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Influence of Coastal Upwelling on the Air-Sea Gas Exchange of CO_2 in a Baltic Sea Basin

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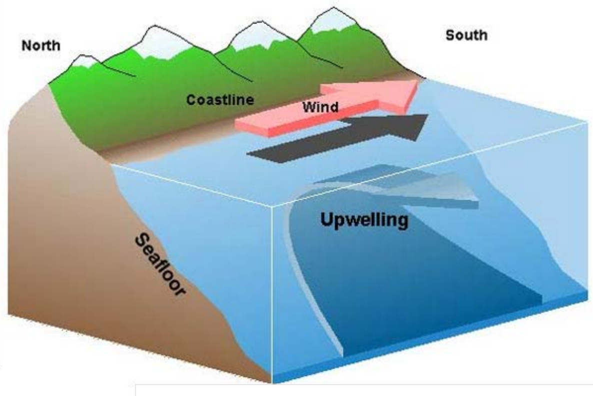
Background and aim

- Upwelling brings water with relatively high concentration of CO_2 to the sea surface.
- An increase of sea surfarce pCO_2 affect the air-sea CO_2 flux.
- Hence, the net CO_2 uptake/release in the region might be altered.



> ➢ The aim of the present study is to estimate the effect of upwelling on the air-sea exchange of CO_2 off the east coast of Gotland.

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Flux estimation methods

- Bulk estimated flux

$$F_{CO_2} = kK_0 \Delta pCO_2$$

$$k = (0.222u + 0.333u^2)\sqrt{660/Sc}$$

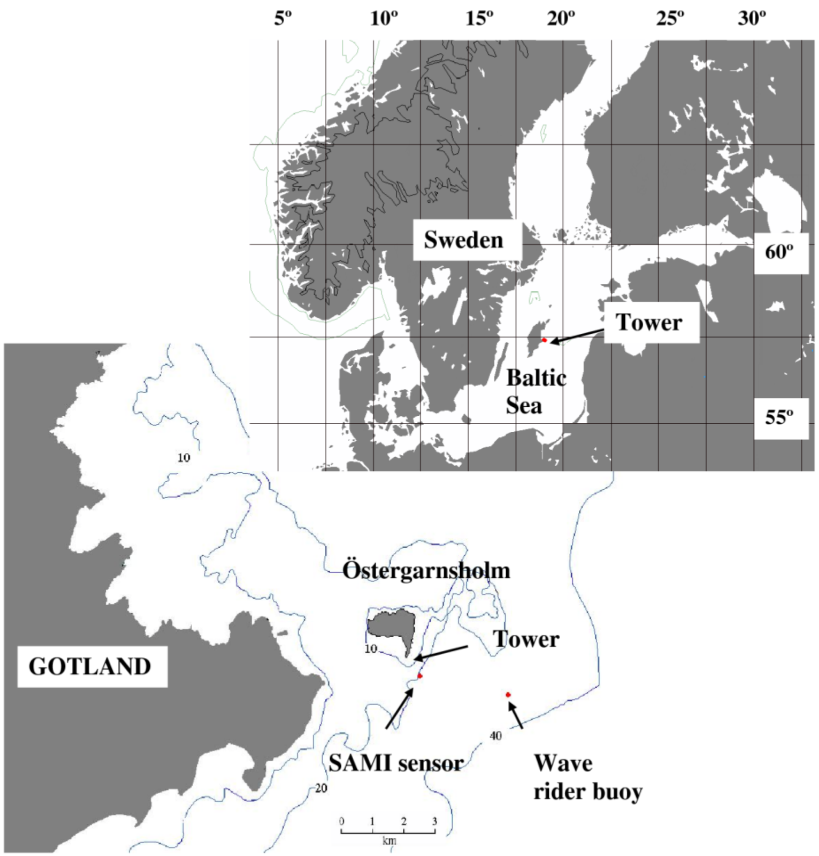
(Nightingale et al., 2000)

- Eddy-covariance measured flux

$$F_c = \rho_d \overline{w'c'}$$

Methods and measurements:

The Östergarnsholm site



- High frequency turbulent flux measurement (10 m height).
- pCO_{2a} (10 m height)
- pCO_{2w} and SST (4 m depth), 1 km southeast from the tower.
- SST (0.5 m depth), 4 km southeast from the tower (FMI).

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Methods and measurements:

The upwelling events

Four upwelling periods during July and October were selected using in-situ measurement.

Signatures of upwelling:

- Southwesterly winds
- Moderate to high wind speed
- Rapid drop in SST
- Increase in pCO_{2w}

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Methods and measurements:
Satellite SST data

- Daily SST data from the Advanced Very High Resolution Radiometer (AVHRR), onboard the National Oceanic and Atmospheric Administration (NOAA) satellites is used.
- A gap filling technique is applied which provides maximum coverage in space.
- The gap filling technique is based on 'nearest-neighbor-in-time'.

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Methods and measurements:

Upwelling detection method

- A upwelling detection method inspired by Lehmann et al. (2012).
- The upwelling area is restricted by SST anomaly (SSTA) and the distance from the coast.

In the present study:

- SSTA is defined as the difference between SST and SST_0.
- Upwelling criteria: SSTA>1ºC within 50 km from the coast.

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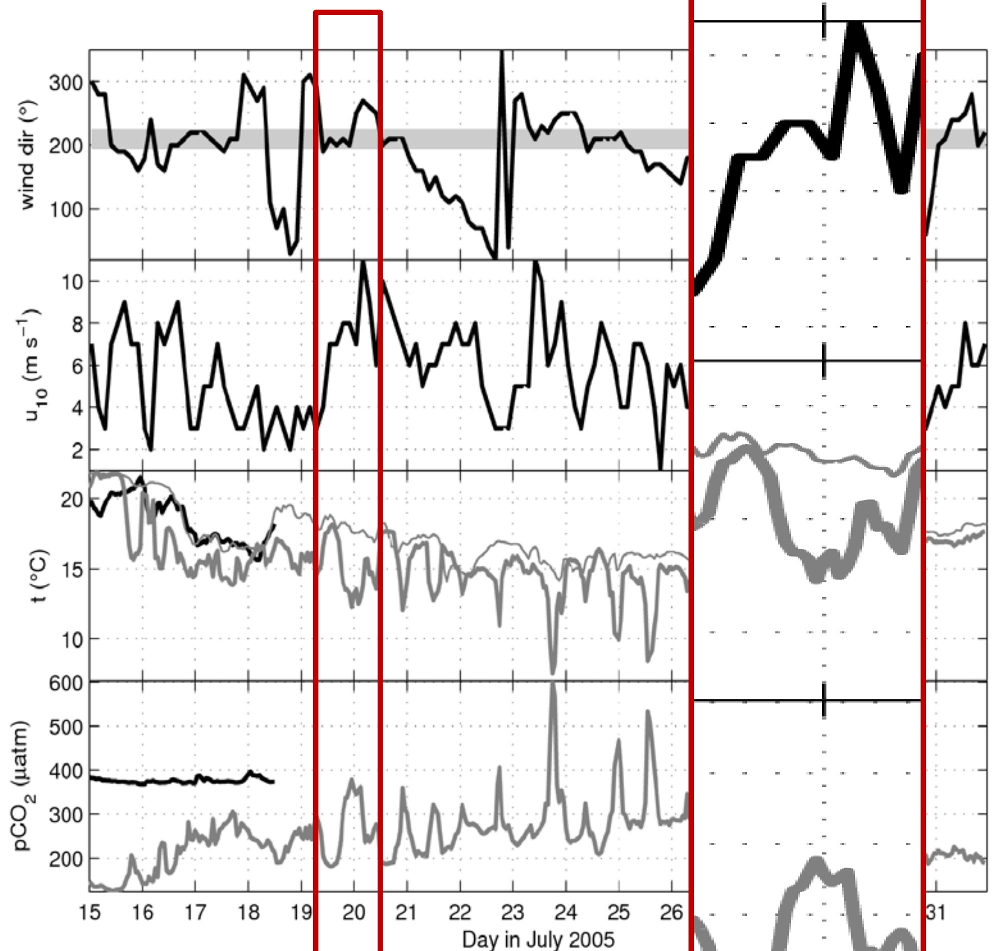
Results:

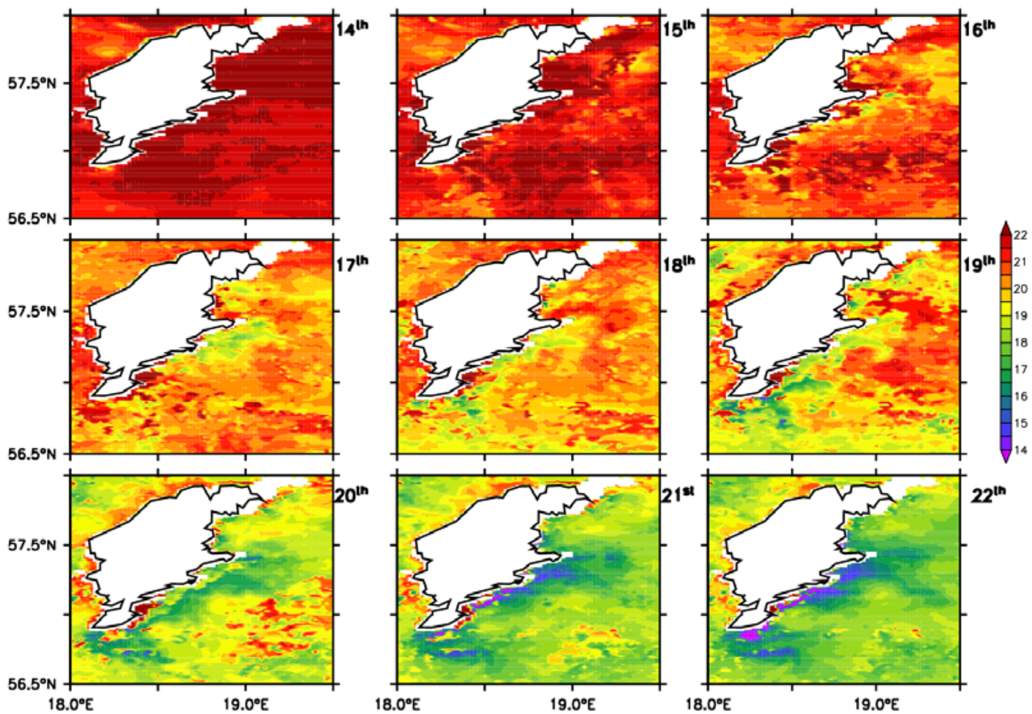
Description o upwelling period

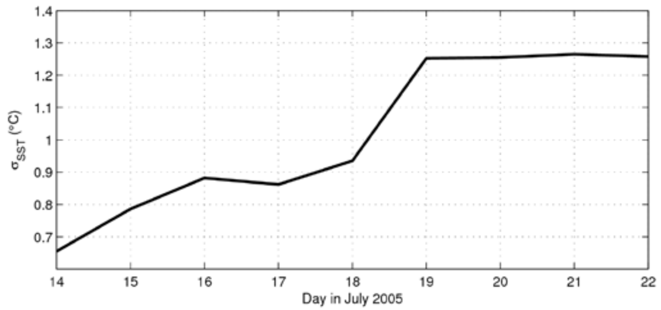


Intermittent upwelling due to variable winds

Results:

Description of one upwelling period

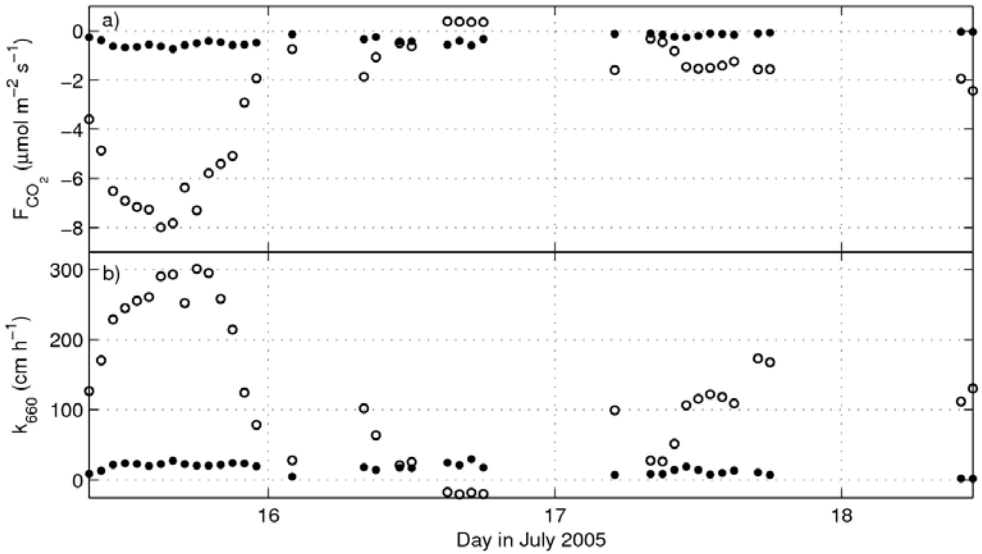




Increasing heteorogenity during upwelling

Results:

Air-sea exchange of CO_2



- • Bulk formulation
- o Eddy-covariance measurement

- Large differences between estimates with the bulk formula and measurents.
- This is at least partly due to horizontal heteorogenity and sea surfase measurement not in the flux footprint area.

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Results:

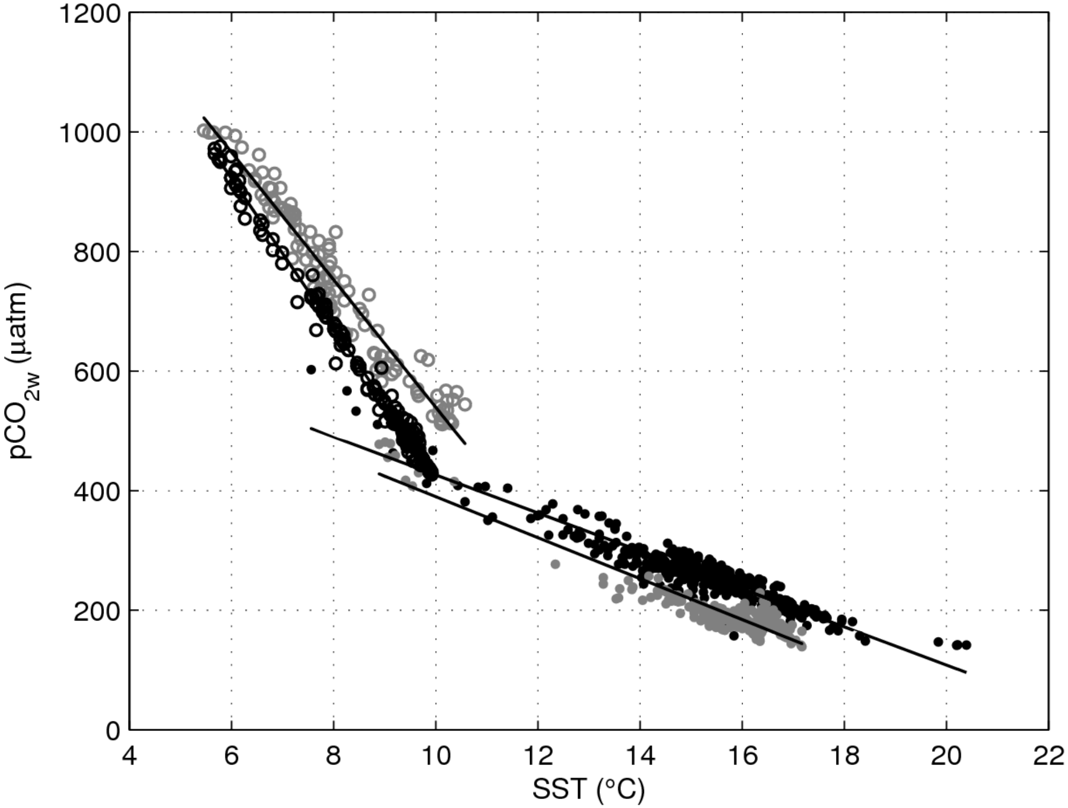
The air-sea CO_2 uptake/release

Assumptions:

- SST-pCO_{2w} relation during upwelling.
- Horizontally homogenous wind speed in the upwelling area.
- Estimate SST and pCO_{2w} during non-upwelling conditions.
- SST and pCO_{2w} horizontally homogenous during non-uppwelling conditions.

Results:

SST-pCO_{2w} relation



- Period 1 (July 2005)
- Period 2 (July 2007)

- Period 3 (October 2008)
- Period 4 (October 2008)

Period	r
1	-0.94
2	-0.91
3	-0.97
4	-0.99

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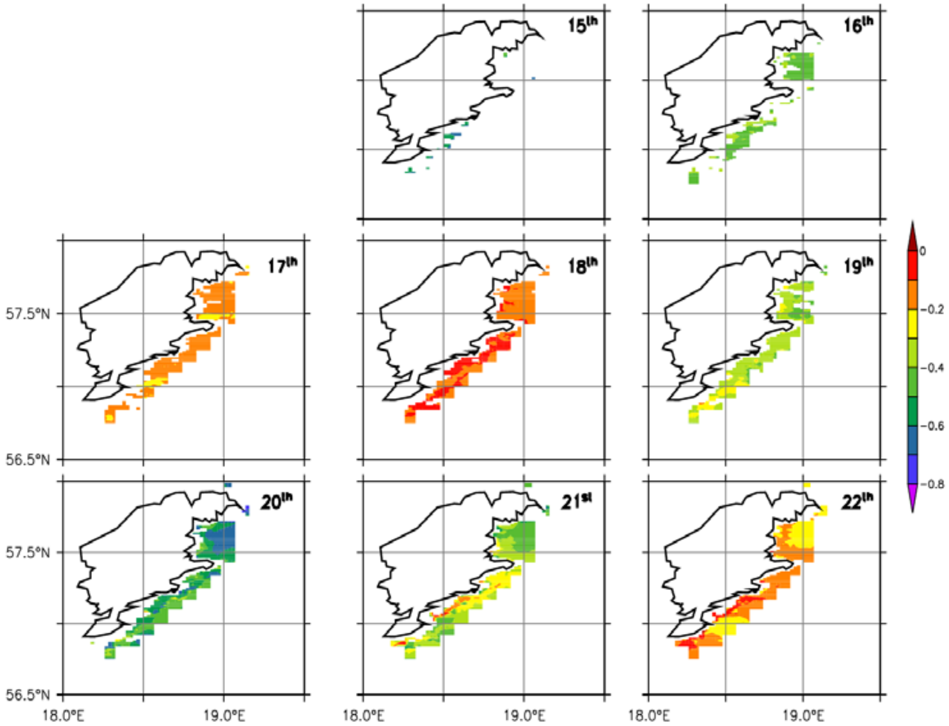
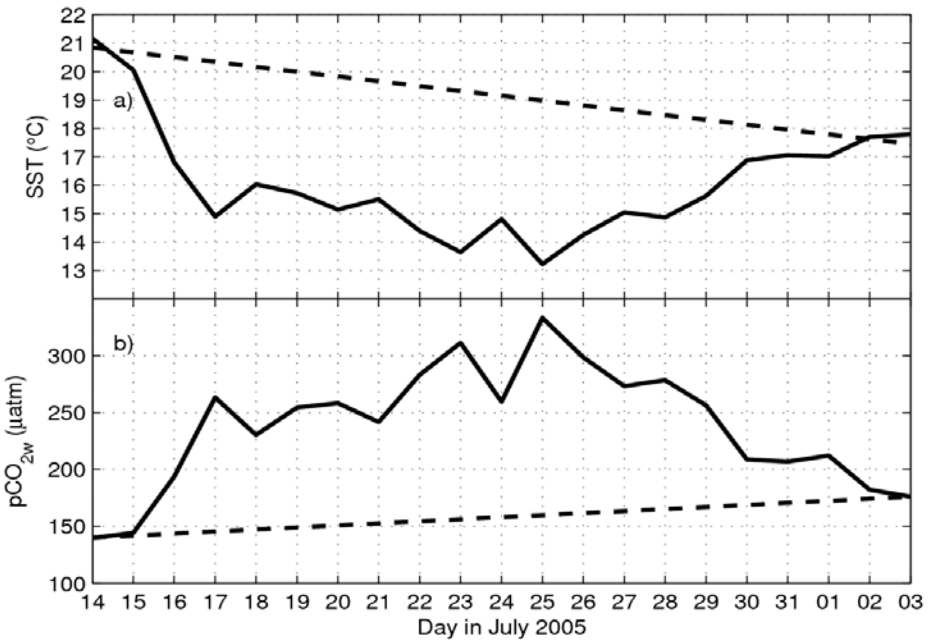
Results:
Fluxes and upwelling area



- The upwelling area is estimated using the upwelling detection method.
- The pCO_2 flux is estimated using bulk formulation.

Results:

Non-upwelling conditions



—— Upwelling

- - - - Non-upwelling

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Results:
Satellite derived CO_2 exchange

Period	Non-upwelling ($Gg\ CO_2$)	Upwelling ($Gg\ CO_2$)	Absolute difference ($Gg\ CO_2$)	Absolute relative difference (%)
1	-25.5	-20.5	5.0	19
2	-9.2	-3.8	5.4	59
3	+7.3	+22.7	15.4	211
4	+9.4	+32.8	23.4	250

- Period 1 and 2 - the pCO_2 uptake decreases.
- Period 3 and 4 - the pCO_2 release increases.

During upwelling, less pCO_2 is taken up by the ocean.

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Discussion: How does uppwelling impact the air-sea exchange of pCO_2 in the entire Baltic Sea?

- Norman et al. (2013) estimated the Baltic Sea carbon budget using a 1D-model (Omstedt et al., 2009).
- The model showed that the Baltic Sea is a net sink of 0.22 mol CO_2 yr^{-1}.
- ➢ Based on knowledge of the spatial and temporal extention of upwelling in the Baltic Sea, **a rough estimate** of the impact of upwelling on air-sea exchange in the entire Baltic Sea was performed.
- ➢ During upwelling the uptake of CO_2 decreases by up to 25% compared to non-upwelling scenarios.

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Conclusions

- The CO_2 net uptake/release in the area surrounding Gotland differs by 19-250% compared to non-upwelling conditions.
- The pCO_2 uptake is smaller during upwelling.
- A rough estimate shows that the total pCO_2 uptake in entire Baltic Sea could decrease by 25% when including upwelling.

➢ **To include upwelling is of major importance when estimating the carbon budget.**

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Thank you for the attention!