Supporting Information for

# Mesoscale temporal wind variability biases global air-sea gas transfer velocity of $CO_2$ 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* ($\lambda > 0$ – scale parameter and $\beta > 0$ – 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 quadradic 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,

$$< k >= a\langle U^2\rangle \neq a\langle U\rangle^2.$$

Approaches to correct for this inequality are expressed in the form:

$$< k >= a\langle U^2\rangle = a\langle U\rangle^2 C_2,$$

where, by definition,

$$C_2 = \frac{\langle U^2\rangle}{\langle U\rangle^2}.$$

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

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

After some algebra, it can be shown that

$$\langle U^2\rangle = \lambda^2\Gamma\left(\frac{2+k}{k}\right),$$

where $\Gamma(.)$ is the gamma function. The $\langle U\rangle$ can also be evaluated from

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

After some algebra, it can be shown that

$$\langle U\rangle = \lambda\,\Gamma\left(\frac{1+k}{k}\right).$$

Hence,

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

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

$$C_2 = \frac{\langle U^2\rangle}{\langle U\rangle^2} = \frac{\Gamma(2)}{[\Gamma(3/2)]^2} = 1.27.$$

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 $CO_2$ 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 | Wanninkholf(1992) | Quadratic | 18.88 | 19.02 | 0.74% | 16.73 | 16.85 | 0.72% | -11.39% | -11.41% |
| 2 | Wanninkholf and McGillis(1999) | Cubic | 18.37 | 18.55 | 0.98% | 13.24 | 13.35 | 0.83% | -27.93% | -28.03% |
| 3 | Nightingale et al.(2000) | Quadratic | 15.75 | 15.86 | 0.70% | 14.21 | 14.3 | 0.63% | -9.78% | -9.84% |
| 4 | McGillis et al.(2001) | Cubic | 19.85 | 20.02 | 0.86% | 15.14 | 15.25 | 0.73% | -23.73% | -23.83% |
| 5 | McGillis et al.(2004) | Cubic | 16.48 | 16.59 | 0.67% | 13.94 | 14.02 | 0.57% | -15.41% | -15.49% |
| 6 | Weiss et al.(2007) | Quadratic | 25.31 | 25.49 | 0.71% | 22.78 | 22.93 | 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 | 26.85 | 27.07 | 0.82% | 20.68 | 20.83 | 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 $CO_2$ 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 | Method 1 (point-by-point $k_b$) | | Method 2 ($(\sigma_u/<U>)^2$ =0.15) | | Method 3 (R2=1.27, R3=1.91) | | Method 4 ($R_2$=1.23, $R_3$=1.78) | | Method 5 (Zonal averaged $R_2/R_3$) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | corrected k | Bias | corrected k | Bias | corrected k | Bias | corrected k | Bias | corrected k | Bias |
| 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 | 7.75% | 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% |

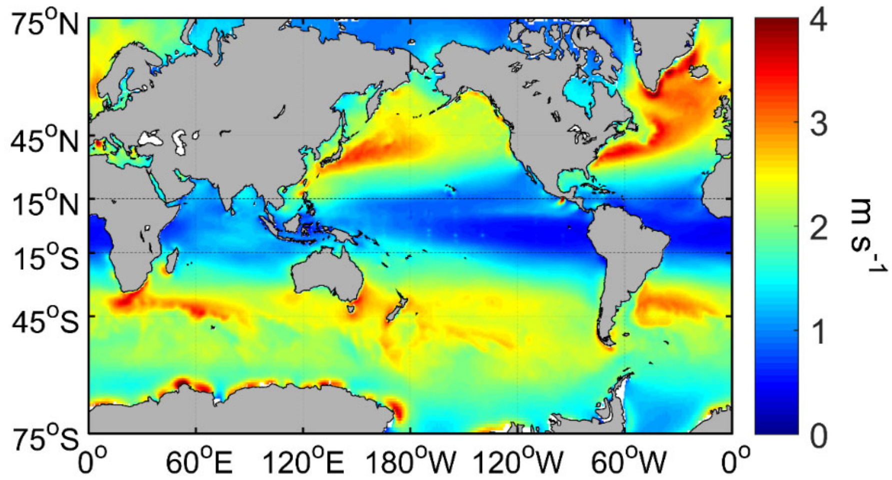


**Figure S1**. Spatial pattern of standard deviation of wind speed around the averaged wind speed within a month.

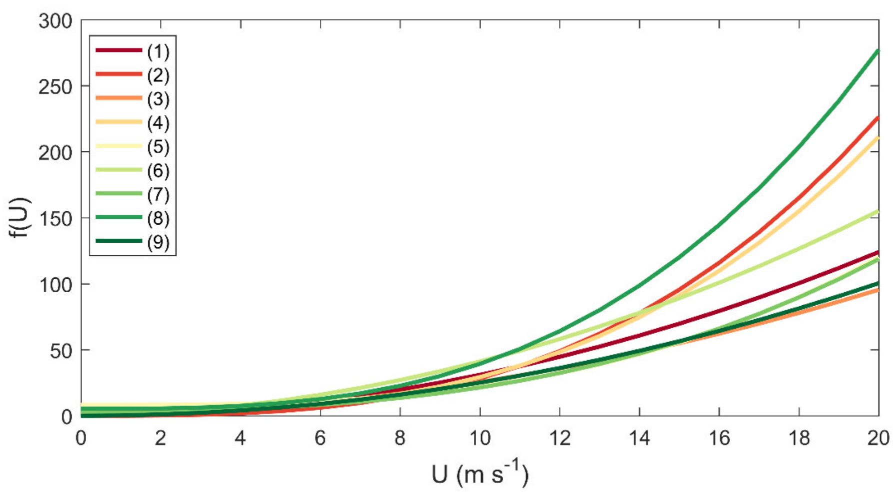


**Figure S2**. Relations for f(U) and wind speed for the 9 parameterizations.

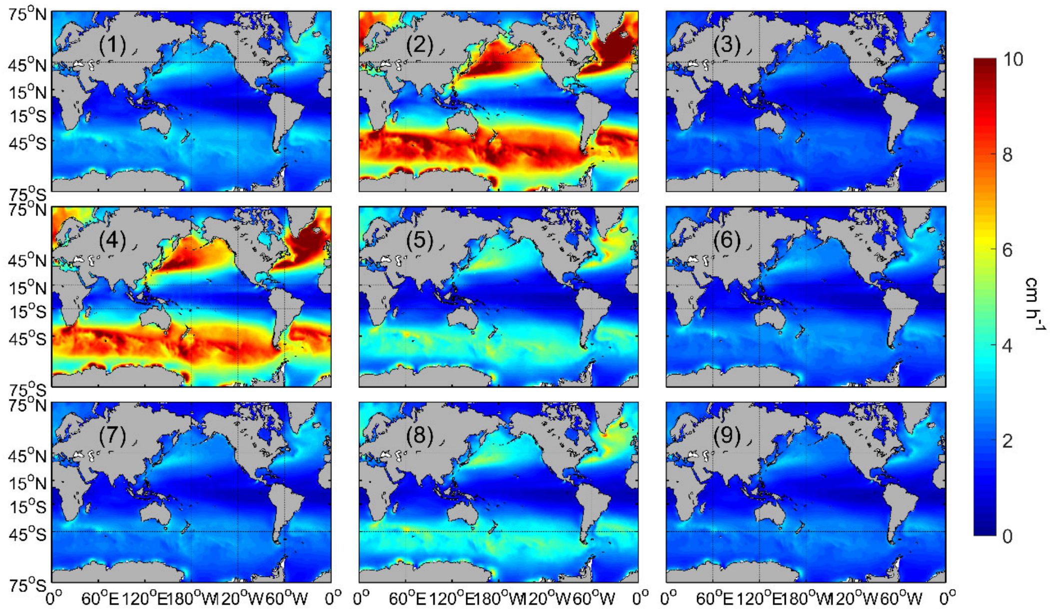


**Figure S3**. Spatial pattern of annual mean difference 6-hourly k and monthly k for the 9 k parameterizations listed in Table 1.

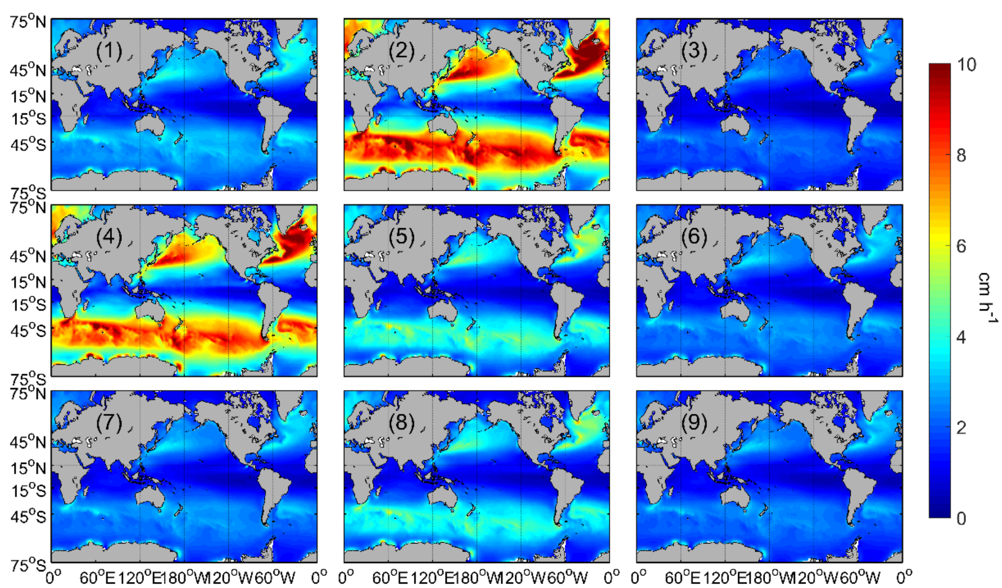


**Figure S4**. Spatial pattern of annual mean bias estimated from the new model for the 9 k parameterizations listed in Table 1.

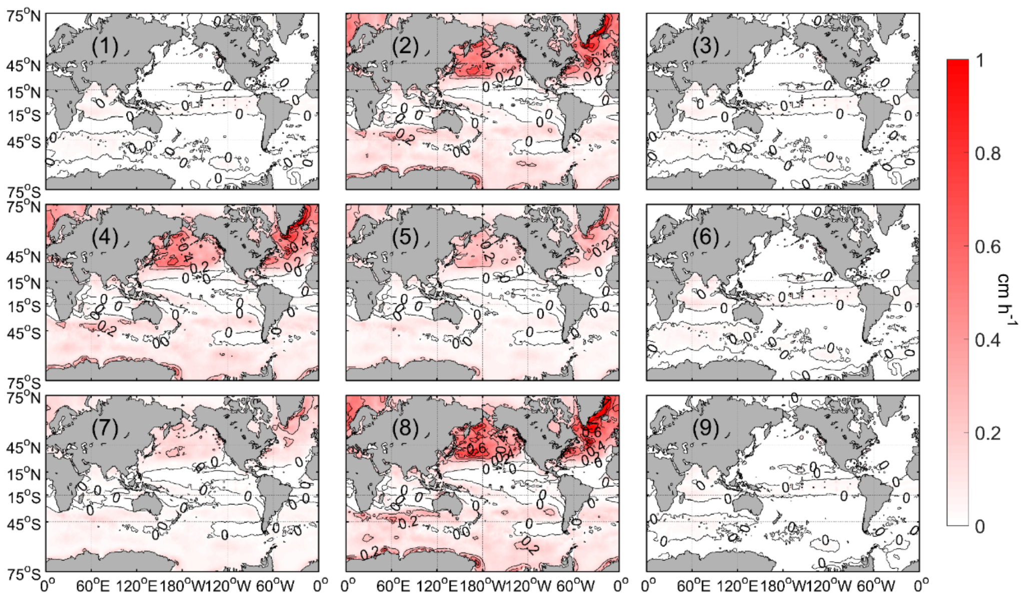


**Figure S5.** Spatial pattern of mean bias in gas transfer velocity (k) for $CO_2$ estimated from the difference in term 1 and term 2 of Equ. (9) for the parameterizations presented in Table 1.