Air-sea gas transfer velocity for gases of different solubility (CO$_2$, O$_2$ and CH$_4$)

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What controls the exchange?

Parameters
- Wind
- Heat Flux
- Fetch
- Mixing Depths
- Chemi. / Biol. Properties

Processes
- Micro Breaking
- Small Scale Turbulence
- Large Scale Turbulence
- Waves
- Bubbles, Spray
- Rain
- Surface Films

Kinematic Forcing
- Turbulence in the Air
- Turbulence in the Water
- Dynamics at the Interface

Quantities (For Example CO₂)
- Transfer Velocity $K$
- Partial Pressure Difference $\Delta p_{CO₂}$

Air-Sea CO₂ Flux

Thermodynamic Forcing
- Sea Surface Temperature
- Transport
- Biology

COST735 book (Garbe and Rutgersson et al)
Types of water basins:

- **Open ocean**
  - Spray, bubbles
  - waves

- **Marginal and coastal seas**
  - Spray, bubbles, waves
  - buoyancy

- **Shore areas**
  - Spray, bubbles, waves
  - buoyancy
  - surfactants

- **Lakes**
  - buoyancy
  - Surfactants

- **Wind speed**
- **Waves**
- **Wind speed and waves**
- **Temperature difference**
- **Chem/biol properties**
- **Temperature difference**
- **Chem/biol properties**
- **Wind speed?**
Sensitivity of gas transfer velocity to whitecap coverage

COST735 book (Garbe and Rutgersson et al) based on models from Woolf et al (2007)
Controls of diffusive fluxes:

For vertical flux of gas (here for CO$_2$). Using EC method

$$F_{CO_2} = \overline{w' c'} \text{ (turbulent vertical flux)}$$

$$F_{CO_2} = k K_0 (p_{CO_2w} - p_{CO_2atm})$$

Observations of fluxes.

Calculate fluxes

$$k = \frac{\overline{w' c'}}{K_0 (p_{CO_2w} - p_{CO_2atm})}$$

$$k_{660} = \frac{\overline{w' c'}}{K_0 (p_{CO_2w} - p_{CO_2atm})} \sqrt{\frac{Sc}{660}}$$
Heat flux globally (indicates air-sea temperature difference):

Mean (1958-2011) Sensible Heat Flux

From WHOI OAflux
The Östergarnsholm-site, CO₂ and O₂

Data for air-sea interaction investigations, meteorological data as well as buoy data (wave, pCO₂ etc). Has been shown to well represent open sea conditions.
Adventsfjorden, a Svalbard fjord, CO$_2$

Arctic conditions, large air-sea temperature differences.

Tower on the shore during 2 months.

Water sampling
Swedish lake system, used at two lakes (Tämnaren, Erken), CO\textsubscript{2} and CH\textsubscript{4}

Relatively low winds

Carbon dioxide and methane
Fast response oxygen optode

Fast response oxygen optode Microx TX3 (PreSens Precision Sensing GmbH)

Uses luminescence lifetime technique

No cross-sensitivity

Methane fluxes, LI-7700, open path system

IR gas analyser, good results for fluxes, some drop in high-frequency response.

Sahlée et al., (2013) BLM
1. Dependence of wind speed

Cubic, quadratic wind dep.
1. Dependence of wind speed, larger for oxygen

Other processes for low winds?
2. Dependence on convection, Lake

Methane diurnal cycle

Methane and carbon dioxide flux increased for water-side convection

Carbon dioxide CO2 wind speed dep

Diurnal cycle for methane

CO2 controlled by water-side convection
Larger transfer velocity for larger mixed layer depth, define convective velocity scale

\[ w = \left( z_{ml} B \right)^{1/3} \]

\[ B = \text{buoyancy at the surface} \]

\[ z_{ml} = \text{mixed - layer depth} \]

B refers to the buoyancy in the water due to cooling and evaporation (colder saltier water is heavier)

From Rutgersson and Smedman (2010)
2. Dependence on water-side convection

2. Dependence on water-side convection

Carbon dioxide flux increased for water-side convection in Arctic fjord and inlands sea for waterside convection.

Studies show for different type of gas and basins

<table>
<thead>
<tr>
<th></th>
<th>Wind</th>
<th>Convection</th>
<th>Surfactants</th>
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<tbody>
<tr>
<td>Lake CO₂</td>
<td>Weak</td>
<td>Yes</td>
<td>Yes?</td>
</tr>
<tr>
<td>Lake CH₄</td>
<td>Weak</td>
<td>Yes</td>
<td>Yes?</td>
</tr>
<tr>
<td>Marginal Sea O₂</td>
<td>Strong</td>
<td>?</td>
<td>No?</td>
</tr>
<tr>
<td>Marginal Sea CO₂</td>
<td>Yes</td>
<td>Yes</td>
<td>No?</td>
</tr>
<tr>
<td>Arctic fjord, CO₂</td>
<td>Yes</td>
<td>Strong</td>
<td>No?</td>
</tr>
</tbody>
</table>
Conclusions

• Need more studies in a variety of basins+conditions for different gases for better understanding of processes (more measurements…).

• Limited size basins with land influence non-wind-driven processes more important.

• Different solubility different processes acts differently.
Thank you!