6th FerryBox Workshop

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

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8-9 September 2014, Tallinn

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Motivation

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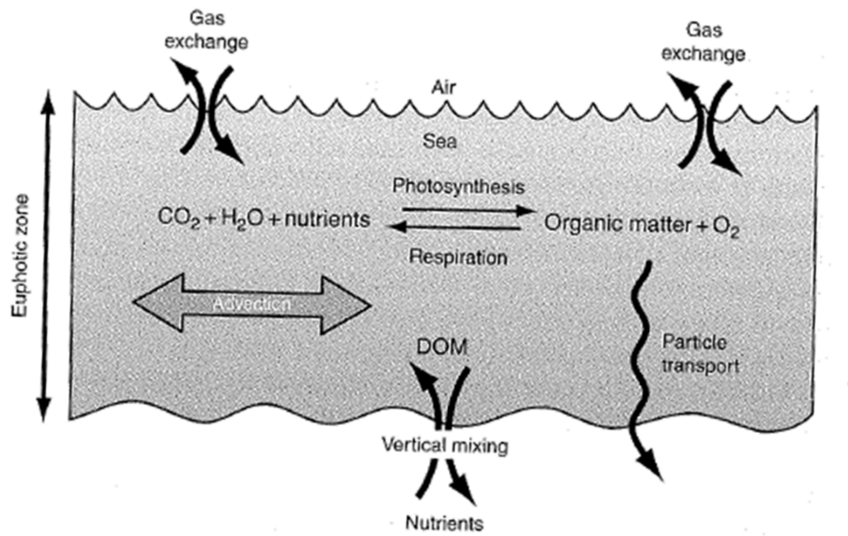
- Marginal seas only 7% of global oceans
- play important role in biogeochemical cycle of carbon, sources and sinks of atmospheric CO_2
- rising atmospheric CO_2 levels alter carbon cycle in oceans → ocean acidification
- high riverine input of nutrients in coastal oceans
  → algae blooms, eutrophication



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

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- 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, ΔO_2, is the difference of observed concentration and saturation concentration
- Gas concentration anomaly for carbon dioxide, ΔCO_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.

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

μ is kinematic viscocity of water, D is diffusion coefficient of the gas

- General parameterization term:

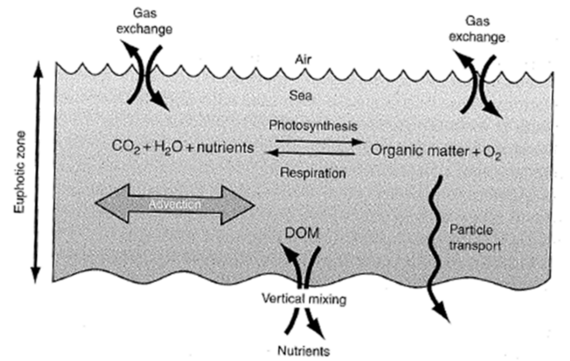
$$k_w = a \cdot Sc^n \cdot U^b$$

- F.e. Wanninkhof, 1992:

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

Challenges: Temperature effect on pCO_2

- Various effects on changes in pCO_2, e.g. biological effects, water temperature, advection, mixing, …
- To remove temperature effects, approach of Takahashi et al. (2002) is commonly used

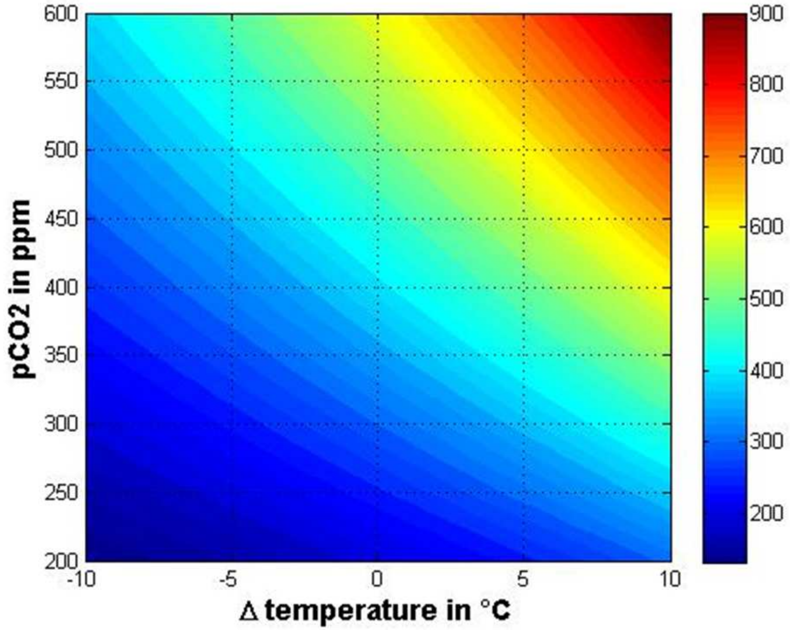


$$pCO_2(const\ T) = (pCO_2)_{obs} \cdot \exp[\frac{\partial \ln pCO_2}{\partial T}(T_{mean} - T_{obs})]$$

$$pCO_2(T_{obs}) = (pCO_2)_{mean} \cdot \exp[\frac{\partial \ln pCO_2}{\partial T}(T_{obs} - T_{mean})]$$

$$\frac{\partial \ln pCO_2}{\partial T} = 0.0423°C^{-1}$$ Takahashi et al. (1993)

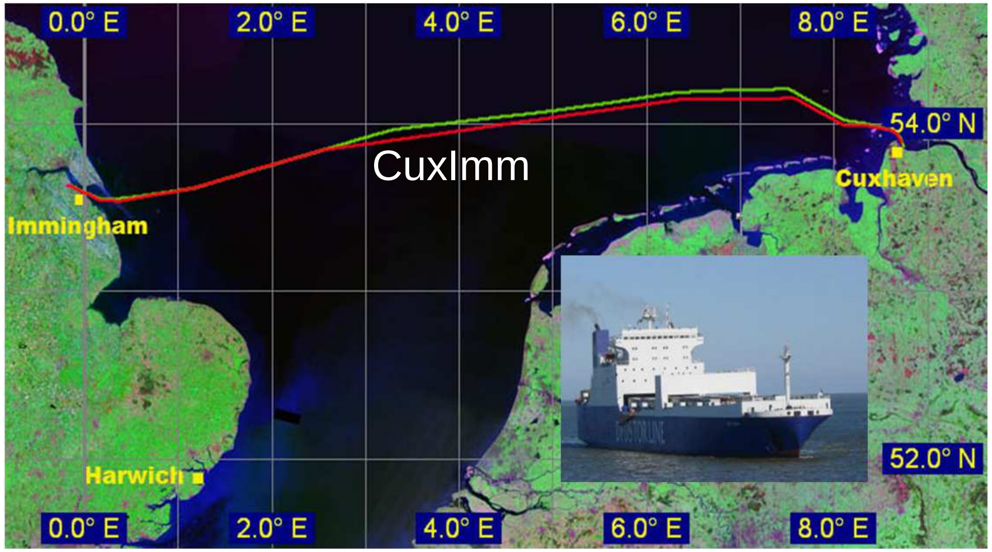
- T/B index: ratio of amplitudes of $pCO_2(T_{obs})$ and of pCO_2(const T)
- hints at biological (T/B < 1) or temperature influence (T/B > 1)



pCO_2 (const T)

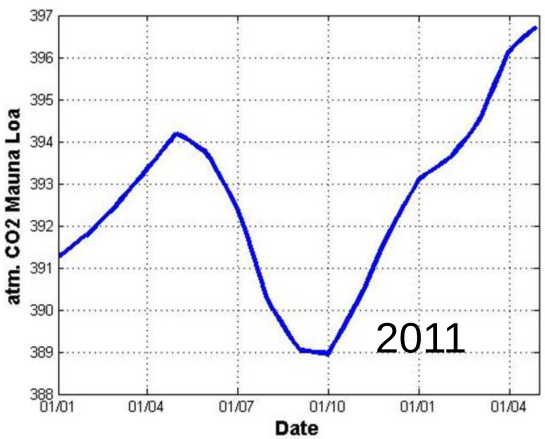
Data sets

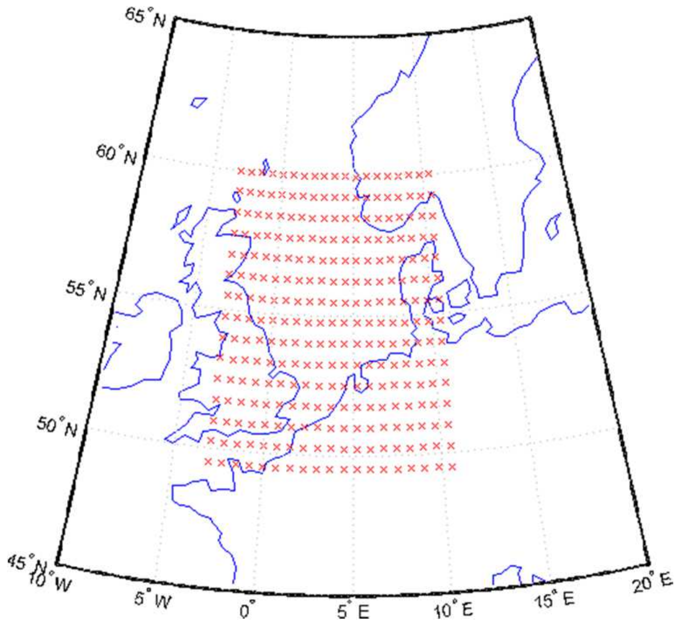
- FerryBox data of TorDania 04/2011 - 04/2012 (CuxImm route)
  - Dissolved oxygen (DO)
  - xCO_2
  - Water temperature
  - Salinity



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

- Atmospheric CO_2 from Mauna Loa Obs. (Hawaii)





Part of ERA-Interim 0.75° grid

Uncertainties: Evaluation of FerryBox data

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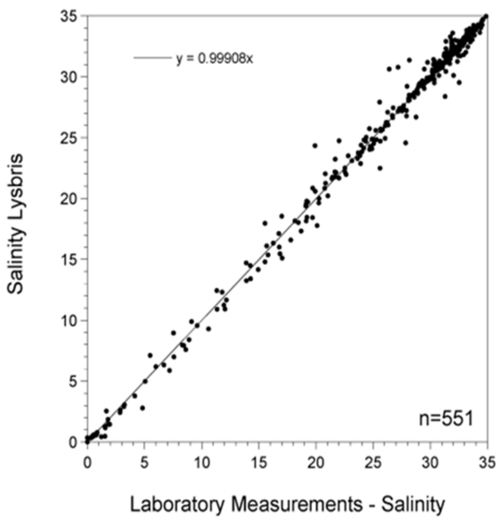
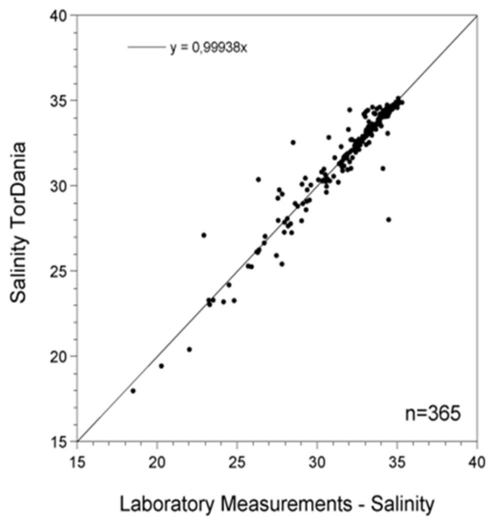
- Comparison of FerryBox water probes:
  - o Underestimation of optode dissolved oxygen concentration by 10-15%
    - o Evaluation every 1-2 months, in harbour
  - o FerryBox Salinity measurements in good agreement to lab evaluation
- Water temperature comparison FerryBox and MARNET:
  - o FerryBox offset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

Salinity

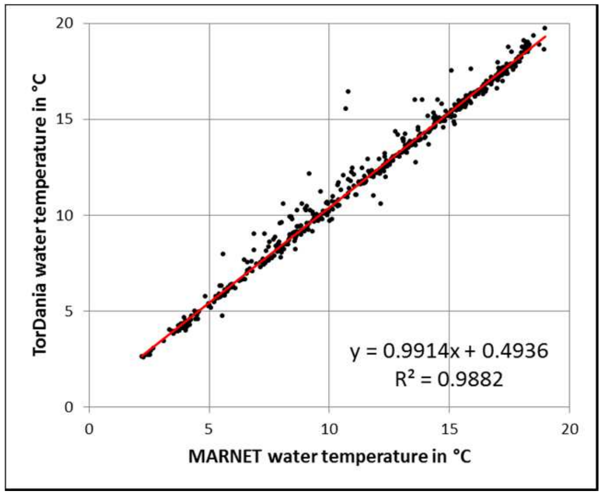




FB – Lab comparison of

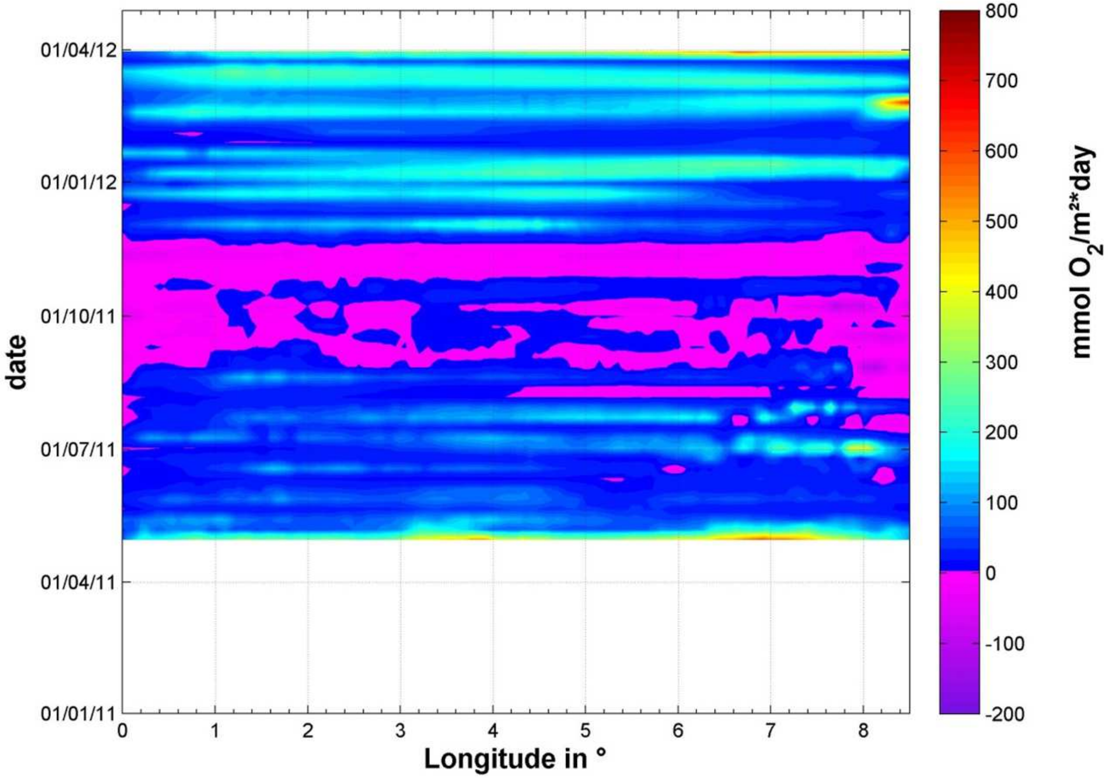
LysBris (2009-2012) TorDania (2007-2011)

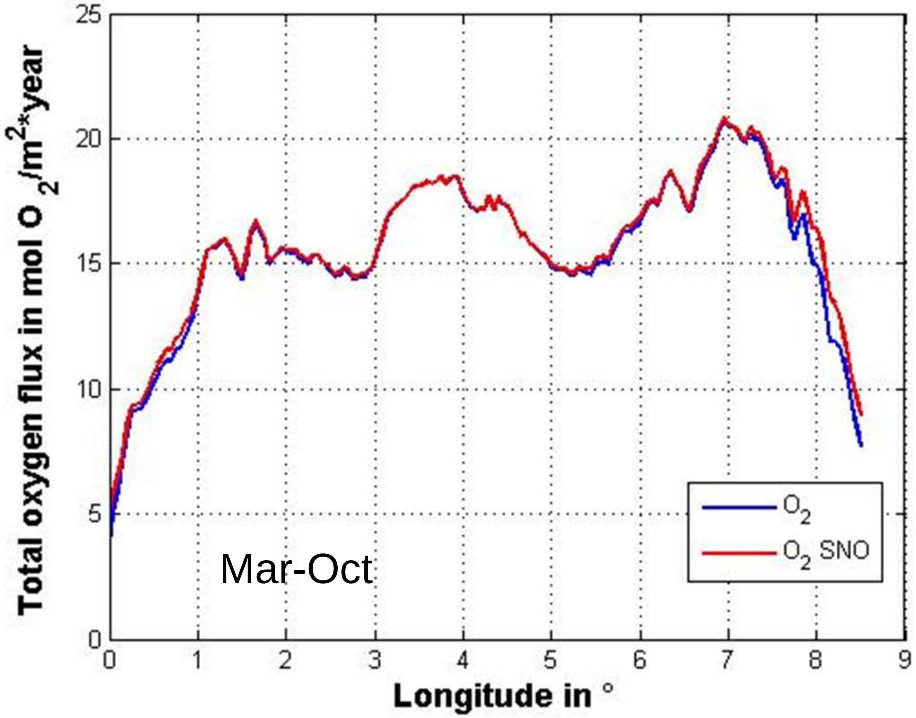
Water temperature



Comparison FB and MARNET
„Deutsche Bucht“ 2007-2011

Benefits: Oxygen flux estimates CuxImm 2011-2012





SNO = Seasonal Net Outgassing

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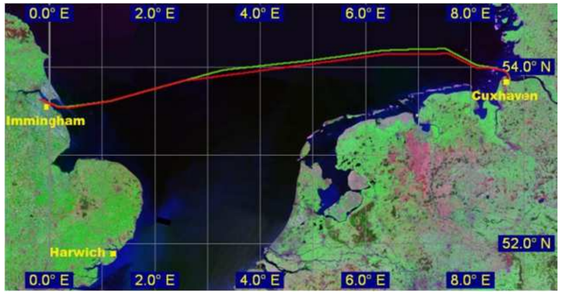
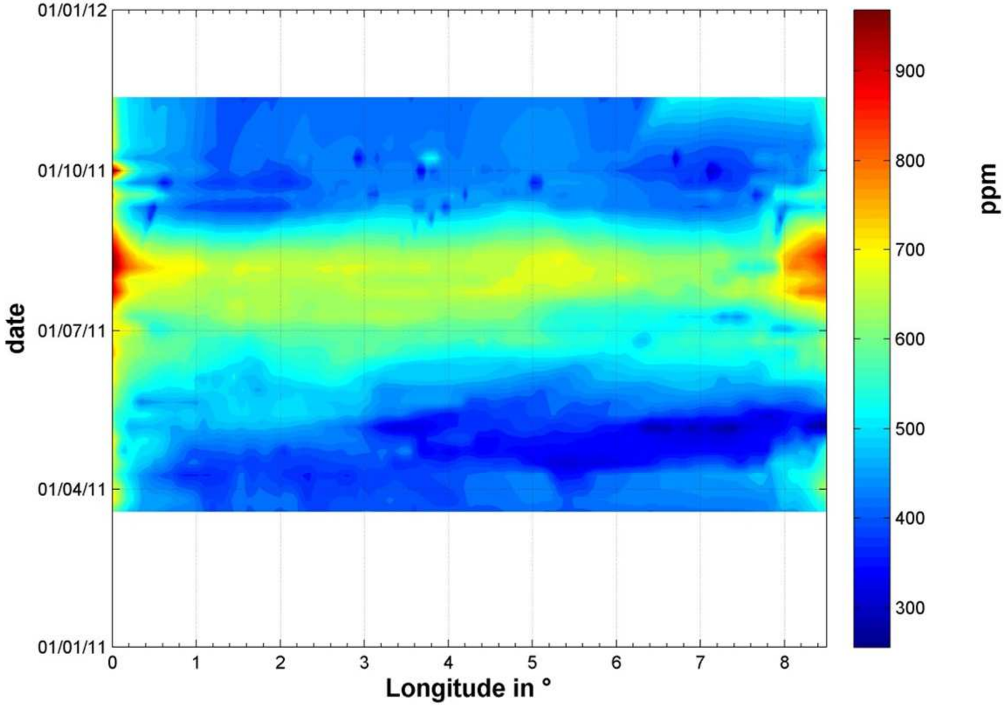
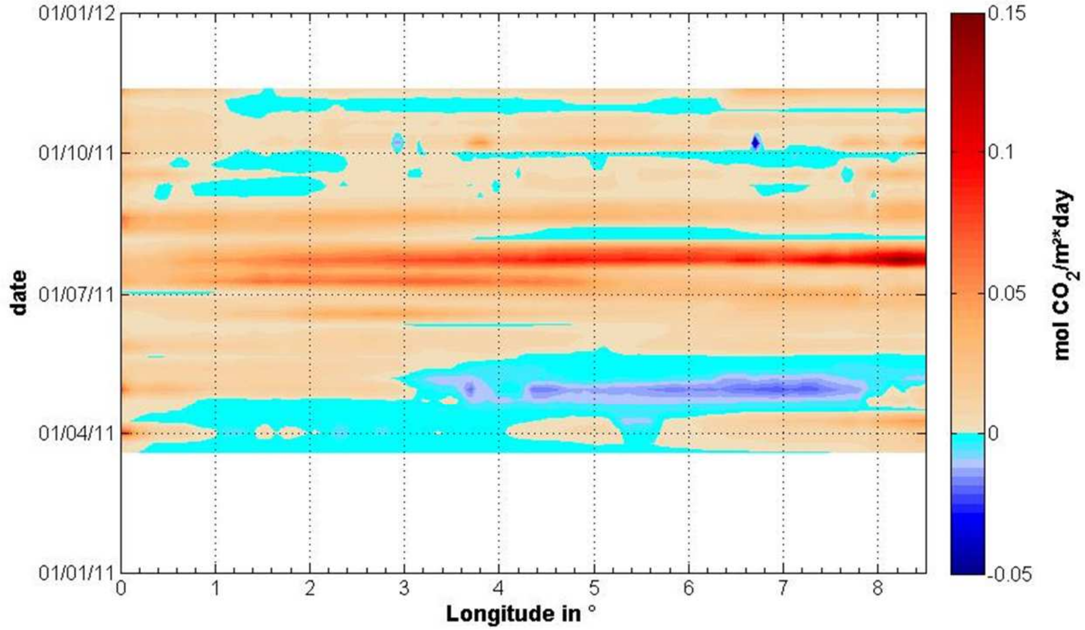
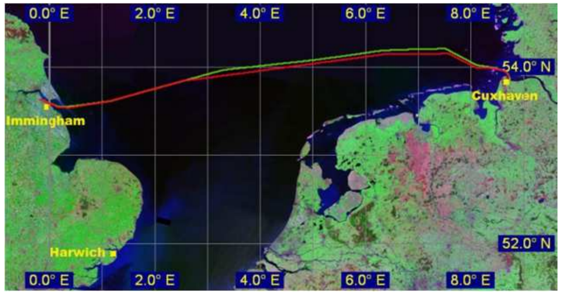


Benefits: xCO_2 and CO_2 flux estimates CuxImm 2011







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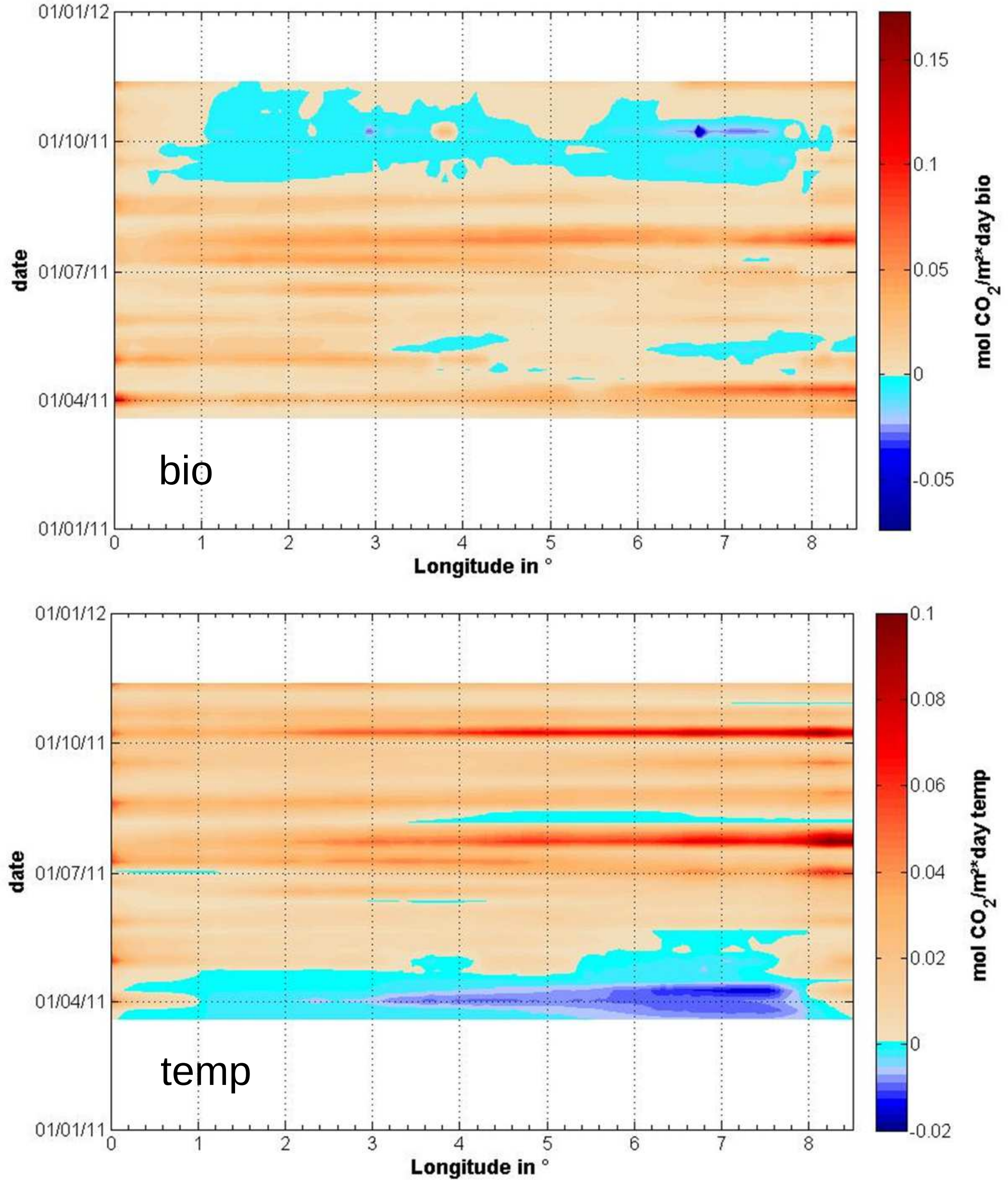
Benefits: Carbon flux estimates CuxImm 2011



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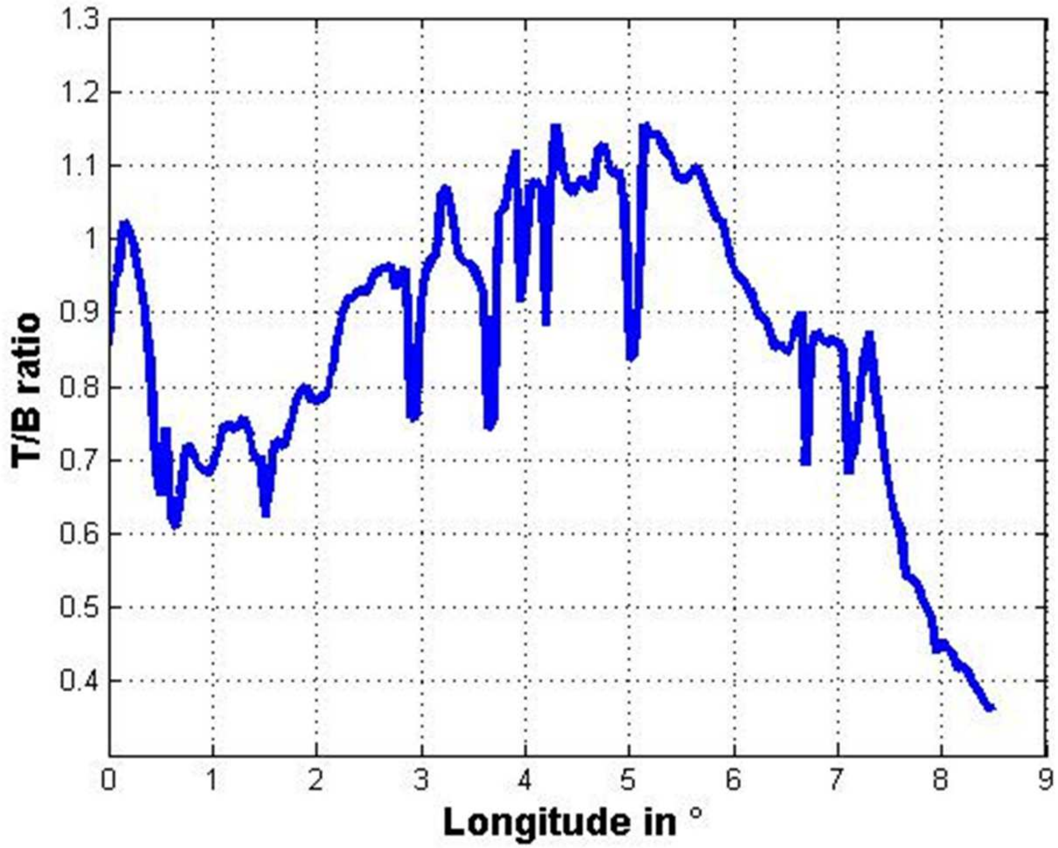
Benefits: Effects on Carbon fluxes



T/B ratio: biological (T/B < 1) or temperature influence (T/B > 1)

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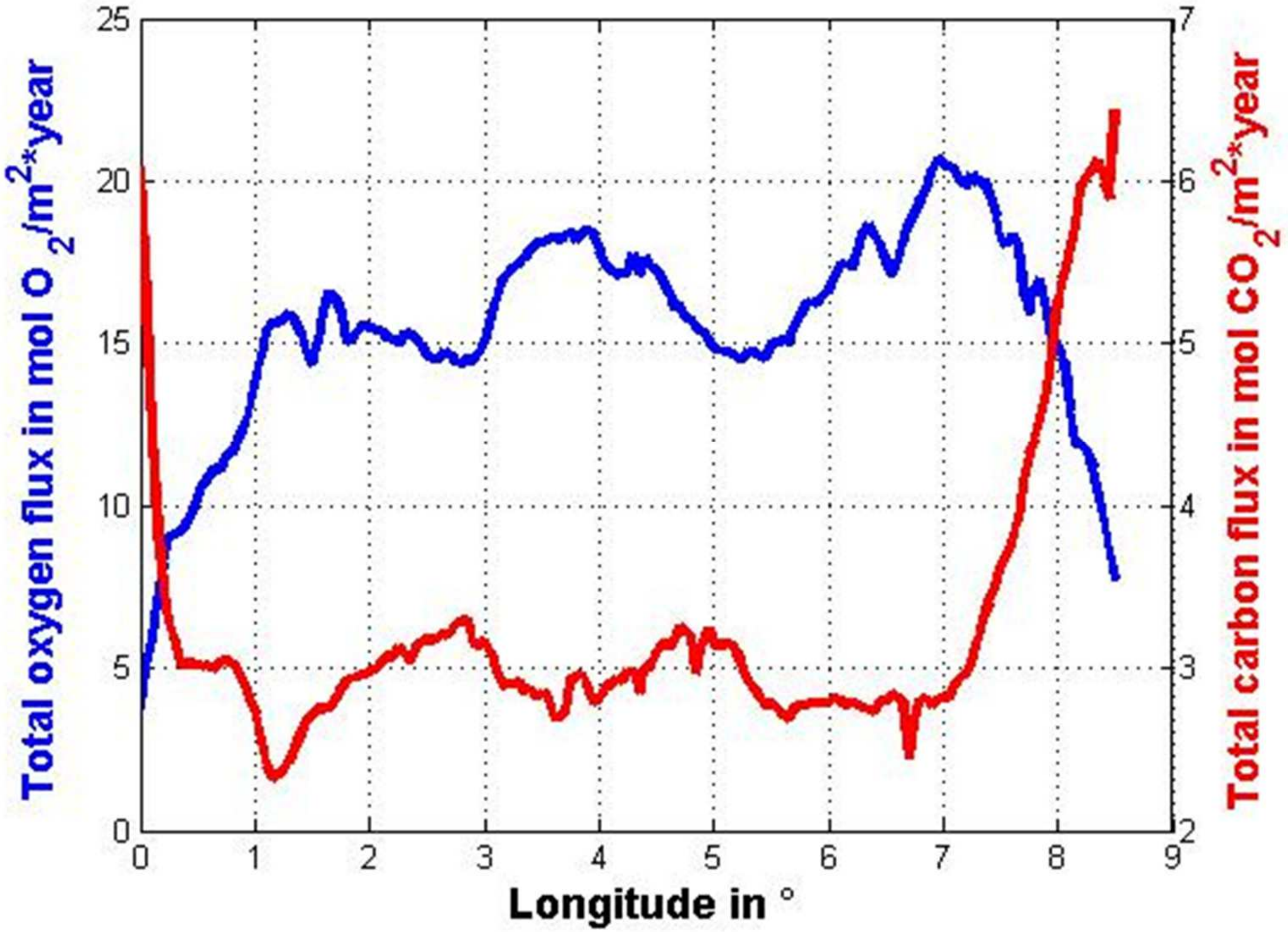
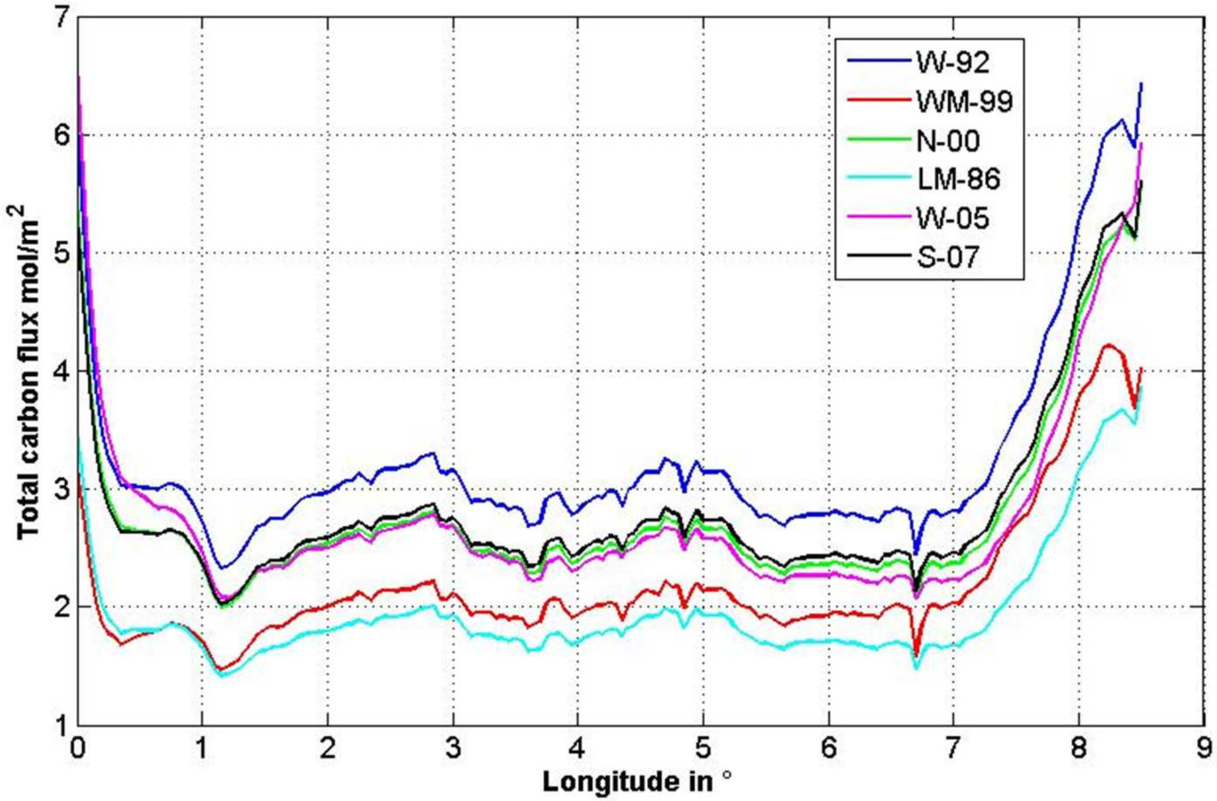
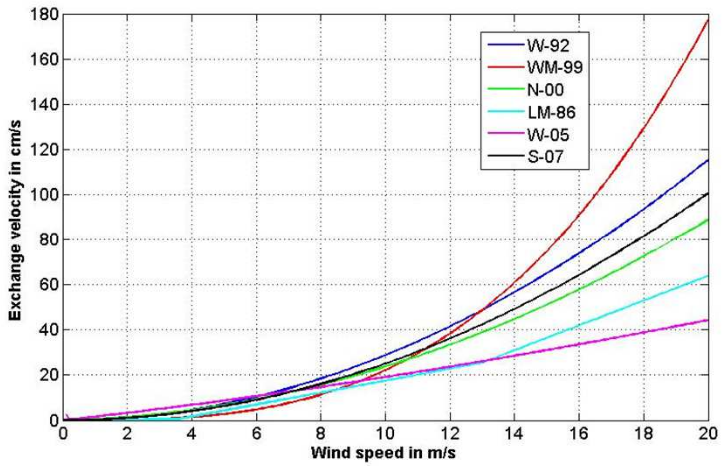
Benefits: Oxygen and Carbon fluxes



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...

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- 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!
DFDS TOR LINE

Redfield ratio

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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 5. Molecular Ratio of P, N, C, O_2, and $CaCO_3$ Changes in the Atlantic and Indian Oceans

	Number of Stations	σ_θ	P	N	CO_2	$(O_2 - 2N)$	$-O_2$	$CaCO_3$
Redfield ratio*	—	—	1	16	106	106	138	—
North Atlantic	32	27.00	1	17.6 ± 0.6	97 ± 9	130 ± 6	165 ± 7	15 ± 4
	57	27.20	1	16.8 ± 0.5	88 ± 6	139 ± 6	173 ± 6	8 ± 3
South Atlantic	16	27.00	1	16.7 ± 0.7	102 ± 7	131 ± 6	165 ± 6	8 ± 2
	14	27.20	1	16.7 ± 1.2	95 ± 10	150 ± 2	182 ± 9	8 ± 4
Atlantic mean	119	27/27.2	1	17.0 ± 0.4	96 ± 6	138 ± 9	171 ± 8	10 ± 4
South Indian	22	27.00	1	15.2 ± 0.6	112 ± 6	138 ± 7	169 ± 8	15 ± 4
	21	27.20	1	14.5 ± 0.5	125 ± 7	145 ± 5	174 ± 6	19 ± 6
Indian mean	43	27/27.2	1	14.9 ± 0.4	119 ± 5	142 ± 5	172 ± 5	17 ± 4
Atlantic and Indian mean	162	27/27.2	1	16.3 ± 1.1	103 ± 14	140 ± 8	172 ± 7	12 ± 5

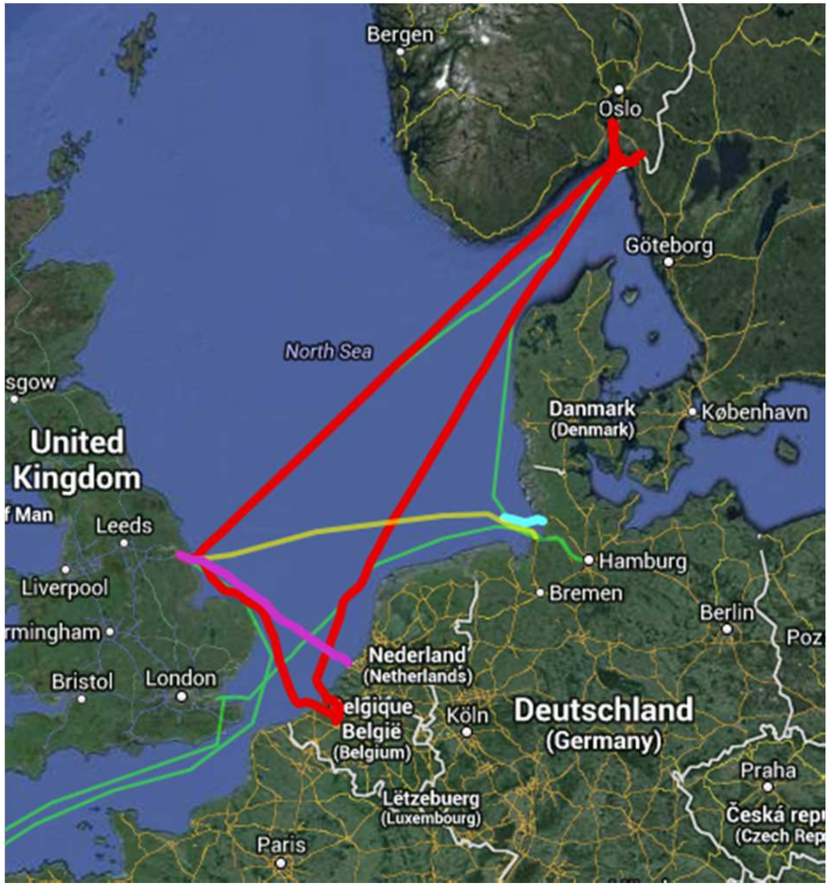
For the oxidation of nitrogen a reaction $NH_3 + 2O_2 = NO_3^- + H_2O + H^+$ (i.e., $N : O_2 = 1 : 2$) is assumed.
*Utilization by plankton after *Redfield et al.* [1963].

Takahashi et al. (1985)

HZG FerryBox routes

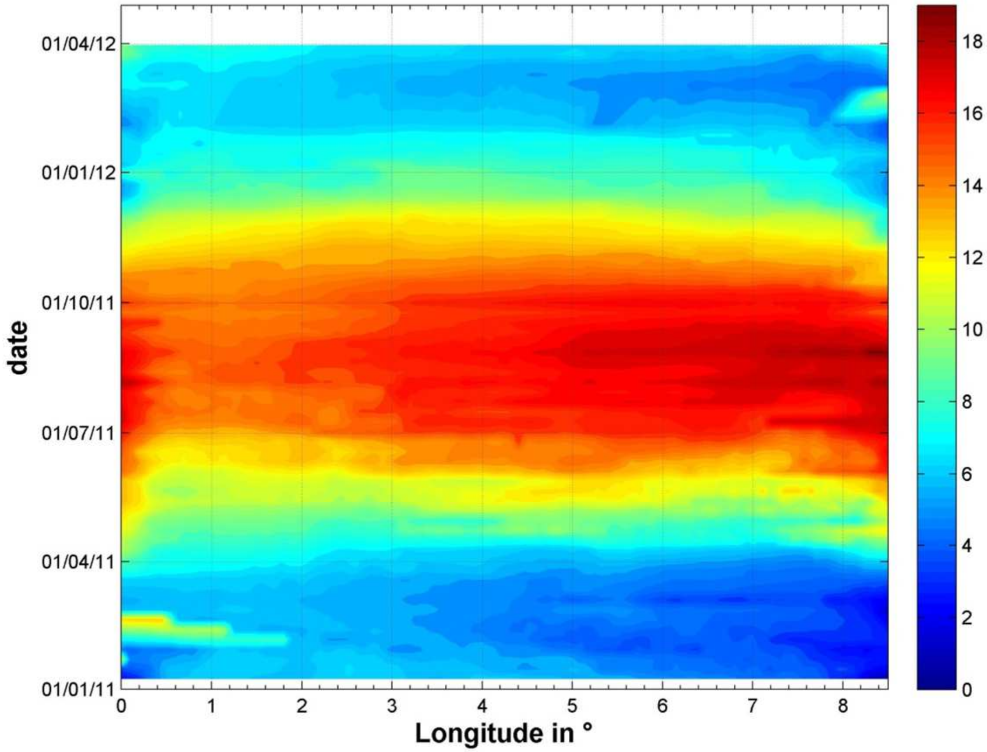
- Operation of currently three routes:
  - Helgoland-Büsum / Helgoland-Cuxhaven: „Funny Girl“
  - England-Norway-Belgium: „LysBris“
  - Rotterdam-Immingham: „Hafnia Seaways“

  - Former route: Cuxhaven-Immingham „TorDania“ (until 04/2012)
  - coming soon: re-activated Cuxhaven-Immingham route „Selandia“ (starting 2014/2015)

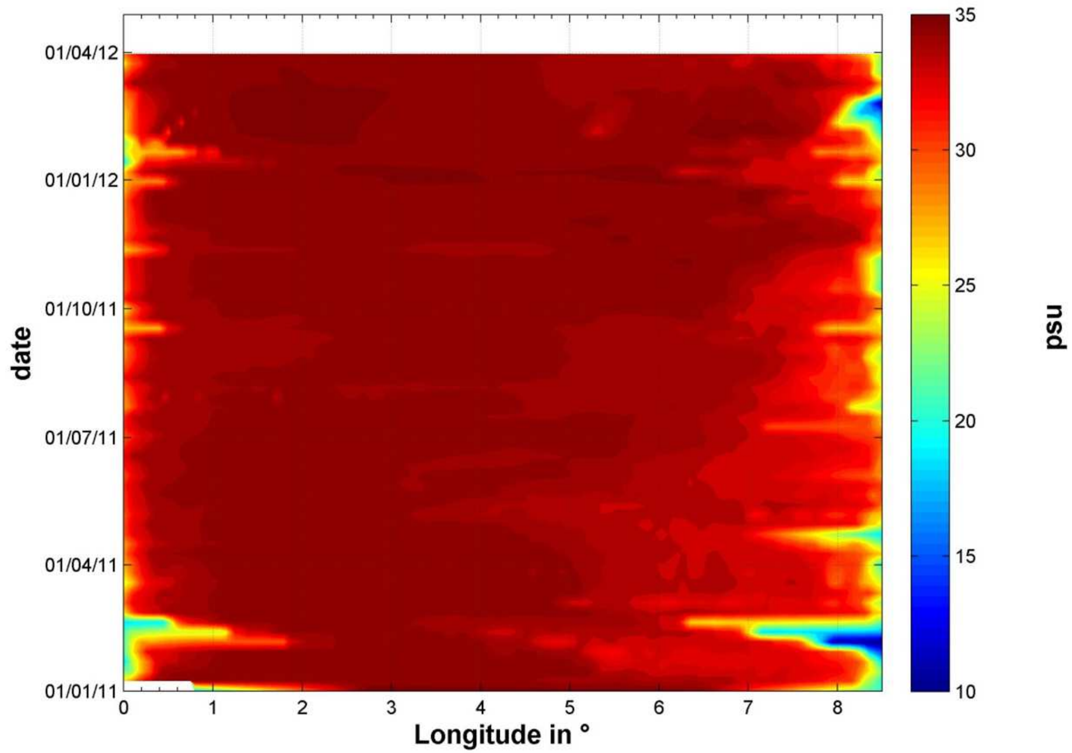


HZG – FerryBox routes:
- Lysbris
- Funny Girl
- Hafnia Seaways

FerryBox data sets



Water temperature

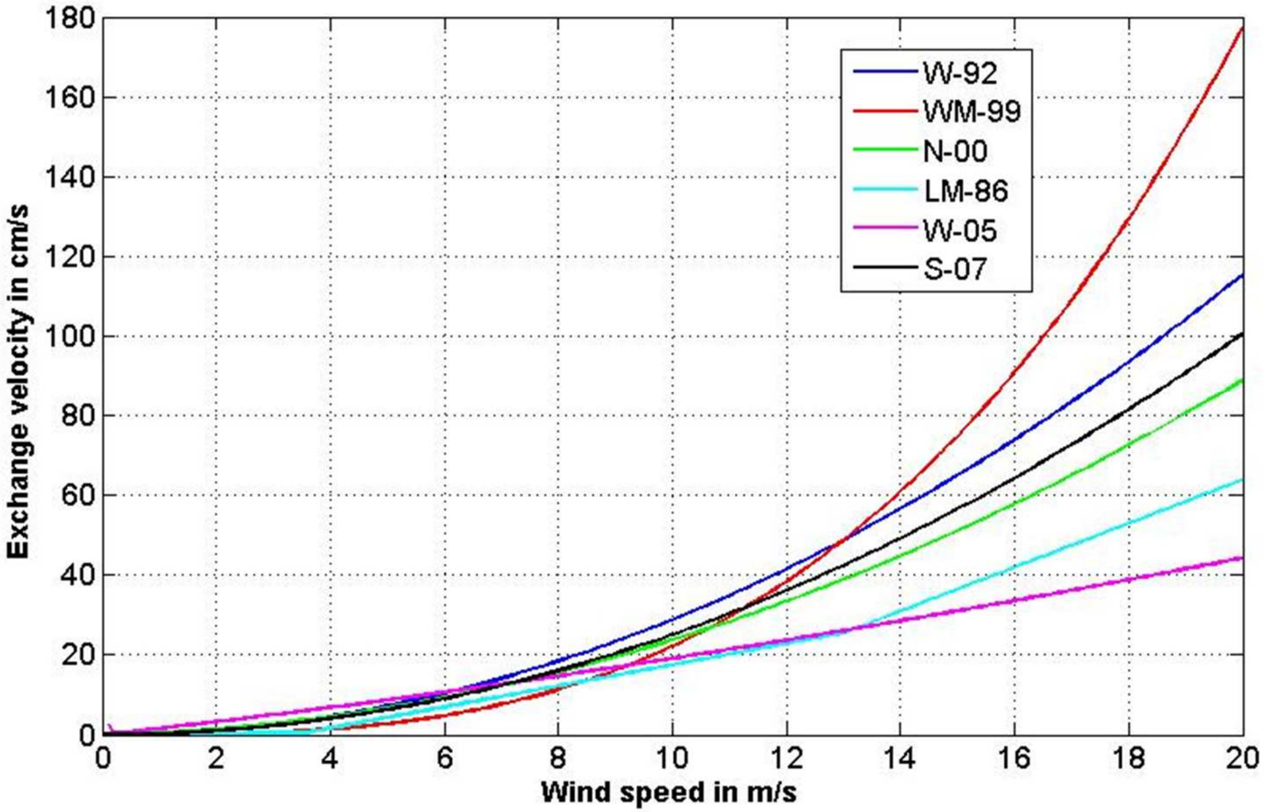


Salinity

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

Uncertainties: Parameterization scheme solutions



Parameterisation schemes for exchange velocity of air-sea flux of oxygen in dependance of wind speed U_{10}:

W-92: Wanninkhof, 1992:

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

WM-99: Wanninkhof & McGillis, 1999:

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

N-00: Nightingale, 2000:

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

LM-86: Liss & Merlivat, 1986:

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

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

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

W-05: Woolf, 2005:

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

S-07: Sweeney et al., 2007:

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