Supporting Information for

Mesoscale temporal wind variability biases global air-sea gas transfer velocity of CO₂ and other slightly soluble gases

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Text S1

In this analysis, it is assumed that a Weibull distribution can be fitted to the probability density function (PDF) of the 6-hour wind velocity data (U) and the best-fit parameters of the Weibull distribution (λ > 0 – scale parameter and β > 0 – shape parameter) are determined. In general,

\[ f(U) = \frac{\beta}{\lambda} \left(\frac{U}{\lambda}\right)^{\beta-1} \exp\left[-\left(\frac{U}{\lambda}\right)^\beta\right]. \]

For a quadratic gas transfer velocity parameterization:

\[ k = a U^2, \]

where \( a \) is a constant. What is sought is the mean \( k \) at large scales that are much longer than 1 hour (indicated by \( <> \)). Using standard averaging rules,

\[ < k >= a< U^2 > \neq a<U^2>. \]
Approaches to correct for this inequality are expressed in the form:

\[ < k >= a(U^2) = a(U)^2 C_2, \]

where, by definition,

\[ C_2 = \frac{(U^2)}{(U)^2}. \]

If the PDF of \( U \) is known, then \( <U^2> \) can be linked to the Weibull parameters using

\[
(U^2) = \int_0^\infty U^2 f(U) dU = \int_0^\infty U^2 \frac{k}{\lambda} \left(\frac{U}{\lambda}\right)^{k-1} \exp \left[-\left(\frac{U}{\lambda}\right)^k\right] dU.
\]

After some algebra, it can be shown that

\[ (U^2) = \lambda^2 \Gamma\left(\frac{2 + k}{k}\right), \]

where \( \Gamma(.) \) is the gamma function. The \( <U> \) can also be evaluated from

\[
(U) = \int_0^\infty U f(U) dU = \int_0^\infty U \frac{k}{\lambda} \left(\frac{U}{\lambda}\right)^{k-1} \exp \left[-\left(\frac{U}{\lambda}\right)^k\right] dU.
\]

After some algebra, it can be shown that

\[ (U) = \lambda \Gamma\left(\frac{1 + k}{k}\right). \]

Hence,

\[ C_2 = \frac{(U^2)}{(U)^2} = \frac{\Gamma\left(\frac{2+k}{k}\right)}{\left[\Gamma\left(\frac{1+k}{k}\right)\right]^2}, \]

and only varies with \( k \) not \( \lambda \). For a Rayleigh distribution \( k=2 \), the correction can be arranged as:

\[ C_2 = \frac{(U^2)}{(U)^2} = \frac{\Gamma(2)}{\left[\Gamma(3/2)\right]^2} = 1.27. \]

Similar steps are taken for a cubic relation

\[ k = a U^3. \]

For a Rayleigh distribution \( k=2 \), the correction can be arranged as:
\[ C_3 = \frac{\langle U^3 \rangle}{\langle U \rangle^3} = \frac{\Gamma(5/2)}{[\Gamma(3/2)]^2} = 1.91. \]

Table S1

Estimates of gas transfer velocity for CO₂ using wind speeds at two temporal resolutions (6-hourly and monthly) and spatial resolutions (0.5°×0.5° and 5°×5°). Spatial bias of 6-hourly k (or monthly k) are the deviations of k in 5°×5° from k in the resolution of 0.5°×0.5°. Similarly, temporal bias of k at 0.5°×0.5° (or 5°×5°) are the deviations of monthly k from the 6-hourly k.

| Serial NO | Reference | Relation | 6-hourly k (cm h⁻¹) | monthly k (cm h⁻¹) | Temporal Bias |
|-----------|-----------|----------|---------------------|--------------------|---------------|
|           |           |          | 0.5°×0.5° 5°×5° Spatial Bias | 0.5°×0.5° 5°×5° Spatial Bias | 0.5°×0.5° 5°×5° |
| 1         | Wanninkhof (1992) | Quadratic | 18.88 19.02 0.74% | 16.73 16.85 0.72% | -11.39% -11.41% |
| 2         | Wanninkhof and McGillis (1999) | Quadratic | 18.37 18.55 0.98% | 13.24 13.35 0.83% | -27.93% -28.03% |
| 3         | Nightingale et al. (2000) | Quadratic | 18.76 19.14 0.70% | 15.73 15.91 0.63% | -9.78% -9.84% |
| 4         | McGillis et al. (2001) | Cubic | 21.98 22.36 0.86% | 16.43 16.81 0.73% | -23.73% -23.83% |
| 5         | McGillis et al. (2004) | Cubic | 21.46 21.84 0.67% | 15.96 16.34 0.57% | -15.41% -15.49% |
| 6         | Weiss et al. (2007) | Quadratic | 25.31 26.59 0.71% | 22.78 23.26 0.66% | -10.00% -10.04% |
| 7         | Wanninkhof et al. (2009) | Cubic | 14.41 14.52 0.76% | 11.97 12.05 0.67% | -16.93% -17.01% |
| 8         | Prytherch et al. (2010) | Cubic | 28.08 28.56 0.82% | 24.52 24.94 0.73% | -22.98% -23.05% |
| 9         | Wanninkhof (2014) | Quadratic | 15.29 15.4 0.72% | 13.57 13.64 0.52% | -11.25% -11.43% |

Table S2

Summary of corrected k for CO₂ derived by applying the 5 correction methodologies described in the text. The biases are evaluated when referring to k at the 6 hours resolution.

| Serial NO | 6-hourly k \( (\sigma_{U} < U >^2 = 0.15) \) | Method 1 \( (\sigma_{U} < U >^2 = 0.15) \) | Method 2 \( (\sigma_{U} < U >^2 = 0.15) \) | Method 3 \( (R_2 = 1.27, R_3 = 1.91) \) | Method 4 \( (R_2 = 1.23, R_3 = 1.78) \) | Method 5 \( (Zonal averaged R_2/R_3) \) |
|-----------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| 1         | 18.88 | 18.9 0.11% | 19.24 1.91% | 21.25 11.15% | 20.58 9.00% | 19.74 4.56% |
| 2         | 18.37 | 18.26 -0.60% | 19.19 4.46% | 25.28 27.33% | 23.56 28.25% | 20.8 13.23% |
| 3         | 15.75 | 15.77 0.13% | 16.00 1.59% | 17.45 9.74% | 16.97 7.55% | 16.36 3.87% |
| 4         | 19.85 | 19.76 -0.45% | 20.61 3.83% | 26.20 24.24% | 24.62 24.03% | 22.08 11.23% |
| 5         | 16.48 | 16.43 -0.30% | 16.89 2.49% | 19.90 17.19% | 19.05 15.59% | 17.69 7.34% |
| 6         | 25.31 | 25.33 0.08% | 25.74 1.70% | 28.09 9.90% | 27.31 7.90% | 26.32 3.99% |
| 7         | 14.41 | 14.38 -0.21% | 14.81 2.78% | 16.66 13.51% | 15.99 10.96% | 14.91 3.47% |
| 8         | 26.85 | 26.72 -0.48% | 27.84 3.69% | 35.15 23.61% | 33.18 23.58% | 29.76 10.84% |
| 9         | 15.29 | 15.3 0.07% | 15.58 1.90% | 17.20 11.10% | 16.66 8.96% | 15.98 4.51% |
**Figure S1.** Spatial pattern of standard deviation of wind speed around the averaged wind speed within a month.

**Figure S2.** Relations for $f(U)$ and wind speed for the 9 parameterizations.
Figure S3. Spatial pattern of annual mean difference 6-hourly k and monthly k for the 9 k parameterizations listed in Table 1.

Figure S4. Spatial pattern of annual mean bias estimated from the new model for the 9 k parameterizations listed in Table 1.
Figure S5. Spatial pattern of mean bias in gas transfer velocity (k) for CO₂ estimated from the difference in term 1 and term 2 of Equ. (9) for the parameterizations presented in Table 1.