

# Projected Changes in Baltic Sea Upwelling in Climate Change Scenarios

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How does upwelling affect

- Vertical transport (of nutrients)?
- Communication between Coastal Zone and open Baltic?
- Feedback to the atmosphere?

Upwelling plays a potential role for

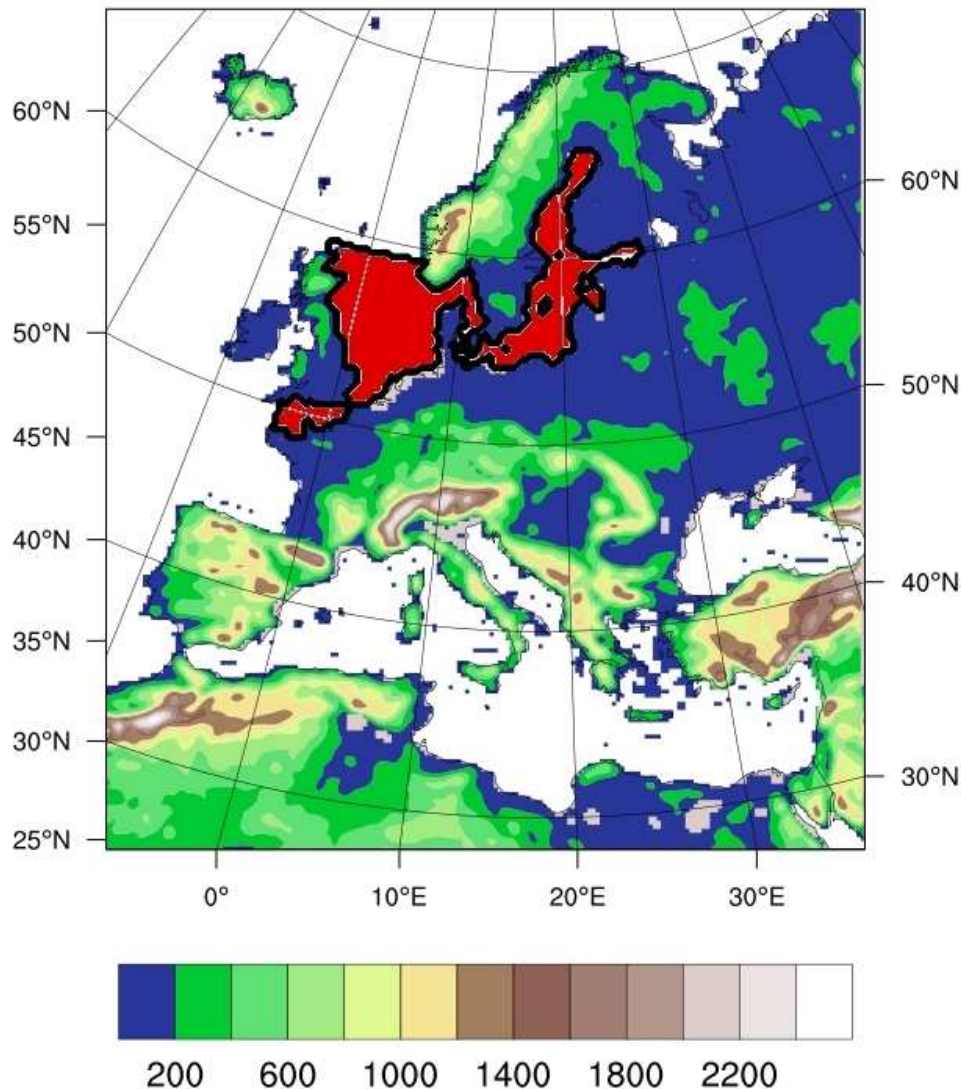
- Algae bloom forecast
- Fisheries
- Weather prediction
- Tourism

(Lehmann & Myrberg, 2008)

# Atmosphere-Ice-Ocean Model RCA4-NEMO

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RCA4 domain and orography



- EURO-CORDEX setup for RCA4
- Resolution:  $0.22^\circ$ , 40 levels
- Flux-coupled every 3 hours to NEMO-Nordic
- Resolution: 2 naut. miles, 56 levels, 5 ice classes
- Boundary conditions: GCM or reanalysis data
- Runoff: E-HYPE hindcast data

## Ensemble of Scenarios with RCA4-NEMO

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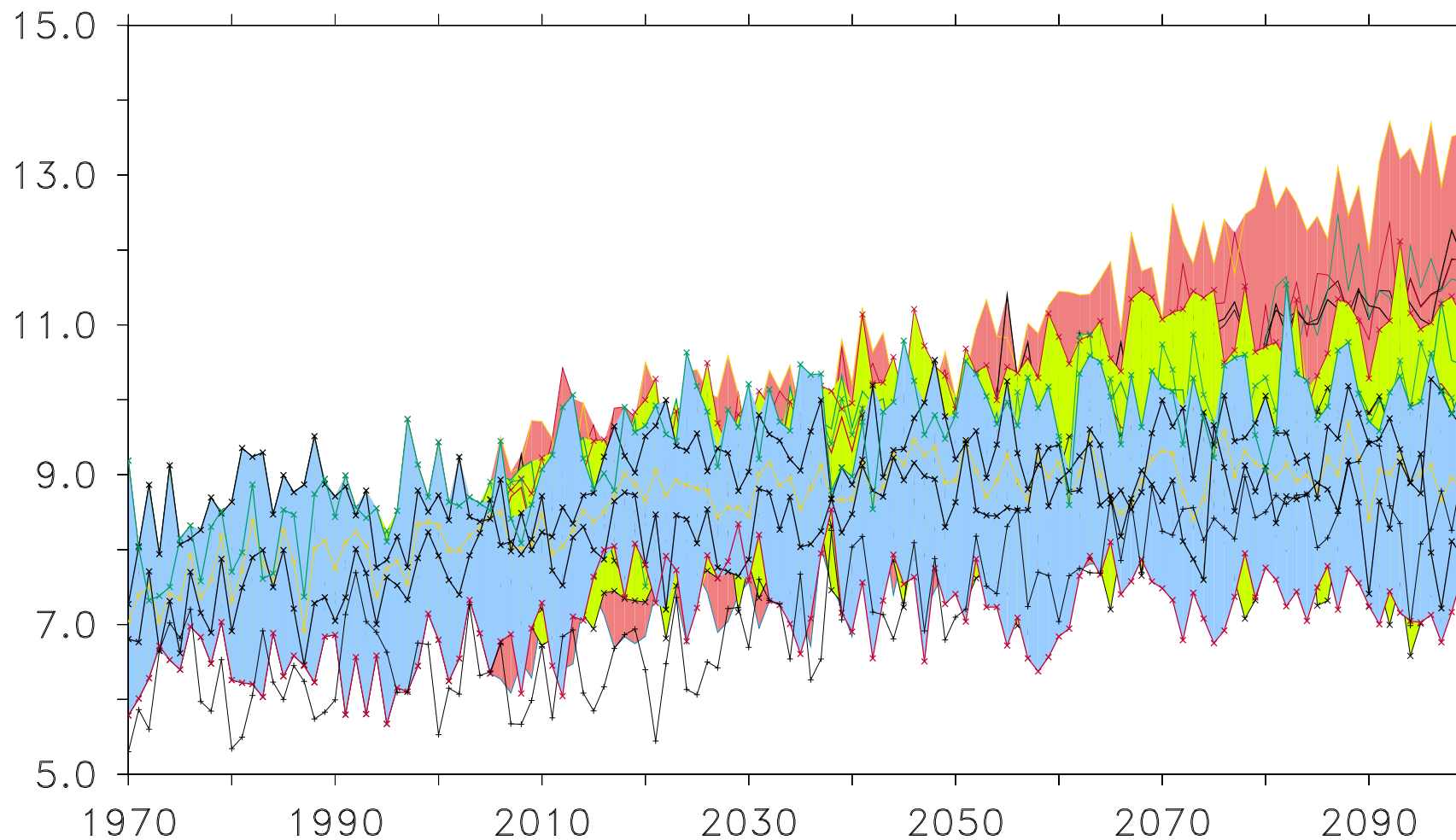
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experiment	historical	RCP 8.5	RCP 4.5	RCP 2.6
ERA40	1961 - 2010			
MPI-ESM-LR	1961 - 2006	2006 - 2099	2006 - 2099	2006 - 2099
EC-EARTH	1961 - 2006	2006 - 2099	2006 - 2099	2006 - 2099
GFDL-ESM2M	1961 - 2006	2006 - 2099	2006 - 2099	2006 - 2099
HadGEM2-ES	1961 - 2006	2006 - 2099	2006 - 2099	2006 - 2099
IPSL-CM5A-MR	1961 - 2006	2006 - 2099	2006 - 2099	

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- 5 different GCMs
- 3 different scenarios
- ECHAM5/MPIOM, SRES A1B
- 1 RCM

# Projected Baltic Sea SST

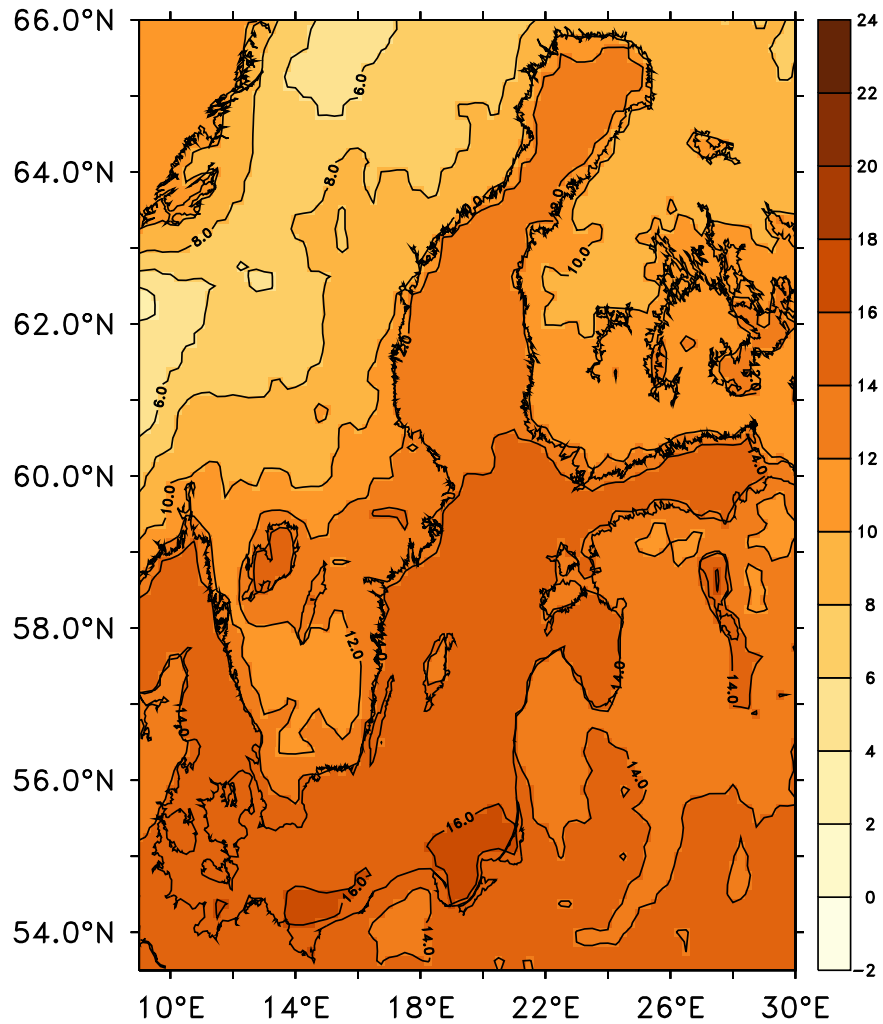


Baltic Sea SST 1970 - 2099 [C]

RCA4-NEMO RCP8.5 (red), RCA4-NEMO RCP4.5 (green),

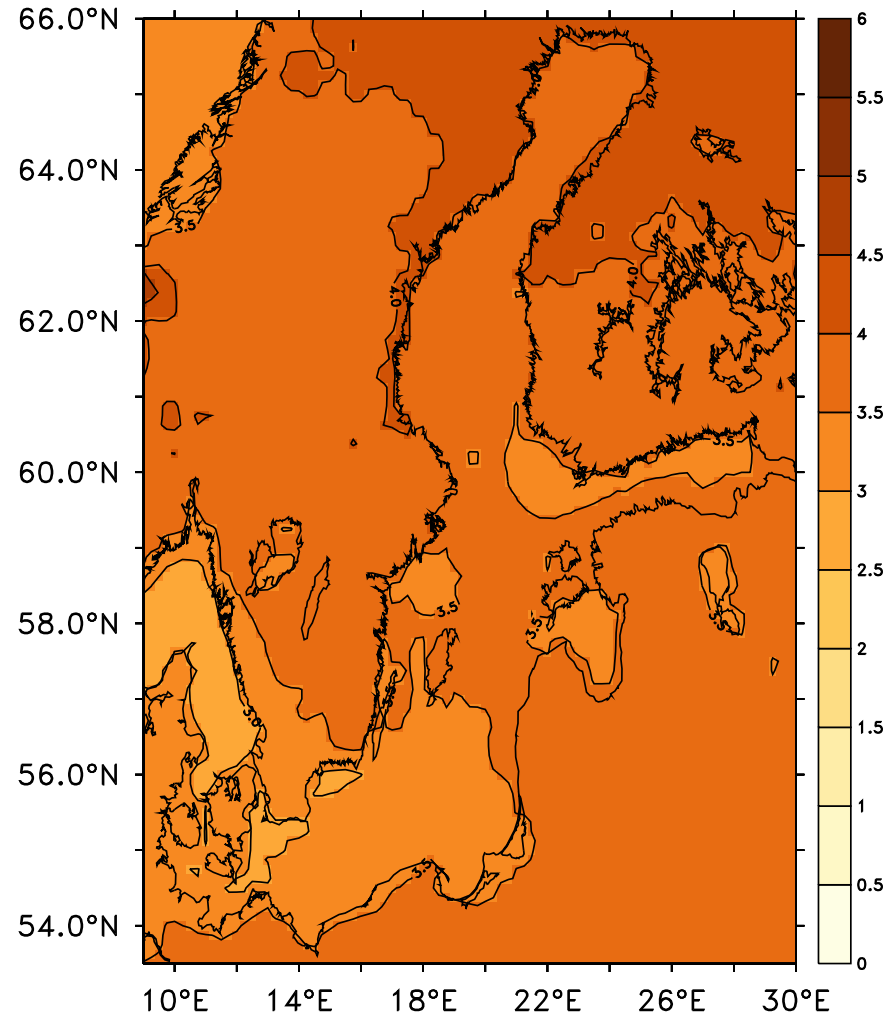
RCA4-NEMO RCP2.6 (blue)

# Differential Heating Due to Climate Change



Summer air temperature [C]

Ensemble median RCP 8.5 1970 to 1999



changes in air temperature [C]

2070 to 2099 minus 1970 to 1999

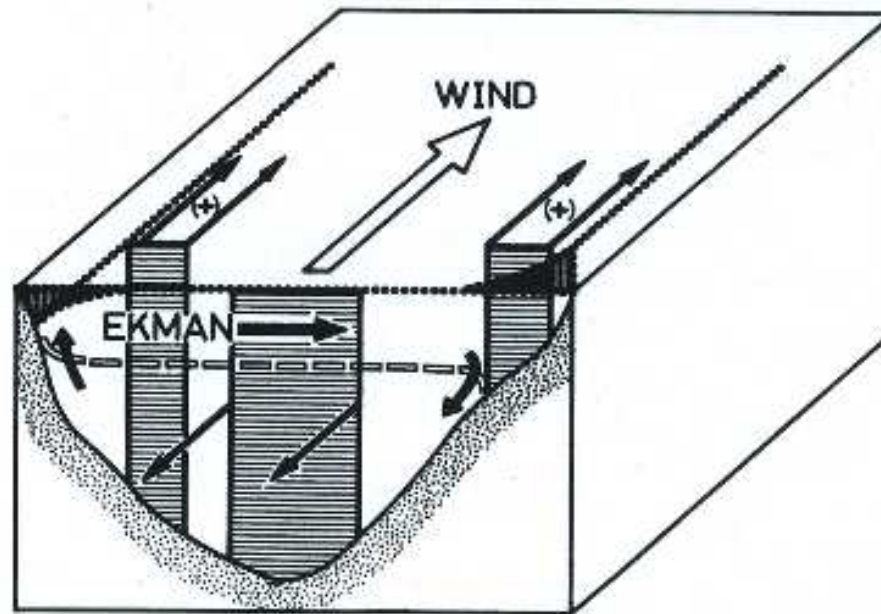


Figure 3. Principle response of an elongated basin to constant wind in length direction of the basin, redrawn from Krauss and Brüggel (1991).

(Lehmann & Myrberg, 2008)



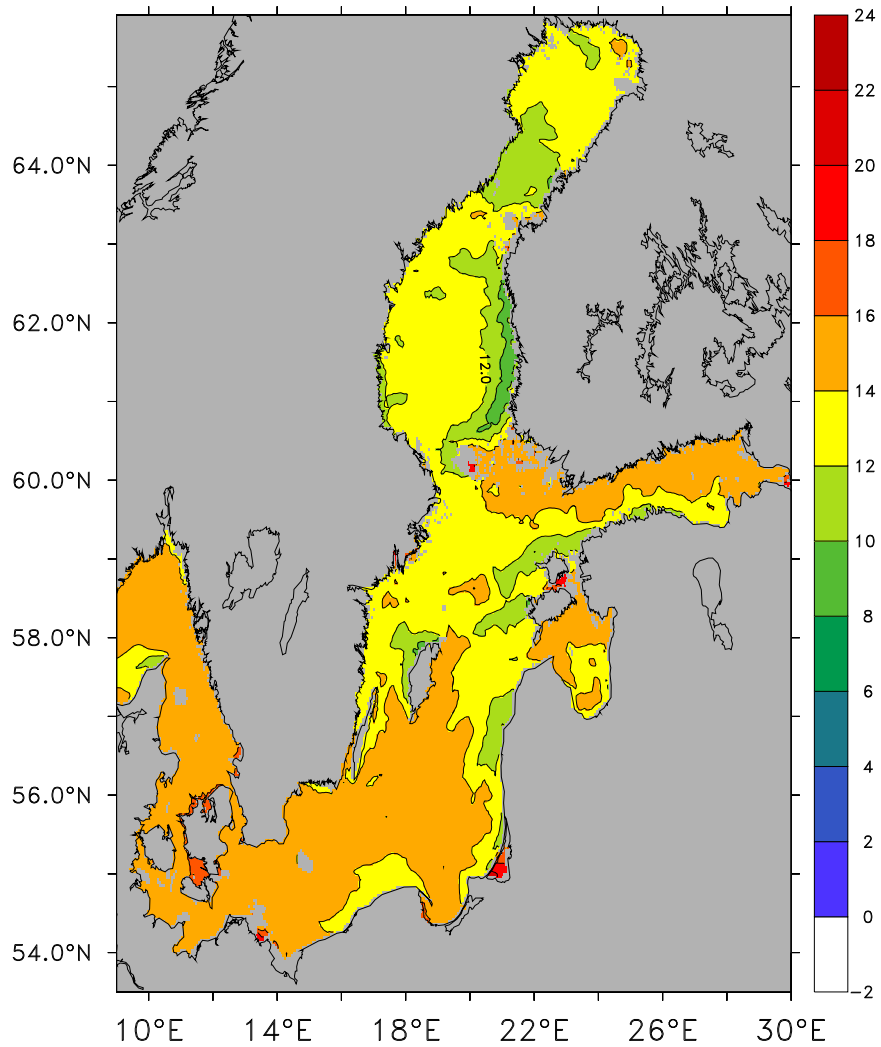


(Lehmann & Myrberg, 2008)

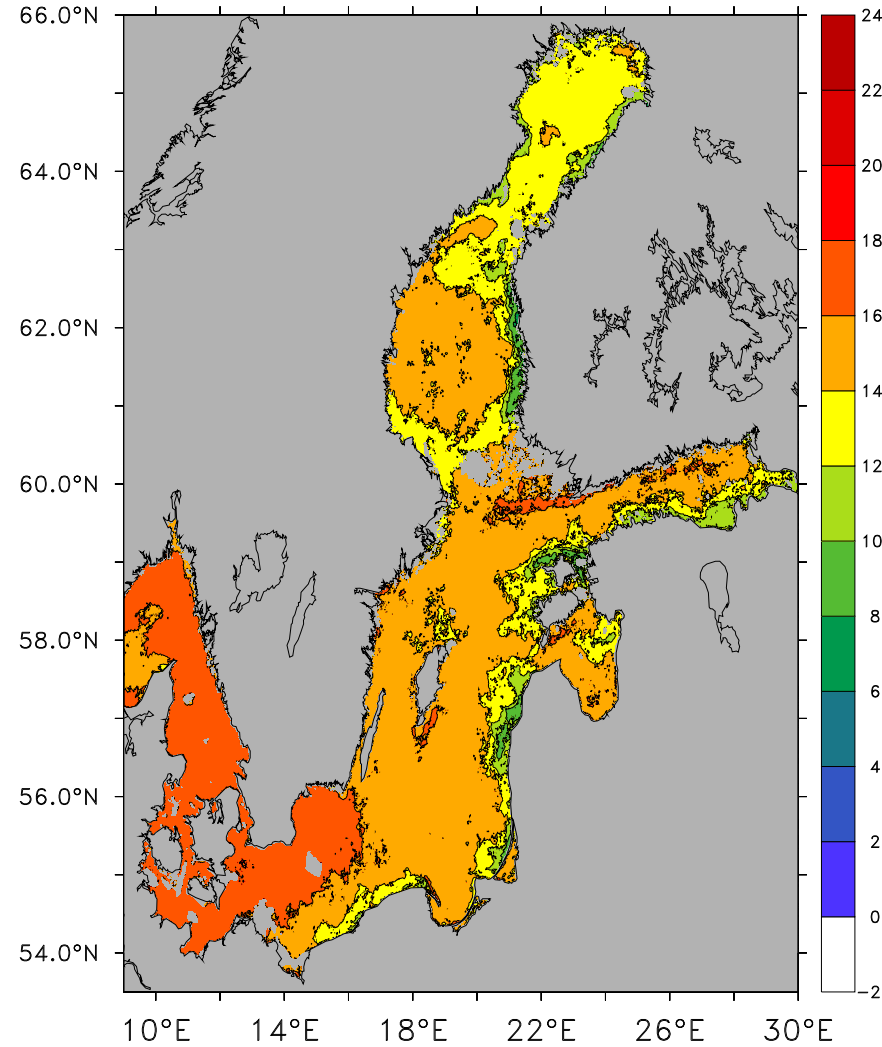
Figure 4. Main upwelling regions in the Baltic Sea due to corresponding general weather conditions, redrawn from Bychkova et al. (1988).



# An Example of an Upwelling Event

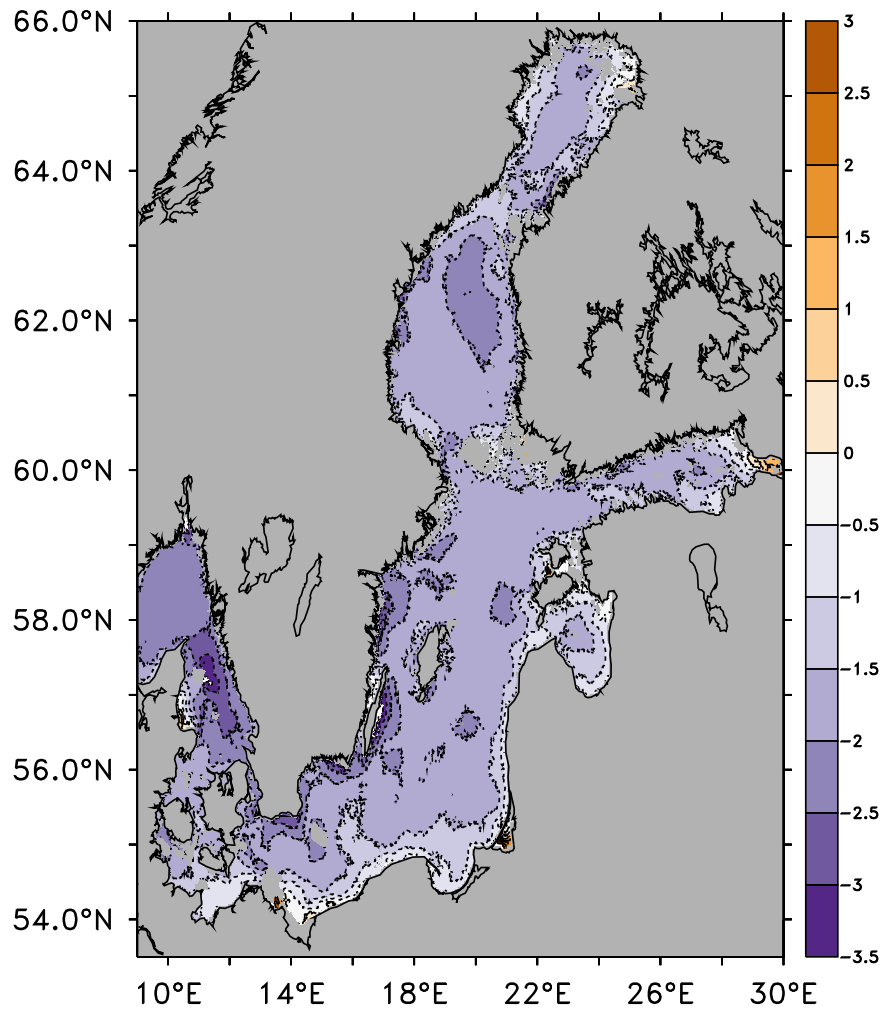


September 1996, SST [C]  
RCA4-NEMO ERA40



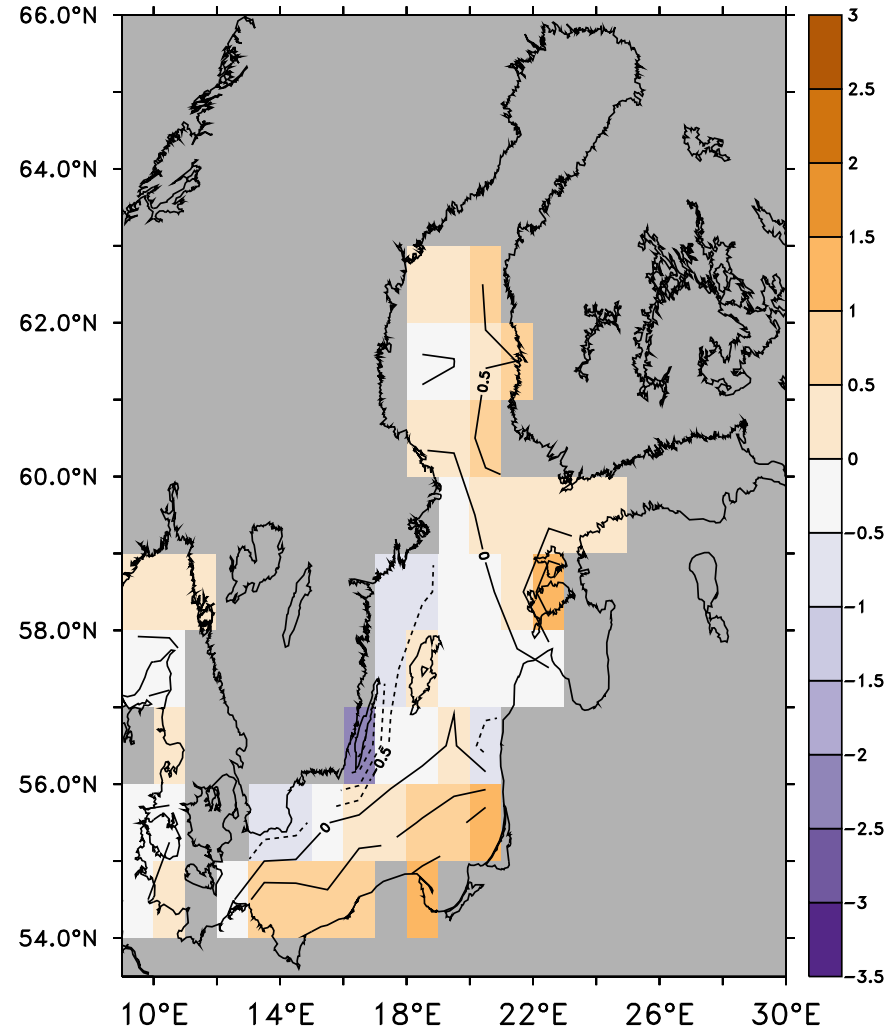
September 1996, SST [C]  
BSH SST

# Model Validation



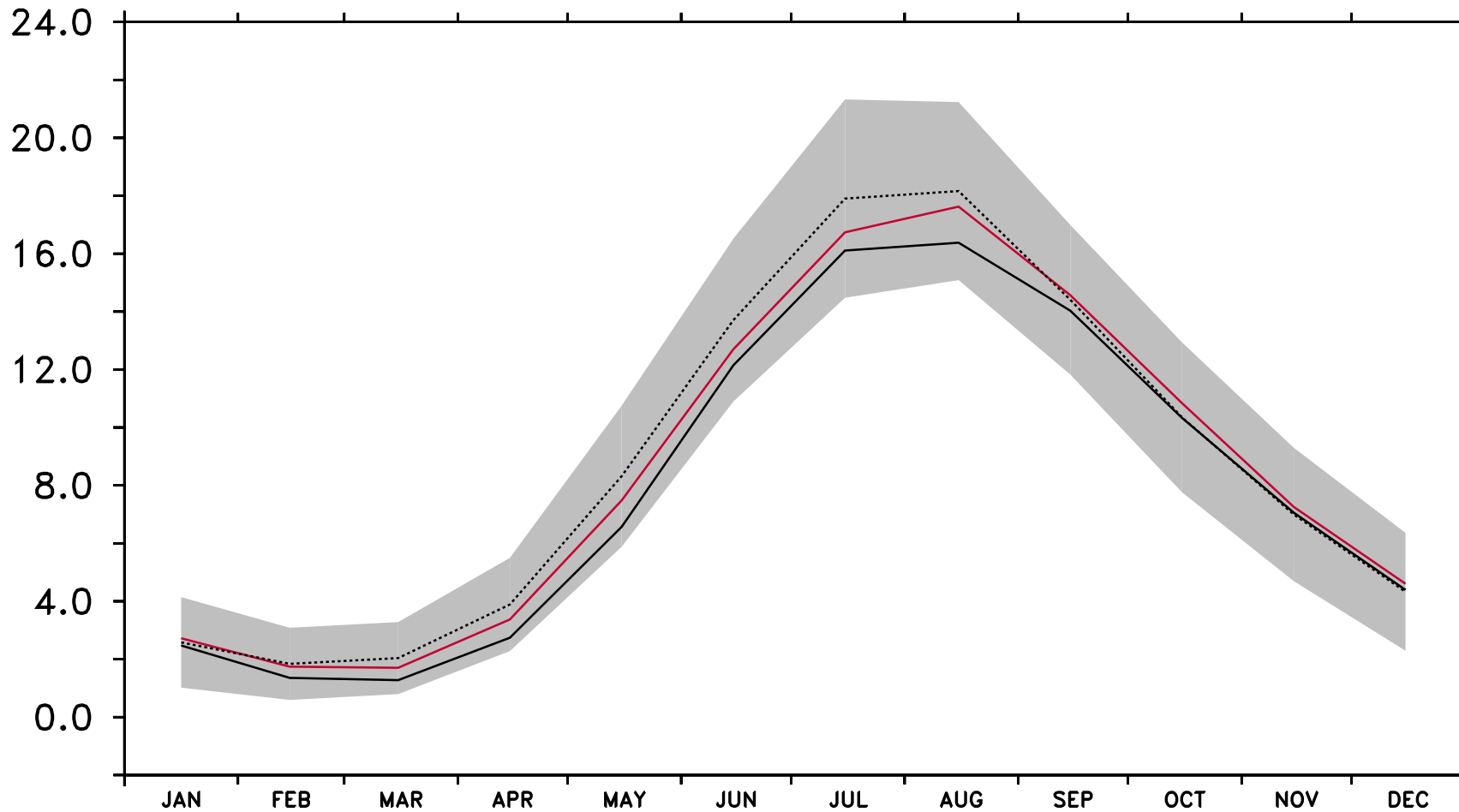
SST bias [C] for RCA4-NEMO Ensemble Median

BSH SST (August 1990 to 2009)



ASMD94 (August 1970 to 1989)

# Model Validation

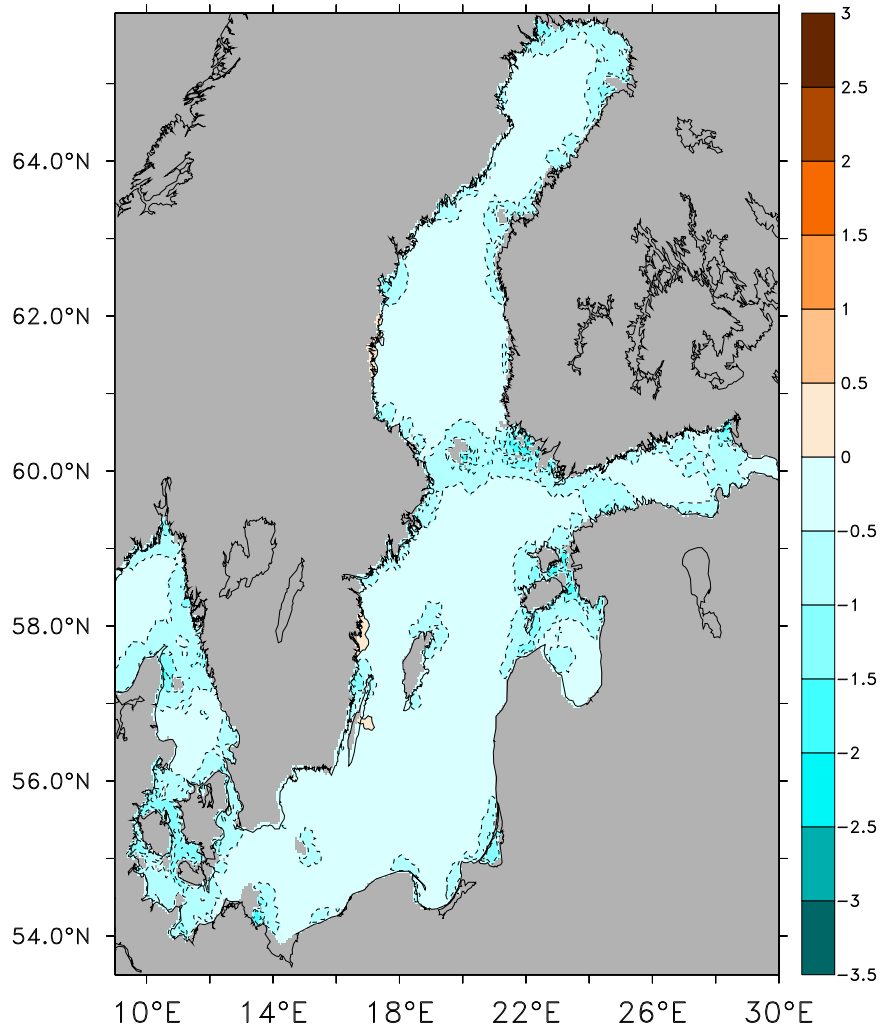


Baltic Sea SST, 1990 - 2009 [C]

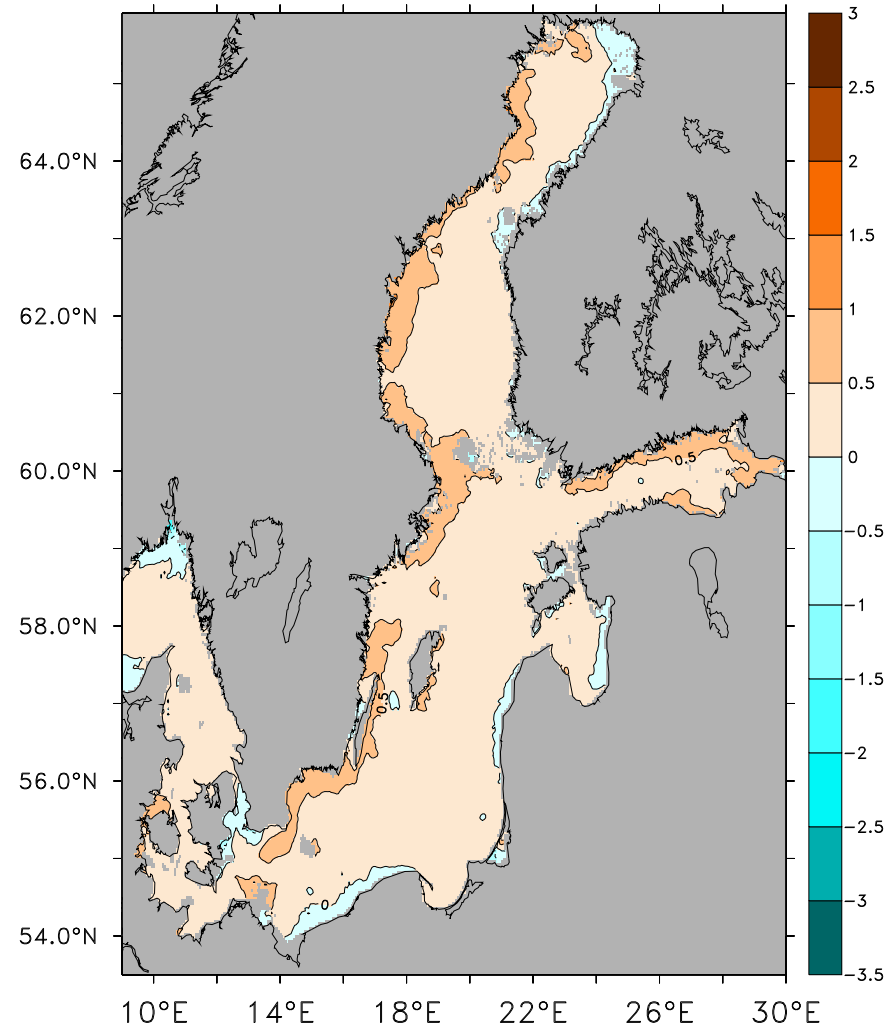
BSH SST (dotted, shading), RCA4-NEMO Ensemble Median (black),

RCA4-NEMO ERA40 Hindcast (red)

# Model Sensitivity

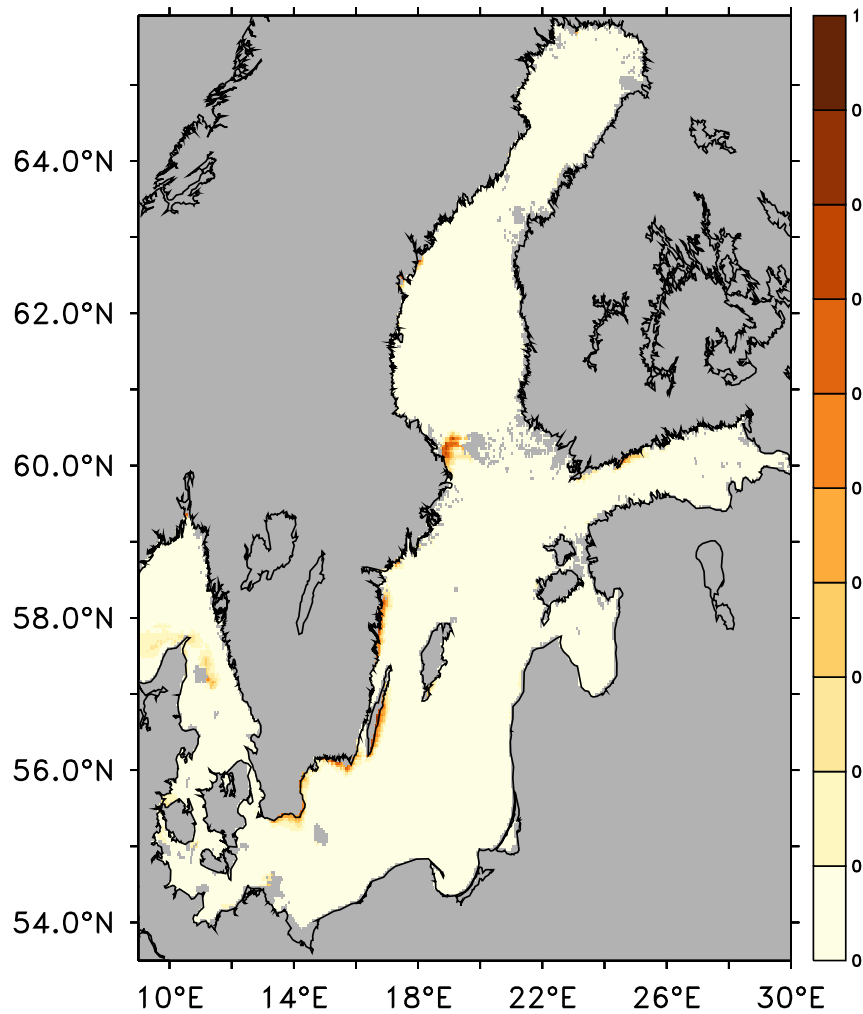


August wind speed 1990 - 2005 [C]  
RCA4-NEMO AO 456 - AO 455

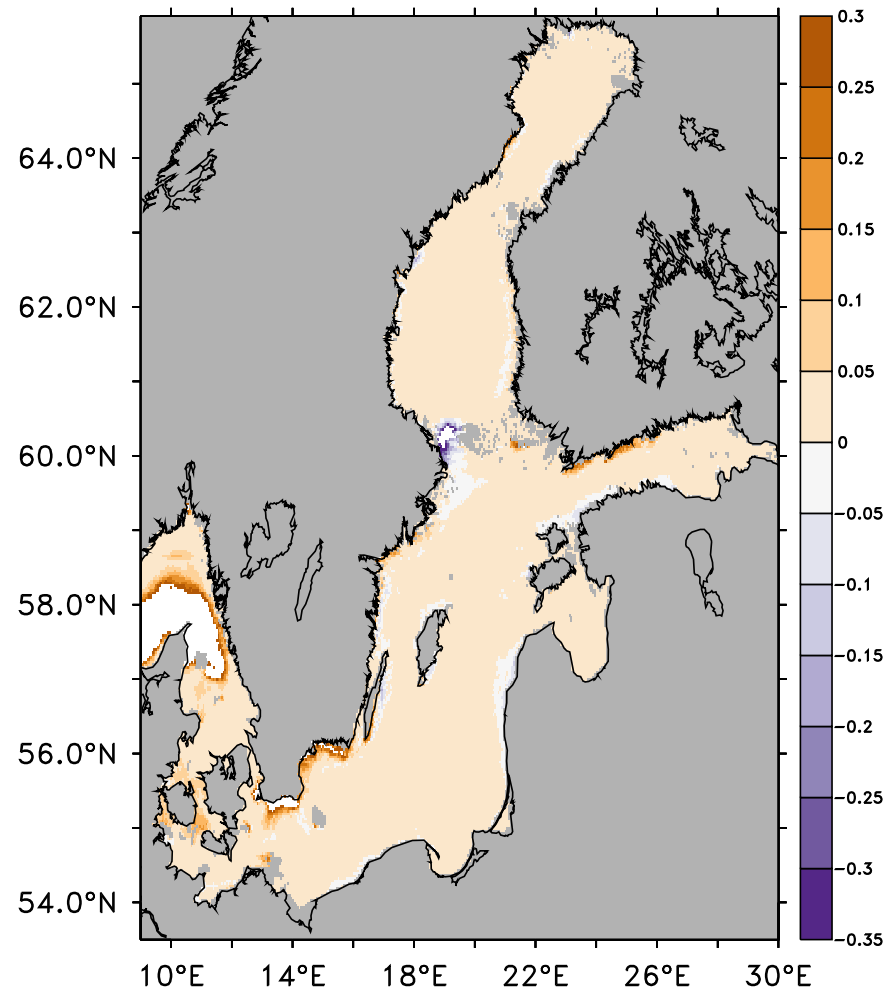


August SST 1990 - 2005 [C]  
RCA4-NEMO AO 456 - AO 455

# Changes in Upwelling Frequency

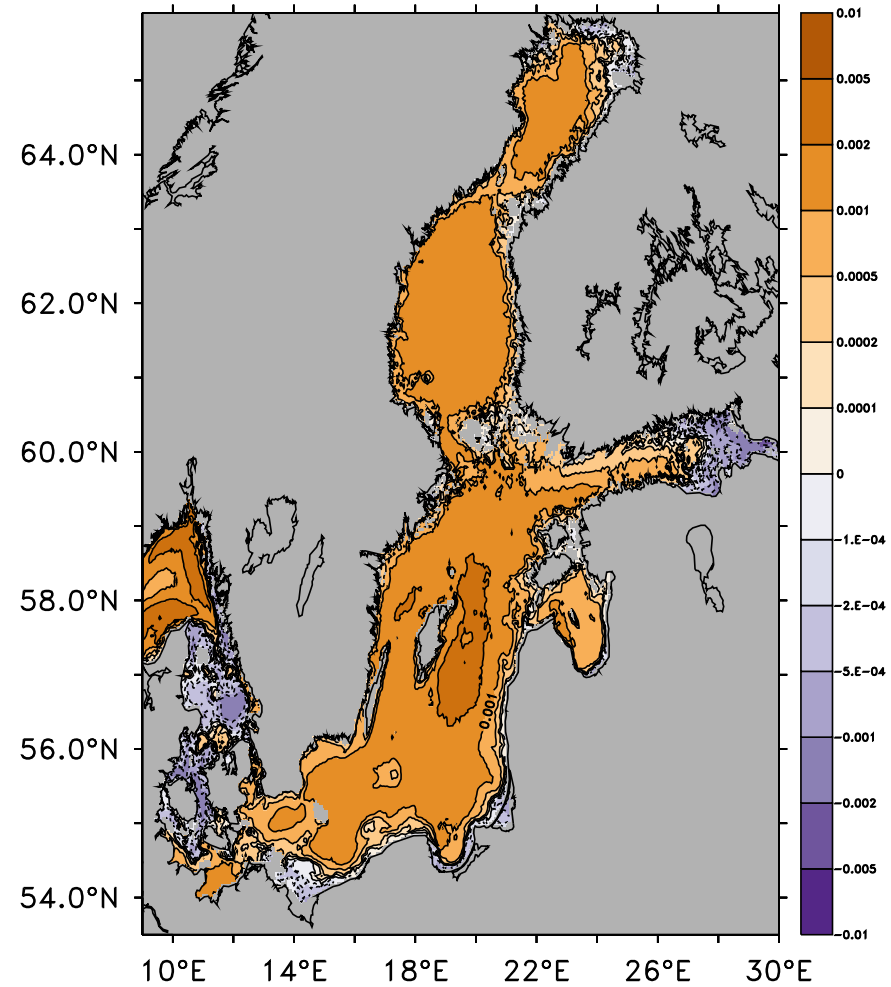
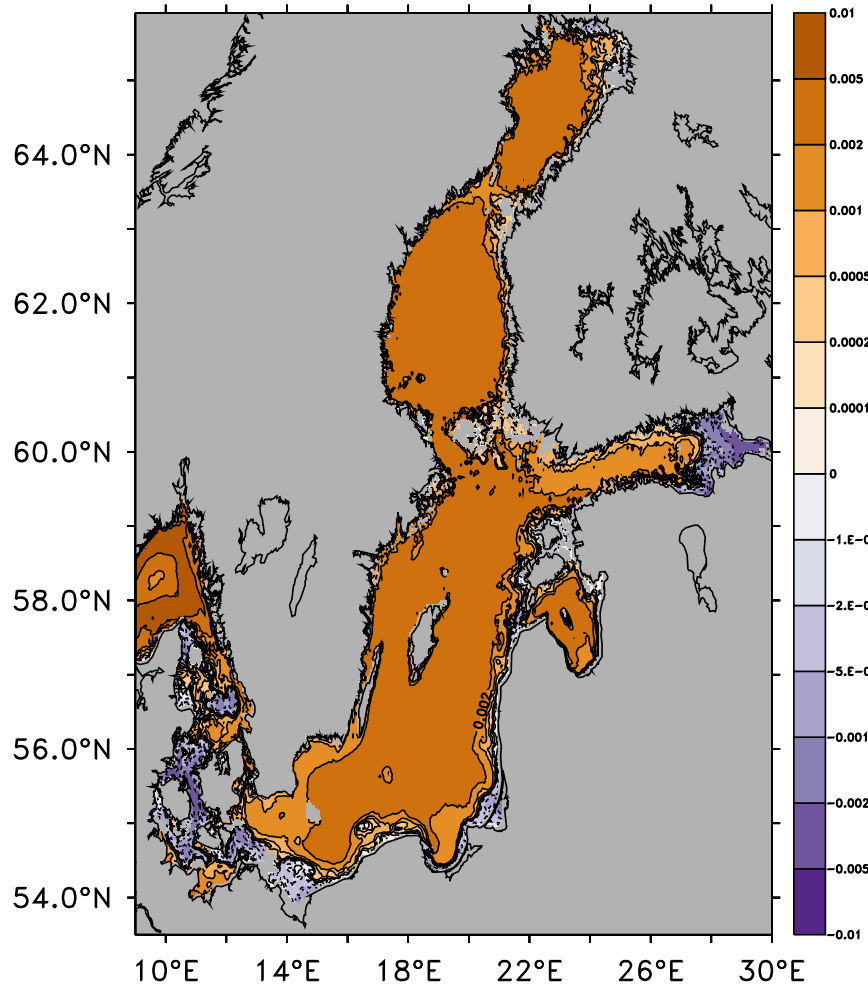


Summer upwelling frequency [1]  
Ensemble median RCP 8.5 1970 to 1999



Changes in upwelling frequency [1]  
2070 to 2099 minus 1970 to 1999

# Changes in Reduced Gravity



Summer buoyancy [ $\text{m/s}^2$ ] change 2070 to 2099 minus 1970 to 1999

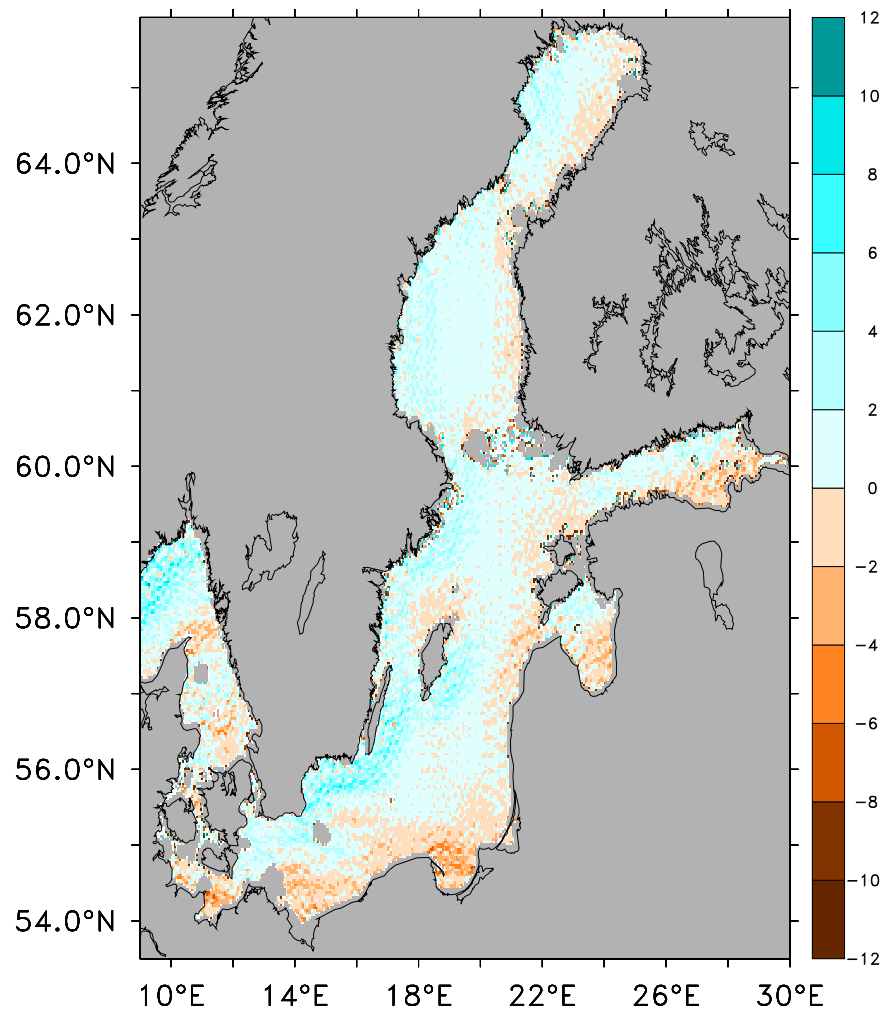
Ensemble median RCP 8.5

Ensemble median RCP 2.6

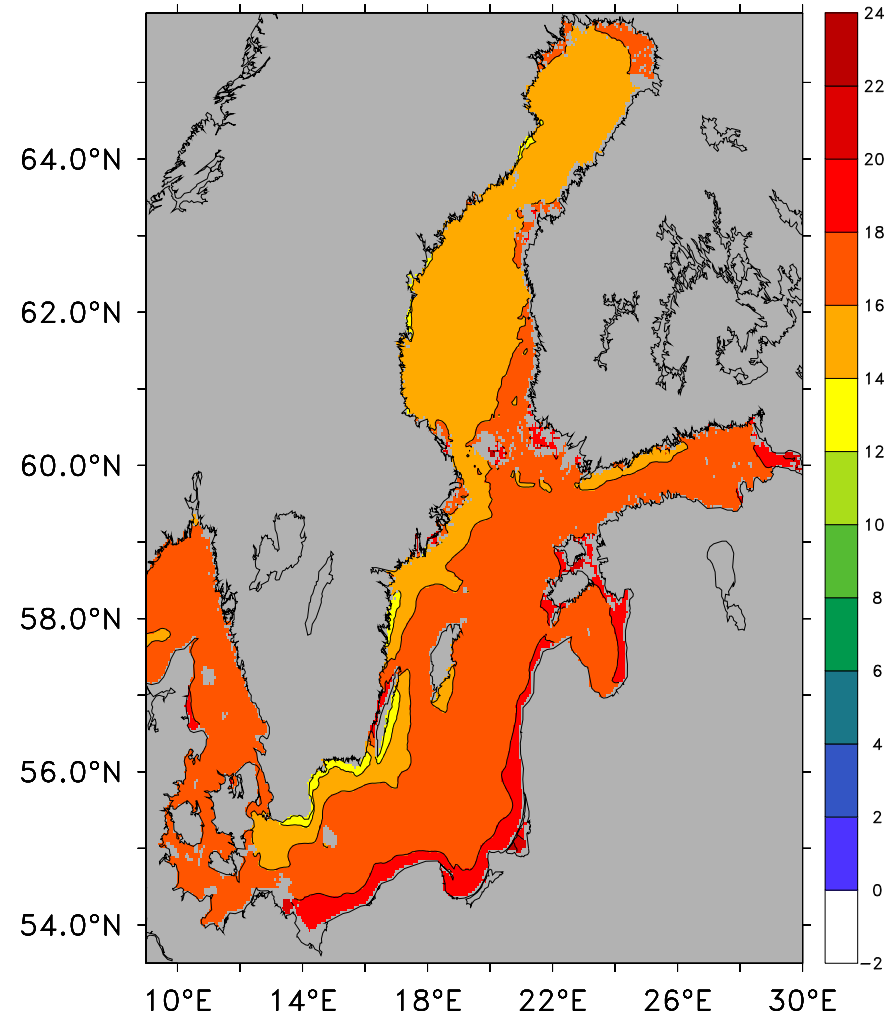
- Projected SST changes indicate increase in upwelling frequency
- One contributor is increased buoyancy
- Estimate favorable wind (wind impulse)
- Calculate offshore Ekman transport (upwelling index)
- Budget upwelling contribution to vertical exchange
- Look into feedback in atmosphere circulation



# Upwelling Signature

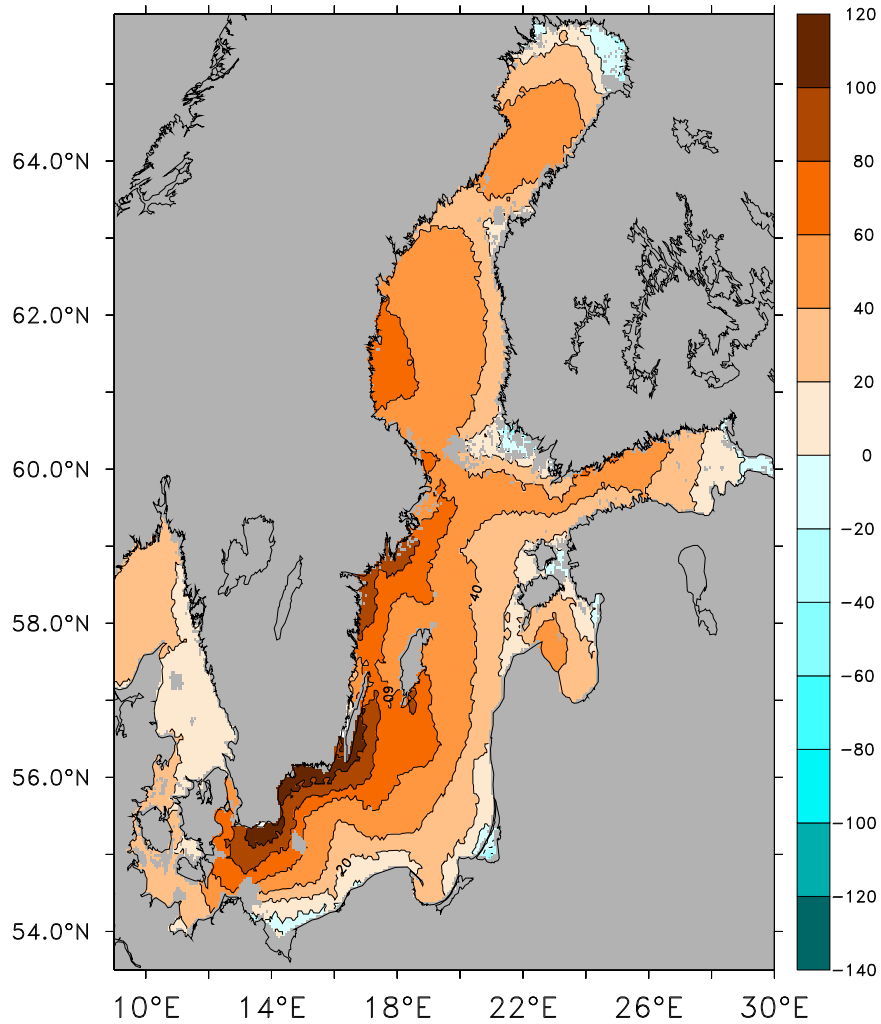


August  $w_{EK}$  1990 - 2009 [ $10^{-5}$  m/s]  
MPI-ESM-LR RCP4.5

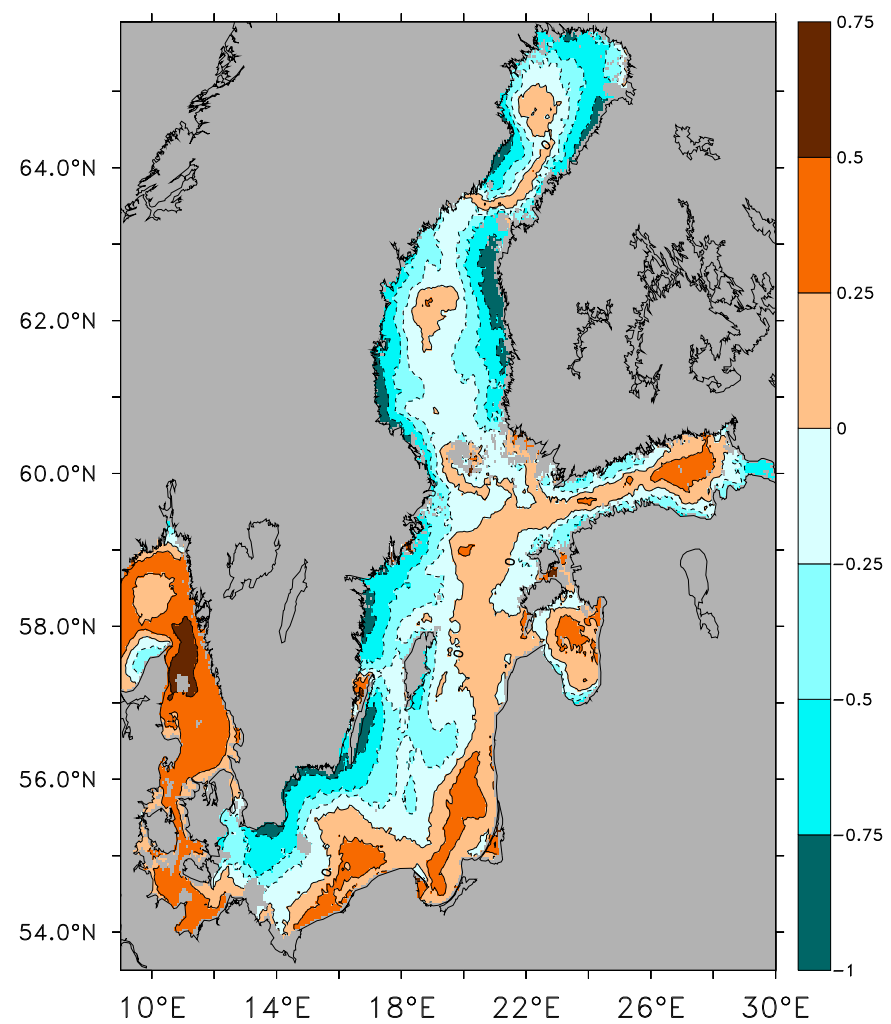


August SST 1990 - 2009 [C]  
MPI-ESM-LR RCP4.5

# Upwelling Signature



August SHF 1990 - 2009 [ $\text{W}/\text{m}^2$ ]  
MPI-ESM-LR RCP4.5



August COR(SST, SHF) 1990 - 2009 [1]  
MPI-ESM-LR RCP4.5