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# A statistical approach on upwelling in the Baltic Sea based on the analysis of satellite data for the period 1990-2009

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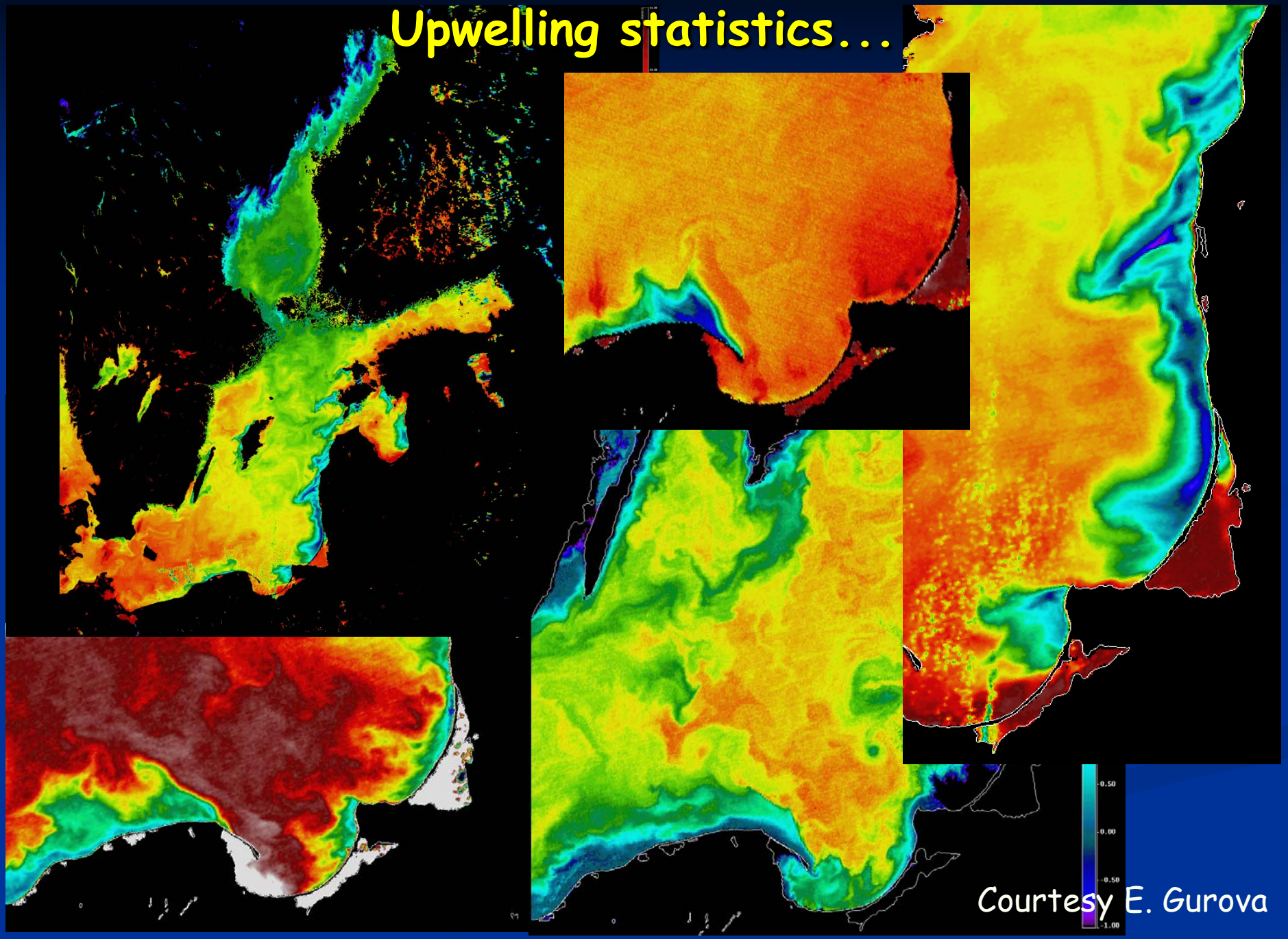
# Upwelling statistics..

- Motivation
- Data and methods
- Results of the visual detection method
- Results of the automatic detection method
- Upwelling wind conditions
- Trends
- Concluding remarks

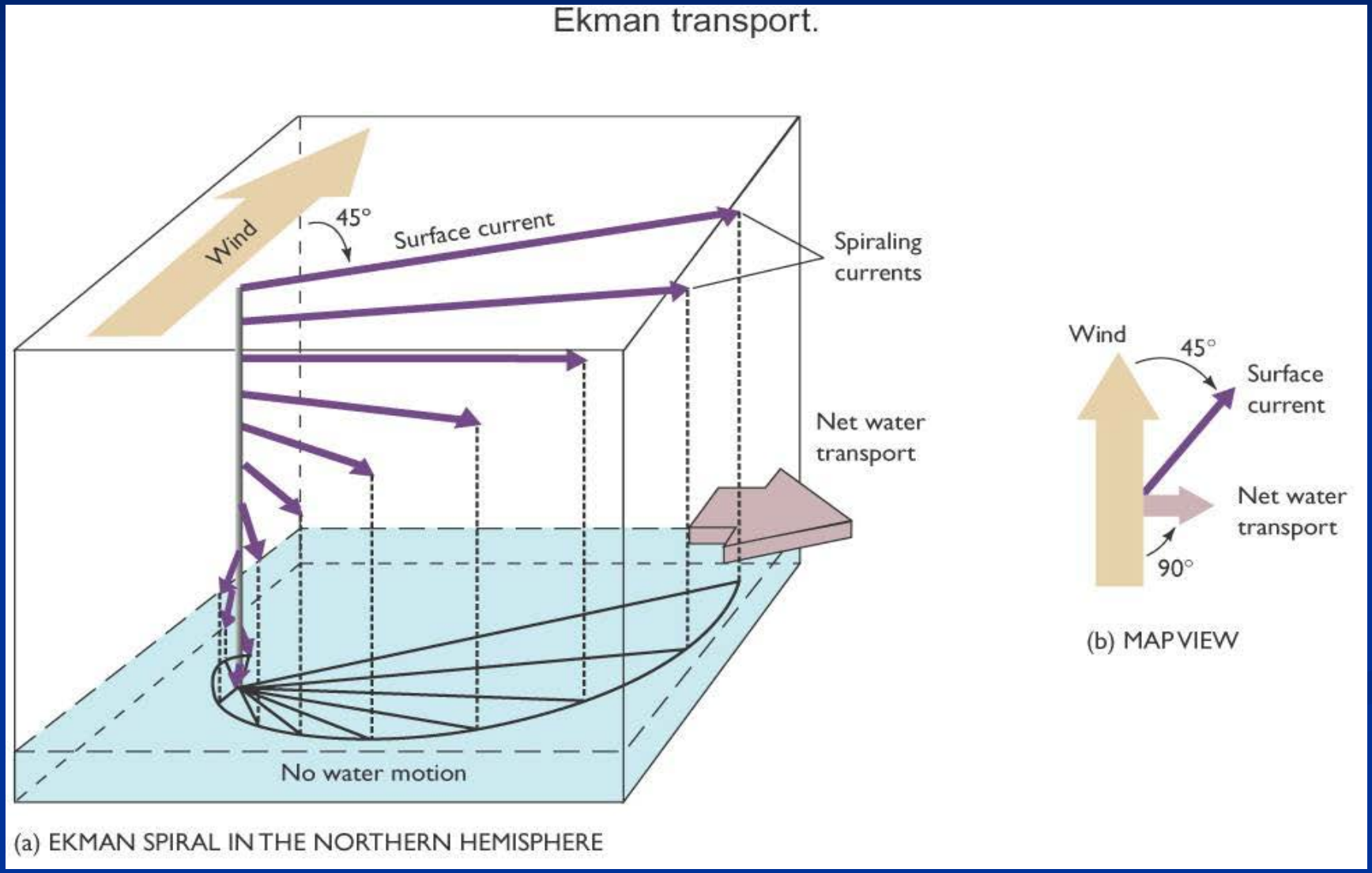
# Upwelling statistics...




Courtesy E. Gurova

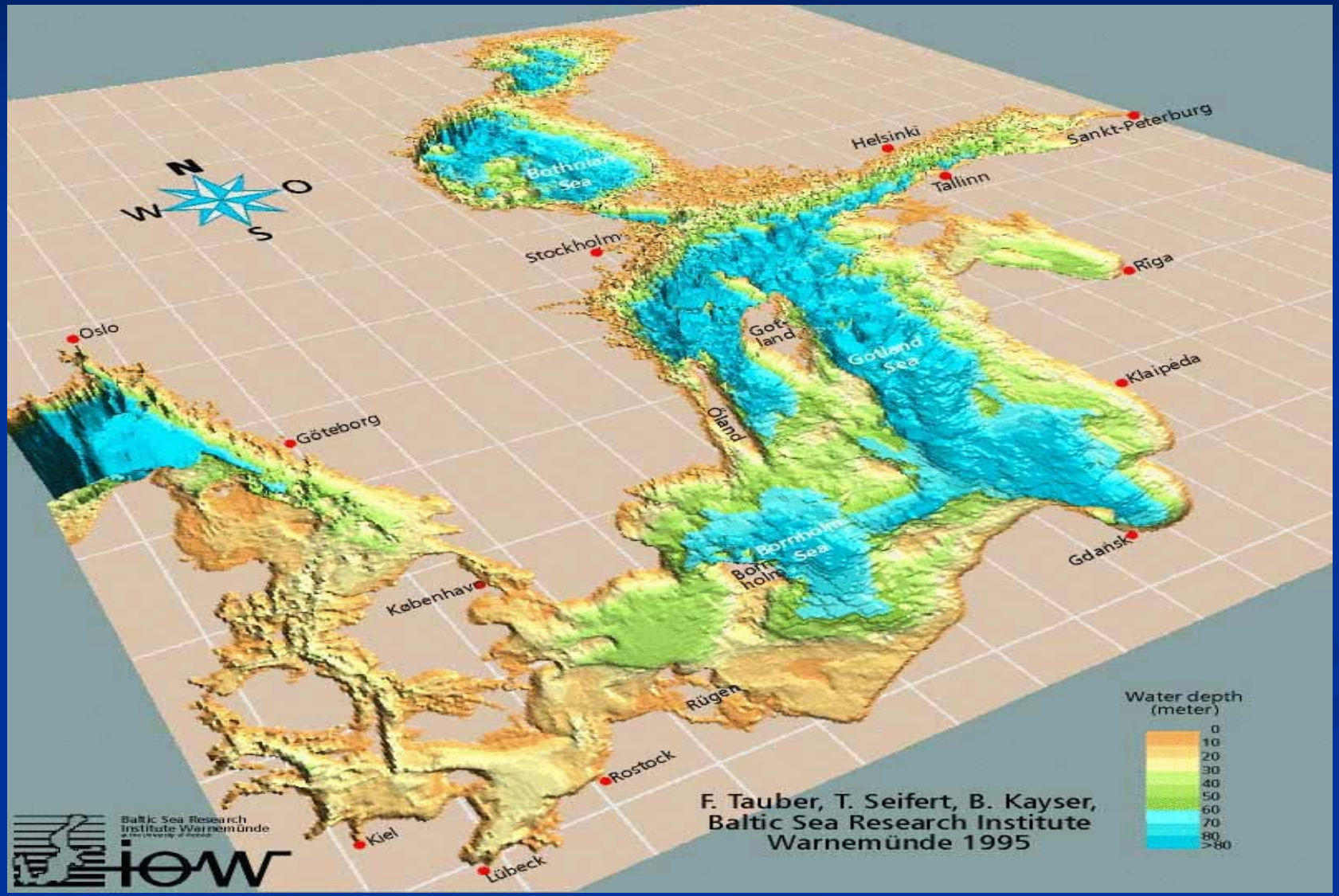
# Upwelling statistics...

- **Motivation (basic principle)**



# Upwelling statistics...

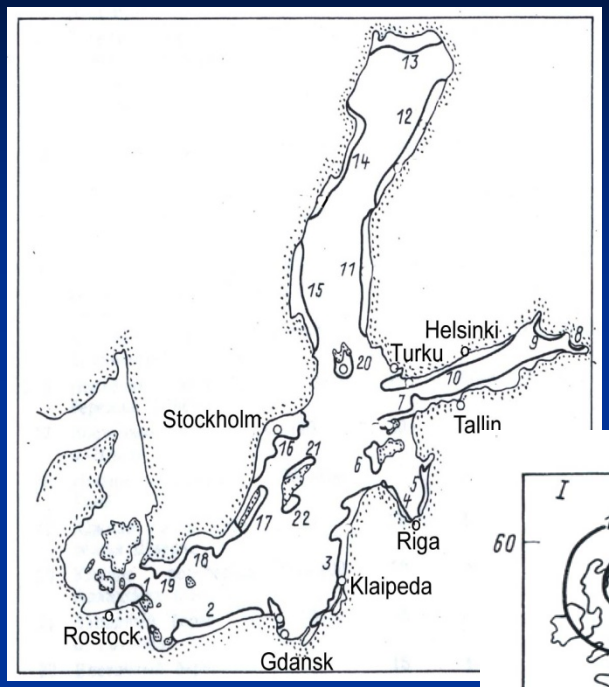
- **Motivation**

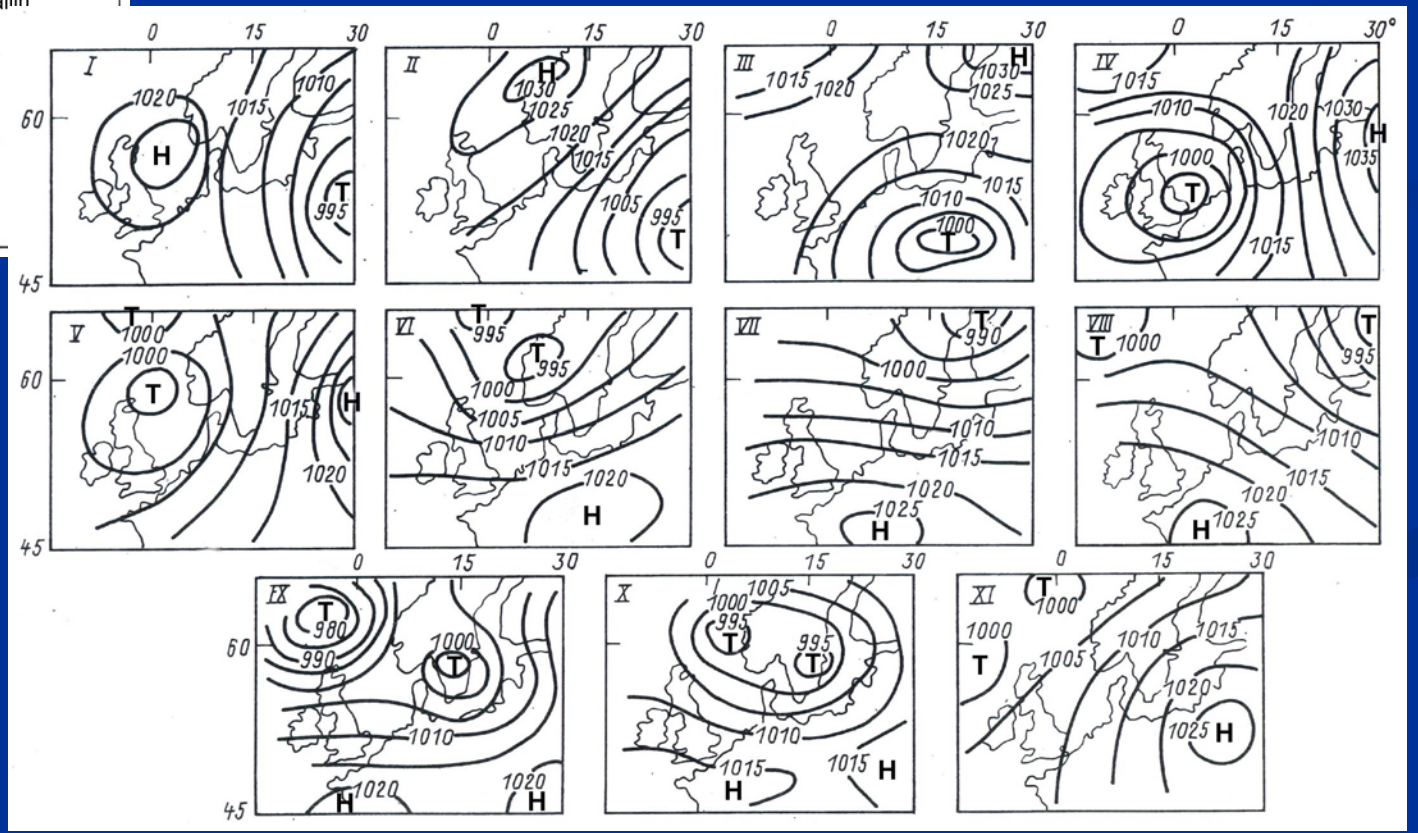


# Upwelling statistics

## Motivation

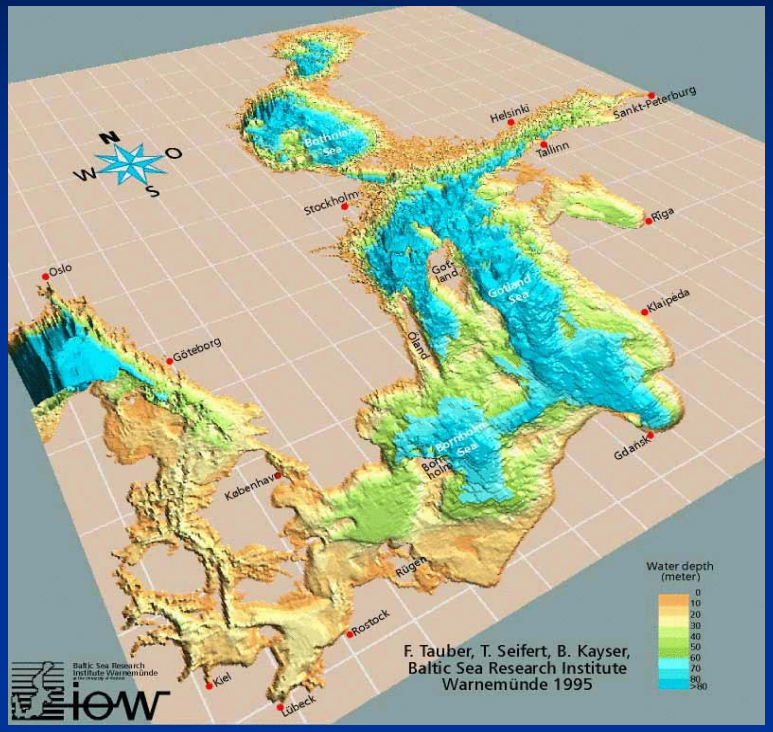
Former analysis of satellite data:
Gidhagen, 1987
Bychkova, Viktorov & Shumaker 1988



# Upwelling statistics...

- **Motivation (upwelling characteristics)**




- vertical motion: $10^{-5}$-$10^{-4}$ ms-1 ~ 1-10 m/day
- horizontal scales: 10-20 km offshore
  100 km alongshore
- temperature drop: 10°C/day
- local temperature gradient: 1°C/km
- lifetime: days-weeks

**simple estimation:**

**w=0.582 x $10^{-6}$ Wind (Hela, 1976)**

**Internal Rossby Radius**

$$L_r = \frac{\sqrt{g \frac{\Delta\rho}{\rho} H}}{f}$$

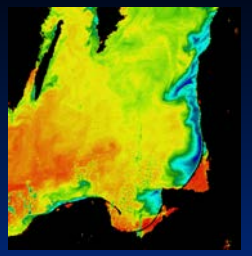
**Hela, 1976:**
**period of strong westerly winds**
**led to upwelling along the southern Finnish coast**
**M= 3 x $10^3$ $m^3 s^{-1}$ /km coastline**

**Transport**

$$M = \frac{\tau}{\rho f}$$

**southern Finnish coast about 270 km**
**=> 6% of the volume of the Gulf of Finland was affected**

# Upwelling statistics...



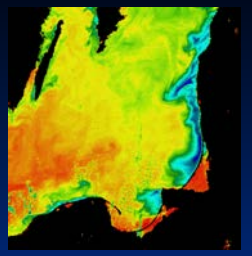
- **Data and methods**

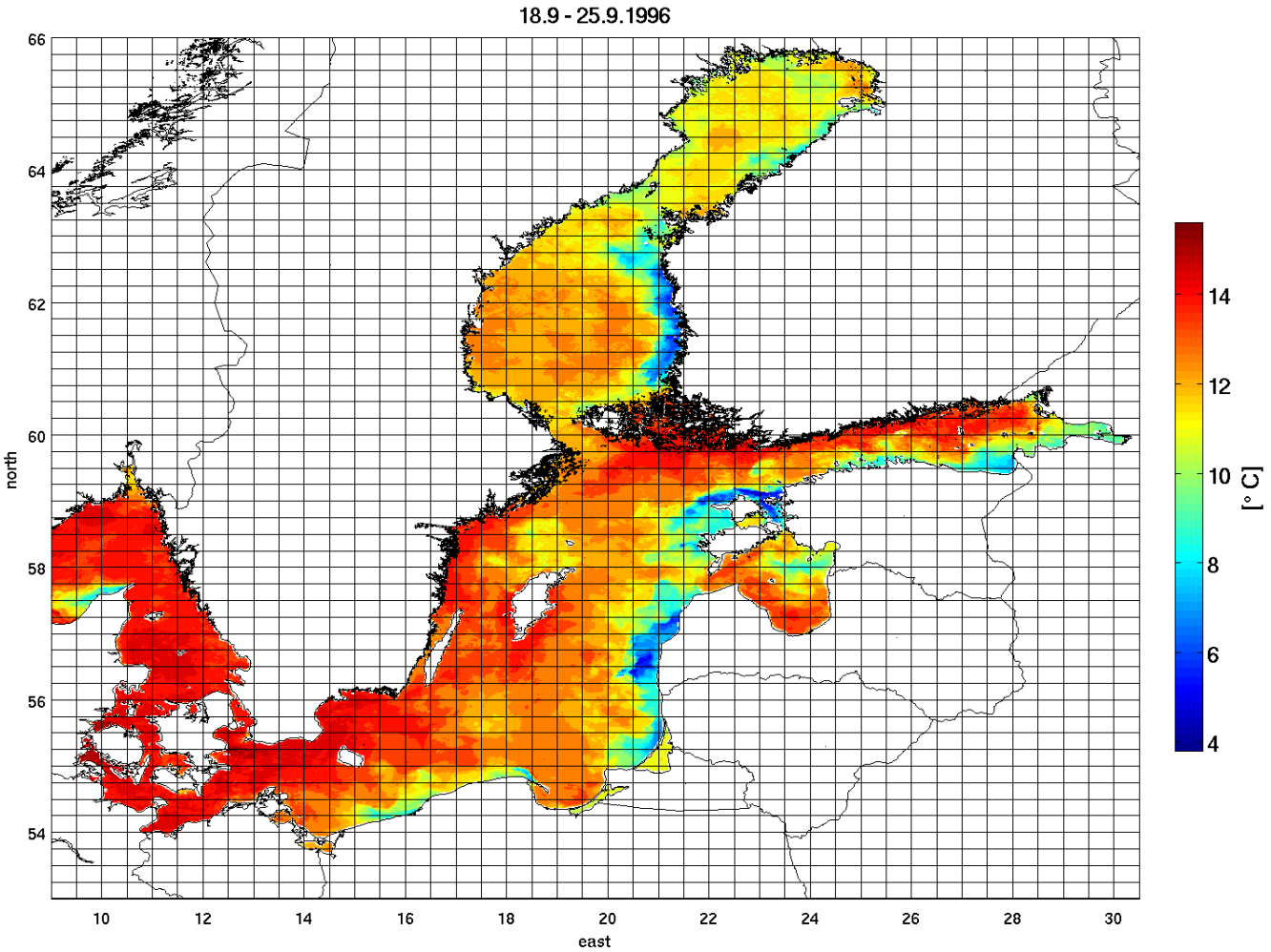
  - SST, weekly composites (AVHRR, BSH Germany) 1990-2009, May-September, 443 weeks, resolution 1 km
  - SST, daily averages, BSIOM (Kiel, Germany), 1990-2009, May-September, 3060 days, resolution 2.5 km
  - 10 m wind based on SMHI-Met data, daily averages 1990-2009, May-September, resolution 2.5 km

  - Visual detection method of temperature drop within grid cells 0.25 x 0.5°, 443 satellite pictures analyzed
  - Automatic detection method, temperature drop threshold 2.0 and 3.5°C
  - Analysis of projected wind components parallel to the coast, > 5.0, 4.25, 3.5 m/s for at least 2 days

# Upwelling statistics...

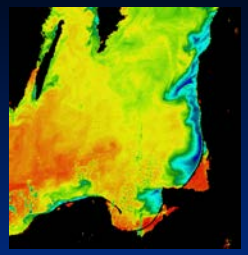
- Data and methods (visual detection)

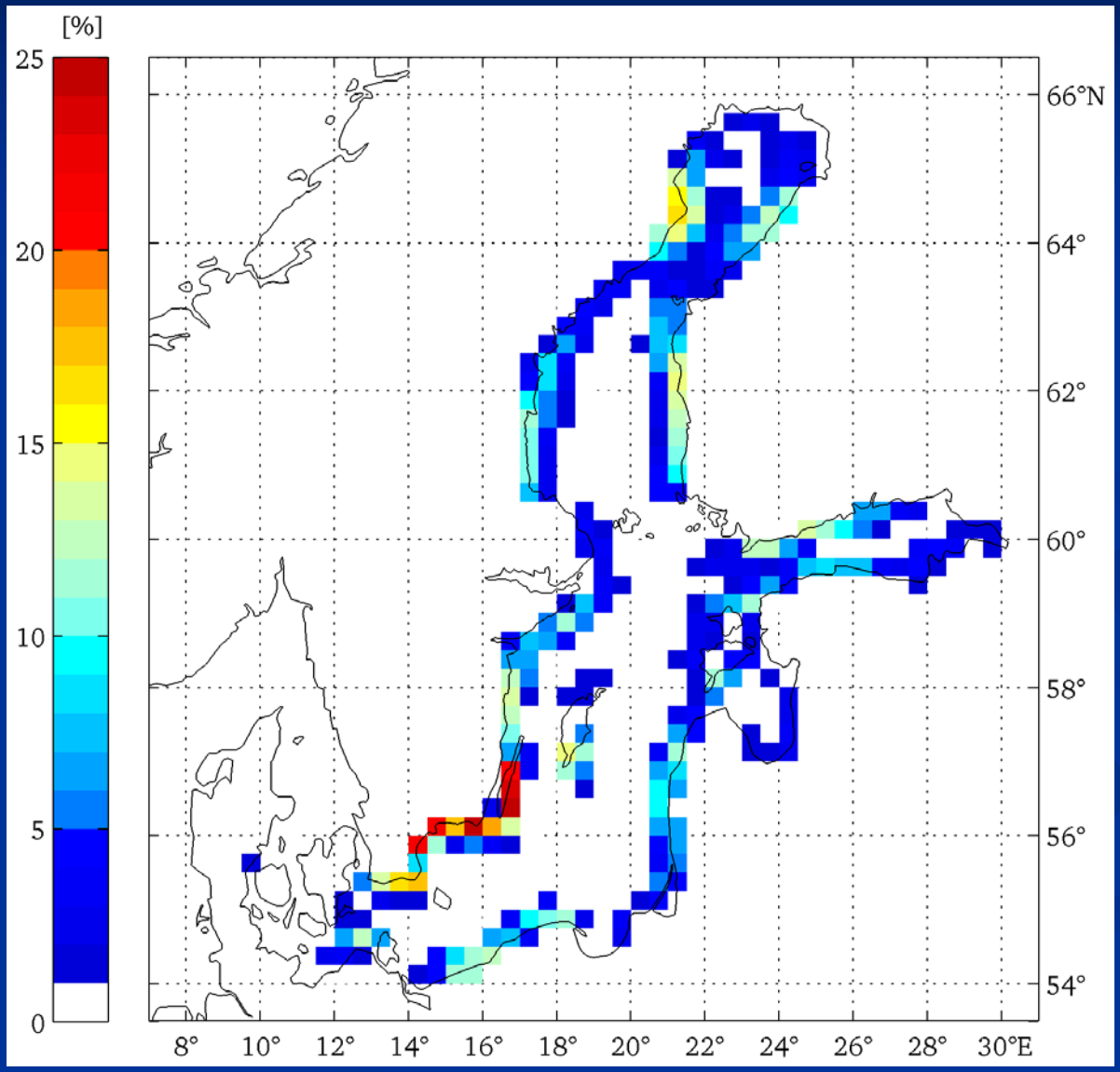




# Upwelling statistics...

- Results of visual detection (443 weeks)





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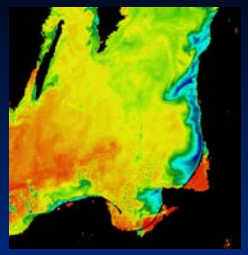
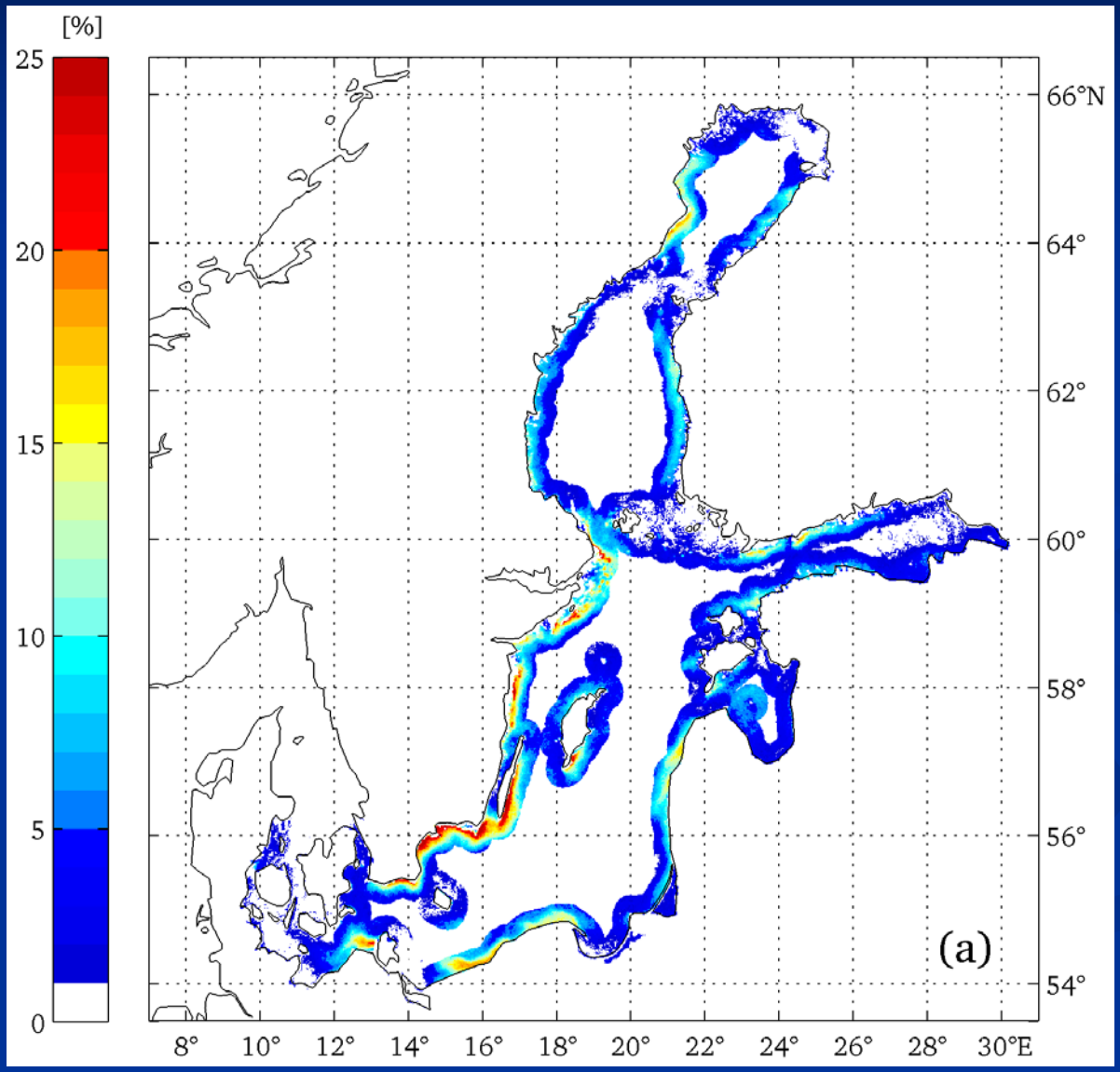
- Results of automatic detection (threshold 2°C)



443 weeks



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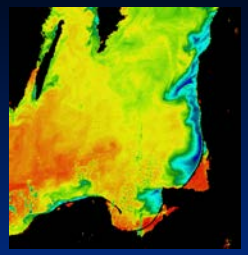

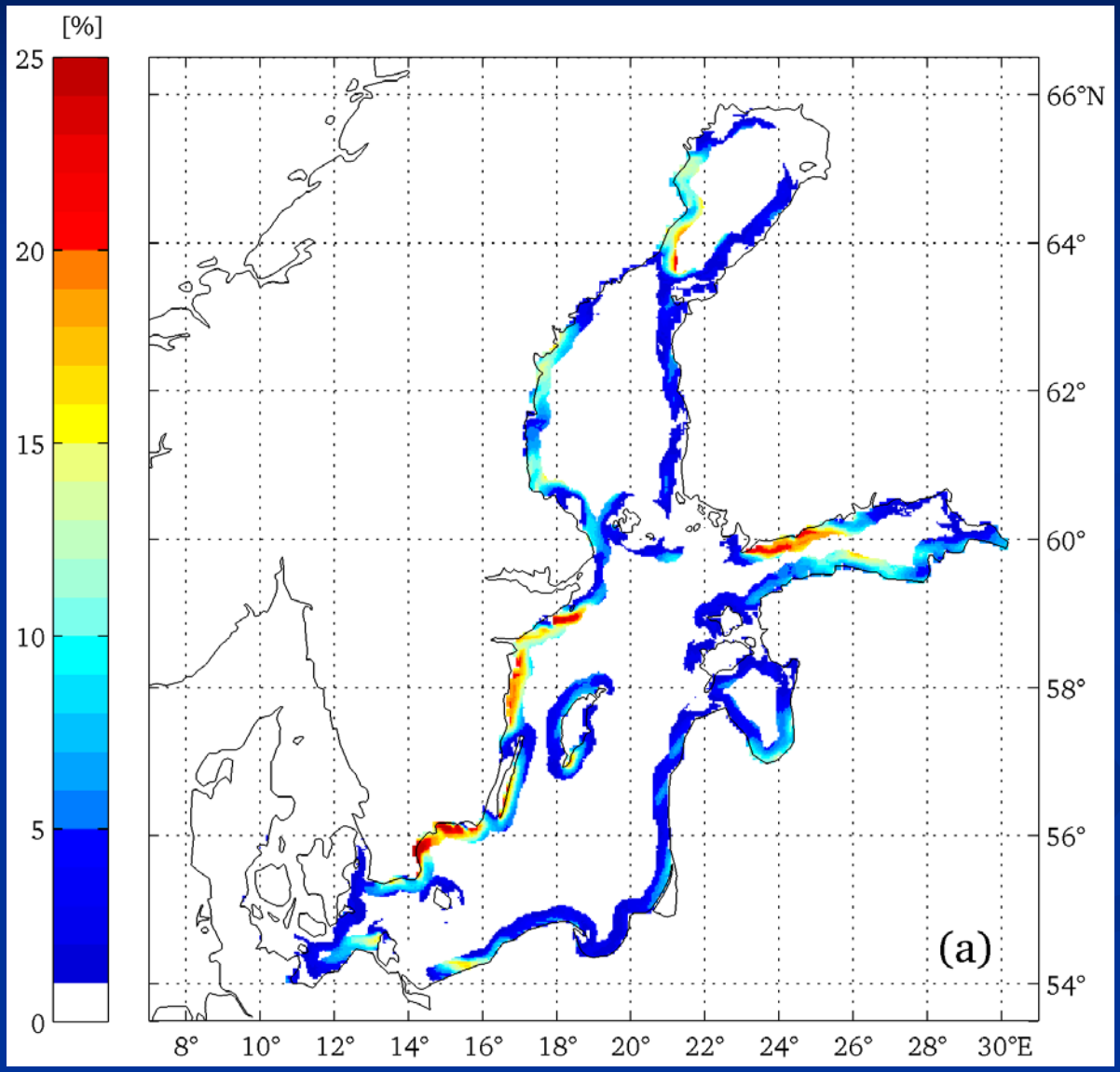


BSIOM
3060 d

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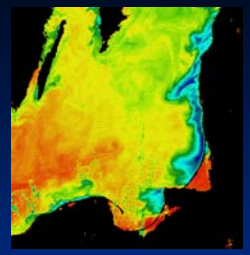

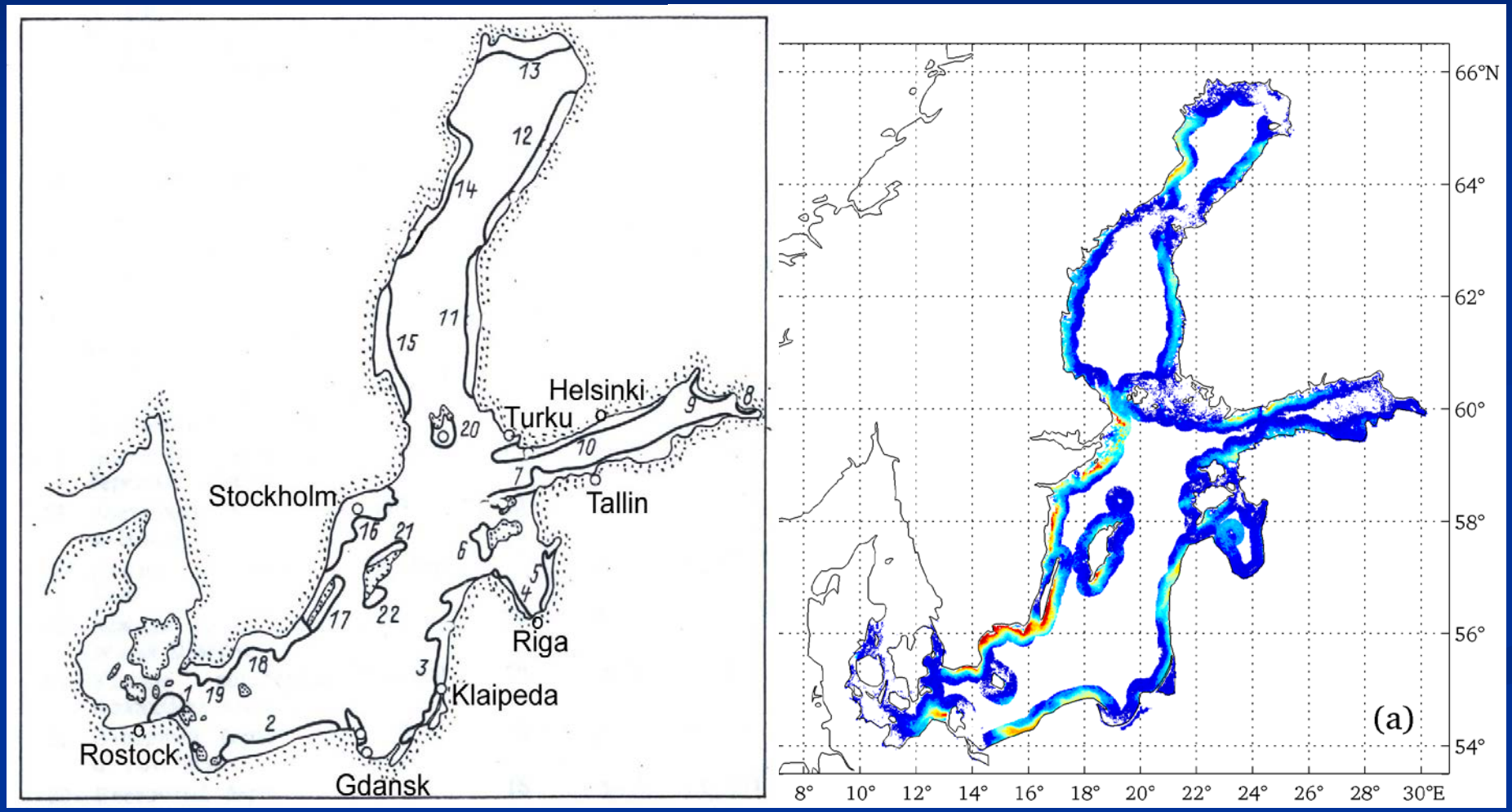


Bychkova et al. 1988

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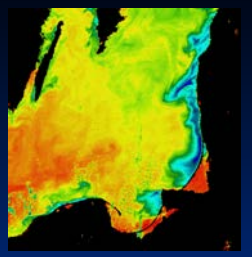
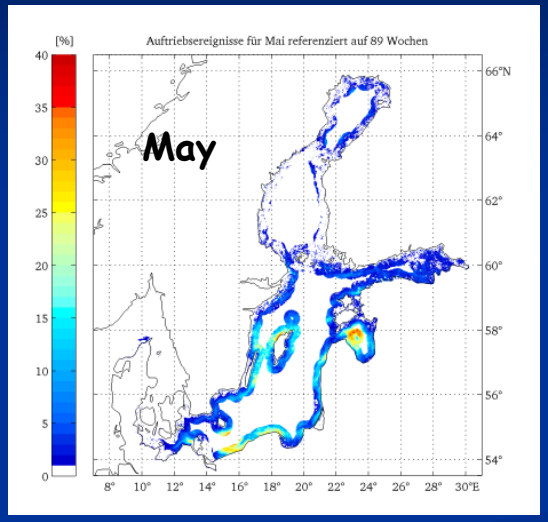
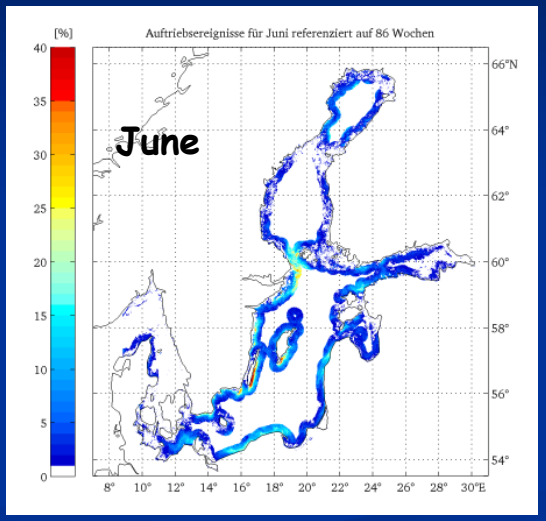
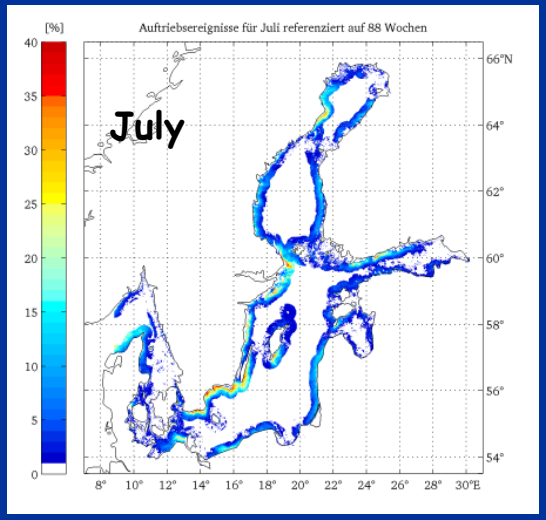
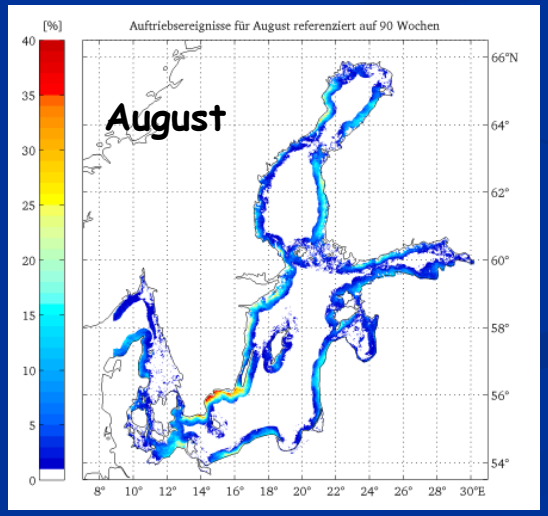
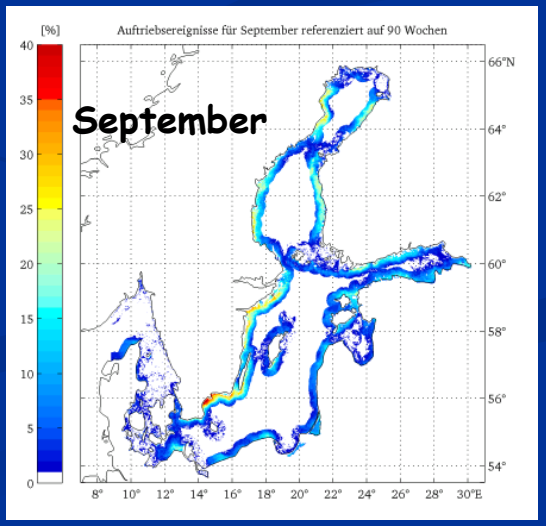


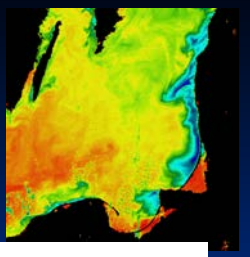



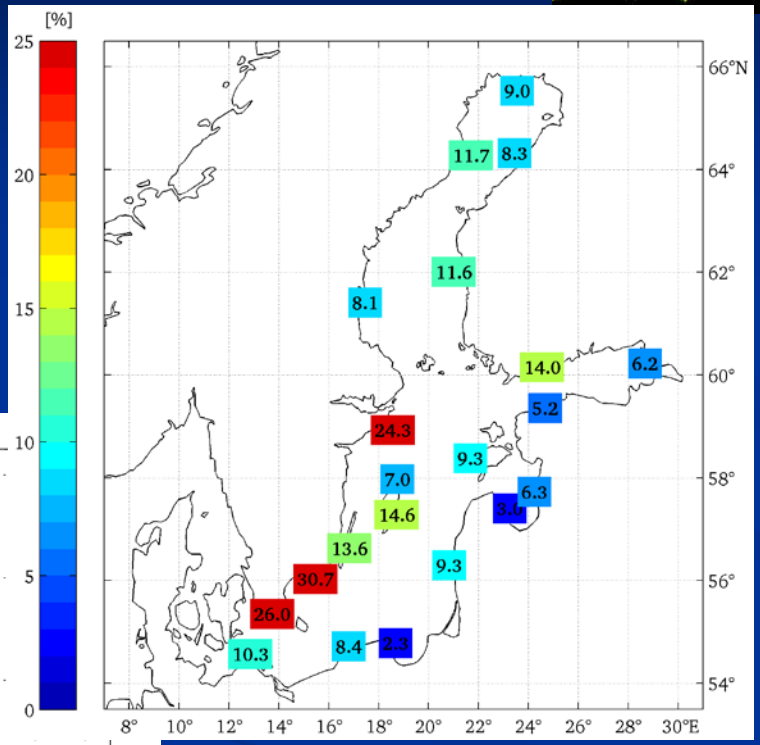



# Upwelling statistics...

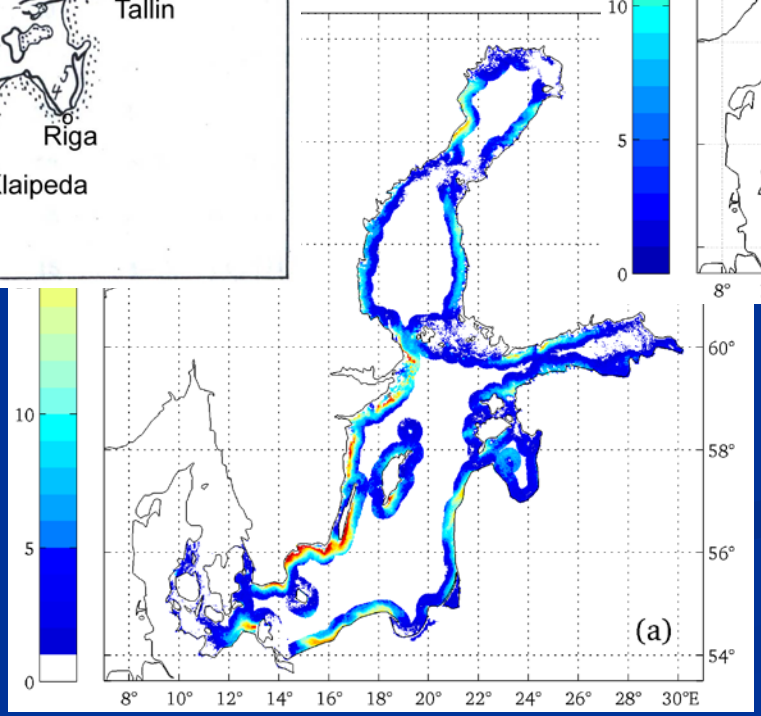
- Upwelling wind conditions




Bychkova et al. 1988



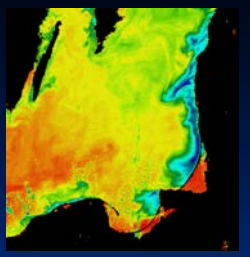

Favorable upwelling wind conditions
> 3.5 m/s for at least 2 days

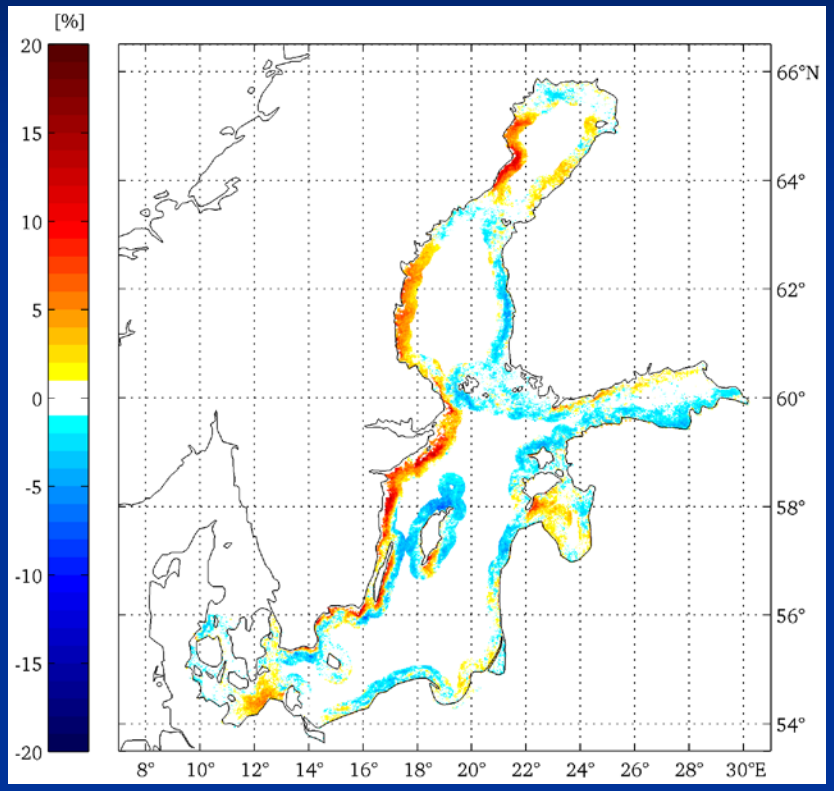



Upwelling threshold 2°C

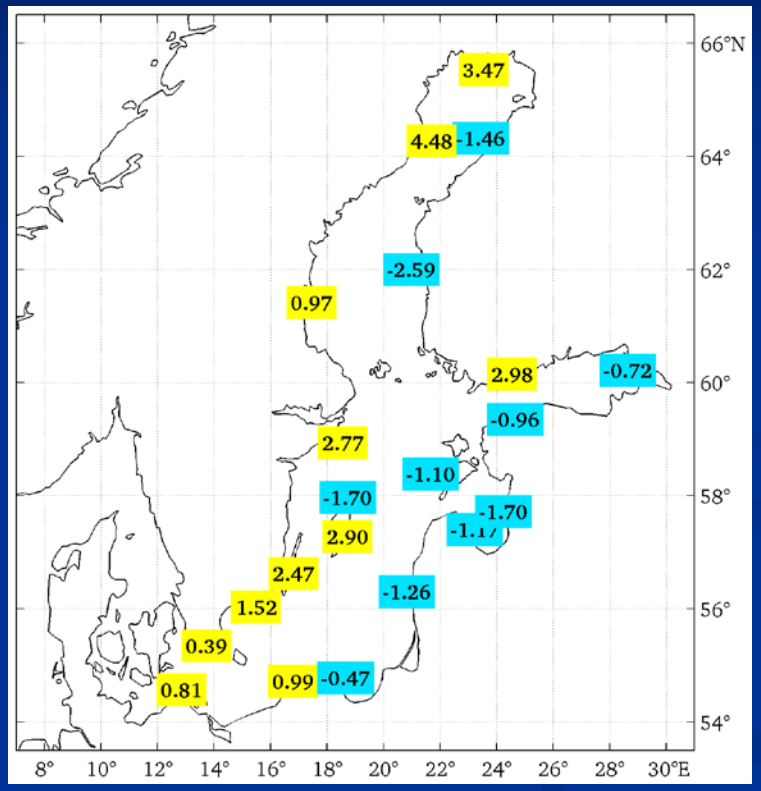
# Upwelling statistics...

- Trends % per decade






Upwelling trend 1990-2009, threshold 2°C
1 % corresponds to ~ 15 days




Favorable wind trend 1990-2009, threshold > 3.5 m/s for at least 2 days, 1 % corresponds to ~ 15 days

Höflich, 2011

# Upwelling statistics concluding remarks

- For the first time an upwelling statistics for the thermal stratified period and for individual months May to September has been obtained for the entire Baltic Sea
- Different methods have been applied to different data sources (satellite & model SST) to detect upwelling, the overall agreement is very high which confirms the robustness of the results
- Our results fit very well with earlier studies presented by Gidhagen (1987) and Bychkova et al. (1988)
- Most frequent upwelling can be found along the Swedish coast and the Finnish coast in the Gulf of Finland which is related to prevailing wind conditions
- For the period 1990-2009 a positive trend in the frequency of upwelling along the Swedish coast and the Finnish coast in the Gulf of Finland can be found which is in line with a positive trend in favorable wind conditions forcing upwelling i.e. an increase of south-westerly winds
- For the east coast of the Baltic Proper and the Finnish coast of the Bay of Bothnia the opposite is true.