Comparing parameterizations of gas transfer velocity and their effect on the global marine CO$_2$ budget

Susanne Ufermann and David K. Woolf

Centre for the observation of Air-Sea Interaction & fluXes (CASIX) National Oceanography Centre Southampton, UK

e-mail: ufermann@soton.ac.uk
phone: +44 (0)2380 592726
Acknowledgements

**Data sources:**

- **ECMWF ERA-40**
  
  http://www.ecmwf.int/products/data

- **KNMI (Sofia Caires, ERA-40 $u^*$ and $H_s$)**
  

- **REMSS (QuikSCAT, AMSR)**
  
  http://www.remss.com

- **NOAA's Climate Diagnostics Centre (Reynolds OI)**
  
  http://www.cdc.noaa.gov/cdc/data.reynolds_sst.html

- **Ifremer (ERS)**
  
  http://www.ifremer.fr/cersat/english

- **Taro Takahashi et al. ($\Delta pCO_2$)**
  
  http://islscp2.sesda.com

- **Scott Doney & Rik Wanninkhof, Christine Gommenginger**
Factors affecting air-sea gas transfer

From http://www.uea.ac.uk/env/solas - Wade McGillis

Susanne Ufermann, Comparing parameterizations of gas transfer velocity, Liège, 2-6 May 2005
37th International Liège Colloquium on Ocean Dynamics, Gas Transfer at Water Surfaces
Overview

• Parameterizations of gas transfer velocity
  – Traditional $u_{10}$-based parameterizations
  – “New” parameterizations
  • Glover et al. (2002)
  • Woolf (2005)
  • ALT1 & ALT2

• Satellite data
  – Data characteristics
  – Corrections

• Global & regional flux results

• Conclusions
Parameterizations of gas transfer velocity

$u_{10}$-based parameterizations

**Liss & Merlivat, '86** •
3 parts: $k \sim u$

**Wanninkhof, '92** •
$k \sim u^2$

**Wanninkhof & McGillis, '99** •
$k \sim u^3$

**Nightingale et al., '00** •
$k \sim u^2$
Parameterizations of gas transfer velocity

“New” parameterizations

Glover et al., ‘02

\[ k \sim \frac{1}{\sigma_{Ku}} - \frac{1}{\sigma_{C}} \]

Woolf, ‘05:

- non-breaking
  \[ k_0 \sim u^* \]
- breaking
  \[ k_1 \sim u^* H_s \]
- total
  \[ k = k_0 + k_1 \]
Mean square slope algorithm

Total mean square slope yields

\[ k = 1.49 \times 10^{-3} \cdot \frac{0.38}{\sigma_{Ku}} + 1 \times 10^{-6} \]

from Bock et al., JGR 1999.
Altimeter-based algorithms

- Based on Woolf (2005)

\[ k = k_J + k_b \]

- Non-breaking contribution
- Whitecapping contribution

- \[ k_J = a/\sigma_{Ku} + b \] from Bock et al. (1999)

- \[ k_b = u^* H_s / \nu_w \]

- ALT1: \[ k_J : k_b = 3:1 \] dominant direct transfer
- ALT2: \[ k_J : k_b = 1:3 \] dominant whitecapping
## Satellite data

<table>
<thead>
<tr>
<th></th>
<th>Reynolds SST</th>
<th>HadISST</th>
<th>AMSR SST</th>
<th>ERA40 Hs</th>
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<td><strong>ERASST u10</strong></td>
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<td><strong>ERS u10</strong></td>
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<tr>
<td><strong>AMSR u10</strong></td>
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<tr>
<td><strong>ERA40 u10</strong></td>
<td>1x1</td>
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<tr>
<td><strong>ERA40 u</strong>*</td>
<td>1x1</td>
<td></td>
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</tr>
</tbody>
</table>
Satellite data

- $u_{10}, \text{SST}$
  - Scatterometer (QuikSCAT): 2000 – 2004
- $u^*, H_s, \sigma_{Ku}$
  - gridded to 1.5º x 1.5º
Time series

SST: Reynolds IO
wind: ERA-40, monthly, R corr.
SSS: NADC
$\Delta p\text{CO}_2$: Takahashi et al., 02
$k$: Wanninkhof, 92

global flux, 1982 – 2001
assuming no trend in $\Delta p\text{CO}_2$
Air-sea flux of CO₂ in 2001

[mol/(m² month)]

Jan  Feb  Mar  Apr

May  Jun  Jul  Aug

Sep  Oct  Nov  Dec

Air-sea flux of CO₂ in 2001

[mol/(m² month)]

Jan  Feb  Mar  Apr

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National Oceanography Centre, Southampton
Satellite data - corrections

Wind distributions

Flux differences resulting from Rayleigh distribution of wind speed vs. realistic distribution (calculated from 12hr QuikSCAT data, 2000-2004)

\[ R = \frac{u^n}{u^n} \]  
with \( n = 2,3 \)

Global flux:

\[ \Delta F = 0.2 - 0.6 \text{ Gt C/yr} \]
Satellite data - corrections

**Skin effect**

Flux differences resulting from skin effect (sst – 0.17°C for $u_{10} > 6$ m/s) mainly affecting $pCO_{2w}$, but also solubility and transfer velocity.

**Global flux:**

$\Delta F = 0.3 – 0.6 \text{ Gt C/yr}$
Wind speed ≠ wind speed

Scatterometer (QuikSCAT) vs Model re-analysis (ERA-40)
Wind speed ≠ wind speed

\[ R_{\text{QSCAT}} - R_{\text{AMSR}} \quad \% R_{\text{QSCAT}} \]

QuikSCAT vs AMSR-E wind speed

QS wind speed [m/s] vs AMSR [m/s]

1:1 fit

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**Results: $u_{10}$-based $k$ parameterizations**

<table>
<thead>
<tr>
<th></th>
<th>ERS1 scatt.</th>
<th>QuikSCAT</th>
<th>ECMWF ERA40</th>
<th>AMSR-E</th>
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</thead>
<tbody>
<tr>
<td>LM’86</td>
<td>-1.0</td>
<td>-0.9</td>
<td>-0.9</td>
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<tr>
<td>NG’00</td>
<td>-1.5</td>
<td>-1.5</td>
<td>-1.3</td>
<td></td>
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<tr>
<td>W’92</td>
<td>-1.9</td>
<td>-1.8</td>
<td>-1.6</td>
<td>-1.5</td>
</tr>
<tr>
<td>WG’99</td>
<td>-2.6</td>
<td>-2.7</td>
<td>-2.1</td>
<td>-2.2</td>
</tr>
</tbody>
</table>

$\Delta F$ (k parameterization): 300% (150% W’92/WG’99)

$\Delta F$ (data source): 20%
## Results: Global fluxes

<table>
<thead>
<tr>
<th></th>
<th>Mean Transfer Velocity [cm/h]</th>
<th>Net Sink [Gt C/yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wanninkhof '92 ((u^2))</td>
<td>18.2</td>
<td>1.60</td>
</tr>
<tr>
<td>Wanninkhof &amp; McGillis ((u^3))</td>
<td>17.7</td>
<td>2.13</td>
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<td><strong>(k_j:k_b=3:1)</strong></td>
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<tr>
<td>Altimeter 1 (a/\sigma_{Ku} + c + b u^* H/\nu)</td>
<td>18.4</td>
<td>1.01</td>
</tr>
<tr>
<td><strong>(k_j:k_b=1:3)</strong></td>
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<td></td>
</tr>
<tr>
<td>Altimeter 2 (x(a/\sigma_{Ku} + c) + y b u^* H/\nu)</td>
<td>18.4</td>
<td>1.66</td>
</tr>
</tbody>
</table>
Transfer velocity
North Atlantic summer (Apr-Sep)

W’92
k = 13.3 cm/h

WG’99
k = 11.2 cm/h

ALT1
k = 15.3 cm/h

ALT2
k = 11.1 cm/h
Transfer velocity
North Atlantic winter (Oct-Mar)

\[ W'92 \quad k = 22.2 \text{ cm/h} \]

\[ ALT1 \quad k = 19.9 \text{ cm/h} \]

\[ WG'99 \quad k = 25.0 \text{ cm/h} \]

\[ ALT2 \quad k = 22.6 \text{ cm/h} \]
Transfer velocity

Summer N Atlantic
(Apr – Sept)
ALT2 – W’92

Winter N Atlantic
(Oct – Mar)
ALT2 – W’92
Inter-annual variability

Sensitivity of whitecapping \( (u^*H/\nu) \) in the North Atlantic to the NAO Index.
Results: Regional fluxes

Summer North Atlantic sea-air flux [Gt C/y]
- W’92 -0.19
- WG’99 -0.19
- ALT1 -0.24
- ALT2 -0.20

Winter North Atlantic sea-air flux
- W’92 -0.31
- WG’99 -0.37
- ALT1 -0.36
- ALT2 -0.41
Summary

• Global mean transfer velocities of new parameterizations are similar to conventional ones, global fluxes vary significantly

• regionally bubble mediated part of the transfer contributes significantly to net flux (e.g., winter NA)

• significant inter-annual variability
Conclusions

- measuring wind speed is tricky
- flux calculations need documentation (wrt data sources and processing) & error bars - ~30% between scatterometers and passive microwave or model re-analysis
- $k$ parameterizations which go beyond simple wind speed dependence show promise but require validation
- revised regional & global CO$_2$ fluxes