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Final Report

Name of the researcher	Tom Cox
Selection Year	2012
Host institution	University of Antwerp
Supervisor	Patrick Meire
Period covered by this report	From 1/11/2013 to 31/12/2015
Title of the project	New eyes on the world: Signal processing for interpreting biogeochemical time series.

1. Objectives of the proposal (1 page)

The overall objective of this research is to explore and develop advanced signal processing tools to high frequency biogeochemical time series. This will result in new methods and enhanced theoretical and practical understanding of existing methods for estimating ecosystem scale parameters such as gross primary production and sediment respiration. The development of advanced data processing software tools is crucial to exploit the full power of these data. This research focusses on two themes: Aquatic Eddy Correlation (AEC) flux measurements and frequency domain methods to study gross primary production (Fourier method).

In a first period, the main focus was the Fourier method for estimating gross primary production from continuous oxygen measurements. The main objective was to theoretically define and ground-truth the newly developed method, and to make it available to the scientific community. Concomitantly the accuracy of the method was investigated. The second objective was to test the applicability of the Fourier-method different aquatic systems. The third objective was the development and dissemination of open source software to make the new method available for routine application by the research community. Finally we also explored further developments of the Fourier method that allow a quasi continuous observation of GPP.

Concerning the second sub-theme of this research (AEC) the overall objectives were to resolve a number of issues related to the accuracy and reliability of the EC flux estimates, and to develop software tools for swift data analysis. Recent developments demanded some rethinking of the original project objectives. First, in a January 2015 paper by Holtappels *et al.* (*Aquatic Eddy Correlation: Quantifying the Artificial Flux Caused by Stirring-Sensitive O_2 Sensors*, PLoS ONE 10(1)) it was demonstrated that the electrochemical oxygen that sensors that were hitherto in use, were strongly affected by stirring. We anticipated that the AEC community would shift to the newly developed fast oxygen optodes that had also recently become available. Thus, the focus of our work shifted from quantifying the accuracy of EC flux estimates measured with stirring sensitive electrodes, to building an Eddy Correlation device equiped with non-stirring sensitive fast optodes. Additionally, we started work on another application of AEC, namely the derivation of floc settling velocities from observed Reynolds fluxes of SPM, estimated from the backscatter of an ADV (Acoustic Doppler Velocitymeter). In principle this application allows for the simultaneous in-situ observation of dynamics of suspended matter (floc dynamics and settling dynamics) and the potentially related dynamics of the oxygen. There exist a lot of observational evidence on the relation between SSC and O_2 (Abril *et al.* 1999; Talke *et al.* 2009, Lanoux *et al.* 2013). But the link between O_2-dynamics and SSC-induced feedbacks on turbulence and flow received surprisingly little attention (the paper Abril et al (2009) being a notable exception). As such the interaction between oxygen dynamics and suspended matter dynamics is a very much underdeveloped research domain.

2. Methodology in a nutshell (1 page)

Frequency domain methods to study gross primary production

The derivation of the Fourier method was based on an mathematical analysis in the frequency domain of the governing equation of oxygen dynamics in aquatic systems. This resulted in a relation between time averaged GPP and the amplitude of the diel harmonic in an oxygen time series. Concommitantly, this theoretical analysis sheds light on the effect of different kinds of noise on GPP estimates based on oxygen time series. Synthetic data simulated with a series of computer models was used to assess the performance and accuracy of the method for different aquatic systems. As such the applicatibility of the Fourier-method was confirmed for systems ranging from small ponds to well mixed estuarine and coastal systems. Further ground-truthing was done by applying the method to oxygen time series from the Scheldt estuary (Belgium) and comparing it with 14C-based GPP measurements. The applicability of the method to other systems was investigated applying it to oxygen time series, collected from established and new contacts in the international research community. A good collaboration with researchers from Germany and The Netherlands allowed us to apply the Fourier method to data series from different parts of the Dutch and German Wadden Sea, the Elbe estuary, and the German bight. Software to perform the analysis was developed and distributed to the community as an open source R-package. This software package contains all the functions to perform all necessary data processing steps to derive a GPP estimate from observed oxygen time series.

Aquatic Eddy Correlation flux measurements

An AEC device for measuring sediment oxygen fluxes was built, by adapting an available Acoustic Doppler Velocity meter (ADV) to allow analog inputs. Ultra fast micro-optodes (Pyroscience) were purchased. The interface between the micro-optode and the ADV was developed in cooperation with NIOZ, and custom build at the electronics workshop of that institute.

The applicability of AEC techniques to observe in-situ dynamics of suspended particles, and to estimate floc settling velocities was tested during 3 field campaigns in a Sieperda tidal creek. During these campaigns, a combination of optical and acoustic devices was deployed (ADCP, ADV, OBS, LISST) during 2 to 5 tidal cycles. This allowed a detailed characterisation of floc sizes, suspended sediment concentrations, flow conditions and turbulence. The interpretation of the results required us to revisit the theory behind the AEC technique to estimate floc settling velocity in such a highly non-stationary system such as Sieperda creek.

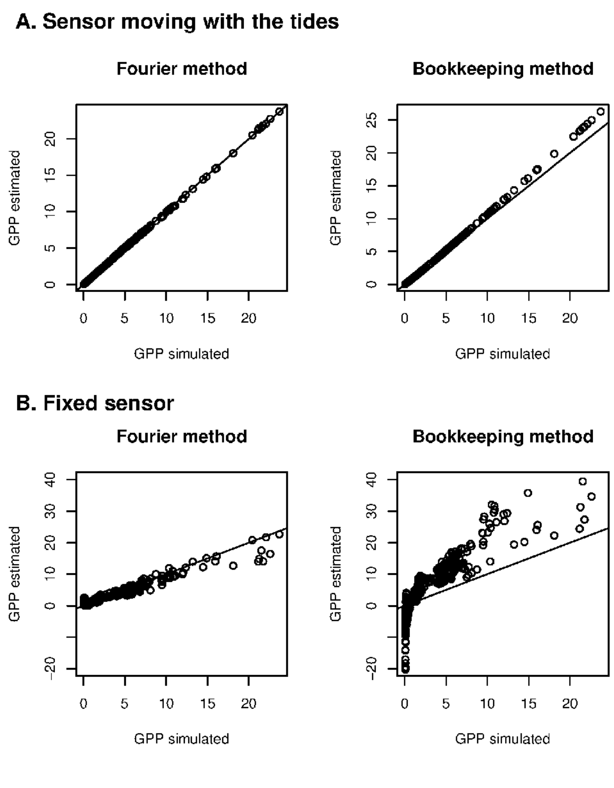
In collaboration with NIOZ-Yerseke, R-scripts were further developed and compiled in an open source R-package. This contains functions to perform all necessary data processing steps to derive a flux estimate from observed time series. The software also allows for automatic diagnostic report generation containing statistics and graphics, useful for quick examination of results and for problem solving.

3. Results (8-10 pages)

3.1 Ground-truthing Fourier method and communicating to scientific community

Cox, T.J.S.; Maris, T.; Soetaert, K.; Kromkamp, J.; Meire, P. & Meysman Filip (2015), 'Estimating primary production from oxygen time series: a novel approach in the frequency domain'. *Limnology And Oceanography:Methods* **13**, 529-552. DOI: 10.1002/lom3.10046

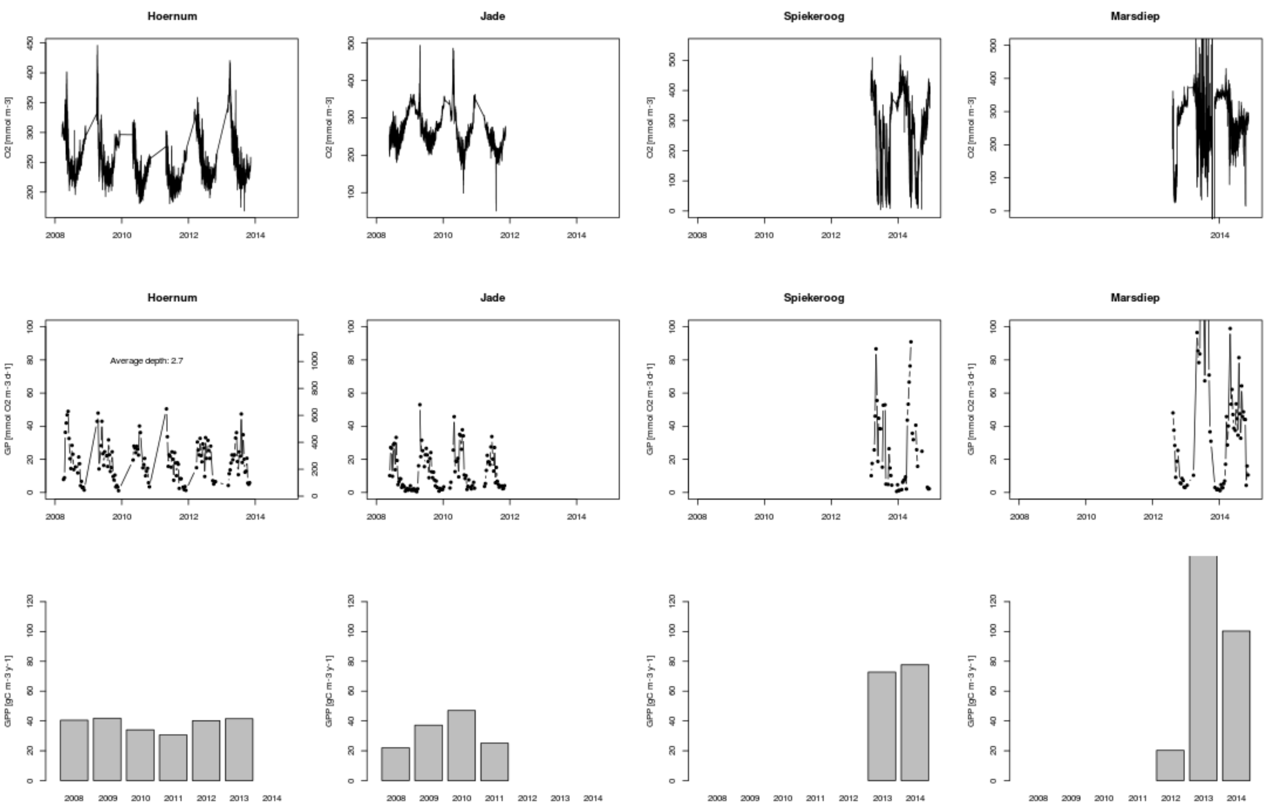
Abstract: Based on an analysis in the frequency domain of the governing equation of oxygen dynamics in aquatic systems, we derive a new method for estimating gross primary production (GPP) from oxygen time series. The central result of this article is a relation between time averaged GPP and the amplitude of the diel harmonic in an oxygen time series. We call this relation the Fourier method for estimating GPP. To assess the performance and accuracy of the method, we generate synthetic oxygen time series with a series of gradually more complex models, and compare the result with simulated GPP. We demonstrate that the method is applicable in systems with a range of rates of mixing, air–water exchange and primary production. We also apply the new method to oxygen time series from the Scheldt estuary (Belgium) and compare it with 14C-based GPP measurements. We demonstrate the Fourier method is particularly suited for estimating GPP in estuarine and coastal systems where tidal advection has a large imprint in observed oxygen concentrations. In those systems the Fourier method performs significantly better than the bookkeeping method (see figure 1). As such it enlarges the number of systems where GPP can be estimated from in situ oxygen concentrations.



By shifting the focus to the frequency domain, we also gain some useful insights on the effect of observational error and of stochastic drivers of oxygen dynamics on metabolic estimates derived from oxygen time series. In particular we have provided a theoretical underpinning of some simulation results published by Batt & Carpenter (2012). The analysis in the frequency domain not only correctly explains the expected error on the GPP estimate introduced by a random process error, it also explains why it is invariant under changes of the observational error (see fig 2, 3 and 4 of Batt & Carpenter (2012)). This result clearly demonstrates the power of shifting the attention towards the frequency domain.

3.2 Testing the applicability of the Fourier-method in other aquatic systems

In cooperation with researchers from the Helmholz-Zentrum Geesthacht and the university of Hamburg (De.), the applicability of the Fourier method was tested, making use data from the North-Sea, the German Bight, the German Wadden Sea, the Elbe estuary and a coastal inlet (Jadebusen). Together with researchers from the NIOZ (Nl.), the applicability was further investigated on data from the Dutch Wadden Sea and the Western Scheldt estuary.



The main preliminary results of these analyses, and of the model studies described in the manuscript above, is that the Fourier method indeed lives up to the expectations, and can provide robust estimates of GPP in estuaries and coastal systems. Depending on mixing rates, bathymetry, and light availability in the water column, a consistent upward or downward bias can be observed. Preliminary results indicate the possibility to partly correct for this bias either based on theoretical grounds, or on parallel deployment of O2 sensors that span the vertical or horizontal gradient.

Some preliminary results are described in internal reports

Cox, TJS (2013) Continue O2-metingen aan de overloop van Hansweert: GPP berekeningen met de Fourier methode. Voorstudie. Universiteit Antwerpen, Onderzoeksgroep Ecosysteembeheer, ECOBE 013-N50.

Cox, TJS (2015) PRocess–Oriented Observation of Oxygen in Coastal EcosystemS (PROCESS). Amended version of Final report. University of Antwerp, Ecosystem Management Research Group, ECOBE 014-R178b

Short summary of this report: One step towards a better understanding of coastal dynamics has been to develop new observation methods enabling an enhanced spatial and or temporal resolution. The HZG has initiated an observation network for the coastal North Sea (COSYNA). The aim of this cooperation is to combine the expertise by Antwerp University to analyse O2 time series with the COSYNA observational data by HZG covering both parts of the Wadden Sea and the coastal North Sea to quantify seasonal and regional differences in primary production.

In this final report, we present results from the analysis of O2 time series from observation stations Hörnum Tief, FINO1, FINO3, North Sea Buoy III and Elbe 1. As part of the screening of the quality of the data sets we first applied the Fourier-method to 'raw' data. Results from were used to identify relevant sets of O2 time series, i.e. where the GPP signal in the time series is strong enough. In a second step improved the GPP estimates by proper data handling, in particular by interpolating small gaps in the time series and by splitting the time series when gaps were too large to be interpolated. Next, the time series were splitted at the larger gaps to obtain subsets of continuous, equally sampled observations. These continuous subsets are subdivided in 10 day intervals on which the Fourier method is applied.

We elaborated most on the Hörnum Tief data-set as it was the largest and most consistent. The results show remarkable inter-anual variability in GPP. The observed annual peak in 10d averaged GPP roughly varies between 800 and 1400 mg C/m2/d. The seasonal pattern seems not invariable: in 2008, 2009 and 2011 a classical pattern is observed, with a clear spring bloom and a weak summer bloom. But in 2010 a strong summer bloom seems to have occurred. In 2010 and 2011 observations started only in May: and we don't know whether the 2010 and 2011 spring blooms were similar than other years, or maybe weaker or stronger. The spring bloom itself is also variable, as can be seen from comparing 2012 and 2008 observations. Whereas in 2008 a strong spring bloom is apparent in the GPP data, in 2012 this is much less pronounced.

However, one of the more intriguing results is the relative stability of annual production, in spite of the internannual variability in seasonal patterns. From the Fourier derived production, we derive production values between 111 and 113 gC/m2/y in 2008, 2009, 2012 and 2013. In 2010 and 2011 it is clear from Figure 2 that significant production probably took place outside the observation interval. Nevertheless, also in 2010, corrected annual production lies within this range.

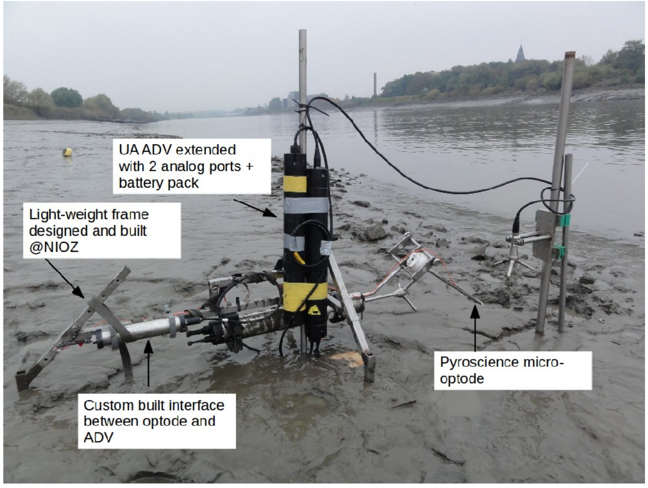
The annual averages of GPP calculated as such were 20% lower than the estimate obtained from O2 bottle incubations for the List tidal basis in 2004. We investigated the possible explanations for this lower estimate. It seems that the combined effect of truncated sinusoid approximation and the diel fluctuations in horizontal fluxes and air water exchange seems serious candidates to explain all or almost all the difference between the Fourier estimate and the result from Loebl et al (2007). A more in depth analysis of the effects of diel fluctuations in horizontal fluxes is however needed to validate this.

3.3 Software development: Fourier method

An R-package (*GPPFourier*) that contains all necessary software to pre-process oxygen time series and to apply the Fourier method has been developed. The package contains a vignette that explains the basic functionality. The two core functions implementing the Fourier method are GPPFourier() and GPPFourierPreprocess(). GPPFourier() is the workhorse function of the package. It calculates GPP for a single time series of O2, regularly sampled at a fixed sampling rate. Before computing the Fourier amplitude at diel frequency, the time series is preconditioned with GPPFourierPreprocess(). This function allows for detrending and low pass filtering (simple moving average) the time series, and it confines the data set to an integer number of days. (it is called from within GPPFourier()). Apart from the core functions, 2 higher level functions are provided to process a long data series in consecutive blocks of pre-defined length (WindowGPPFourier()) and to analyse multiple consecutive time series with a time gap in between, pasted together in a single data frame (WindowGPPFourier.gts()).

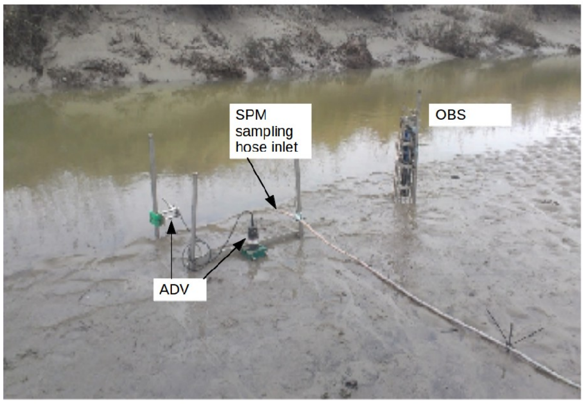
The package has been distributed to researchers from Belgium, the U.S., New Zealand, Germany, Denmark and The Netherlands, who are currently using it to apply the Fourier method to their systems.

3.4 Development of an AEC device with fast micro-optodes to measure O2 fluxes



The ultra fast micro-optodes (Pyroscience) come with an OEM module. To record the analog output of this module with the data logger of the ADV, an electronic interface has been designed and built in cooperation with NIOZ. The interface incorporates a chargeable battery, and circuitry to start the optode together with the ADV and to charge the battery. The titanium housing makes it deployable in all environments, from shallow water to the deep sea. The ADV (Nortek) available at the university of Antwerp was extended with 2 analog input ports to allow simultaneous recording of 2 optodes measuring at high frequency. Different frames for easy depoloyment of the instruments were designed and built in cooperation with NIOZ. The frame in the picture above is the most promising. It is light-weight, one person can carry the frame with all devices mounted on it. It allows for quick deployment in accessible mudflats and marshes, while it is also possible to deploy it from a ship. Additional funding for building the frame was acquired from the University of Antwerp research fund (7500 euro).

3.5 Setup to measure Reynolds Fluxes of suspended sediment in a tidal creek



In 2015 two measurement stations were established along the main channel of the Sieperda mars. The core of the measurement stations consists of an ADV, an OBS (optical backscatter sensor), a LISST (Laser In Situ Scattering and Transmissometer) and a submersible pump intake to sample suspended particulate matter (SPM). The figure above shows a typical setup (LISST is not visible).

With this setup we could investigate the performance of two techniques for in-situ estimation of settling velocities, both with minimal impact on particle populations and turbulence field. The “Stokes method”, estimates settling velocity from Stokes' law applied to particle size distributions from on LISST measurements. The “Reynolds flux method” estimates Reynolds fluxes from the direct observation of turbulent fluctuations with the ADV. Under stationary conditions, these Reynolds fluxes are proportional to settling velocity and the SPM concentration.

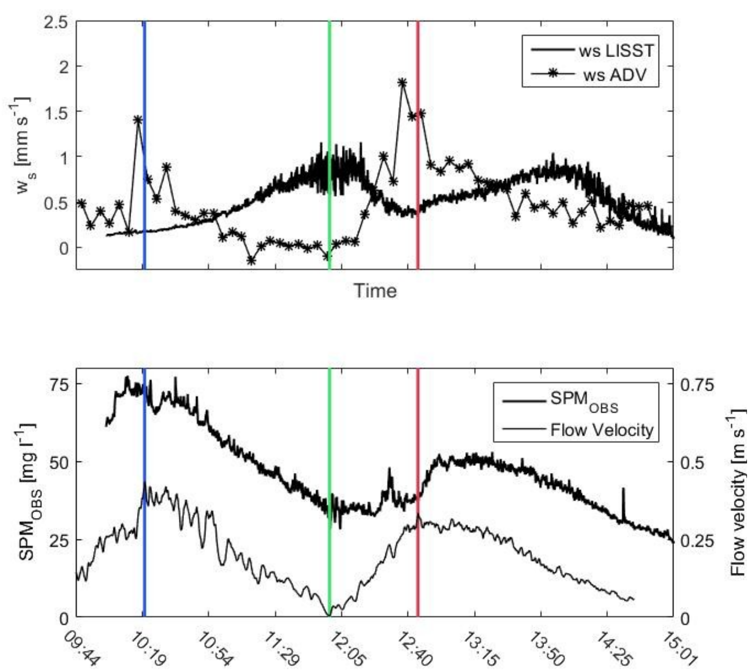
Part of the results of this measurement campaign are presented in a paper submitted to Journal of

Geophysical Research: Oceans.

Schwarz, C; **Cox, TJS;** Van Engeland, T; D. van Oevelen, J. van Belzen, J. van de Koppel, K. Soetaert, T.J. Bouma, P. Meire, S. Temmerman (*submitted to Journal of Geophysical Research: Oceans – in review*). Field estimates of settling velocities in a tidal creek: effects of non-stationarity.

Abstract:
A short-term intensive measurement campaign focused on flow, turbulence and suspended sediment concentration and settling was carried out in an intertidal creek in the Scheldt estuary. Settling velocity estimates between a laser diffraction (LISST) and an acoustic Doppler technique (ADV) were compared over one tidal cycle. Results suggest that flocculation processes play an important role in controlling sediment transport processes. During high water slack flocculated particles reached sizes up to 190 µm, whereas at maximum flood and maximum ebb tidal stage floc sizes only reached up to 54.7 µm and 71.2 µm respectively. This indicates that flocculation processes are mainly governed by turbulence induced shear rate. A comparison of settling velocity estimates between the LISST and the ADV revealed that, although tidal averages are comparable, temporal variations in estimated settling velocities within a tidal cycle are following opposite trends. We provide an in-depth discussion of the assumptions underlying the acoustic Doppler technique and argue that the observed differences in settling velocity estimates are due to violations of equilibrium assumptions. We further reason that tidal averaged settling velocity estimates are comparable between the two methods, because of a morphodynamic equilibrium of our investigated system, which needs to be evaluated when applied to a specific field situation.

The most important observation during our campaign was the major difference between methods: the temporal evolution during the tidal cycle of settling velocity derived from Reynolds fluxes (ws ADV) and settling velocities derived from particle size distribution (ws LISST) show opposing trends. The wsADV estimates show maxima during the initial phases of both flood and ebb. After reaching their maximal values, the wsADV estimates decrease towards the end of both flood and ebb phases.



During high water slack, the wsADV estimates are close to 0 mm s^{-1}, while wsADV estimates are always non-zero at the end of ebb. This temporal pattern is in major contrast with the results derived from the particle distributions (wsLISST). Although wsADV and wsLISST exhibit a similar range, there is a clear difference in tidal variation. Around maximum flood and maximum ebb wsADV settling velocity estimates exhibit their highest values, where wsLISST estimates show their lowest values, and vice versa. Surprisingly though, the averages over the tidal cycle are in close correspondence at Station1: 0.48 mm s^{-1} wsADV and 0.51 mm s^{-1} wsLISST.

This motivated us to revisit derivation of the Reynolds-flux method. In a straight channel with zero bottom slope and constant cross-section, the Reynolds averaged continuity equation for suspended sediment can be approximated as [*Fugate and Friedrichs*, 2002b; *Voulgaris and Meyers*, 2004].

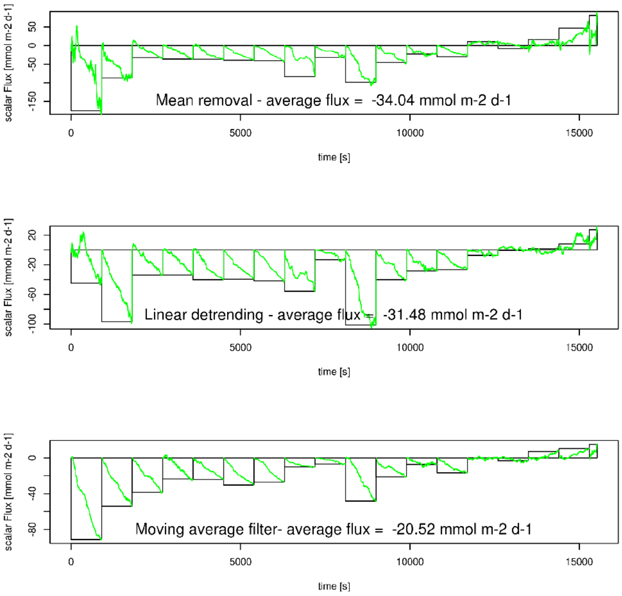
$$\frac{\partial \langle C \rangle}{\partial t} + \frac{\partial \left(\langle u \rangle \langle C \rangle \right)}{\partial x} = w_s \frac{\partial \langle C \rangle}{\partial z} - \frac{\partial}{\partial z} \langle w' C' \rangle \qquad ()$$

where the z-axis is pointing upwards, *C* is the SPM concentration, *u* horizontal velocity, *w* vertical velocity, w_s is the settling velocity as a positive scalar, and < . > denotes Reynolds averaging. Under stationary conditions, i.e. no concentration change over time or length axis, a balance exists between the two terms on the right hand side of the equation: upward turbulent transport (second right-hand side term) equals gravitational settling (first right-hand side term). After vertical integration between the bed and the sensor height, and provided that there is no sediment flux to or from the bed a simple relation between the Reynolds flux and settling velocity is derived

$$w_s = \frac{\langle w' C' \rangle}{\langle C \rangle}$$

However, field conditions violate these assumptions as channels have a more complex geometry and experience non-stationary sediment flux conditions. The Reynolds-flux method requires that the continuity equation is predominantly governed by the aforementioned vertical balance. In Sieperda tidal creek, the governing equilibrium assumptions are not fulfilled, leading to the observed mismatch in settling velocity estimates from the adapted Stoke's (wsLISST) and Reynolds-flux method (wsADV). Specifically, we attribute the mismatch to two phenomena; (1) the presence of transient vertical fluxes during accelerating and decelerating flow, and (2) the importance of horizontal flux divergence.

3.6 AEC derived oxygen fluxes



During one of the field campaigns in Sieperda tidal creek, also the first tests were performed with the AEC device with fast micro-optodes to measure O2 fluxes. These results look very promissing. The data quality is very good, compared to older results with electrochemical oxygen sensors. However a similar temporal variability during the tidal cycle can be observed as with the Reynolds flux method to estimate settling velocities: fluxes seem too high during accelerating flow and too low during deceleration. This is in accordance with theoretical results from Holtappels *et al.* 2013.

The large impact of non-stationarity is an important drawback for the application of aquatic eddy correlation techniques in such dynamic environments as estuaries and coasts. Preliminary results indicate that tidally averaged results are still reliable. However, we only have some empirical evidence, and it seems there is no theoretical guarantee that tidal averaging reduces the impact of non-stationarity effectively to zero. This requires further research.

3.7 Software development: Aquatic Eddy Correlation

The R package for analysing EC data is used by researchers at Ifremer, NIOZ, and UA. It is currently fully documented, and includes example data sets. Researchers from different international research institutions (Ifremer (Fr.), NIOZ (Nl.), AWI (De.)) asked us for collaboration on their Eddy Correlation research. This work was focussed on solving data analysis and software issues, as well as interpreting EC results, quality assessment, etc.

4. Valorisation/Diffusion (including Publications, Conferences, Seminars, Missions abroad...)

Peer reviewed publications

Cathalot, C.; Van Oevelen, D.; **Cox, T.J.S.**; Kutti, T.; Lavaleye, M.; Duineveld, G. & Meysman, F. J. R. (2015), 'Cold-water coral reefs and adjacent sponge grounds: Hotspots of benthic respiration and organic carbon cycling in the deep sea', *Frontiers in Marine Science* **2**(37). DOI: 10.3389/fmars.2015.00037

Cox, T.J.S.; Maris, T.; Soetaert, K.; Kromkamp, J.; Meire, P. & Meysman Filip (2015), 'Estimating primary production from oxygen time series: a novel approach in the frequency domain'. *Limnology And Oceanography:Methods* **13**, 529-552. DOI: 10.1002/lom3.10046

Chambord, Sophie; Maris, Tom, Colas, Fanny; Van Engeland, Tom; Sossou, Akoko-C.; Azémar, Frédéric; Le Coz, Maïwen; **Cox, T.J.S.**; Buisson, Laetitia; Souissi, Sami; Meire, Patrick & Tackx, Michèle (2016) "Mesozooplankton affinities in freshwater reaches of the Scheldt estuary ". *Estuarine Coastal and Shelf Science*. Published on-line 2016-04-27 doi:10.1016/j.ecss.2016.04.016

Schwarz, C; **Cox, TJS;** Van Engeland, T; D. van Oevelen, J. van Belzen, J. van de Koppel, K. Soetaert, T.J. Bouma, P. Meire, S. Temmerman (*submitted to Journal of Geophysical Research: Oceans – in review*). Field estimates of settling velocities in a tidal creek: effects of non-stationarity.

Polsenaere, Pierre ; Maire, Olivier; Rigaud, Sylvain; **Cox, Tom** ; Meysman, Filip; Thouzeau, Gérard and Deflandre, Bruno (*in prep*) 'Benthic oxygen exchanges measured by aquatic Eddy Covariance over contrasted ecosystems of a temperate coastal bay (Bay of Brest, France)

Van Engeland, T; Cox, TJS; Soetaert, K.; Van Oevelen, D. Analysing Eddy Correlation data with the EddyCorrelation R-package (in prep). Target journal: Journal of Statistical Software.

Verschoren, Veerle; Schoelynck, Jonas; **Cox, Tom J.S.**; Temmerman, Stijn; Meire, Patrick (submitted to Ecological Engineering) Opposing effects of aquatic vegetation on hydraulic functioning and transport of dissolved and organic particulate matter in a lowland river: a field experiment.

Oosterlee, L.; **Cox, T.J.S.**; Maris, T.; Vandenbruwaene W.; Temmerman, S.; Meire, P. (*in prep*). Different feedbacks between tidal inundation and elevation change in a natural versus restored tidal marsh with reduced tidal exchange. Target journal: Geomorphology

Oosterlee, L.; **Cox, T.J.S.**; Maris, T.; Temmerman, S.; Meire, P. *(in prep)* How restoration design determines elevation change. Comparison Controlled Reduced Tide (CRT) and Simple Culvert System (SCS)

Oosterlee, L.; **Cox, T.J.S**.; Maris, T.; Vandenbruwaene W.; Temmerman, S.; Meire, P. (*in prep*). Interactions between tidal inundation and elevation change in a restored tidal marsh with reduced tidal exchange

Reports related to the research project

Cox, TJS (2013) Continue O2-metingen aan de overloop van Hansweert: GPP berekeningen met de Fourier methode. Voorstudie. Universiteit Antwerpen, Onderzoeksgroep Ecosysteembeheer, ECOBE 013-N50.

Cox, TJS (2014) PRocess–Oriented Observation of Oxygen in Coastal EcosystemS (PROCESS). Final report. University of Antwerp, Ecosystem Management Research Group, ECOBE 014-R178

Cox, TJS (2015) PRocess–Oriented Observation of Oxygen in Coastal EcosystemS (PROCESS). Amended version of Final report. University of Antwerp, Ecosystem Management Research Group, ECOBE 014-R178b

Cox, T.J.S.; Maris, T (2015) Primaire productie in het Waddengebied: meten en berekenen. Opmerkingen bij het conceptrapport. Universiteit Antwerpen, onderzoeksgroep Ecosysteembeheer. ECOBE 015-R184

Missions abroad

Short research stays at the University of Hamburg and HZG: 13-14/11/2013, 30/09-02/10/2014, 25-27/3/2015

Visit to MPI (Max Planck Institute fur Marine Microbiologie) Bremen 25-26/11/2015

Visits to NIOZ-Yerseke: 14/07/2014, 13/10/2014, 09/12/2014

Visits to NIOZ Texel: 1/10/2015

Workshops, invited talks

Cox, TJS *et al.* (2014) Deriving primary production estimates from continuous oxygen measurements/ Accuracy of the Fourier method and application to the German Bight. Invited talk, HZG, 01/10/2014

Cox, TJS *et al.* (2014) Estimating primary production from oxygen time series: a novel approach in the frequency domain.Primary Production Workshop Roosendaal, Sep 2014

Cox, TJS; van Engeland, T.; Maris, T.; Temmerman, S.; Meire, P.; Soetaert, K.; Tackx, M; Chambord, S. (2015) Unraveling the interaction between SSC, phytoplankton and zooplankton in the Upper Sea-Scheldt. Ems-Scheldt workshop, 12-13 February 2015, Delmenhorst, Germany

Cox, TJS *et al* (2015) Estimating primary production from oxygen time series: a novel approach in the frequency domain. Visit MPI Bremen, 26/11/2015

Cox, TJS (2016) Interaction between ecology and sediment dynamics in the Scheldt estuary . Keynote lecture. Ems-Scheldt workshop, 11-12 February 2016 Amersfoort, The Netherlands

Cox TJS, Schwarz, C and Van Engeland T. (2016) Implications of in-situ sediment dynamics measurement at a tidal creek on long-term budgets of tidal wetlands. Workshop on best practices in generating long-term and large-scale observational data sets of SPM concentration. 24-25 February 2016 Brussels, Belgium

Cox TJS (2016) 'Hoe de biologie de waterbeweging stuurt (of was het omgekeerd?)' Symposium "De Schelde door de getijden heen". 25 february 2016, Antwerp, Belgium.

Cox TJS, Schwarz, C and Van Engeland T. (2016) Field estimates of settling velocities in a tidal creek : effects of non-stationarity. ECSA-56 Coastal systems in transition: From a 'natural' to an 'anthropogenically-modified' state. 4-7 September 2016, Bremen, Germany

Meire L, Mortensen J, **Cox TJS**, Rysgaard Søren Use of transect studies and moorings to assess seasonal productivity in a sub-Arctic fjord adjacent to the Greenland Ice Sheet (2016). ASM2016. ArcticNet 12th Annual Scientific Meeting, 5-9 December, Winnipeg, Canada.

5. Future prospects for a permanent position in Belgium

Unfortunately, career opportunities for scientists in Belgian universities are extremely limited. I submitted a proposal for an FWO post-doc grant, was ranked by the scientific committee, but not granted the position.

6. Miscellaneous