Remote sensing algorithm for sea surface \( \text{CO}_2 \) in the Baltic Sea

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Context

- Problem for the quantification of the oceanic sink is thus the spatial and temporal distribution of available in-situ pCO$_2$ data
- Constrain the carbon fluxes in the Baltic sea remains particularly challenging
- Worldwide networks of measurements of surface water pCO$_2$ have been initiated in the 1990s (Poisson et al. 1993; Takahashi et al., 1993-2009 Jamet et al, 2007...).
- Data available can be use to this type of study in the Baltic Sea
Swedish National Spaceboard project focusing the Baltic Sea:

- Remote sensing algorithms for sea surface $CO_2$ and $CO_2$ flux
  Anna Rutgersson, Tiit Kutser, Melissa Chierici, Gaëlle Parard, Sindu Parampil, Erik Sahlée, Maria Norman ... 

→ Estimate $pCO_2$ variability in the global Baltic Sea with satellite data
→ Estimate the $CO_2$ fluxes in Baltic sea at several scale
Data availability and validation
  – In situ data (Mooring, ship)
  – Satellite data

Method : Self Organising Maps: Statistical Neuronal Approach

First Results

Conclusions and Perspectives
Data: Availability and Validation

- Measurement of pCO$_2$ (SAMI sensor) and SST (4 m depth) at Östergarnsholm station since June 2005-July 2012
- Wave mooring (SST (0.5 m))

- Strong variation of SST and pCO$_2$ → upwelling events

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In situ data: VOS and SMHI (Validation)

Ship measurements VOS comparison with the SAMI data (CDIAC+SOCAT database (Schneider et al, 2006)
- Comparison (0.2° around the SAMI sensor (black square) & Time )
- Quite good correlation factor (0.98) and STD=9 μatm

SMHI mooring in Baltic sea compare to SAMI data (Not used yet)
- $pCO_2$ compute with carbonate relation (TA and pH )
- Quite good
- Need validation

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No data yet for this two basin between 2005 and 2011

VOS cruises + SAMI + SMHI estimation 2005-2011
Satellite DATA

– Daily:
  ▪ SST:
    – Federal Maritime and Hydrographic Agency (BSH) processing the data from AVHRR-NOAA . 2005-2012
    – GRHSST product for Baltic sea 2007-2011
  ▪ Chlorophyll: JRC MERSEA Ocean Colour Products:
    – SeaWiFS: standard OC4-V4 algorithm, reprocessing 5.1 by the Goddard Space Flight Center (NASA) 2002-2011
    – MODIS-AQUA : reprocessing 1.1 by the Goddard Space Flight Center (NASA)
  ▪ CDOM: Modis (need to validate)

– Monthly
  ▪ Photosynthetically Active Radiation (PAR): Averages from:
    – SeaWiFS (Sept. 1997 - Dec. 2004) 4 km monthly
    – MODIS-Aqua (Jul. 2002 - Jun. 2011) 4 km monthly,
  ▪ Primary Production: Source: http://oceancolor.gsfc.nasa.gov
    – SeaDAS 6.2

– NOT Satellite Data:
  ▪ Mixed Layer Depth: hydrodynamic model General Estuarine Transport Model - www.getm.eu)
Comparison: SST satellite & SST mooring

- Daily comparison for 2005 → Good correlation (0.95)
- Similar for all year
- But problem with strong variation during upwelling event
- Validation with VOS & SMHI data

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Chlorophyll data

- Monthly spatial coverage quite good compared to the daily spatial coverage
- Interannual and seasonal high variation
- Validate chlorophyll daily and monthly product

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Method: Self Organising Maps

- Input: Multidimensional Data
- Output: A clusterization of the data through projection on a topologically organised 2D map, in a way that respects the underlying variability of the higher dimension.

Observation
- Initially used for the training of the map
- New observations are compared with the elements of the map to classify them.

Self Organising Map:

Classes:
- Arranged by similarity
- Correspond to:
  - an index number representing the position on the SOM
  - a referent vector

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Reconstruction through SOM

Compare the observable data with the corresponding values of all Referent Vectors of the SOM.

- **PCO2**: Observable data
- **Incomplete Vector**: Referent Vector of the i-th Class, \( i \in \{1, \ldots, N_{\text{ref}}\} \)

Takes the value of the most similar referent vector.

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25/09/2013
First results: not enough data at monthly scale

- First test monthly scale: (pCO$_2$, SST, PAR, PP, Chl, MLD)
  - 2 data bases: Construct the Map/ Validate ($\approx$10%)
  - Validation difficult: pCO$_2$ ± 20 μatm
  - High error but not enough data to conclude

- Second test daily scale: (pCO$_2$, SST, Chl, time)
  - pCO$_2$: SAMI sensor + VOS ship data
  - To represent the evolution in time: $time = \sin\left(\frac{Nbday \times 2\pi}{365}\right)$
  - Principal component analysis:
    - 4 parameters stronger link:
      » First mode explain 44 % of the variance of the phenomen
      » First mode explain at 93% by SST strongly anti correlate by time
      » Second mode by chlorophyll
    - All parameters significantly correlated to the first 3 axes.
First results: Repartition

- pCO$_2$ (µ atm)
- SST (°C)
- Chl (mg m$^{-3}$)
- Number of observations
- Time

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First Results: high error on pCO$_2$

- Difference pCO$_2$ high: 56% less than 50 μatm
- 89% less than 1 °C
- 86% less than 2 mg.m$^{-3}$
- Higher error on time

Outliners: ±2σ remove: winter time

<table>
<thead>
<tr>
<th></th>
<th>SST</th>
<th>CHL</th>
<th>pCO$_2$</th>
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<tr>
<td>$R^2$</td>
<td>0.99</td>
<td>0.97</td>
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<td>$\Delta$STD</td>
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<tr>
<td>RMSE</td>
<td>0.85</td>
<td>1.8</td>
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</tr>
</tbody>
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→ Need other parameter like MLD and CDOM
→ Validate all the data used
Data validation and availability:
- SST and pCO$_2$ quite good compare to other data
  - Need to verify in all Baltic Sea
- Difficult to validate: Chlorophyll and CDOM data

Daily scale much better
- Distribution problem Vs number of data: use data before 2005
  - Have more pCO$_2$ data in all basin of the Baltic sea (Gulf of Bothnia and Gulf of Finland)

Estimate the air-sea fluxes in Baltic sea with the pCO$_2$ estimation