Variability of the gas transfer velocity of CO_2 in a macrotidal estuary (The Scheldt)

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✓Introduction

A rigorous estimation of the exchange of CO_2 across the air-water interface is critical to determine ecosystem metabolism and to budget the annual sink or source for atmospheric CO_2 at local, regional and global scales. The flux of CO_2 across the air-water interface (*F*) can be computed according to:

$F = k.)CO_2$ (1)

where)CO_2 is the air-water gradient of the concentration of CO_2 and *k* is the gas transfer velocity of CO_2 (also referred to as piston velocity).

In both open oceanic and coastal environments, highly precise and accurate methods to measure)CO_2 are nowadays available, thus, the largest uncertainty in the computation of *F* comes from the *k* term.

Estuaries have been shown to be characterized by higher *k* values than other aquatic systems due to the strong contribution of tidal currents to the water turbulence (Zappa et al. 2003; Borges et al. 2004). Furthermore, the variable contribution of tidal currents and fetch limitation make *k*-wind relationships site specific in estuaries (Kremer et al. 2003; Borges et al. 2004). This is relevant because constraining adequatetly air-water CO_2 in estuaries is critical in budgeting air-water CO_2 fluxes in the coastal ocean (Borges 2005).

✓Results & discussion

During two cruises in the Scheldt estuary (November 2002 and April 2003), nine stations were occupied during 24 h and flux measurements were carried out approximately every 10 min during daytime. Based on the 295 interfacial CO_2 flux measurements obtained using the floating chamber method and from concomitant measurements of)CO_2, we computed *k*. The binned *k* values are well correlated to wind speed and a simple linear regression function gives the most consistent fit to the data (**Plot 1**). The contribution of the water current to the gas transfer velocity was estimated from the frequently referenced conceptual relationship of O'Connor & Dobbins (1958):

$k_{600current} = 1.719 w^{0.5} h^{-0.5}$ (2)

where $k_{600current}$ is the gas transfer velocity in cm h^{-1}, *w* is the water current in cm s^{-1} and *h* depth in m.

The validity for estuarine environments of this relationship developed for streams has recently been confirmed by Zappa et al. (2003) based on *k* measurements using various micro-meteorological methods in Plum Island Sound estuary, and by Borges et al. (2004) based on floating dome measurements in the Randers Fjord. Assuming that:

$k_{600wind} = k_{600observed} - k_{600current}$ (3)

we established, based on (2) and concomitant *w* and *h* measurements, a linear relationship between $k_{600wind}$ and wind speed:

$k_{600wind} = 1.0 + 2.58 u_{10}$ (4)

where $k_{600wind}$ is the gas transfer velocity in cm h^{-1}, u_{10} is the wind speed referenced at a height of 10 m in m s^{-1} (**Plot 1**).

Assuming that the contributions of wind and water current to water turbulence are additive, an equation that accounts for both wind speed and water current speed can be constructed by summing (2) and (4):

$k_{600} = 1.0 + 1.719 w^{0.5} h^{-0.5} + 2.58 u_{10}$ (5)

At three reference stations - Vlissingen, Hansweert and Antwerpen - that correspond, respectively, to the lower, middle and upper Scheldt estuary, the k_{600} was computed from equation (5), using the hourly time series of measured u_{10} and modelled *w* (CONTRASTE physical model) for the years 1997 to 2001.

The Antwerpen station is characterized on an annual basis by significantly lower k_{600} values than the two other stations, mainly due to the significantly lower wind speeds (**Plot 2**).

On an annual basis, the contribution of *w* to k_{600} (%*w*) is highly significant at the three reference stations, ranging from about 21 to 35% for Vlissingen and Antwerpen, respectively (**Plot 3**).

For the whole 1997-2001 period, lower monthly wind speed averages are observed during spring and summer compared to fall and winter and concomitantly, during spring and summer, k_{600} values are lower and the contribution of *w* to k_{600} increases (**Plot 4**).

✓Conclusions

- Water currents significantly contribute to *k* in the Scheldt (between 20 to 35% on annual scale).
- Spatial and temporal variability (from daily to seasonal scales) of *k* in the Scheldt is mainly related to wind speed variability.
- *k* is highly variable from the lower to the upper Scheldt estuary.
- The use of a constant *k* to compute air-water CO_2 fluxes in estuaries should be avoided and probably induces large errors in the estimates of the CO_2 emission to the atmosphere and overall carbon budget.

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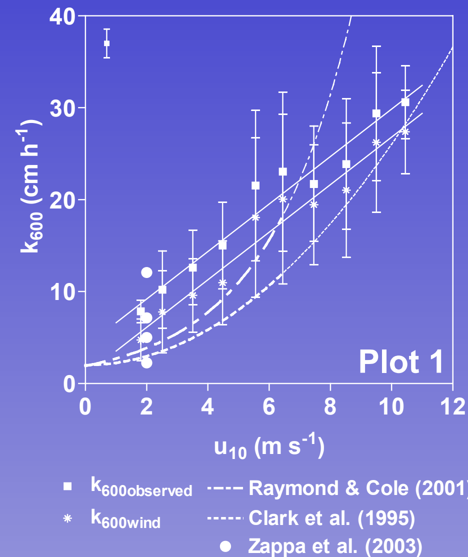

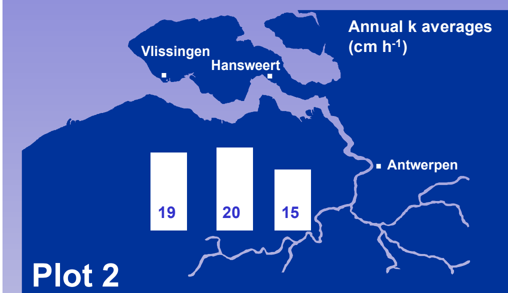

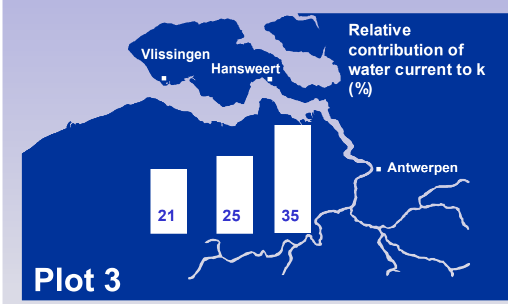

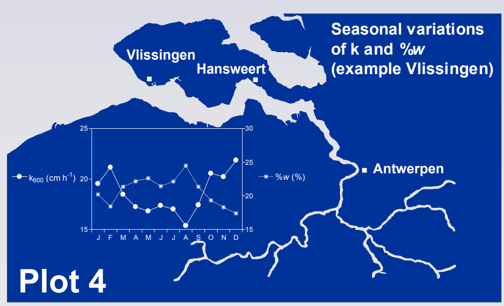

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