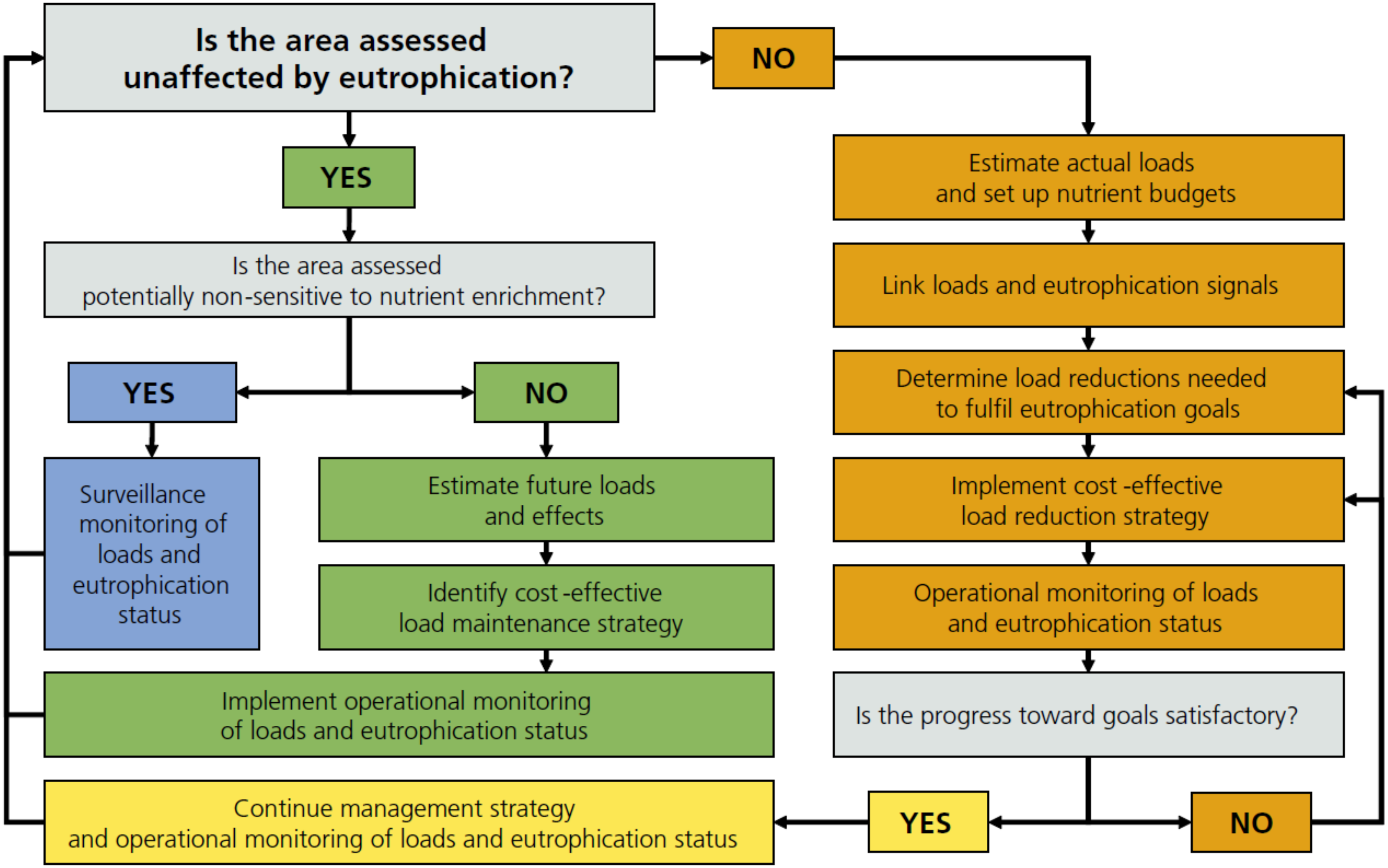


Figure 12. Framework for a Baltic Sea-wide nutrient management strategy. Based on National Research Council (2000) and Backer (2008).

HELCOM BSEP115B (2009)

Eval. of environmental status (left) and all impacts (right)

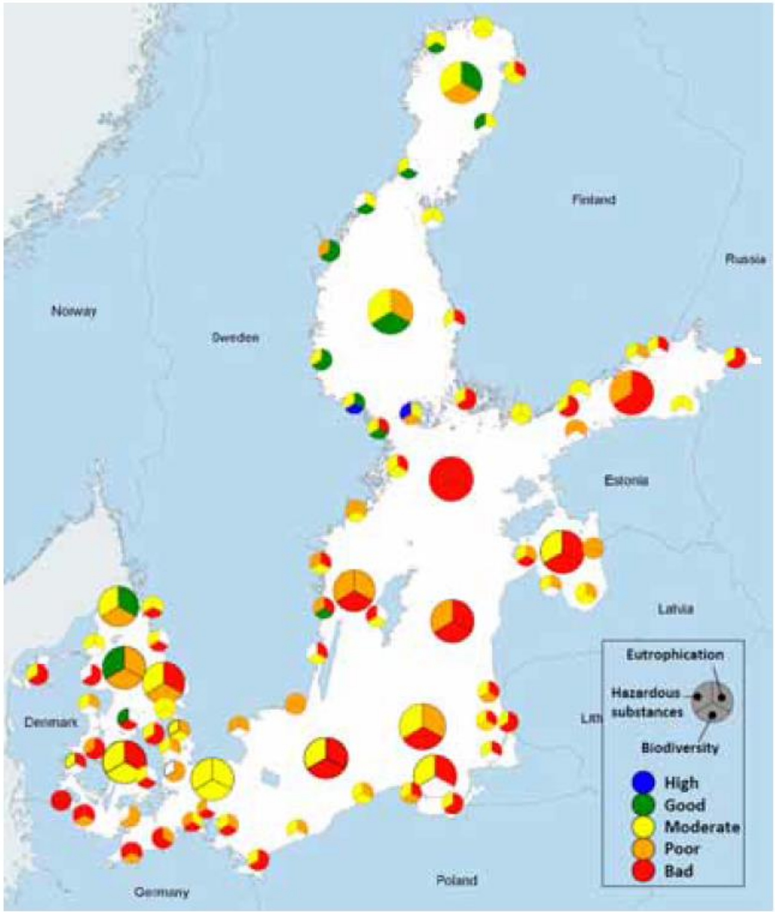
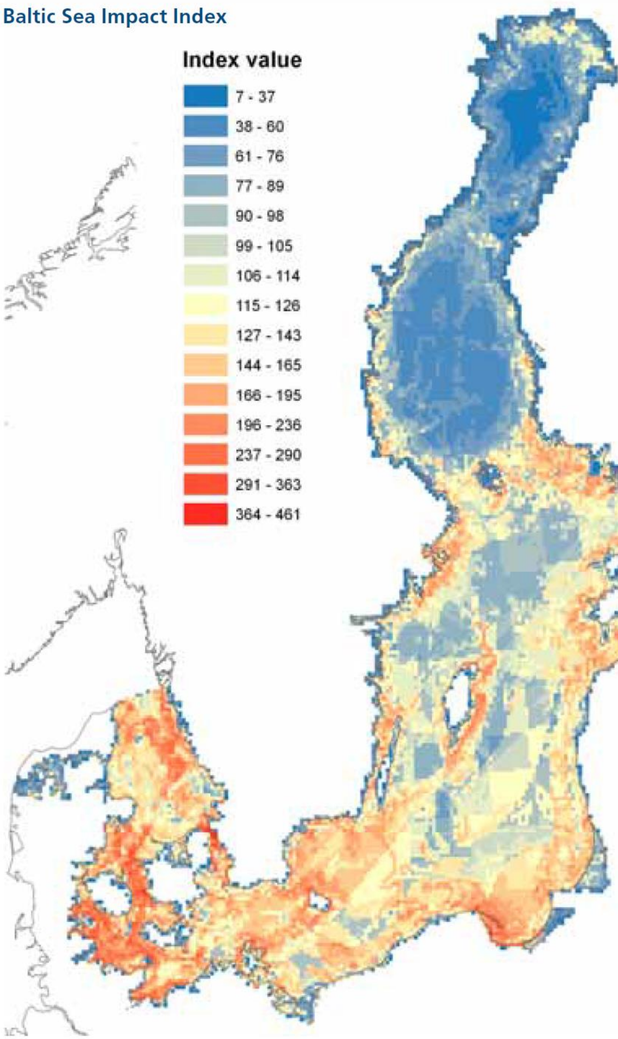


Figure 2.1 Presentation of the 'eutrophication status' from HEAT classifications, the 'hazardous substances status' from CHASE classifications and the 'biodiversity status' from BEAT classifications. See Section 1.6 for details. White areas in the pie charts denote a lack of classification; large pie charts represent assessments of open sea areas and small pie charts of coastal areas.



Index = weighted average of 52 layers

Figure 3.19 Baltic Sea Impact Index (BSII) showing the potential impact of anthropogenic pressures (52 pressure data layers) on 14 biological ecosystem data layers (species/biotopes/biotope complexes) present in areas of 5 km × 5 km. Please note that nitrogen load has not been included in the Baltic Sea Impact Index in the Bothnian Bay since it is not considered to be a pressure in that sub-basin where primary production is strictly limited by phosphorus.

HELCOM BSEP122 (2010)

Concept of arriving a „Good Environmental Status“

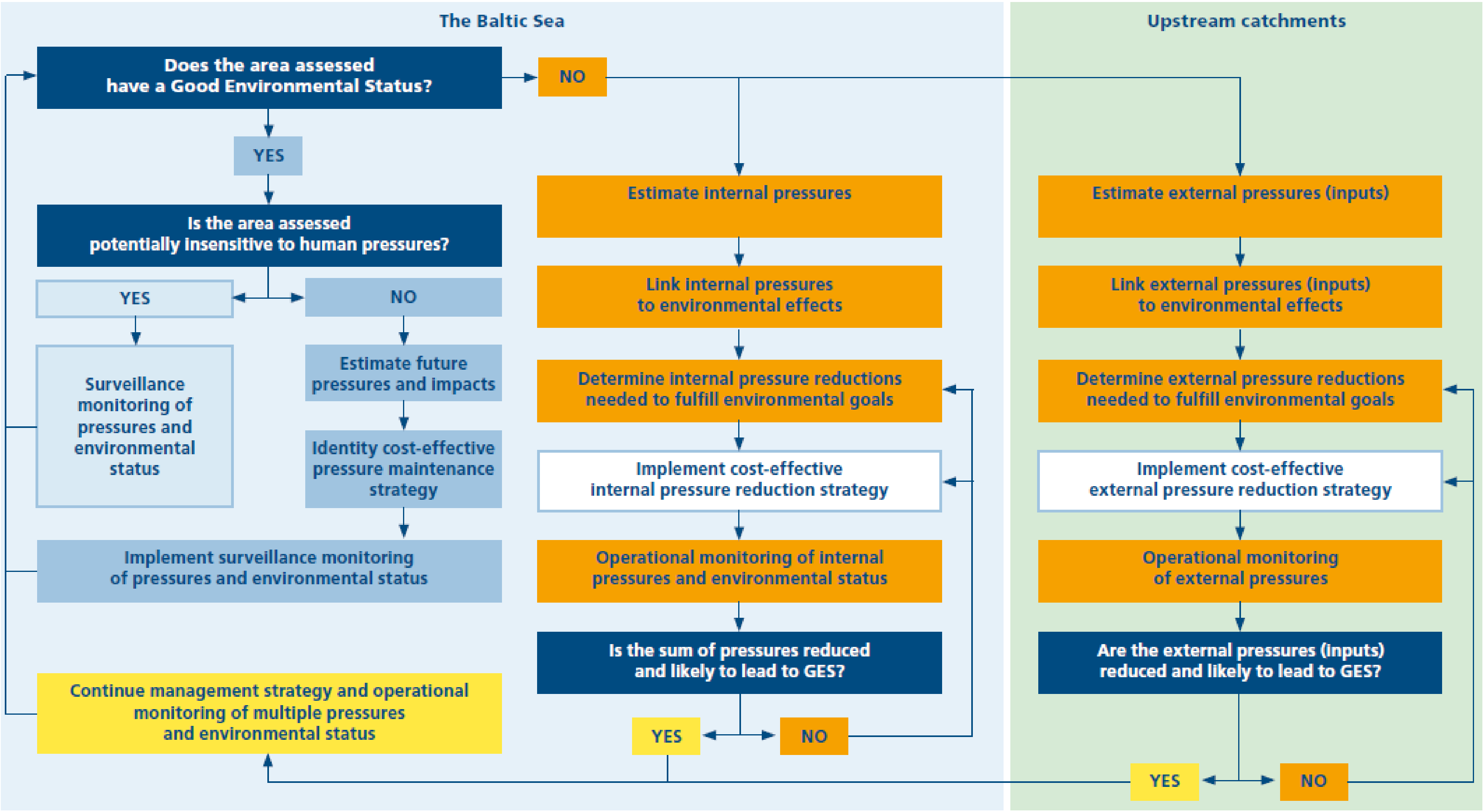
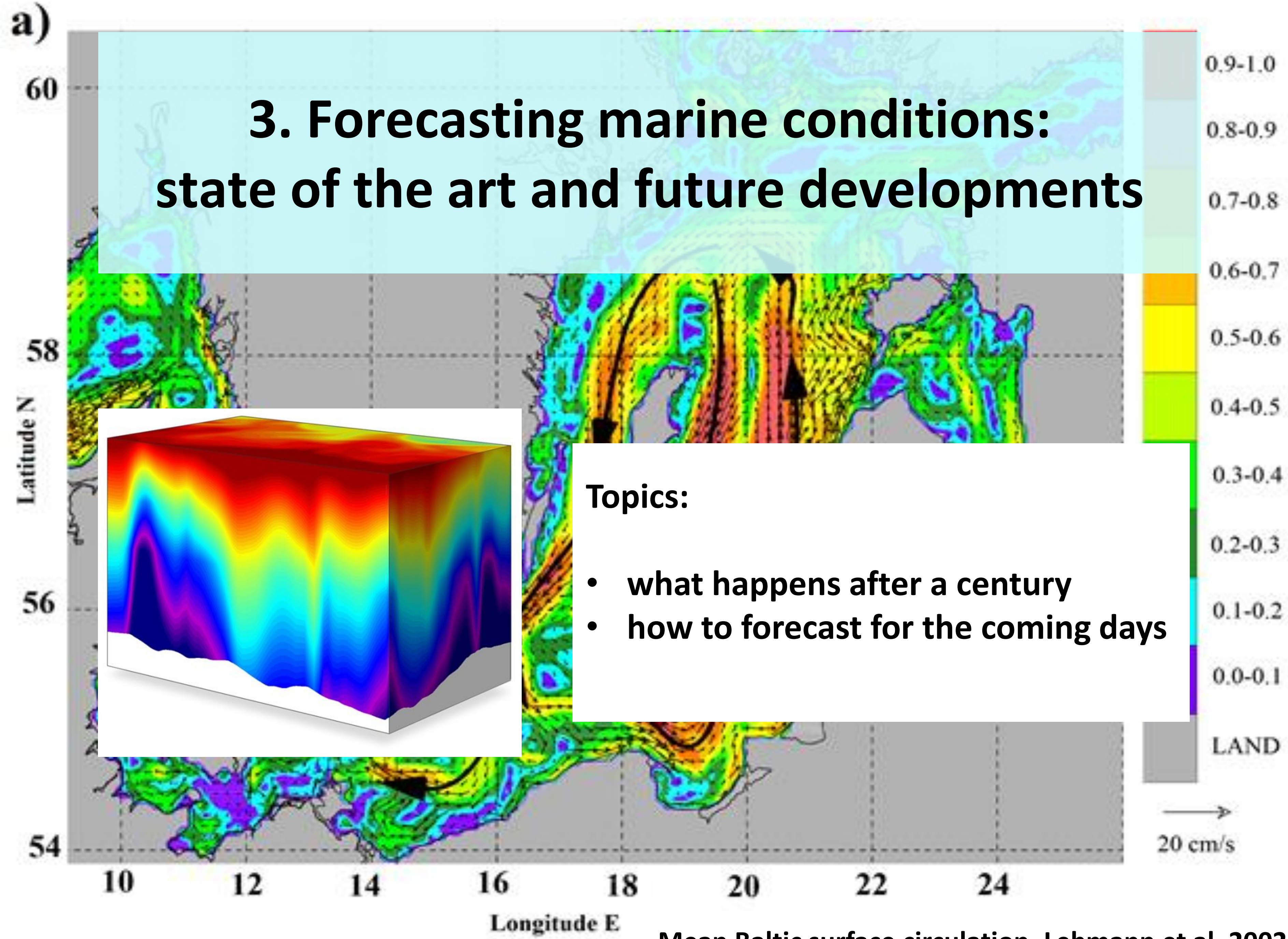


Figure 4.5 Conceptual model for arriving at a ‘Good Environmental Status’ of the Baltic Sea.
GES= ‘Good Environmental Status’. Figure by courtesy of BALANCE, a Baltic Sea Region Interreg IIIB Programme project (www.balance-eu.org).

HELCOM BSEP122 (2010)

3. Forecasting marine conditions: state of the art and future developments



Topics:

- what happens after a century
- how to forecast for the coming days

Mean Baltic surface circulation. Lehmann et al, 2002

Time scales of marine forecasts

Climatic

what is the Baltic Sea state in 2050 and 2100?

what has to be done for the good ecological status, taking into account also changing climate ?

Seasonal

will blue-green algae start blooming in the coming summer?

depends a lot on the wintertime phosphorus conditions

Operational 48+ h

what are the risks that will be created by a coming storm?

are water temperature and algae conditions favorable for beach bathing?

what danger will appear in what location after accidental pollution?

will be there „hidden events“ (like major deep water inflow), that cause rapid change of ecological conditions?

Long-term predictions/projections, methodology

External forcing, climate

Global scenarios, IPCC (HadCM3, ECHAM5)

A1B: fast global economic growth with technology transfer

A2: fragmented global and regional developments

B1, B2: more conservative developments with less GG emissions

Regional refinements: RCAO, CLM

External forcing, human actions

Nutrient loads according to the HELCOM action plan

REF: present loads

BSAP: implementation of the load reduction scenarios

BAU: business as usual – agricultural loads will increase if no measures taken

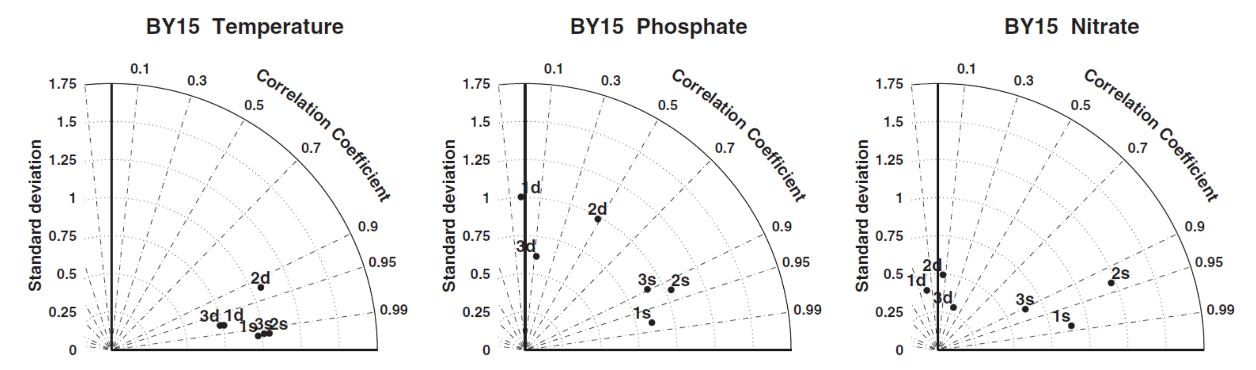
Baltic Sea models

3D: RCO-SCOBI, MOM-ERGOM, GETM-ERGOM

1D: BALTSEM, PROBE-Baltic

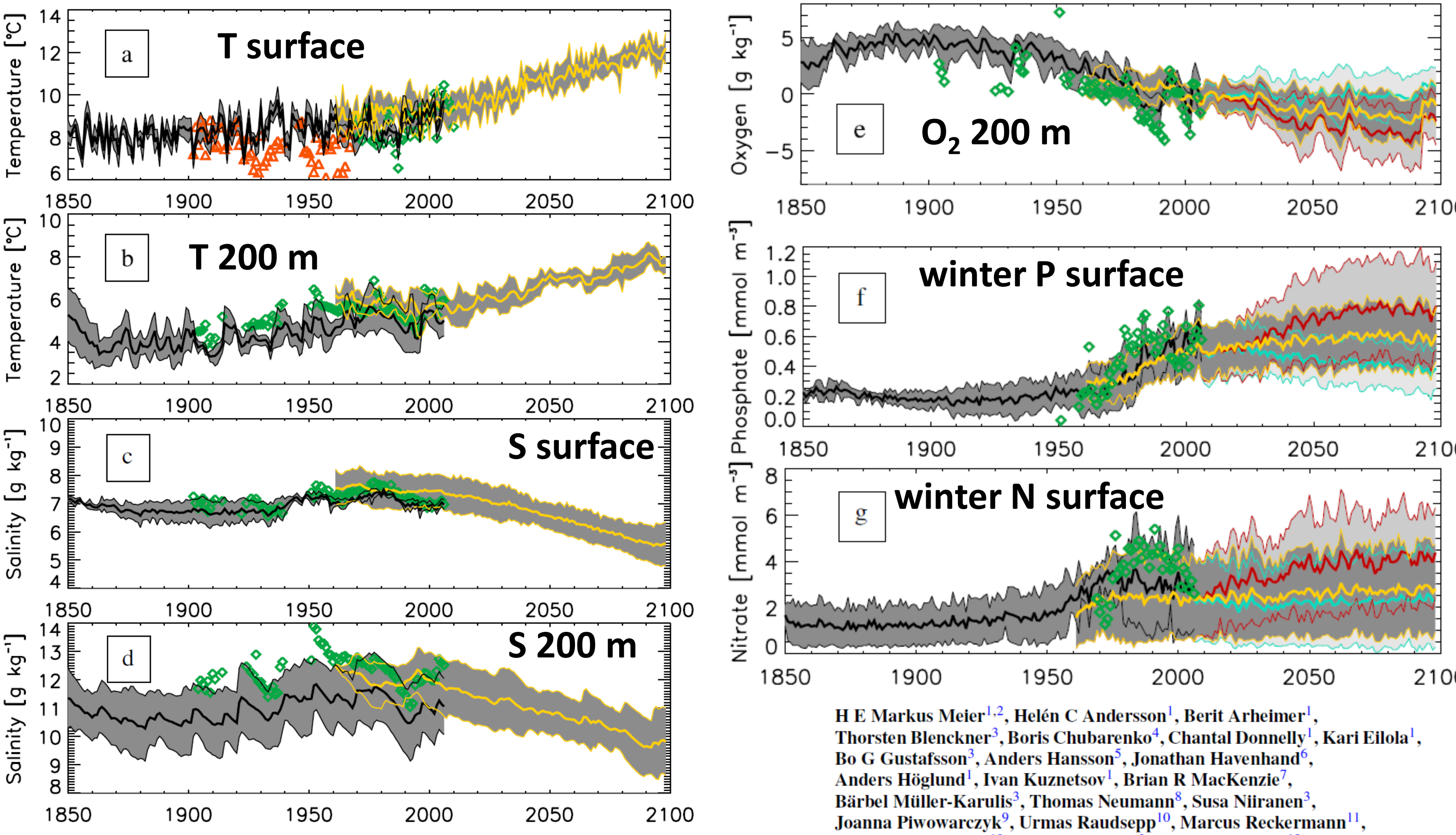
Problem:
quite significant scatter of projection results, especially for Baltic Sea ecology

Eilola et al 2011



Climatic projections, „ensemble“ results

Mean and STDEV (36 cases) of ensemble forecast results. Climate: A1B and A2. Nutrient loads: REF – yellow, BSAP – blue, BAU – red. Points: past observations

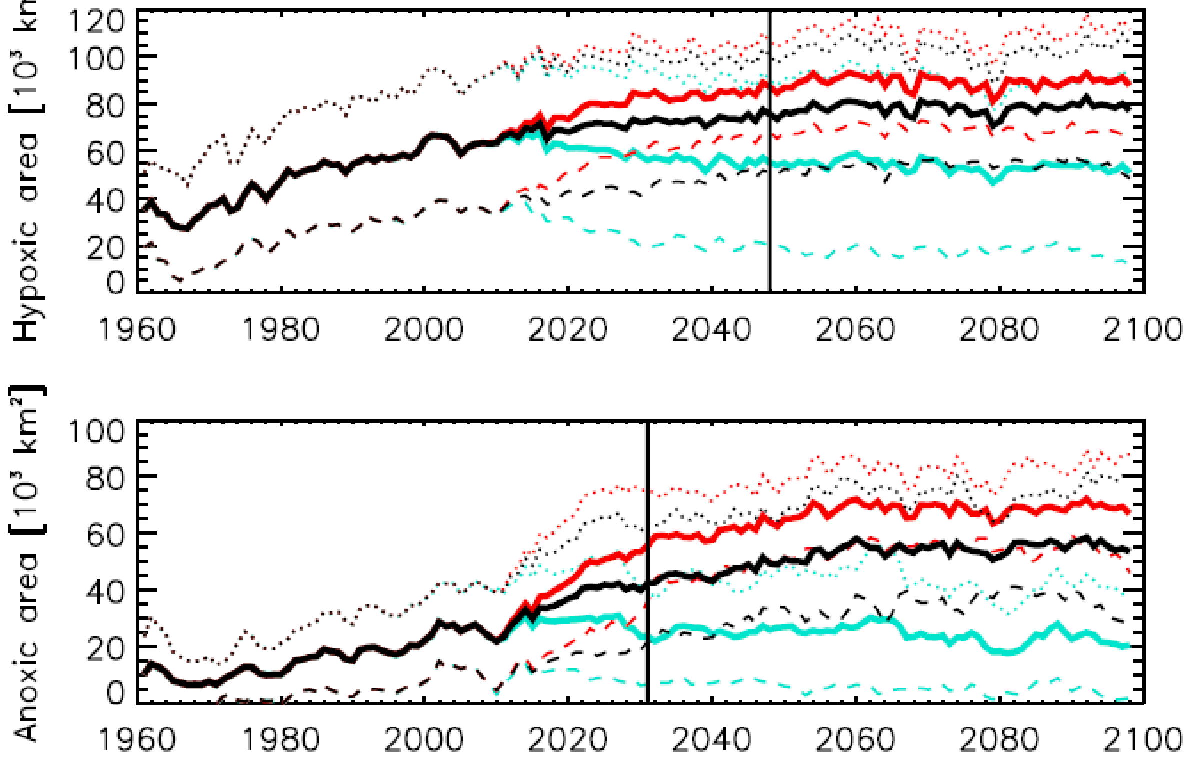


H E Markus Meier[1,2], Helén C Andersson[1], Berit Arheimer[1], Thorsten Blenckner[3], Boris Chubarenko[4], Chantal Donnelly[1], Kari Eilola[1], Bo G Gustafsson[3], Anders Hansson[5], Jonathan Havenhand[6], Anders Höglund[1], Ivan Kuznetsov[1], Brian R MacKenzie[7], Bärbel Müller-Karulis[3], Thomas Neumann[8], Susa Niiranen[3], Joanna Piwowarczyk[9], Urmas Raudsepp[10], Marcus Reckermann[11], Tuija Ruoho-Airola[12], Oleg P Savchuk[3], Frederik Schenk[13], Semjon Schimanke[1], Germo Väli[1], Jan-Marcin Weslawski[9] and Eduardo Zorita[13]

ECOSUPPORT Env Res Lett 2012

Climatic projections, oxygen deficiency

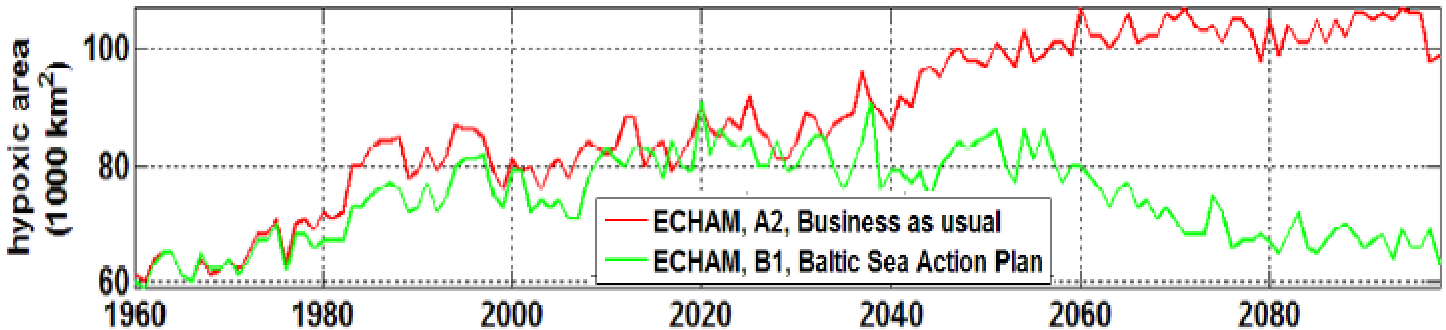
Meier et al 2011 Geophys Res Lett



3 models.
Climate: A1B and A2.
Nutrient load: REF – black, BSAP – blue, BAU - red

Hypoxia will decrease only with nutrient load reduction, other options will not give results

Omstedt et al 2012



Operational forecasts, methodology

External forcing

Weather

„local“ HIRLAM (48-60 h), ECMWF (10 days)

Water and material exchange with the neighboring sea area

operational forecast from larger sea area,

nesting of boundary conditions

Discharge from the land catchment area

HYPE etc

Operational observations for validation and data assimilation

in-situ automatic observing systems

remote sensing of sea surface

classic shipborne observations with automated data delivery

Model systems

hydrodynamics, ice, waves, ecosystem

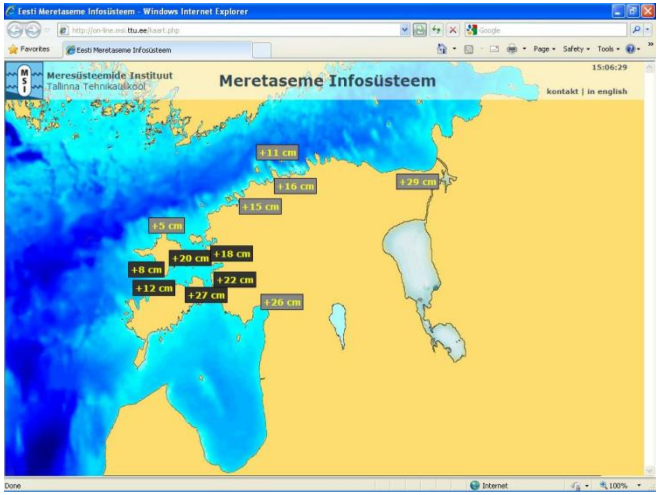
data assimilation, validation of forecasts

Coordinated real-time operations

BOOS, EuroGOOS, ECOMF?

Marine core services are provided with 3 mile (8 km) resolution
Refined downstream services are needed to tackle local problems

Operational oceanography in Estonia



Sea Level Information System home page. Automated observations are presented in real time

Observed (yellow) and forecasted (green) sea level time series in Pärnu. After stronger winds self-oscillations of the Gulf of Riga (5 hours) become visible.

Real-time info 24/7

International cooperation EuroGOOS, BOOS, HIROMB etc

National cooperation: Weather Service, Maritime Administration, harbors, Tallink etc

- Sea level observations and forecast
- Observations at Tallinnamadal
  Lighthouse
- Mariners portal METOC
- Marine environment FerryBox TS, Chl, nutrients etc Tallinn-Helsinki

Numerical forecasts: sea level, currents, temperature and salinity, waves, ice, oil drift

Baltic Monitoring and Forecasting Centre: models

Marine Core Service

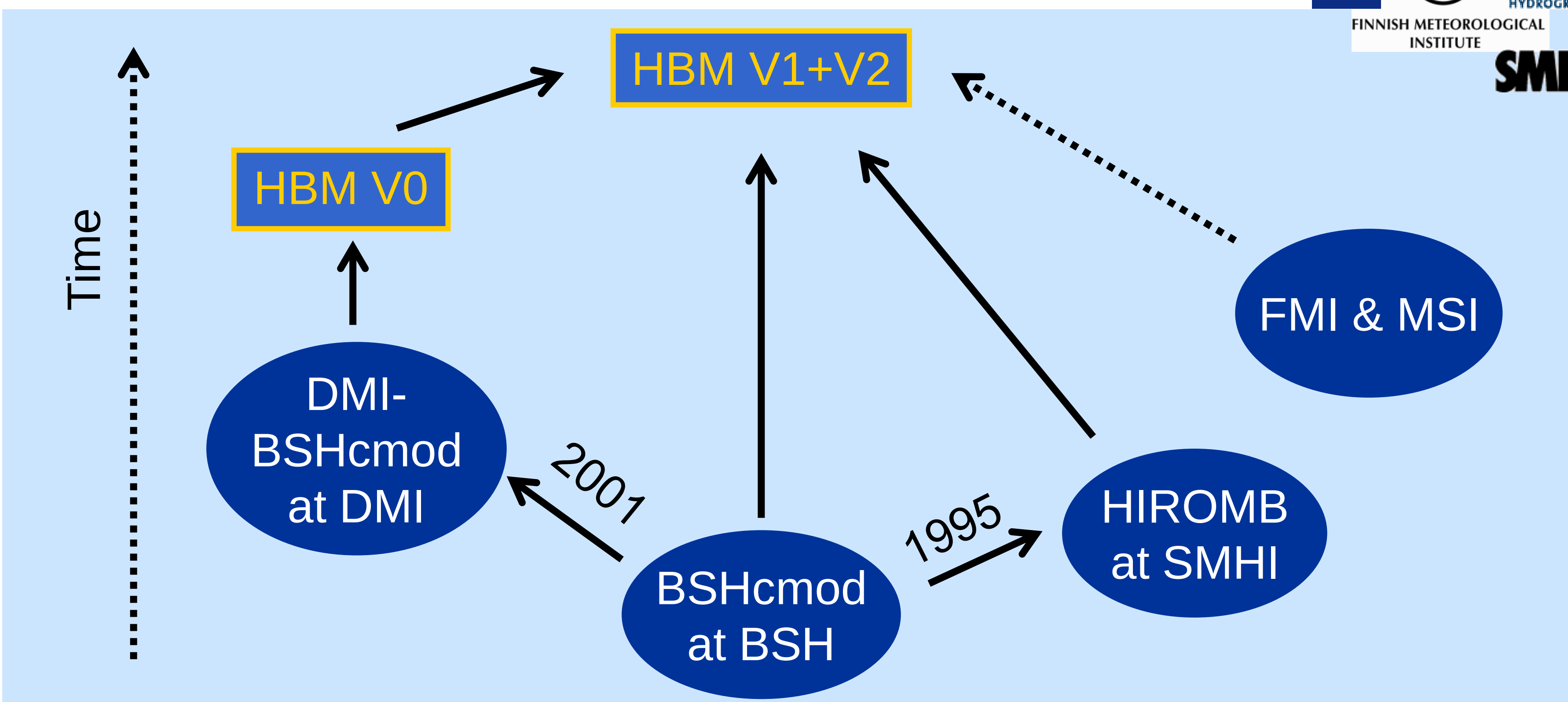
Aim: integrate different operational models into unified forecasting system of new generation

working prototype HIROMB-BOOS-Model HBM

joint development of model physics, source codes and IT platforms

BUNDESAMT FÜR SEESCHIFFFAHRT UND HYDROGRAPHIE

FINNISH METEOROLOGICAL INSTITUTE

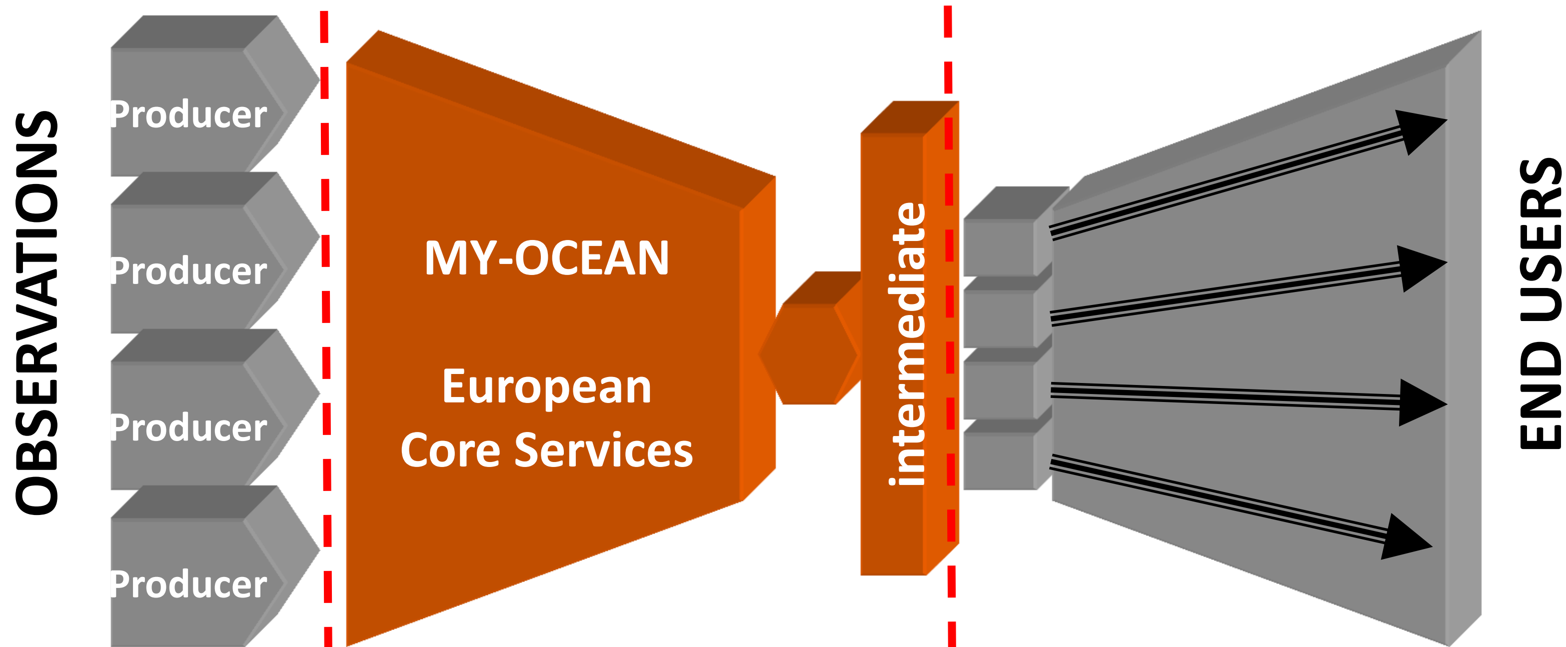


GMES-Copernicus Marine Core Services

myOcean

Marine Core Service

input *(upstream)* → output *(downstream)*



Input service:
... observations from central agencies
eg : Eumetsat SAF or ESA PAC
... national in-situ observations

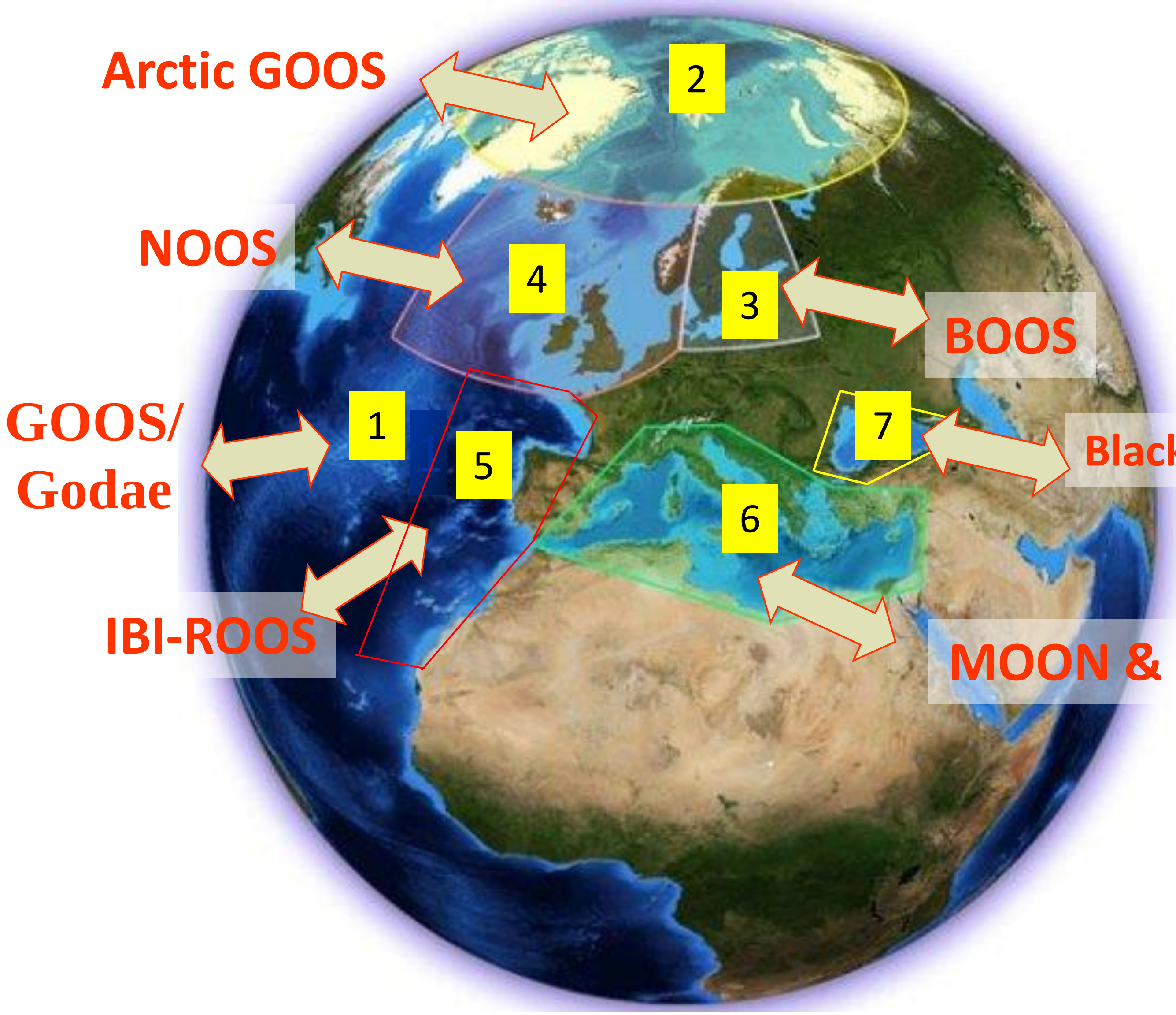
Consolidated products:

Data, models
→ *European added value*

Output service:
... general and specialized products eg for Maritime security, oil spill prevention, marine resources management, climate change, seasonal forecasting, coastal activities, ice sheet surveys

GMES-Copernicus Marine Service regions

Marine Core Service

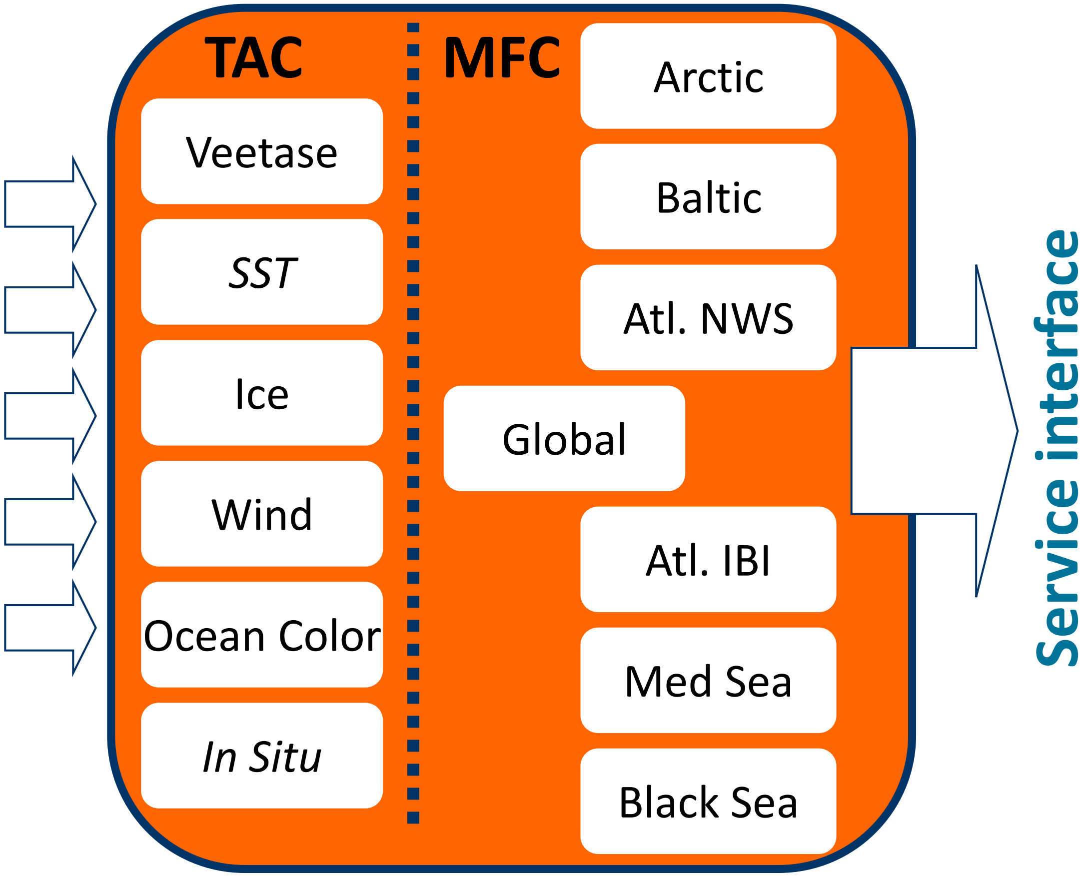


- 1. Global
- 2. Arctic
- 3. Baltic
- 4. NWS
- 5. IBI
- 6. Med Sea
- 7 Black Sea

GMES-Copernicus marine service units

Marine Core Service

13 units

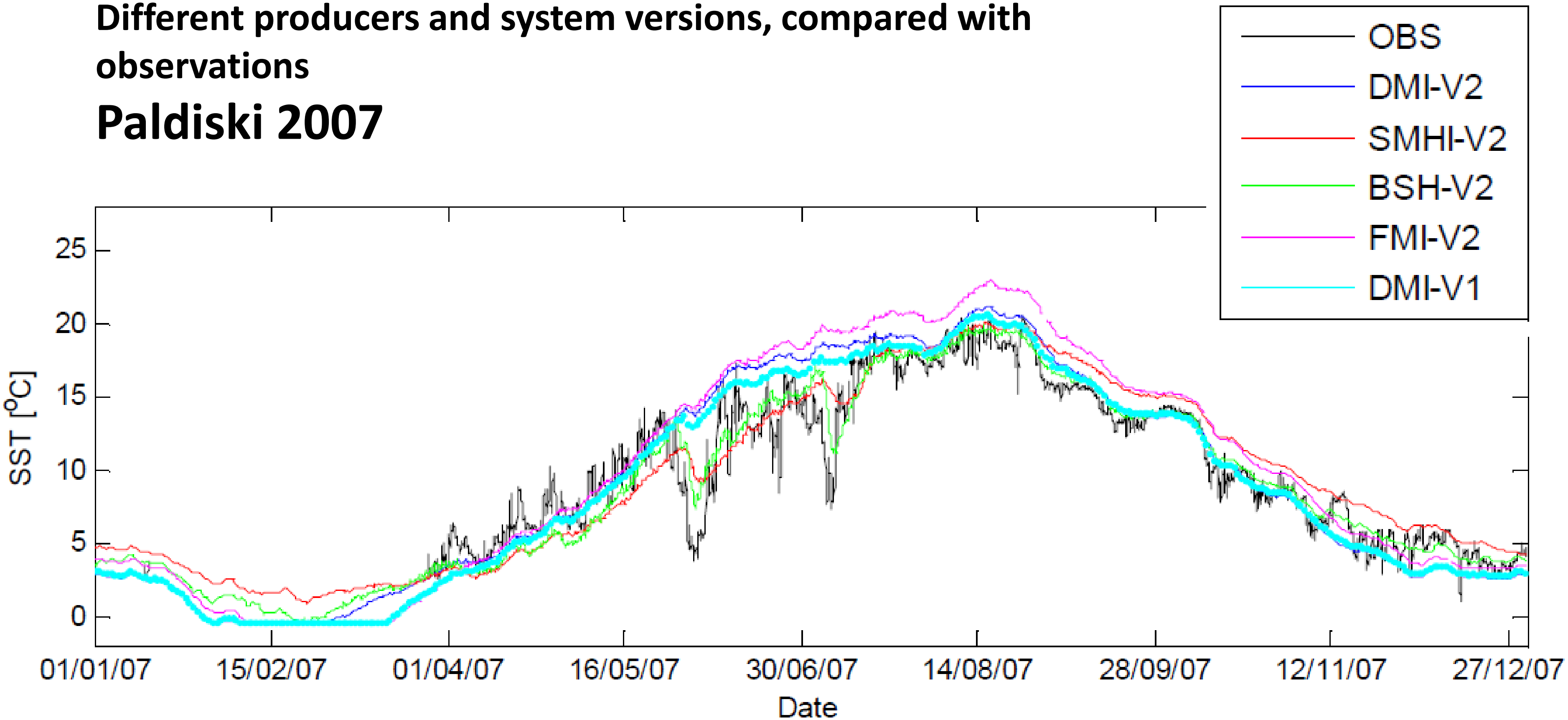


- **6 thematic centres**
  (TAC: Thematic Assembly Center)
  - “Observations”
- **1 global and 6 regional production centres**
  (MFC: Monitoring and Forecasting Centers)
  - “Models / Assimilation”
- Each unit
  - service commitment
  - development, integration and assessment commitment

Operational forecasts, surface temperature calibration

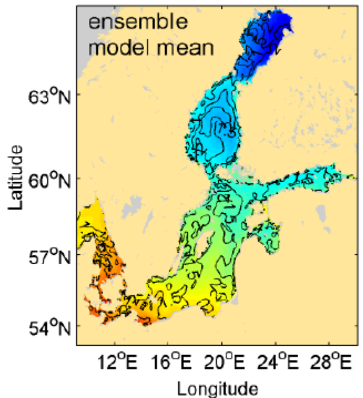
Different producers and system versions, compared with observations

Paldiski 2007

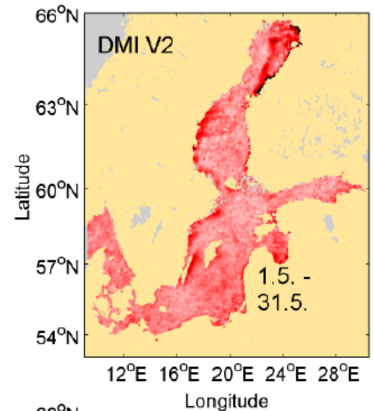


Lagemaa & Väli

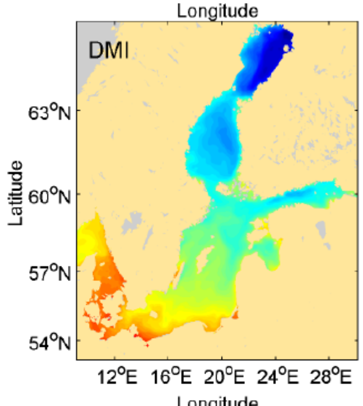
Operational forecasts, analysis

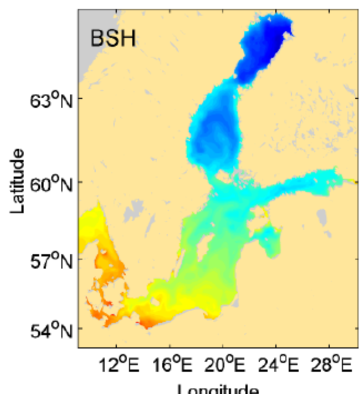


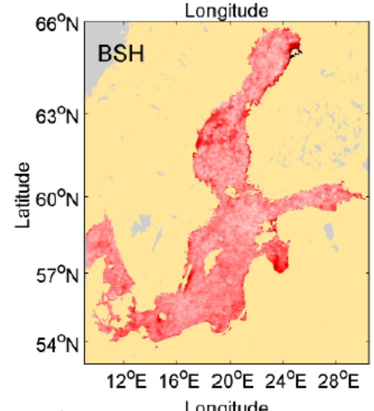
Monthly mean surface temperature, May 2007

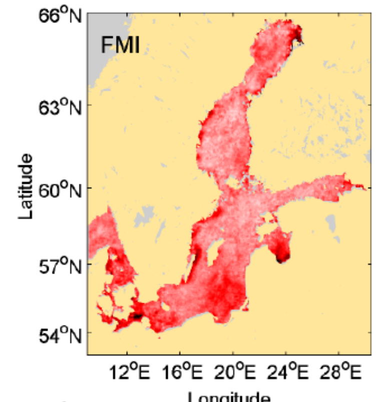


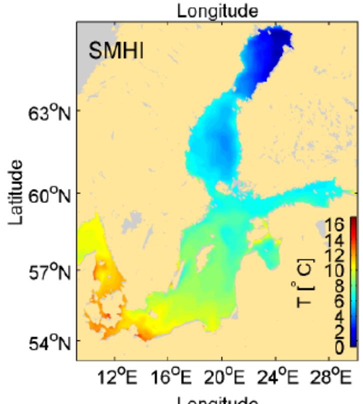
RMS forecast error of surface temperature, May 2007

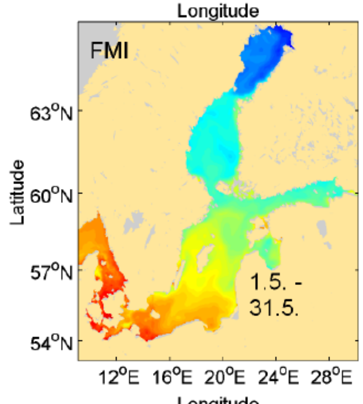


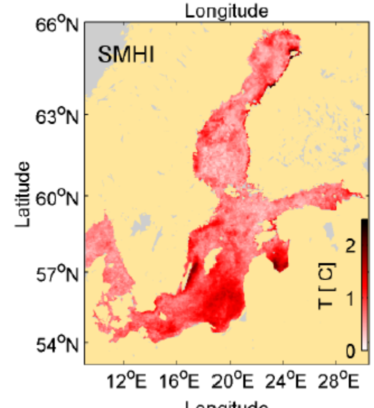


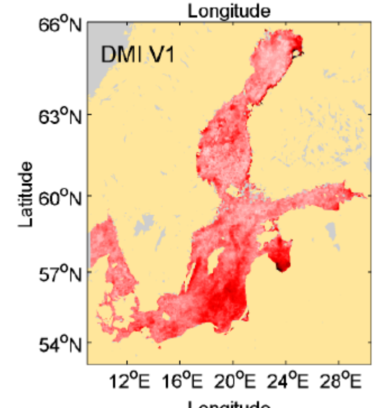




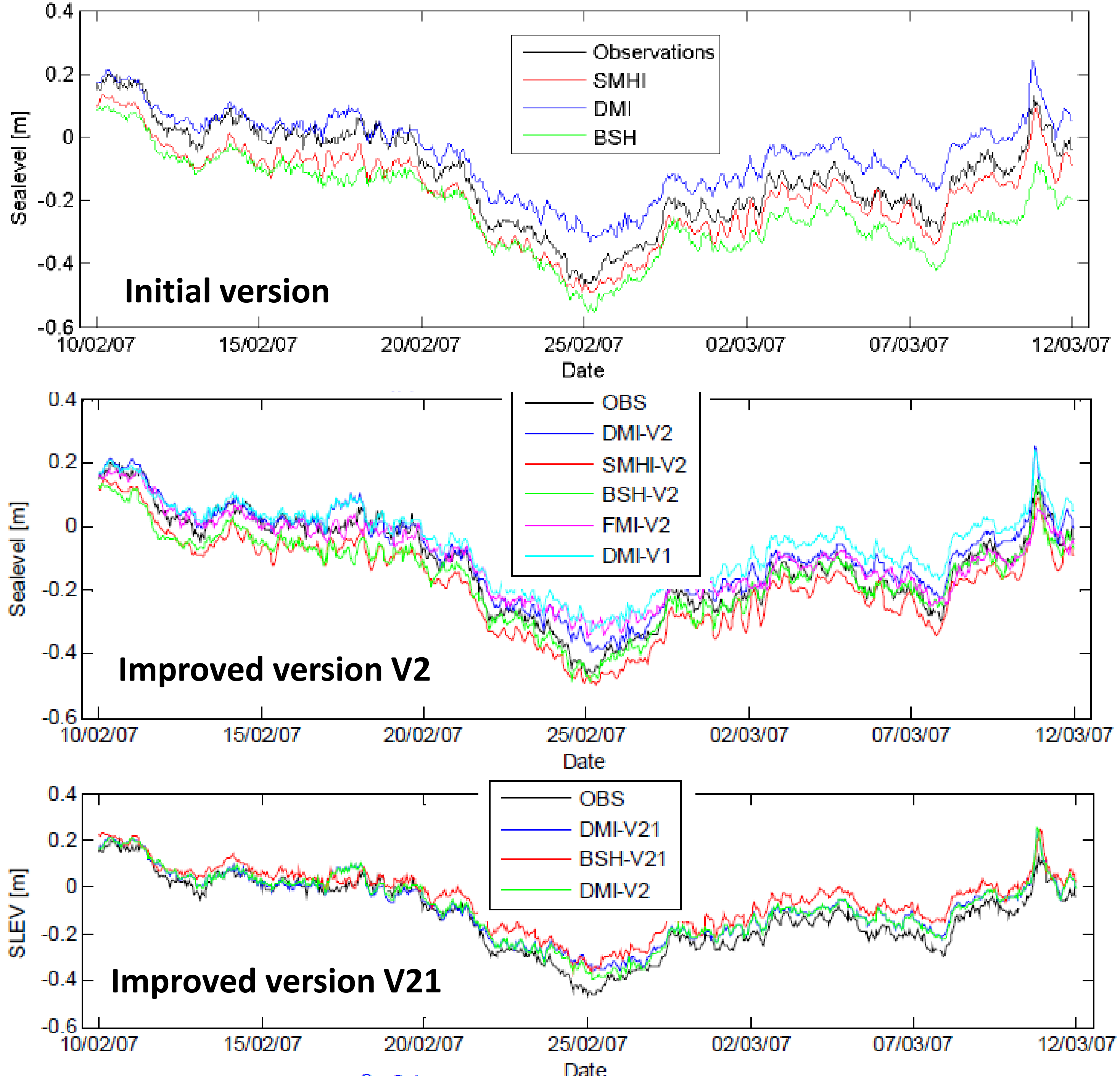








Lagemaa & Väli



Calibration of sea level forecast

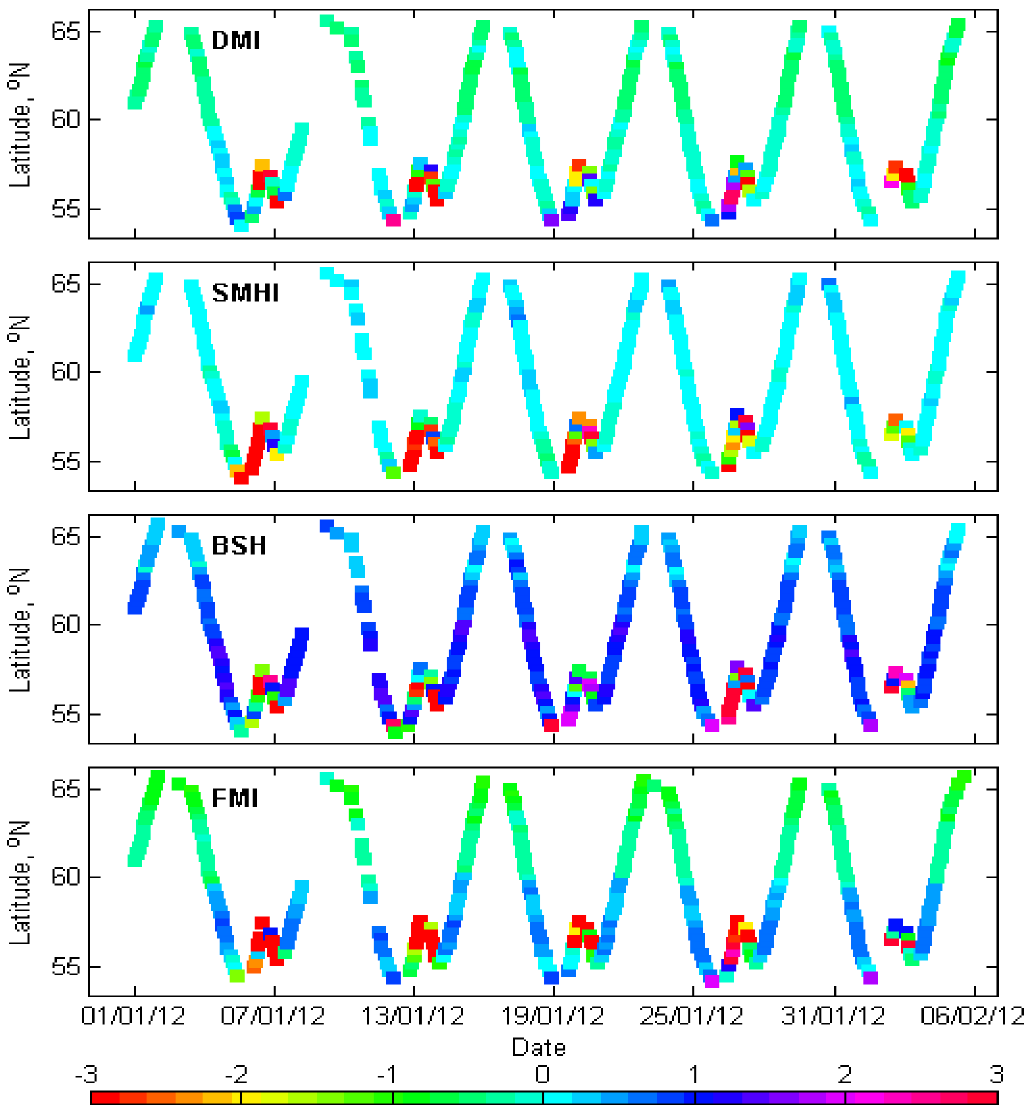
Different producers and system versions, compared with observations

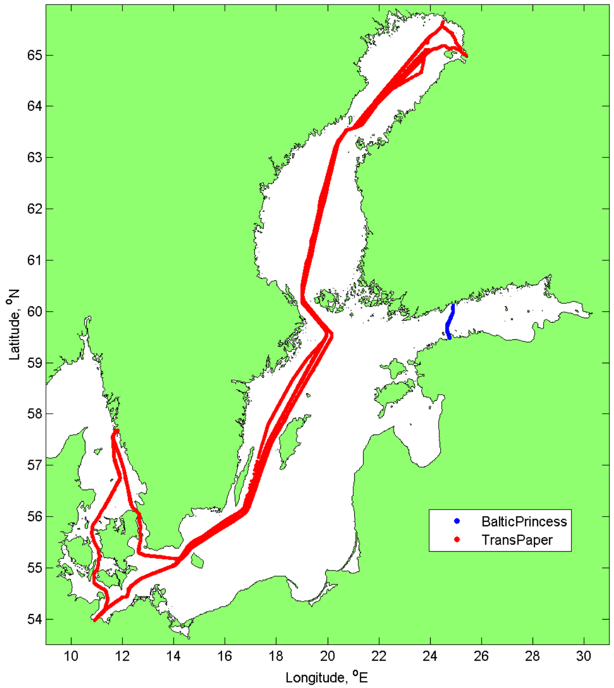
Low sea levels in Sõru 2007

Lagemaa & Väli

Operational forecasts, calibration of surface salinity

Different producers and system versions, compared with FerryBox observations



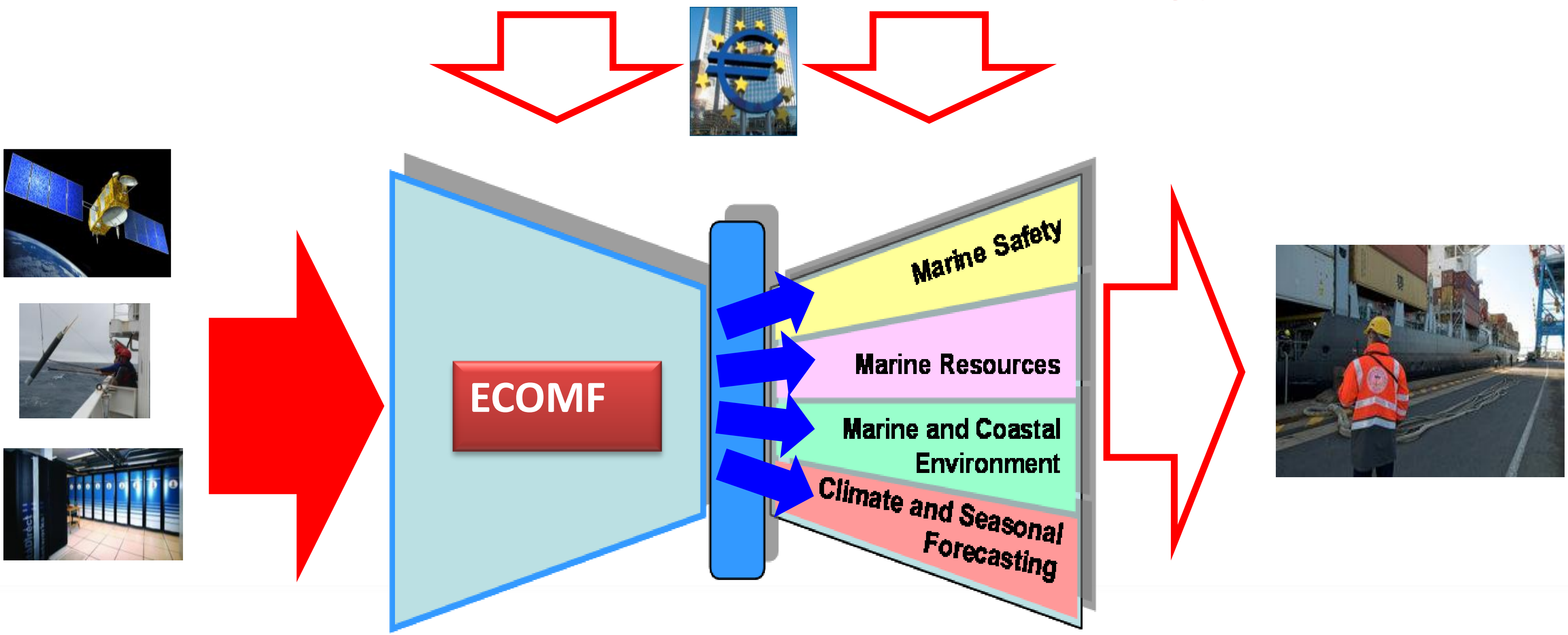


Lagemaa & Väli

New production organization ECOMF?

This is the organization delivering the ocean monitoring and forecasting component of the GMES Marine Service

Analogy to ECMWF



Developments of marine forecasting in near future

Climatic

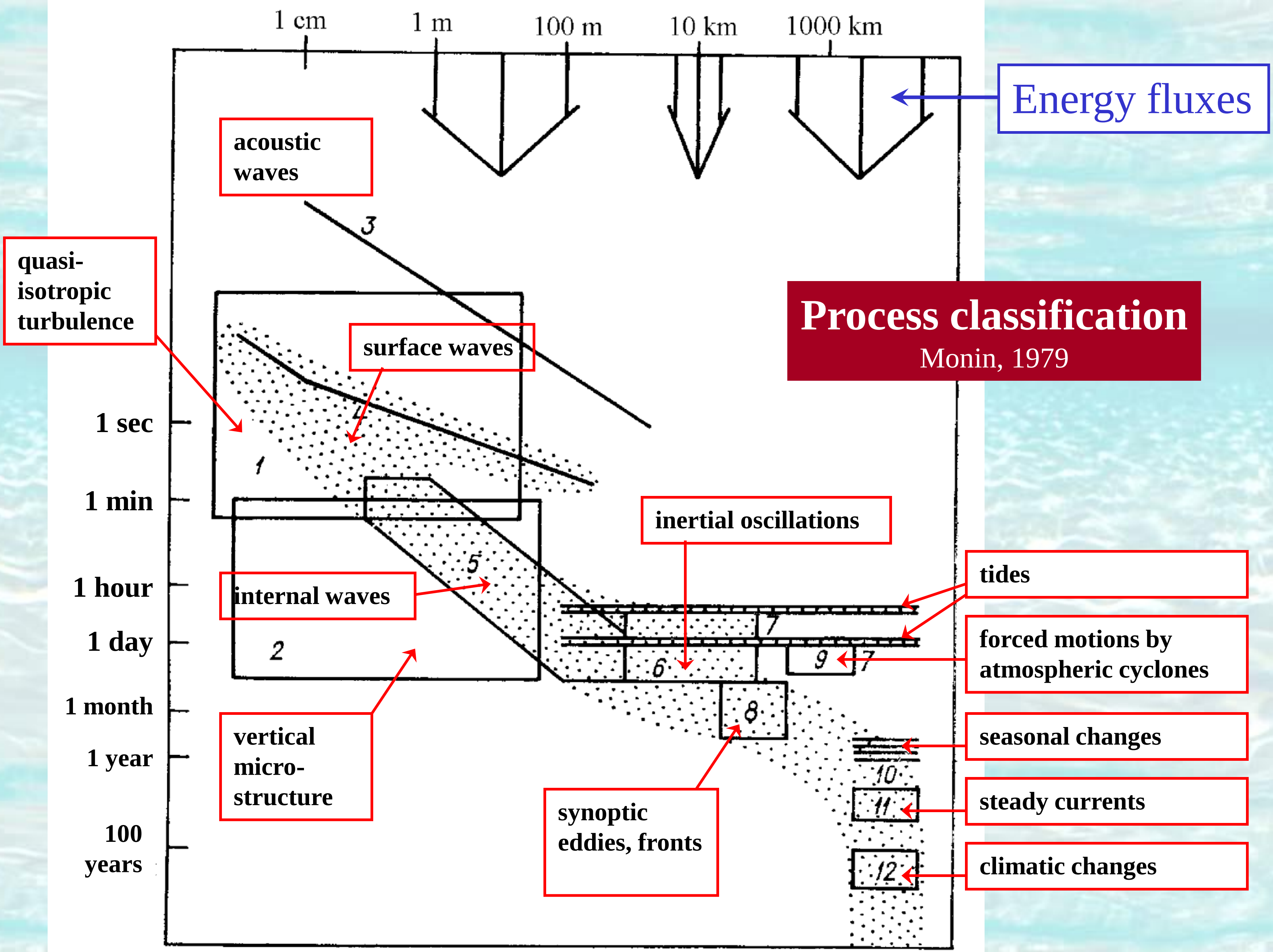
- BONUS, Horizon 2020 etc project calls
- uncertainty „determination“ and reduction (better process knowledge!)
- new variables of interest, extended time span, more local details
- ???

Operational 48+ h

- integration and consolidation of core services
  GMES → EuroGOOS / MyOcean / ECOMF
- development of intermediate services for the benefit of specialized users

In the Baltic Sea the new generation model system HBM (*HIROMB-BOOS Model*) will enable:

- consolidation of development resources (one common model code)
- state-of-the-art IT platforms, fast and reliable
- ecosystem models built in
- improved accuracy
- increased capacity for data assimilation



Process classification
Monin, 1979
Energy fluxes
1 cm
1 m
100 m
10 km
1000 km
1 sec
1 min
1 hour
1 day
1 month
1 year
100 years
acoustic waves
quasi-isotropic turbulence
surface waves
internal waves
vertical micro-structure
inertial oscillations
synoptic eddies, fronts
tides
forced motions by atmospheric cyclones
seasonal changes
steady currents
climatic changes
1
2
3
4
5
6
7
8
9
10
11
12