7th Study Conference on BALTEX, Borgholm, Island of Öland, Sweden

Upwelling dynamics in the Baltic Sea studied by a combined SAR/infrared satellite data and circulation model analysis

Andreas Lehmann, Evgenia Gurova[*] and Andrei Ivanov[**]

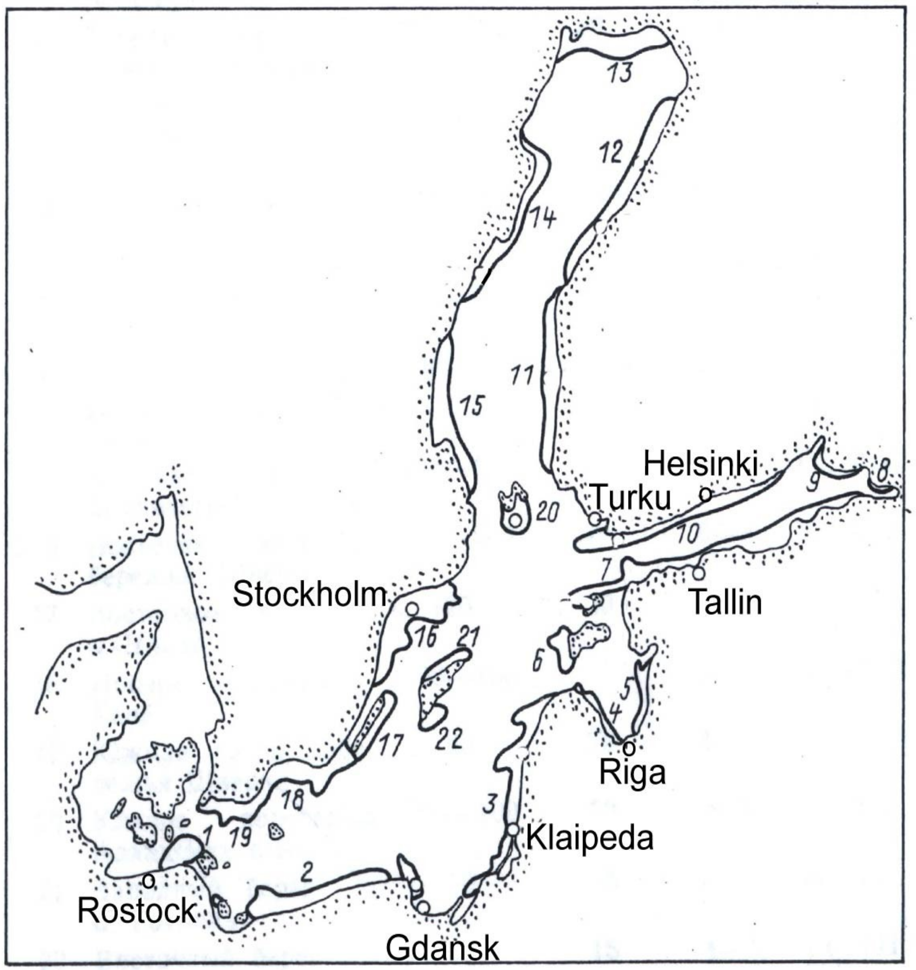
[*]Atlantic Branch of P.P. Shirshov Institute of Oceanology RAS, Kaliningrad, Russia
[**]P.P. Shirshov Institute of Oceanology RAS, Moscow, Russia

GEOMAR

Upwelling dynamics in the Baltic Sea ...

Motivation

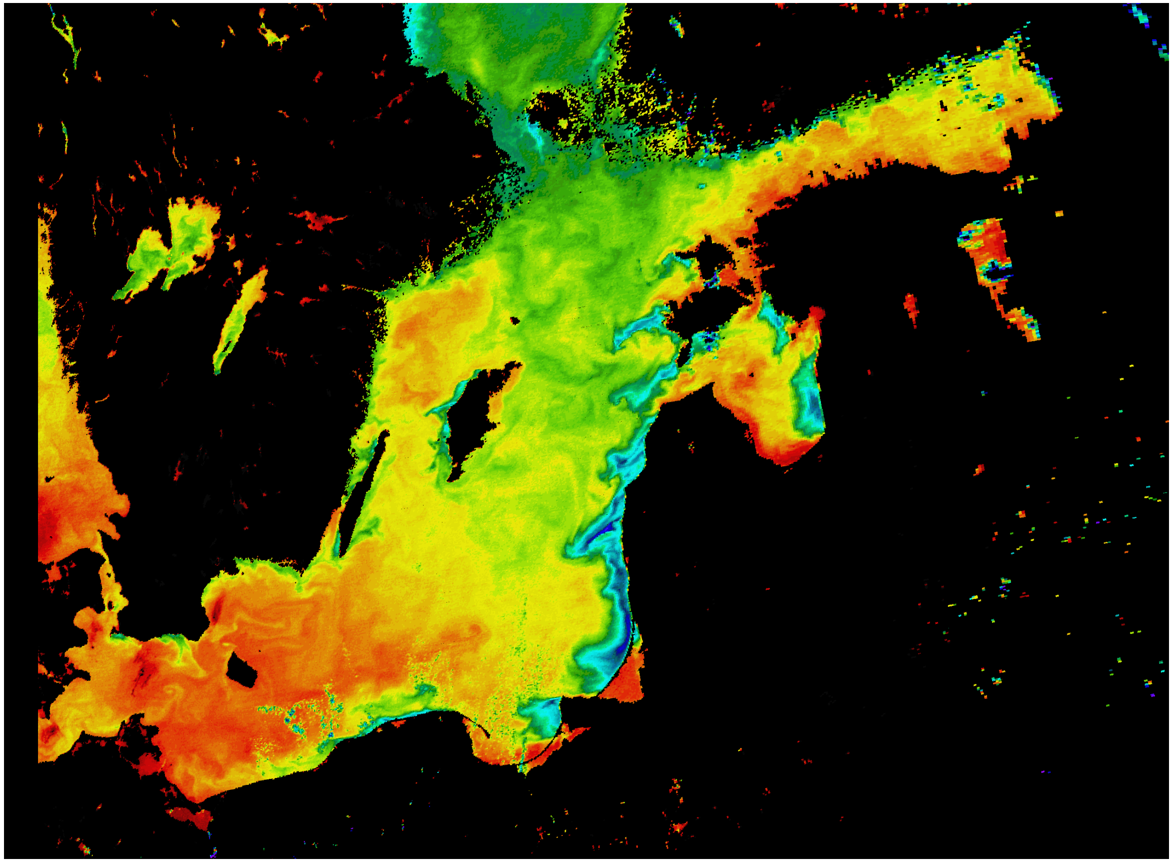
Motivation
Upwelling areas



Bychkova & Victorov 1987

22 upwelling areas

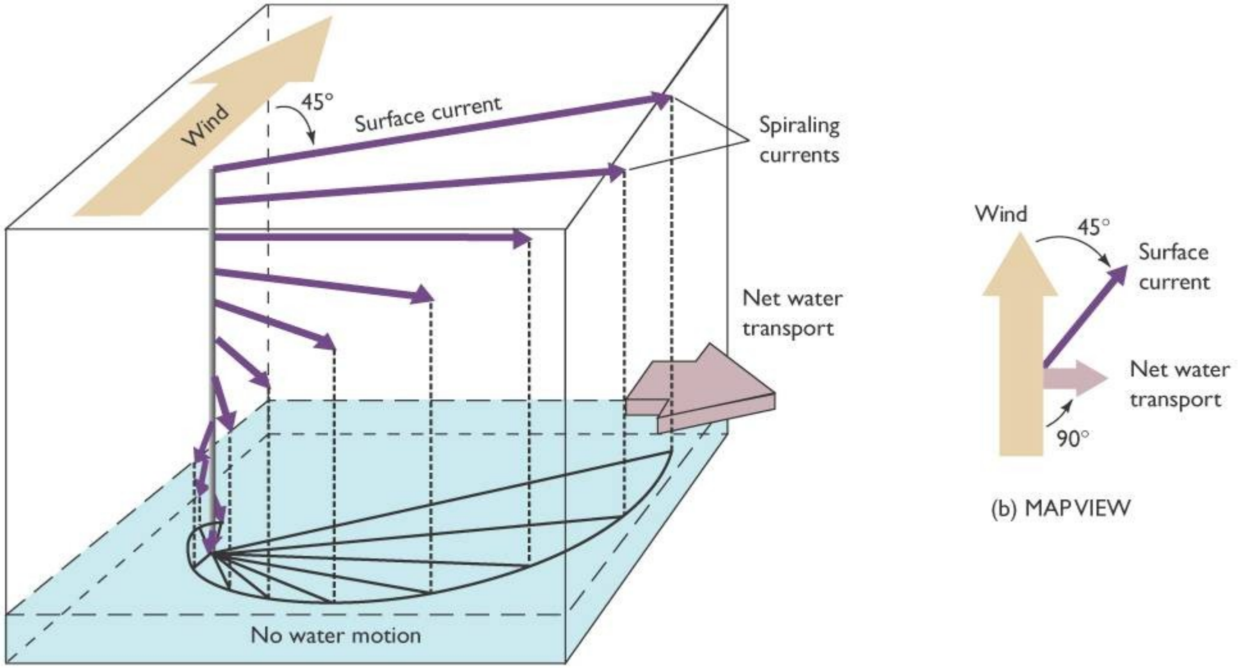
Upwelling 16 July 2006



MODIS SST °C
16 July 2006

Kozlov et al. 2011, ASAR imaging of coastal upwelling in the Baltic Sea

Ekman transport.

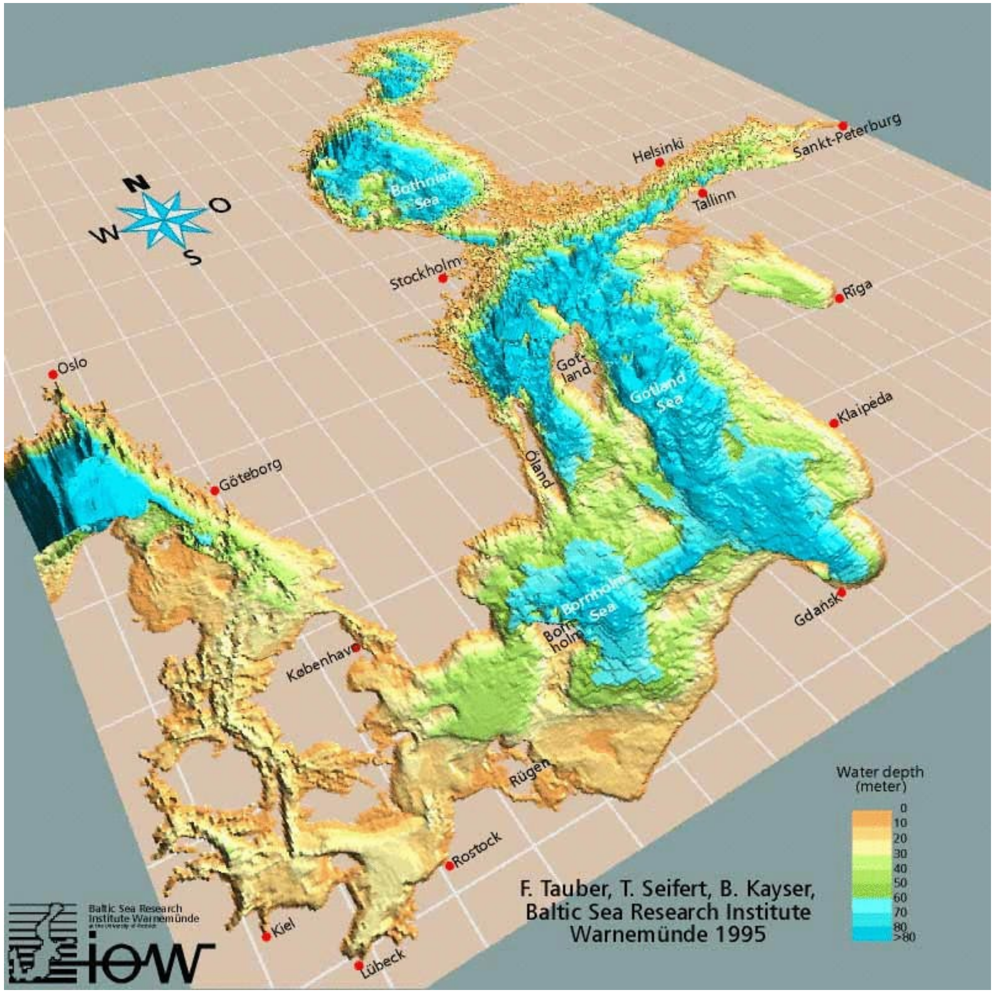


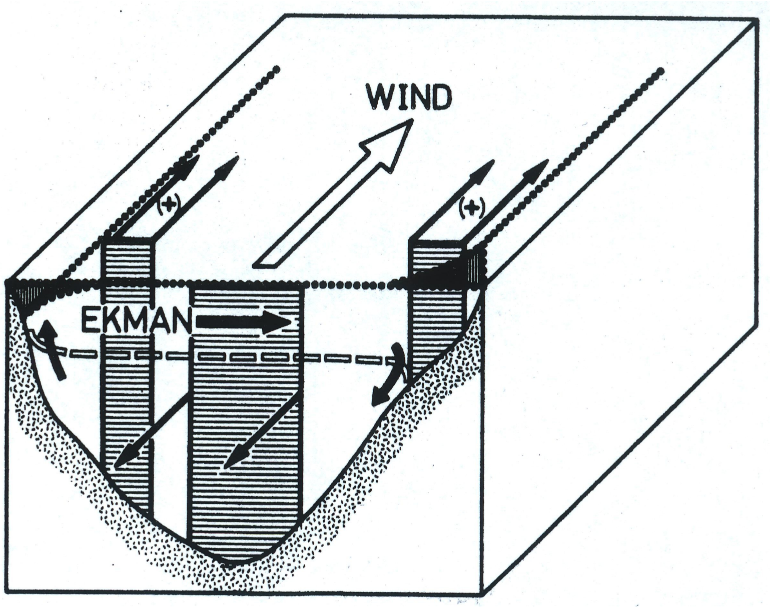
(a) EKMAN SPIRAL IN THE NORTHERN HEMISPHERE

Figure 6.6

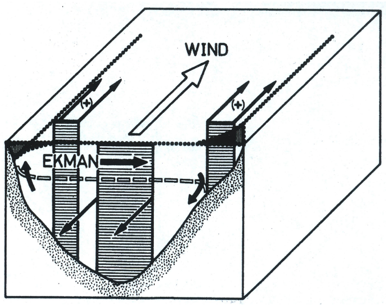
Invitation to Oceanography, 3rd Edition
Paul R. Pinet

Motivation
Basic principles





Krauss & Brügge 1991



Krauss & Brügge 1991

Upwelling can be discriminated into 2 phases (Zhurbas et al. 2008):

1. Active phase
   - Strong wind
   - Strong sea level inclination
   - Cold water reaches the surface
   - Regular upwelling structures

2. Relaxation phase
   - Weakened wind
   - Sea level relaxation
   - Still strong temperature/density gradient exists
   - Filaments, squirts and whirls develop

Upwelling dynamics in the Baltic Sea ...

Material & Methods

Material & Methods
SAR/MODIS data & Hydrodynamic model

- SAR – Envisat ASAR images
  - Back-scattered radar power or normalized radar cross section (NRCS)
  - 2D-picture of sea surface roughness, resolution ~ 150 m

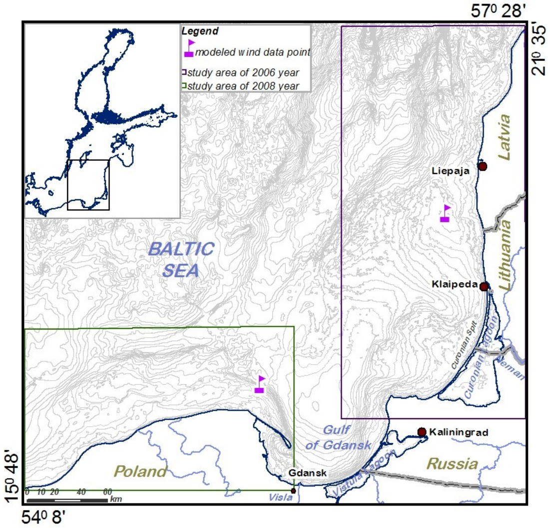
- MODIS (Terra & Aqua)
  - SST band, resolution ~ 1 km

- BSIOM - 3D coupled sea ice-ocean model of the Baltic Sea (Lehmann & Hinrichsen 2000)
  - Horizontal resolution 2.5 km
  - 60 vertical levels
  - Model domain: Baltic Sea including Skagerrak & Kattegat
  - Forcing: river runoff (Kronsell & Andersson 2011), atmosphere SMHI Met data base (Lars Meuller pers. Comm.)
  - Wind stresss drag coefficient is calculated according to Large and Pond (1981) depends on the roughness length and a stability correction.

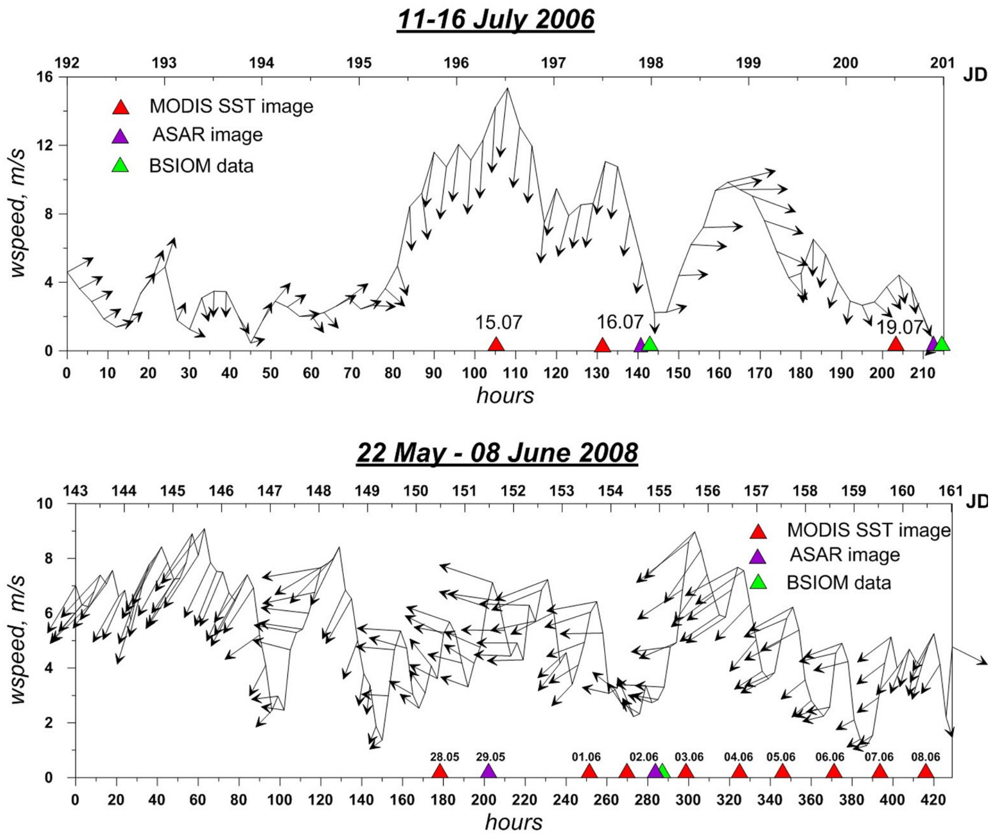
Upwelling dynamics in the Baltic Sea ...

Results

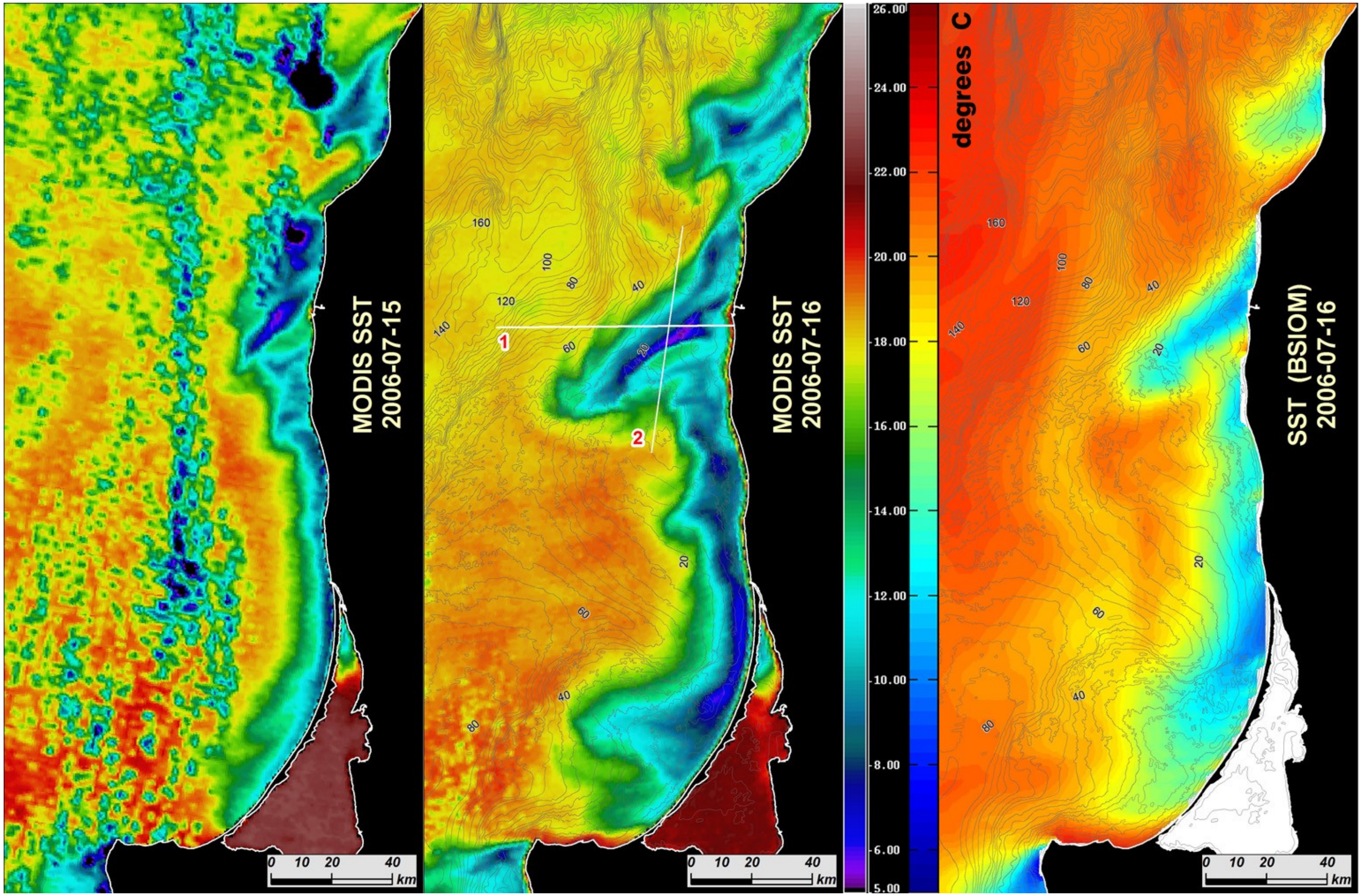
Results
Wind data SMHI Met-data base



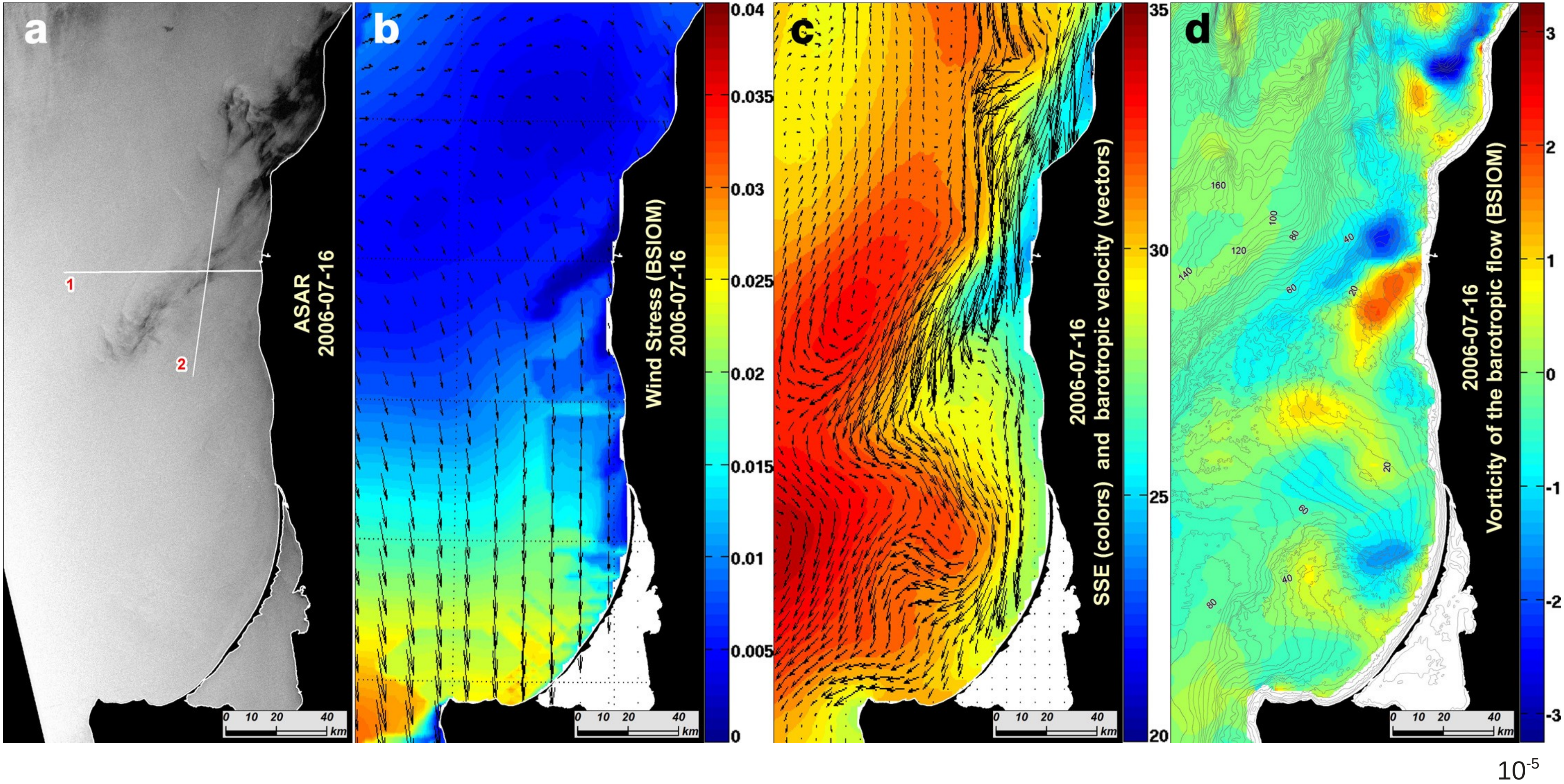
10-m wind, Bumke et al. 1998



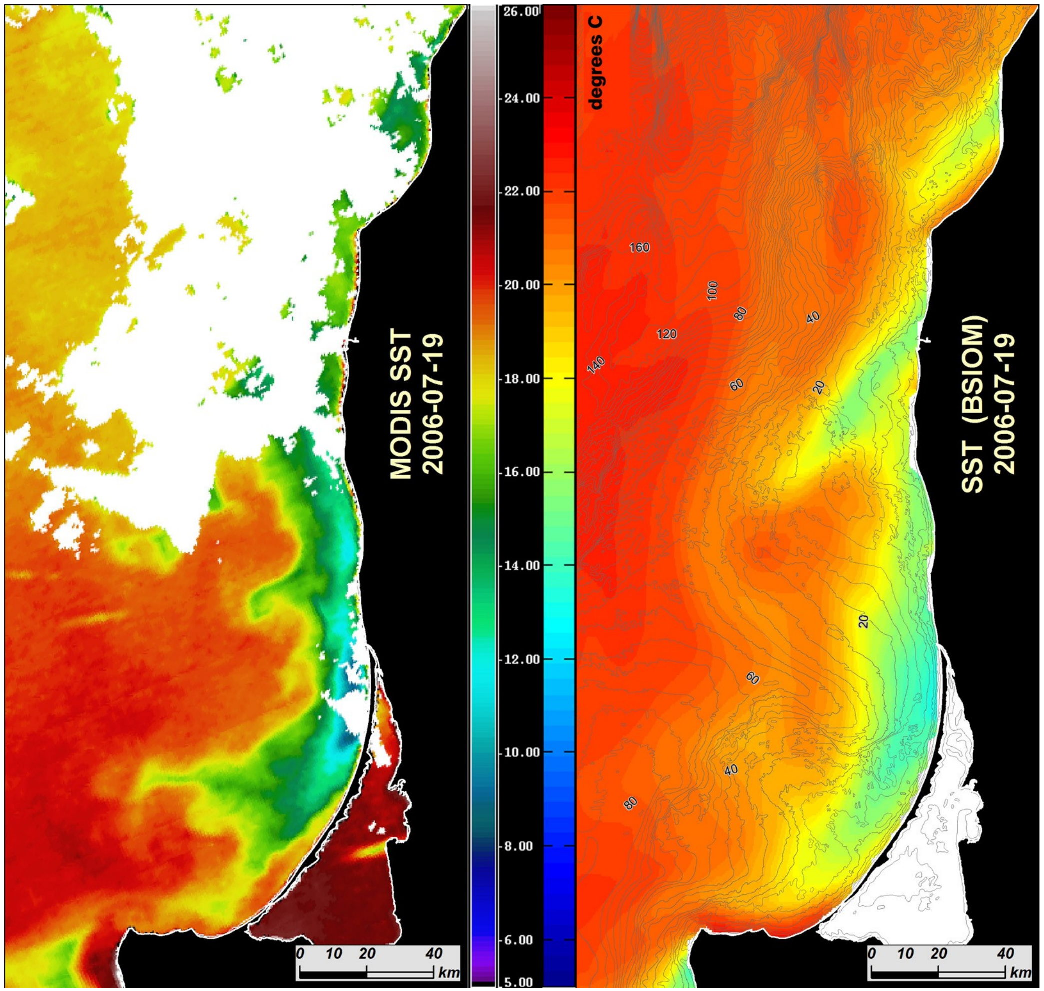
Results
SST °C MODIS & BSIOM



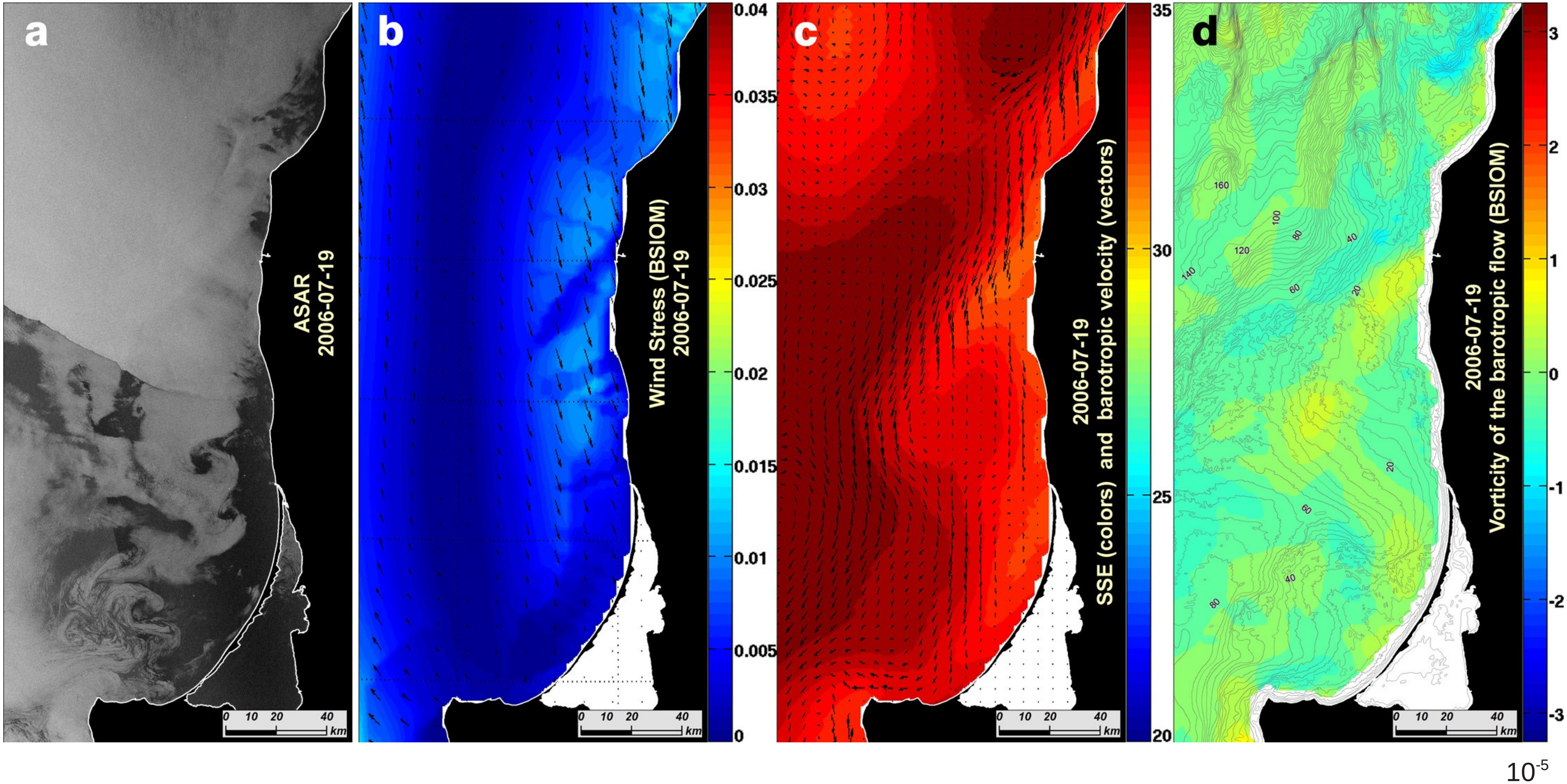
Results
SAR & BSIOM 16 July 2006



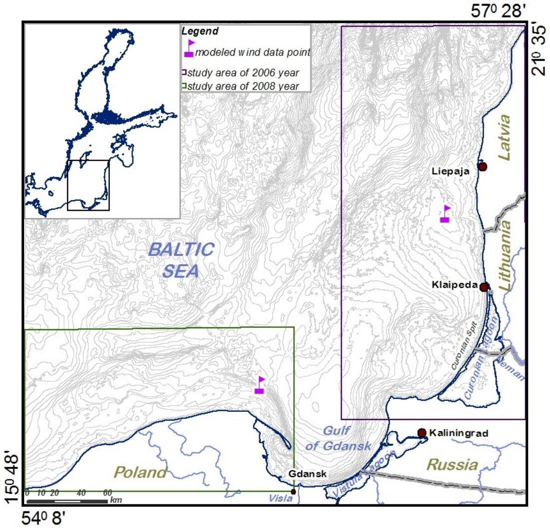
Results
MODIS & BSIOM 19 July 2006



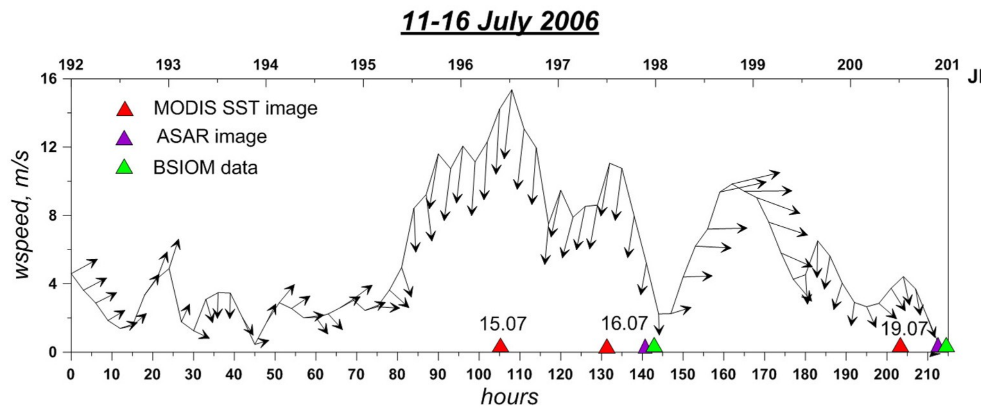
SAR & BSIOM 19 July 2006

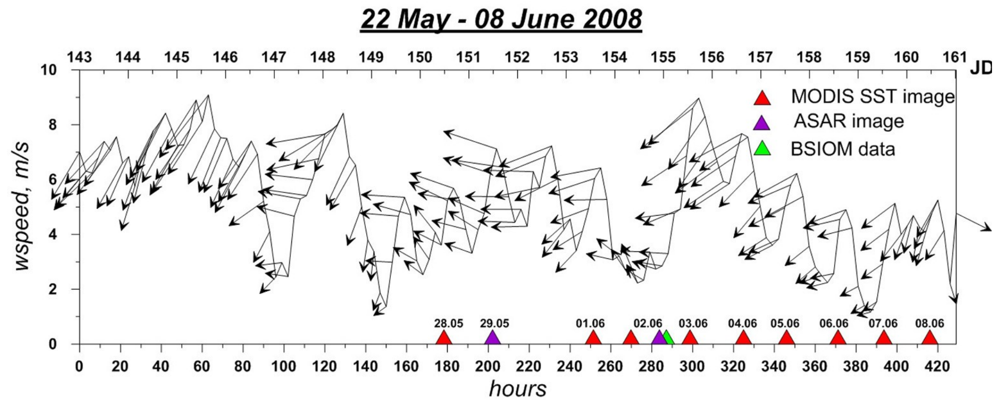


Results
Wind data SMHI Met-data base

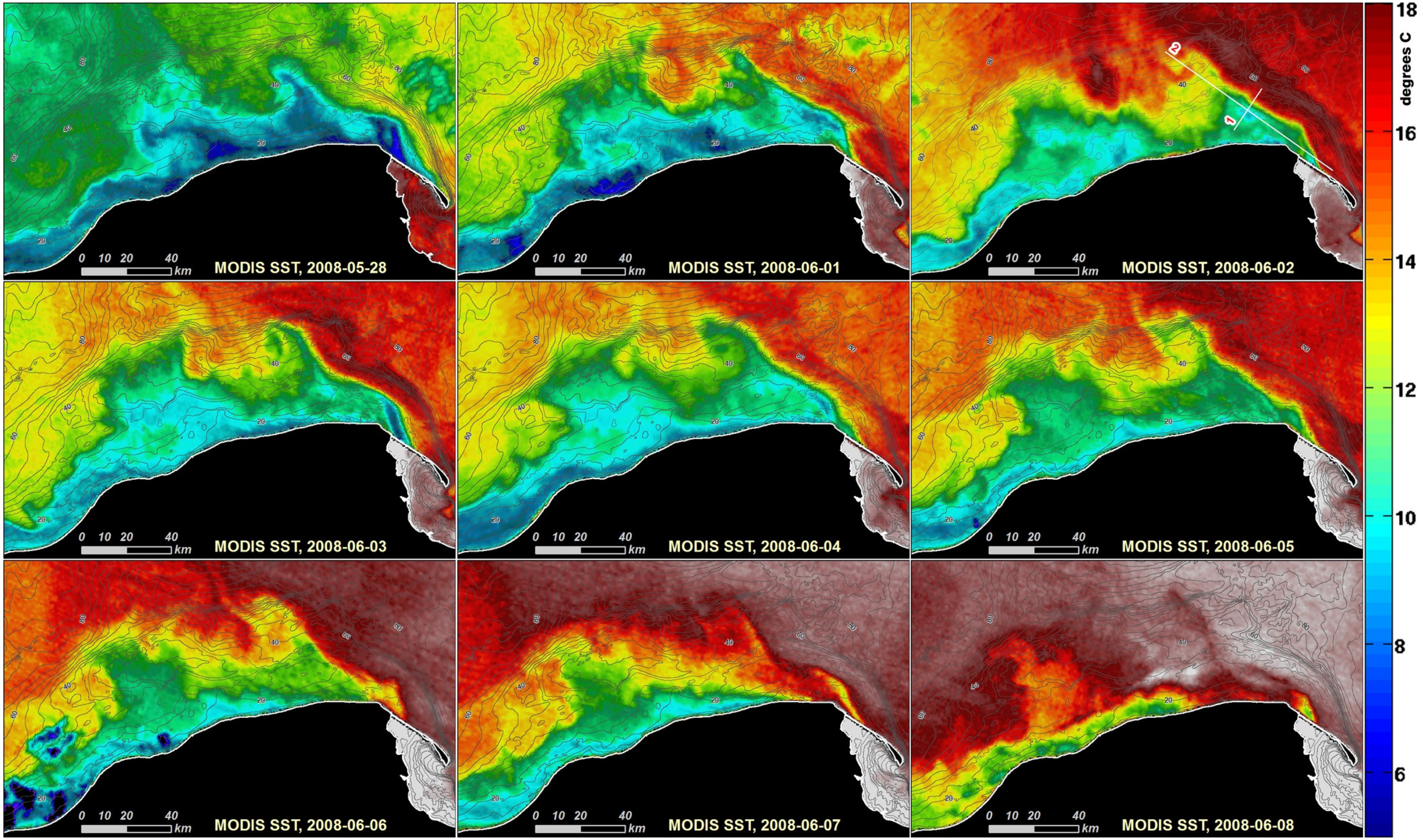


10-m wind, Bumke et al. 1998

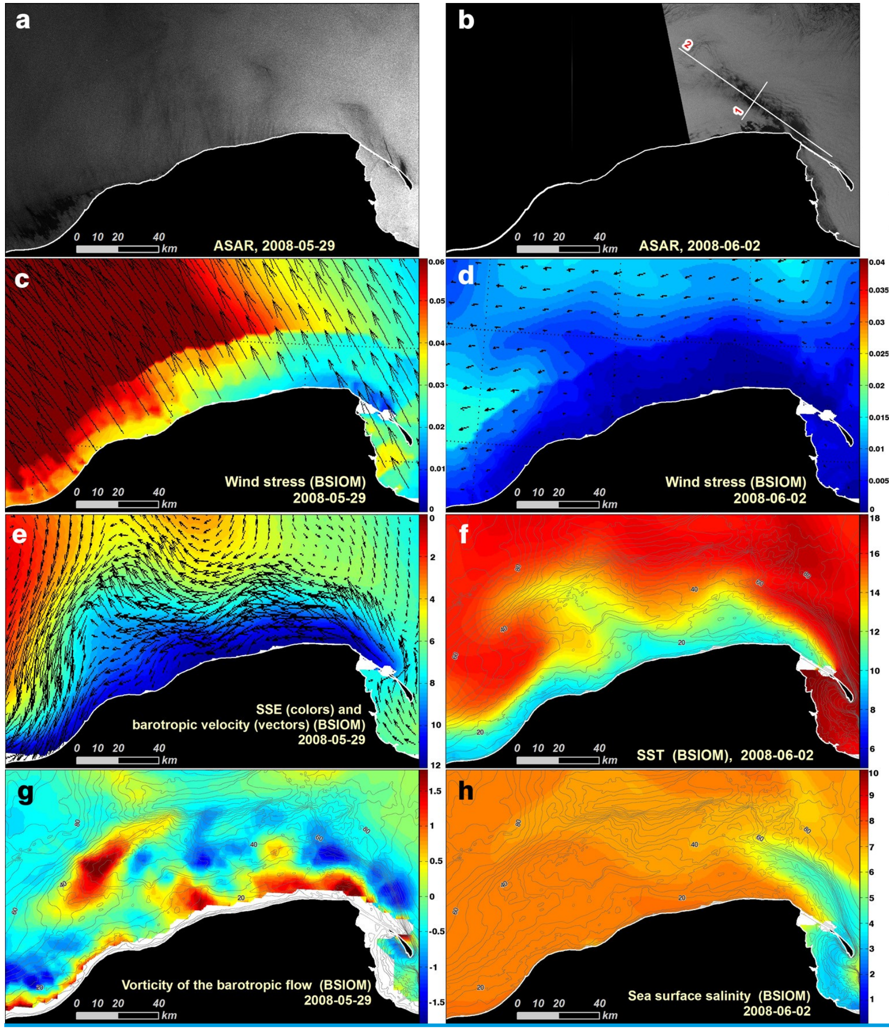


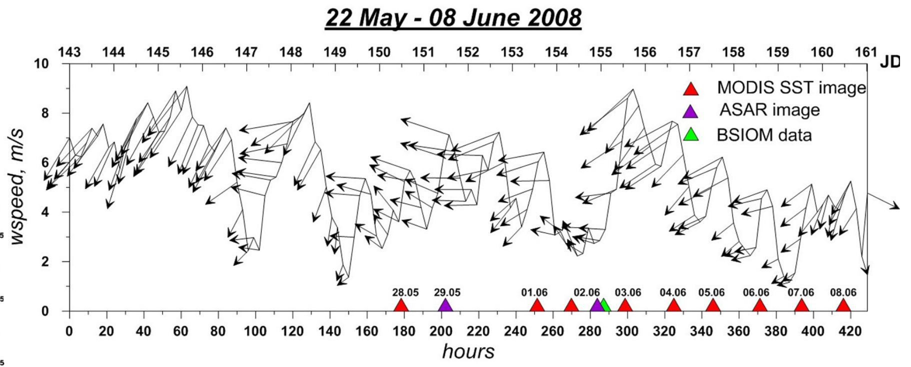


Results
MODIS May/June 2008



Results
SAR & BSIOM 29 May, 2 June 2008





Upwelling dynamics in the Baltic Sea studied by a combined SAR/infrared satellite data and circulation model analysis

Conclusions

Conclusions

- The combined analysis of observations and hydrodynamic model is superior to single methods alone

- Model results are in good agreement with observations (MODIS/SAR)

- Over upwelling areas the wind stress (drag coefficient) can be reduced if the wind speed is below a certain threshold (SAR & BSIOM)

- During the active phase of upwelling:
  - Wind is strong
  - Cold water reaches the surface
  - Strong inclination of the sea level
  - Coastal jet is mainly barotropic
  - Coastal jet is controlled by vorticity dynamics in relation to depth variation in direction of the flow
  - The meandering coastal jet is associated with the position of upwelling structures (regular)
  - Transport of the coastal jet along the coast ~ 10^4 m^3 s^{-1}
  - Transport offshore is in the order of 10^3 m^3 s^{-1}

Conclusions

- During the relaxation phase of upwelling:
  - Wind is weakened
  - Still strong temperature/density gradients exist
  - Relaxation of the sea level inclination
  - Baroclinic jet is associated with the temperature gradient
  - This jet might become instable (irregular) by baroclinic instabilities
  - Filaments, squirts and whirls (Zhurbas et al. 2008) can be produced
  - To simulate the full spectrum of mesoscale variability a horizontal grid resolution of at least 1 km is necessary