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Swedish National Space Board

Impact of Coastal Upwelling on Air-Sea Exchange of CO_2 in a Baltic Sea Basin

Sindu Raj Parampil, Maria Norman, Anna Rutgersson, Erik Sahlée

Department of Earth Sciences, Uppsala University, Sweden

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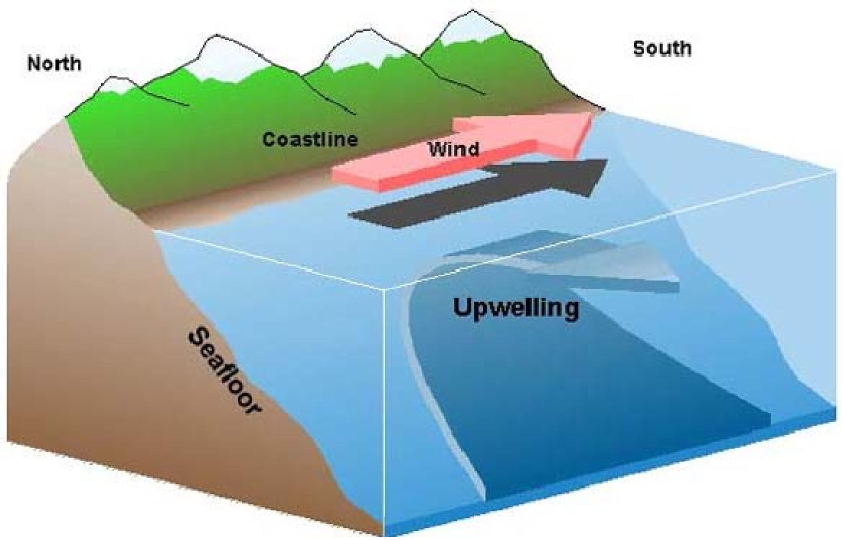
Motivation

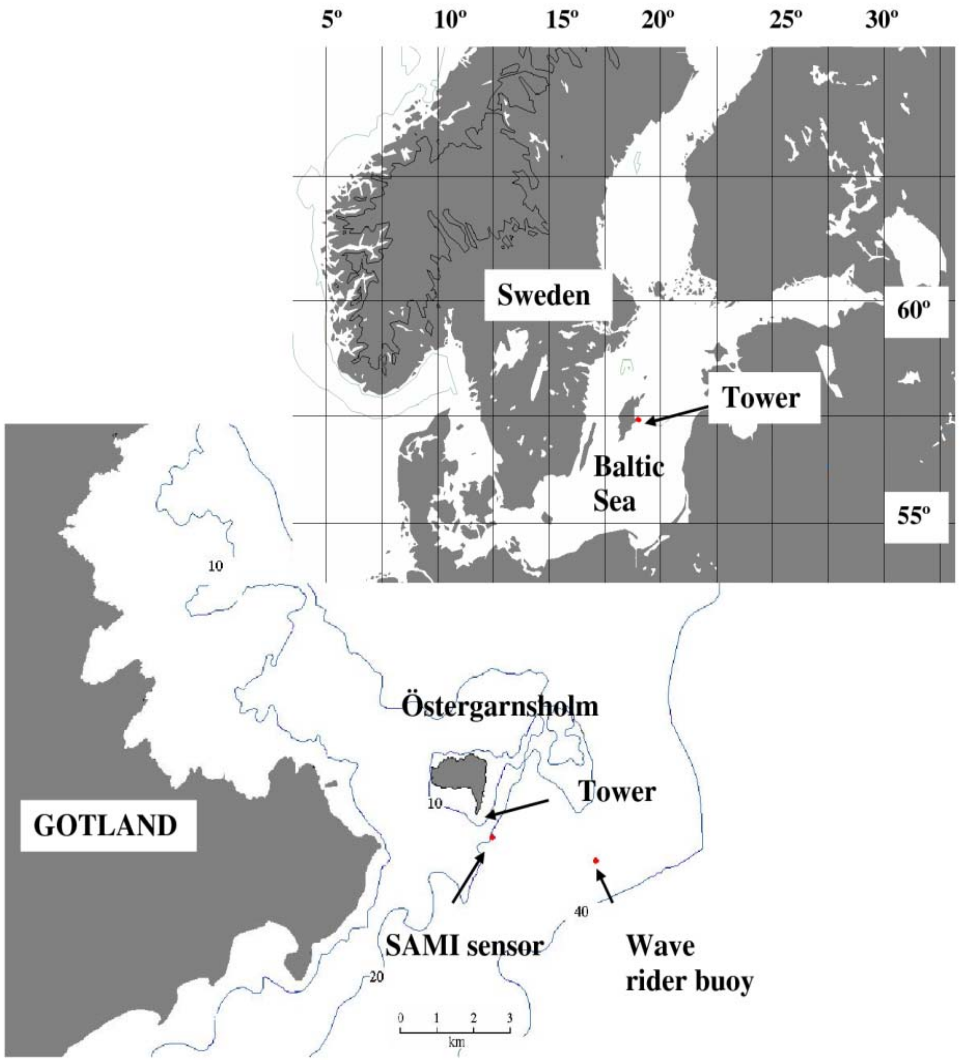
Upwelling brings CO_2-rich subsurface water to surface.

- Increase in sea surface pCO_2
- Altered uptake/release of net CO_2 in the region.



➢ **Estimate effect of upwelling on air-sea exchange of CO_2 off east coast of Gotland.**

Östergarnsholm Site



- High frequency turbulent flux measurements, pCO_{2a} (10 m height)
- pCO_{2w}, SST (4 m depth), 1 km southeast of tower (SAMI).
- SST (0.5 m depth), 4 km southeast of tower (Wave Rider buoy, FMI).

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Satellite SST

- Daily SST: Advanced Very High Resolution Radiometers (AVHRR), onboard NOAA satellites
- Gap-filling applied for optimal spatial coverage.

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Upwelling Events

Signatures of upwelling:

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

From *in-situ* data, four upwelling periods were selected:

15-31 Jul 2005 – Period 1
13-22 Jul 2007 – Period 2
5-14 Oct 2008 – Period 3
24-31 Oct 2008 – Period 4

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Upwelling Detection Method

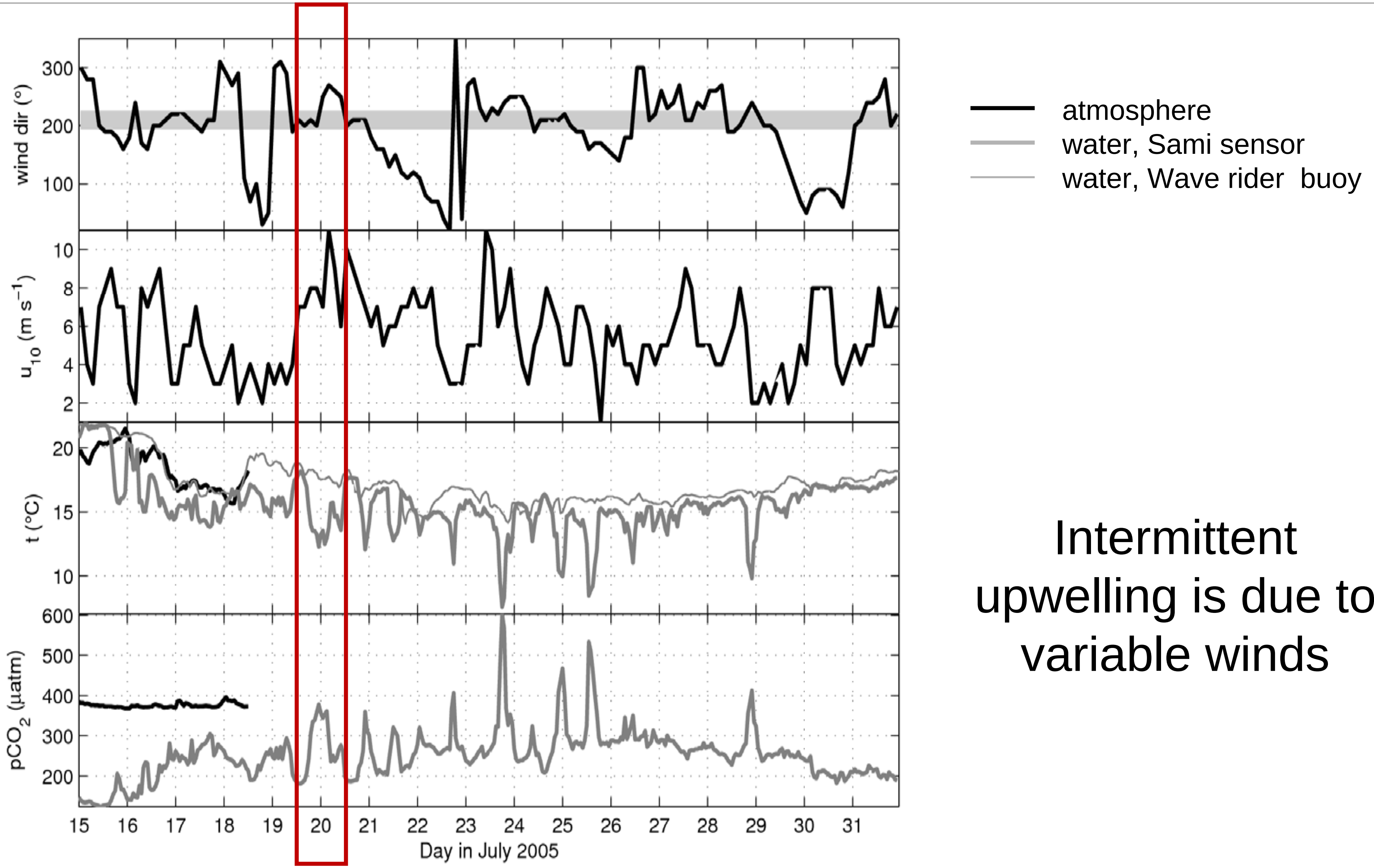
Our method is based on *Lehmann et al. (2012):*

- SST anomaly **(SSTA) =** $\mathbf{SST_{(t=0)} - SST}$
- Distance from the coast

Upwelling criteria:

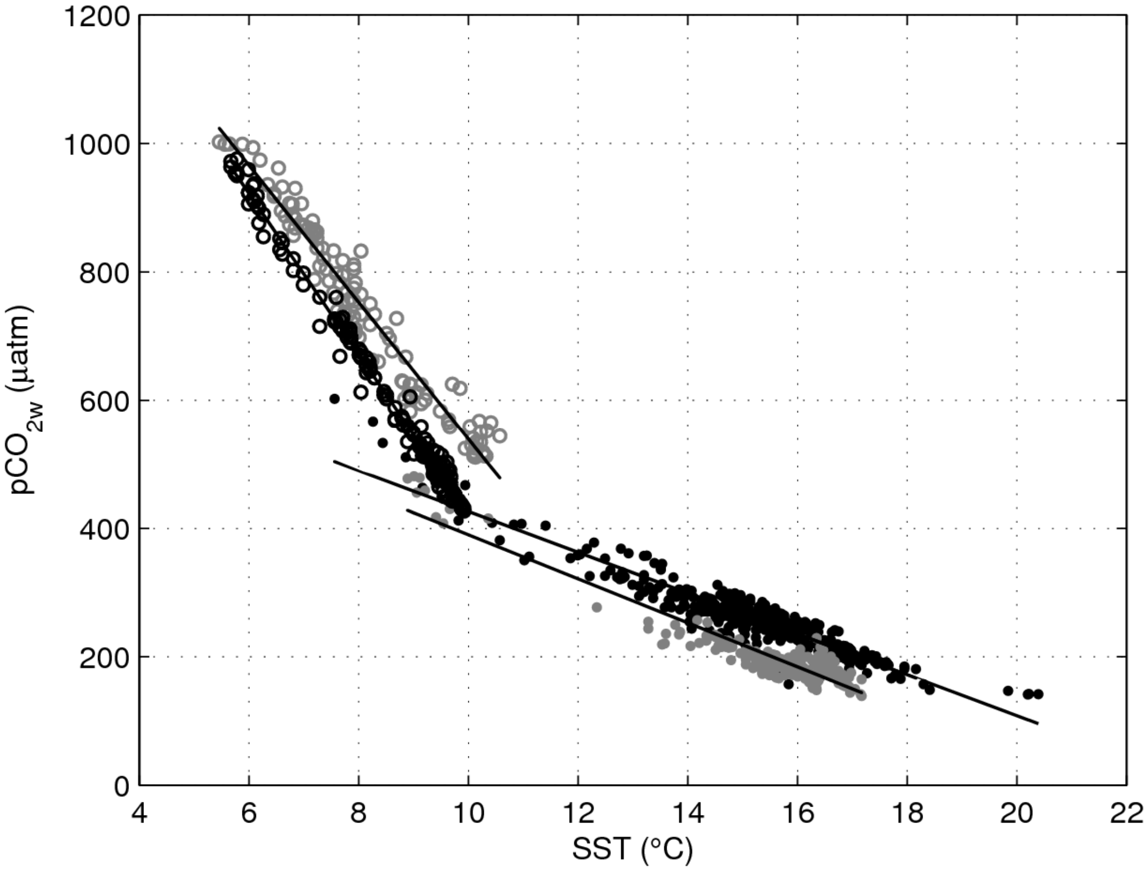
- ➢ **SSTA > 1ºC**
- ➢ **50 km from coast**

Period 1



Intermittent upwelling is due to variable winds

SST-pCO_{2w} Relation



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

- Period 3 (Oct 2008)
- Period 4 (Oct 2008)

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

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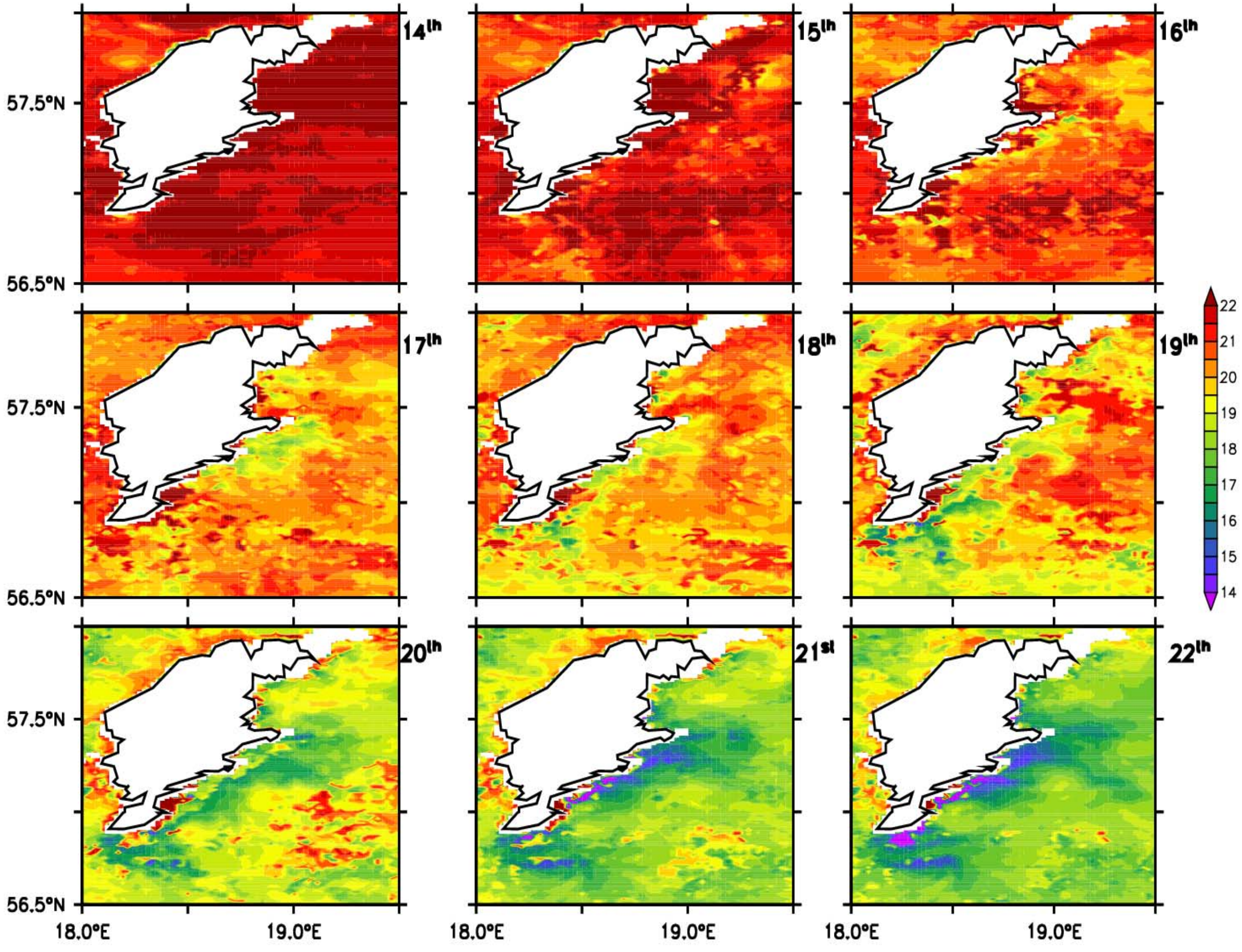
Period 1



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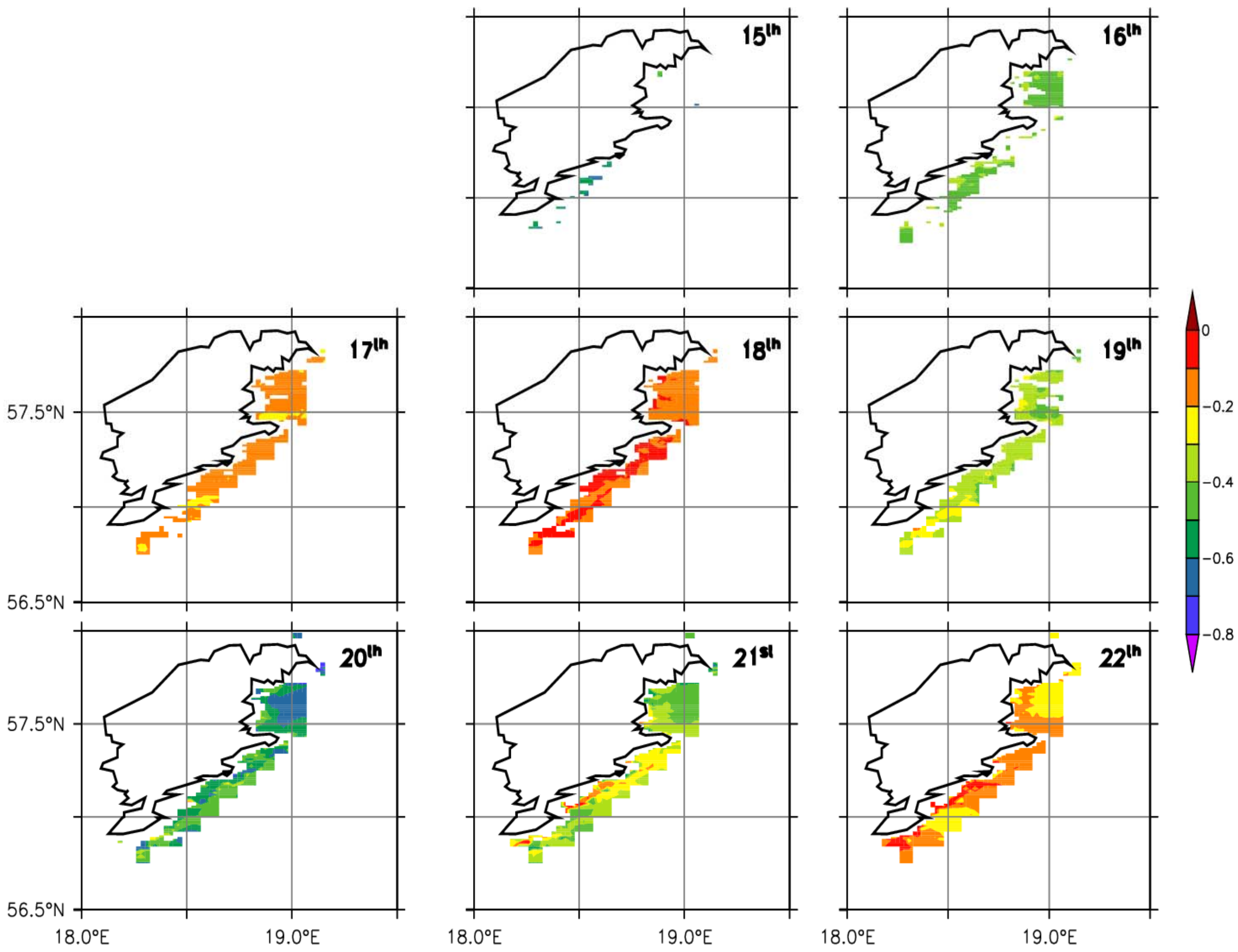
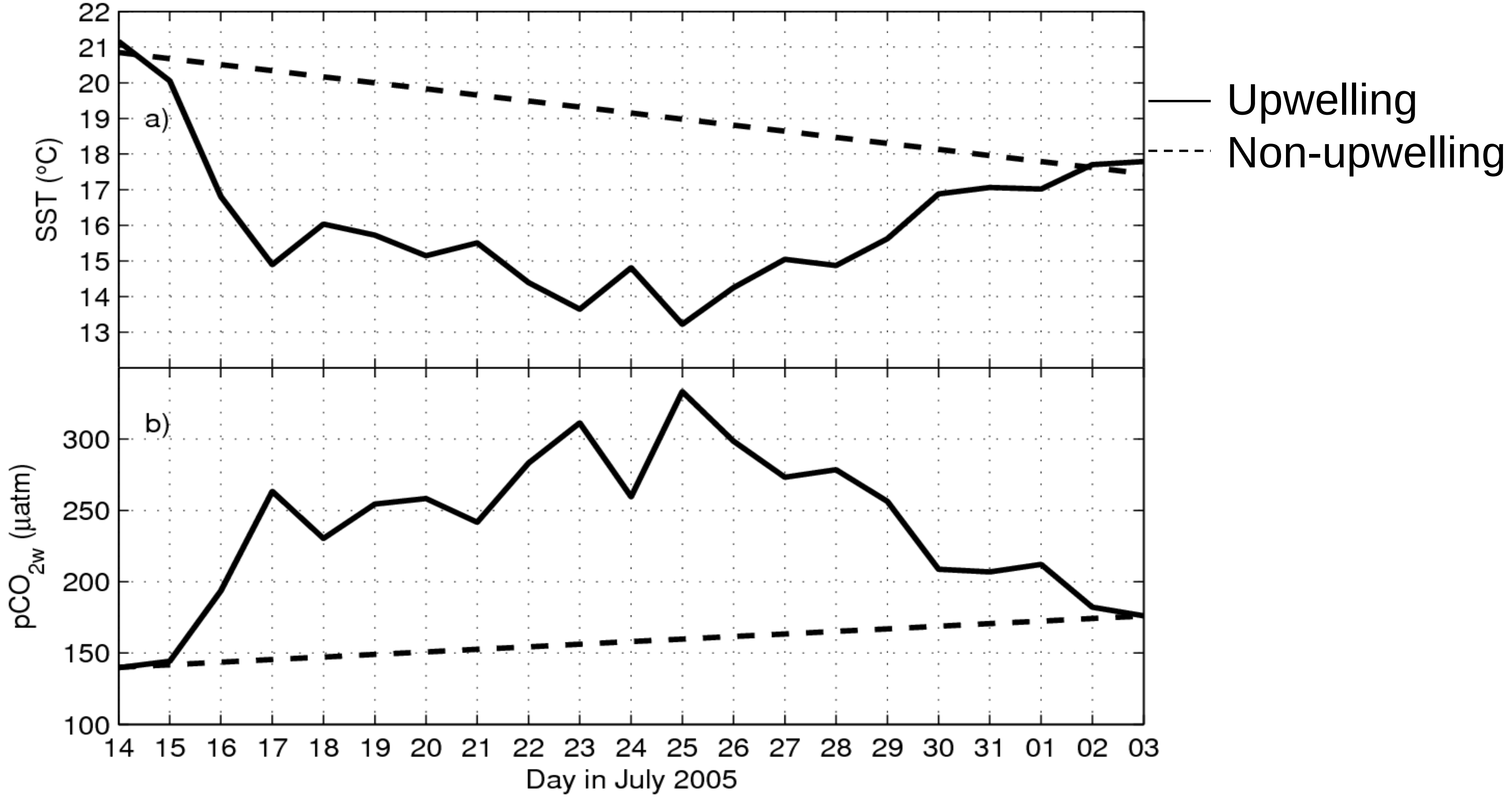
Fluxes in Upwelling Area



Non-Upwelling Conditions



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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: **pCO_2 uptake decreases.**
- Period 3 and 4: **pCO_2 release increases.**

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

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Impact on entire Baltic Sea?

Norman et al. (2013) estimated carbon budget using a biogeochemical model *(Omstedt et al., 2009):*

- **Baltic Sea is a net sink of 0.22 mol CO_2 yr^{-1}.**

Based on spatial and temporal extent of upwelling in the Baltic Sea, a rough estimate shows:

- **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 around Gotland differs by 19-250% compared to non-upwelling conditions.
- The pCO_2 uptake by the ocean is smaller during upwelling.
- A quick estimate shows pCO_2 uptake in Baltic Sea decreases by 25% when upwelling is included.

➢ **Inclusion of upwelling is critical in the estimation of carbon budget.**

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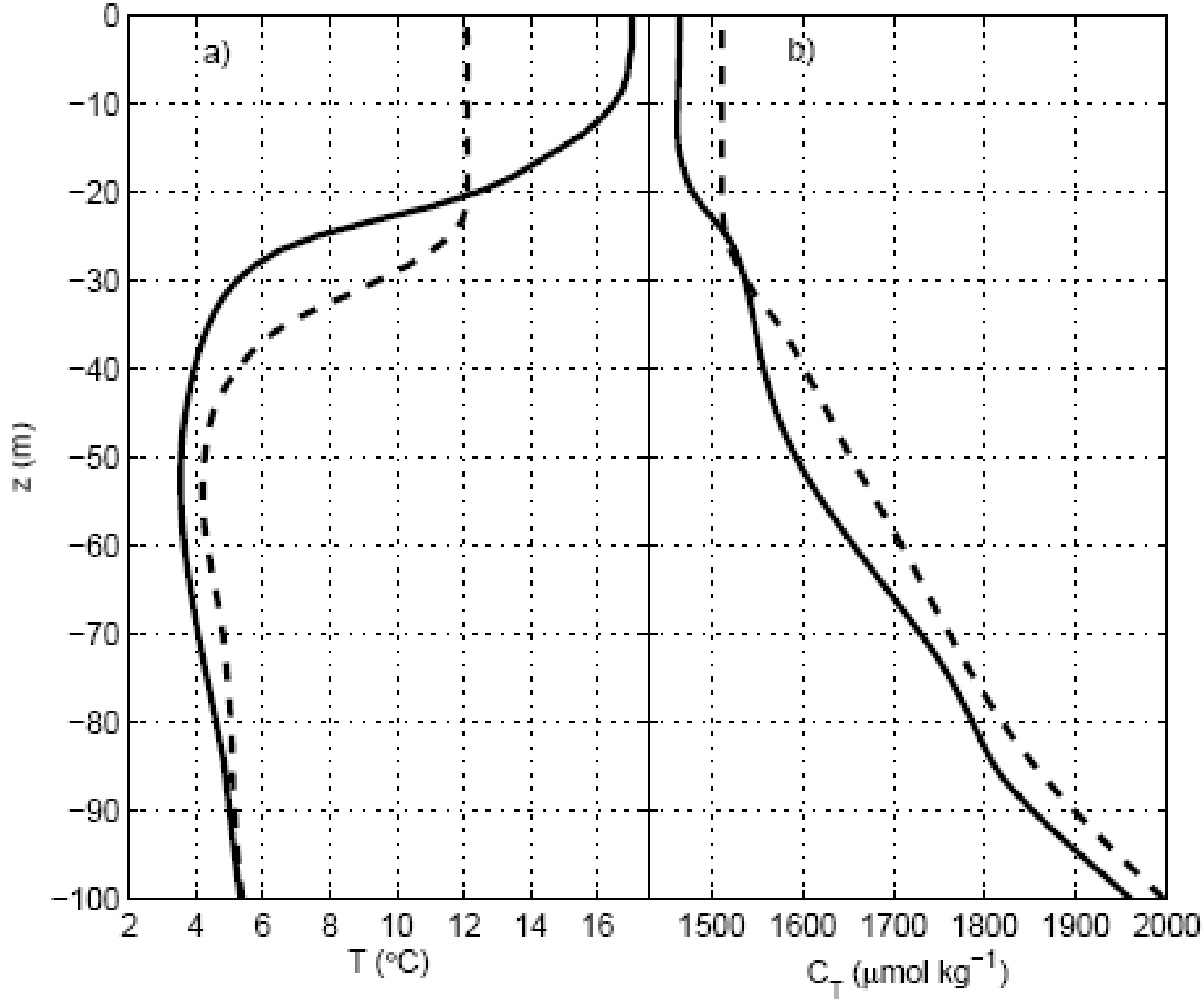

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Flux Estimation Methods

- 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

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

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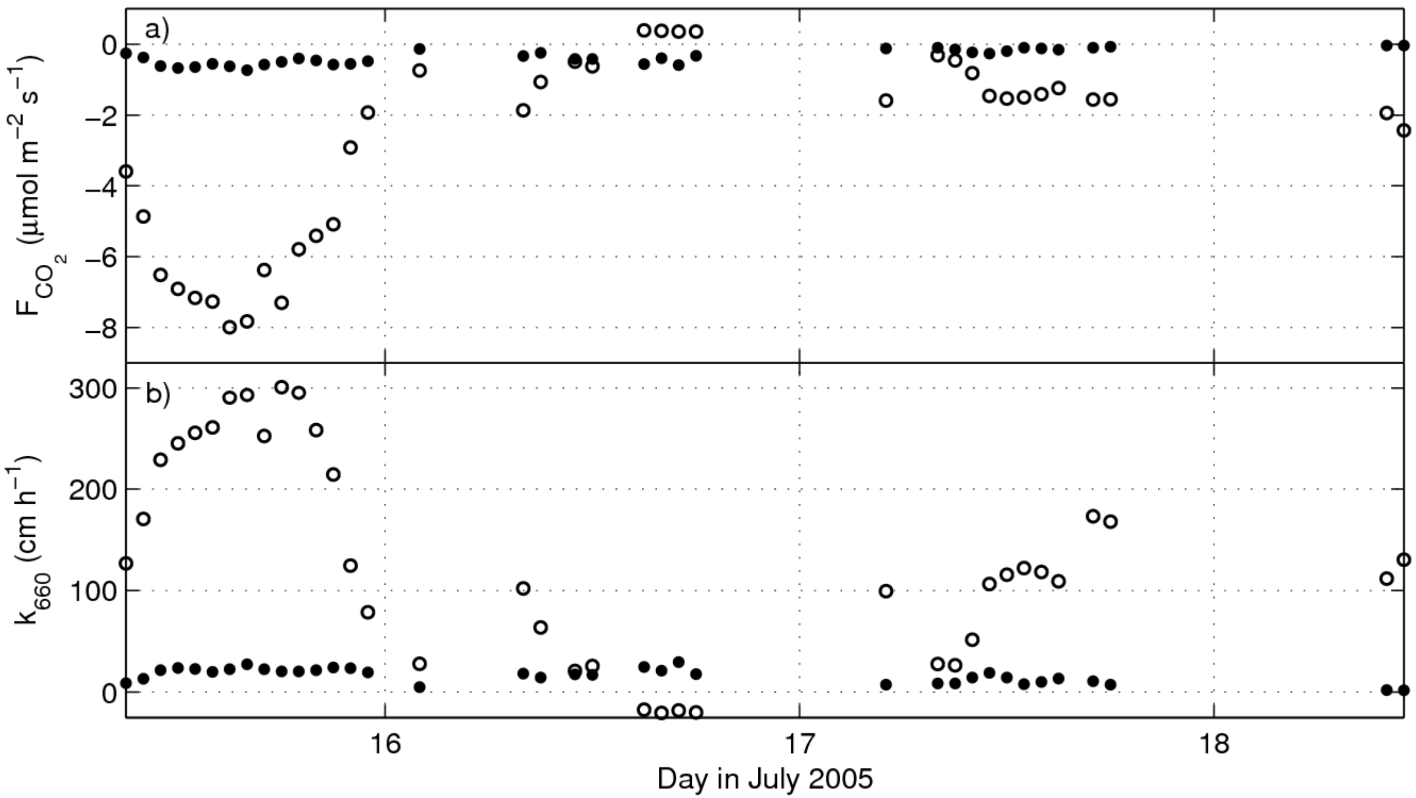
Air-Sea Exchange of CO_2



- • Bulk formulation
- o Eddy-covariance measurement

Large difference is due to **horizontal heteorogenity** and **sea surface measurements not being in the flux footprint area**.