The contribution of FerryBox measurements to estimates of productivity in the North Sea: Challenges, uncertainties and benefits

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Motivation

- Marginal seas only 7% of global oceans
- play important role in biogeochemical cycle of carbon, sources and sinks of atmospheric CO$_2$
- rising atmospheric CO$_2$ levels alter carbon cycle in oceans $\rightarrow$ ocean acidification
- high riverine input of nutrients in coastal oceans $\rightarrow$ algae blooms, eutrophication

Which role plays the North Sea?

Quantification of

Oxygen air-sea fluxes:
- anomaly of oxygen concentration equilibrium drives oxygen air-sea flux
- oxygen fluxes are approximation of new production in shoaling period
- Seasonal Net Outgassing (SNB) is a measure for Net Community Production (NCP) (Bargeron et al. 2006)

Carbon air-sea fluxes:
- are a measure for oceanic uptake of atmospheric carbon dioxide
- understanding and quantifying the carbon fluxes in continental shelf seas and coastal areas
- distinguish different influences on carbon flux variability
Challenges: Calculation of fluxes

- Air-sea flux of gases expressed by gas concentration anomaly and gas exchange velocity:

\[ F = k_w \cdot \Delta O_2 \]

- Gas concentration anomaly for oxygen, \( \Delta O_2 \), is the difference of observed concentration and saturation concentration

- Gas concentration anomaly for carbon dioxide, \( \Delta CO_2 \), is the difference between partial pressure of oceanic carbon dioxide and atmospheric CO\(_2\)

- \( k_w \) is parameterized by wind speed (in 10 m height) and the dimensionless Schmidt number \( Sc \).

\[ Sc = \frac{\mu}{D} = A - bt + Ct^2 - Dt^3 \]

\( \mu \) is kinematic viscosity of water, \( D \) is diffusion coefficient of the gas

- General parameterization term:

\[ k_w = a \cdot Sc^n \cdot U^b \]

- F.e. Wanninkhof, 1992:

\[ k_w = 0.31 \cdot (Sc/660)^{-1/2} \cdot U^2 \]
Challenges: Temperature effect on pCO₂

- Various effects on changes in pCO₂, e.g. biological effects, water temperature, advection, mixing, ...
- To remove temperature effects, approach of Takahashi et al. (2002) is commonly used

\[
pCO₂(const\ T) = (pCO₂)_{obs} \cdot \exp\left[\frac{\partial \ln pCO₂}{\partial T} (T_{mean} - T_{obs})\right]
\]

\[
pCO₂(T_{obs}) = (pCO₂)_{mean} \cdot \exp\left[\frac{\partial \ln pCO₂}{\partial T} (T_{obs} - T_{mean})\right]
\]

\[
\frac{\partial \ln pCO₂}{\partial T} = 0.0423°\ C^{-1} \quad \text{Takahashi et al. (1993)}
\]

- T/B index: ratio of amplitudes of pCO₂(T_{obs}) and of pCO₂(const T)
- hints at biological (T/B < 1) or temperature influence (T/B > 1)

\[
pCO₂\ (const\ T)
\]
Data sets

- FerryBox data of TorDania 04/2011 - 04/2012 (CuxImm route)
  - Dissolved oxygen (DO)
  - \( x \text{CO}_2 \)
  - Water temperature
  - Salinity

- ECMW ERA-Interim reanalysis wind speed data, 0.75° grid, 6-hourly

- Atmospheric \( \text{CO}_2 \) from Mauna Loa Obs. (Hawaii)
Uncertainties: Evaluation of FerryBox data

- Comparison of FerryBox water probes:
  - Underestimation of optode dissolved oxygen concentration by 10-15%
    - Evaluation every 1-2 months, in harbour
  - FerryBox Salinity measurements in good agreement to lab evaluation
- Water temperature comparison FerryBox and MARNET:
  - FerryBox offset accounts to ≈ 0.5 K
    → Heating inside of FerryBox system

Salinity

FB – Lab comparison of
LysBris (2009-2012) TorDania (2007-2011)

Water temperature

Comparison FB and MARNET „Deutsche Bucht“ 2007-2011
Benefits: Oxygen flux estimates CuxImm 2011-2012

SNO = Seasonal Net Outgassing

>0: ↑
<0: ↓
Benefits: $x\text{CO}_2$ and $\text{CO}_2$ flux estimates CuxImm 2011

$>0$: ↑
$<0$: ↓
Benefits: Carbon flux estimates CuxImm 2011

>0: ↑
<0: ↓
Benefits: Effects on Carbon fluxes

T/B ratio: biological (T/B < 1) or temperature influence (T/B > 1)
Benefits: Oxygen and Carbon fluxes
Different parameterization schemes: Results

- Differences between highest and lowest between 1 and 3 mol/m².
Conclusions

Challenges:
• Measuring data, calculation of fluxes
• Effects on carbon flux variability
• Data gaps prevent analysis of annual variability so far

Uncertainties:
• Which parameterisation scheme is best choice?
• Data set evaluation

Benefits:
• Estimation of oxygen and carbon fluxes for FerryBox transect
• Spatial and temporal features of fluxes are determined
• Biological and temperature effects can be assessed (T/B ratio)
what is still to do...

- Datasets over longer timescale
  - more than one seasonal cycle → annual variability (e.g. Petersen et al., 2011 and others)

- Calculations for other Ferrybox routes
  - long timescales
  - continuous data sets

- Quantification of characteristic parameters: SNO, New production, Net Community Production (NCP)

- Comparison to ecosystem model results
Thank you for your attention!
Redfield ratio (Redfield et al., 1963): atomic ratio of carbon, nitrogen and phosphorus found in phytoplankton and throughout the deep oceans. This empirically developed ratio is found to be P:N:C:-O_2 = 1:16:106:138. Valid for Atlantic Ocean.

Revised Redfield ratio (Takahashi et al., 1985):

<table>
<thead>
<tr>
<th>Number of Stations</th>
<th>Number of</th>
<th>P</th>
<th>N</th>
<th>CO_3</th>
<th>(O_2 − 2N)</th>
<th>−O_2</th>
<th>CaCO_3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Redfield ratio*</td>
<td>32</td>
<td>27.00</td>
<td>1.66</td>
<td>97.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>North Atlantic</td>
<td>57</td>
<td>27.20</td>
<td>1.68</td>
<td>88.6</td>
<td>139.6</td>
<td>173.6</td>
<td>8.3</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>16</td>
<td>27.00</td>
<td>1.67</td>
<td>97.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atlantic mean</td>
<td>119</td>
<td>27/27.2</td>
<td>1.70</td>
<td>96.6</td>
<td>138.9</td>
<td>171.8</td>
<td>10.4</td>
</tr>
<tr>
<td>South Indian</td>
<td>22</td>
<td>27.00</td>
<td>1.52</td>
<td>97.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indian mean</td>
<td>43</td>
<td>27/27.2</td>
<td>1.49</td>
<td>119.6</td>
<td>142.5</td>
<td>172.5</td>
<td>17.4</td>
</tr>
<tr>
<td>Atlantic and Indian mean</td>
<td>162</td>
<td>27/27.2</td>
<td>1.63</td>
<td>103.14</td>
<td>140.8</td>
<td>172.7</td>
<td>12.5</td>
</tr>
</tbody>
</table>

For the oxidation of nitrogen a reaction NH_3 + 2O_2 = NO_3^- + H_2O + H^+ (i.e., N:O_2 = 1:2) is assumed. *Utilization by plankton after Redfield et al. [1963].

Takahashi et al. (1985)
HZG FerryBox routes

- Operation of currently three routes:
  - Helgoland-Büsum / Helgoland-Cuxhaven: „Funny Girl“
  - England-Norway-Belgium: „LysBris“
  - Rotterdam-Immingham: „Hafnia Seaways“
- Former route: Cuxhaven-Immingham „TorDania“ (until 04/2012)
FerryBox data sets

Water temperature

Salinity
Data processing…

- Transect data of Tor Dania: every 2-3 days a data set at one point of the transect
- Create grid of 0.05°E (x-axis) x 7 days (y-axis)
- Interpolate model wind data on that grid
Parameterisation schemes for exchange velocity of air-sea flux of oxygen in dependence of wind speed $U_{10}$:

**W-92**: Wanninkhof, 1992:

$$k_w = 0.31 \cdot (\frac{Sc}{660})^{-1/2} \cdot U^2$$

**WM-99**: Wanninkhof & McGillis, 1999:

$$k_w = 0.0283 \cdot u^3 \cdot (\frac{Sc}{660})^{-1/2}$$

**N-00**: Nightingale, 2000:

$$k_w = (0.222u^2 + 0.333u)(\frac{Sc}{660})^{-1/2}$$

**LM-86**: Liss & Merlivat, 1986:

$$k_w = 0.17u \cdot (\frac{Sc}{660})^{-2/3}$$

$$k_w = (2.85u - 9.65) \cdot (\frac{Sc}{660})^{-1/2}$$

$$k_w = (5.9u - 49.3) \cdot (\frac{Sc}{660})^{-1/2}$$

**W-05**: Woolf, 2005:

$$k_w = (56.52\sqrt{C_d}u + 2.5 \cdot 10^{-4}u^{4.04}) \cdot (\frac{Sc}{660})^{-1/2}$$

**S-07**: Sweeney et al., 2007:

$$k_w = 0.27u \cdot (\frac{Sc}{660})^{-1/2}$$