How (well) do models calculate air-sea fluxes?

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Bulk Flux formulation
\[ F = k \cdot s \cdot (pCO_{2w} - pCO_{2a}) \]

Topics:
1) How well are we doing estimating global fluxes?
2) Sustained efforts to observe pCO_{2w} (and pCO_{2air})
3) Better XCO_{2a} estimates
4) Possible biases in pCO_{2w}
5) What about k?
6) Can the models reproduce the observations? (suggested comparison)

“For gas exchange, model groups only need to change the value of the gas transfer coefficient, the formulations and coefficients for Schmidt numbers, and the atmospheric gas histories.” Orr et al. 2017
How well are we doing estimating global fluxes?

Anthropogenic Flux estimate

Air-Sea CO₂ fluxes

Inventory Gruber et al. submitted

State of the climate report, 2018

The oceanic sink for anthropogenic CO₂ from 1994 to 2007, Re-submitted

Average 1994-2007 = 1.68±0.25 Pg C yr⁻¹

Average uptake rate of 2.5±0.3 Pg C yr⁻¹

30±4 % of the global anthropogenic CO₂

Air–sea CO₂ flux and change in inventory estimates need to be reconciled
The Blurring of the observational-modeling divide

The flux estimates require more than in situ observations

- In Situ Obs.
- Remotely sensed Obs/
- Models

➢ A concerted effort is required to produce and validate flux maps
Surface CO₂ observational efforts, pCO₂w, XCO₂a

- NOAA Research supports the largest sustained measurement campaign of surface water pCO₂ from ships, moorings, and ASVs
- Coordination in Europe starting under ICOS
- Strong sustained efforts in Japan and Australia
- Collated in two annually updated/overlapping datasets LDEO & SOCAT (≈ 1 M data points per year; lag ≈ 2 years)
- Effort to improve Best Practices for global operations: Surface Ocean Carbon Observing Network (SOCONET)
  Efforts to: - track,
  - speed-up,
  - improve,
  - harmonize,
  at acquisition phase

- Sustained efforts and resources are required to maintain the global “data pipeline”
- Need a new paradigm in funding
Accuracies of the input parameters to obtain fluxes to 0.2 Pg C

\[ F = k \times s \times (pCO_{2w} - pCO_{2a}) \]

- \( k \approx 20\% \)
- \( s \approx 5\% \)
- \( pCO_{2w} \approx 2 \mu\text{atm} \ (0.5\%) \)
- \( XCO_{2a} \approx 0.2 \text{ppm} \ (0.05\%) \)

Global average air-sea disequilibrium
\( \approx 10 \mu\text{atm} \) “the 1:1:0.2 rule”

- Observational biases and biases in calculations are major issues
Improvements in the input parameters, $pCO_{2a}$

$$pCO_{2a} = (P - p_{H_2O}) \times CO_{2a}$$

- Recommendation: Use a 3-dimensional (position, time) field
Improvements in the input parameters, $pCO_{2w}$

Surface temperature correction

Near-surface gradients:
- Cool skin $\approx 0.2 \, ^\circ C$ lower than bulk $T$
- Skin $T$ is measured from satellites
- Impact $\approx 0.2$-$0.6 \, \text{Pg C}$

Recommendation: Correct all $pCO_{2w}$ values to skin temperature
Improvements in the input parameters, $pCO_{2w}$

Interpolation errors

Data sparsity and possible biases lead to large Interpolation errors

1. Get more targeted observations in missing seasons and regions through (directed) “smart sampling”
   - NN/SOM approaches
   - Biogeographical Provinces
   - Autonomous Surface Vehicles
2. Improve interpolation approaches
Improvements in the input parameters, $pCO_{2w}$

Biases in observations

lower precision measurements/estimates are bias prone.

“Although the 0.36 Pg C yr$^{-1}$ difference in the ASZ stands out, the float-based estimates are higher than the ship-based fluxes in almost all regions. On average, the float-based estimates were $3.6\pm3.4\mu$atm higher than the ship-based $pCO_2$” Gray et al, (2018 )

- Fully characterize all sensors and calculations
- Be sure measurement/estimate is “fit for purpose”
Improvements in the input parameters, $k$

$$k_{660} = 0.251 <u^2>$$

Functionality seems to “work” and overall agreement with (good) direct flux measurements.
Improvements in the input parameters, $k$

$$k_{660} = 0.251 \langle u^2 \rangle$$

Relationship is based on fitting a parameterization with wind to match global $^{14}$C inventory

Not an unique solution:

“Results support a linear or lower increase of gas transfer velocity with wind speed in the global ocean (best-fit exponent: $0.5 \pm 0.4$; global mean rate: $20 \pm 3$ cm hr$^{-1}$ at a Schmidt number of 660)” Krakauer et al., 2006
Improvements in the input parameters, wind

\[ k_{660} = 0.251 \ <u^2> \]

“Uncertainty in [satellite] derived wind speed is the dominant uncertainty in \( k \) “
Jackson and Wick, 2014

Significance differences in global wind products:
Wind products:
- CCMP
- ECWMF
- NCEP
- Coastal wind product- problems/ land/see breeze
- Satellite estimates [(passive/active) radiometry]

Notably, NCEP-2 and some coastal wind products are quite different

- \( k_{660} = 0.251 \ <u^2> \) is “tuned” to CCMP (6-hr, ¼°) resolution
Improvements in the input parameters, $k$

More sophisticated approaches related to boundary layer turbulence and bubble enhancements.

- Use Ocean Model Intercomparison Project (OMIP) to assess dependency and/or other (physically based) algorithms (COARE-G)
Comparison with regional time series

Weekly time series from 2002-2018
500 cruises

Trend 2002-2018:
Air: 2.2 μatm yr⁻¹
Water: 1.7 μatm yr⁻¹

➢ Can models reproduce the observations?
Take home messages

- There is a mismatch between fluxes and inventories of 0.8 Pg C yr\(^{-1}\)
- Check if models reproduce seasonal and interannual variability
- Use models in diagnostic mode to address issues with k parameterization
- Easy “fixes” in models:
  - Use improved MBL-XCO\(_2\) product
  - Correct for skin temperature
  - Consistent use of wind products