Relationship Between Wind Speed and Gas Exchange Over the Ocean, Revisited

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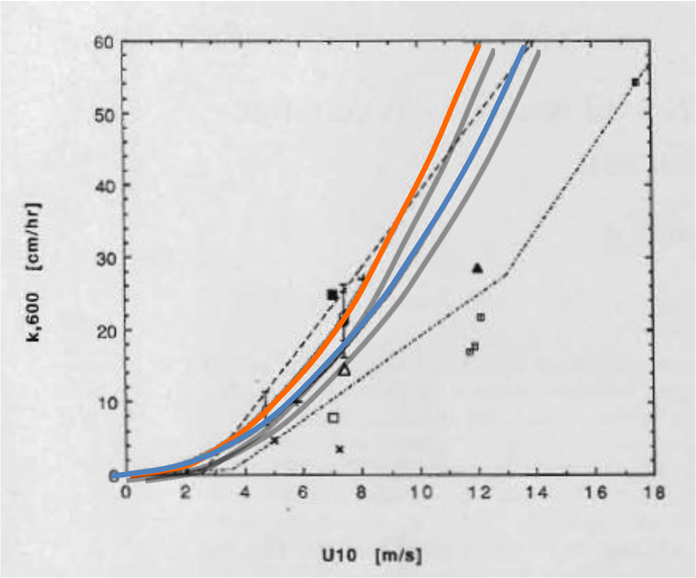

Fig 1. W-92

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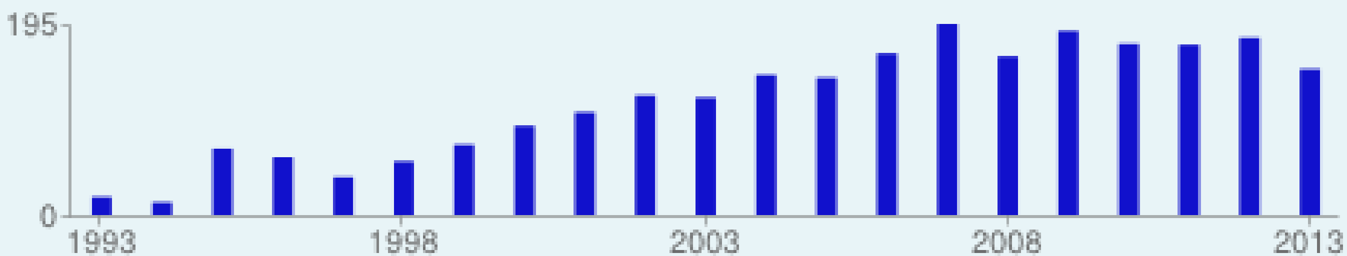

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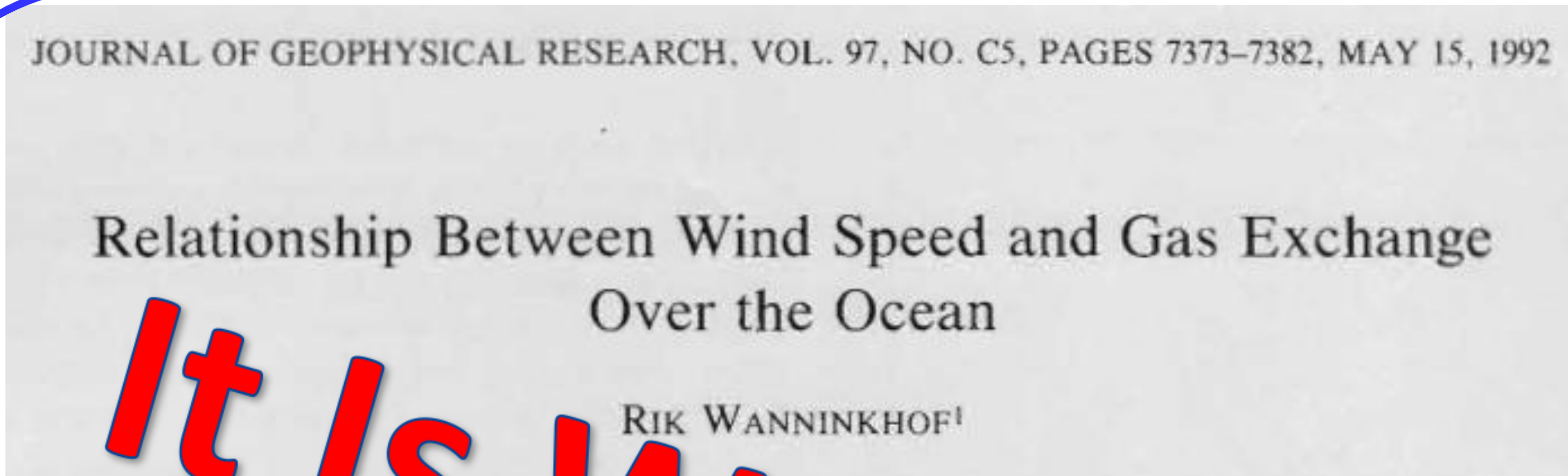

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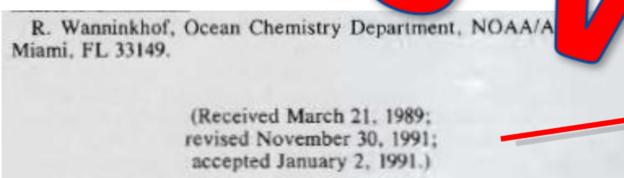
It Is Wrong !!!!



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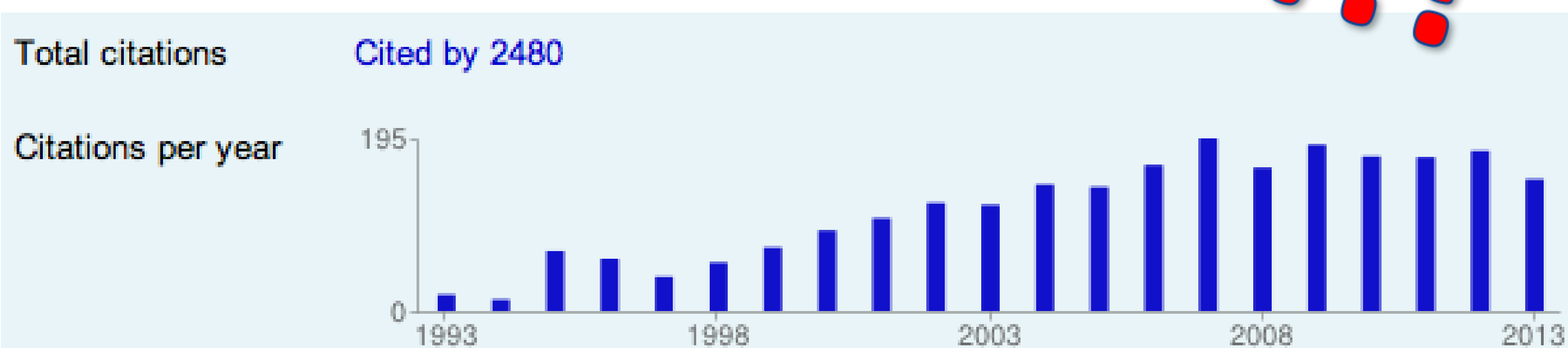

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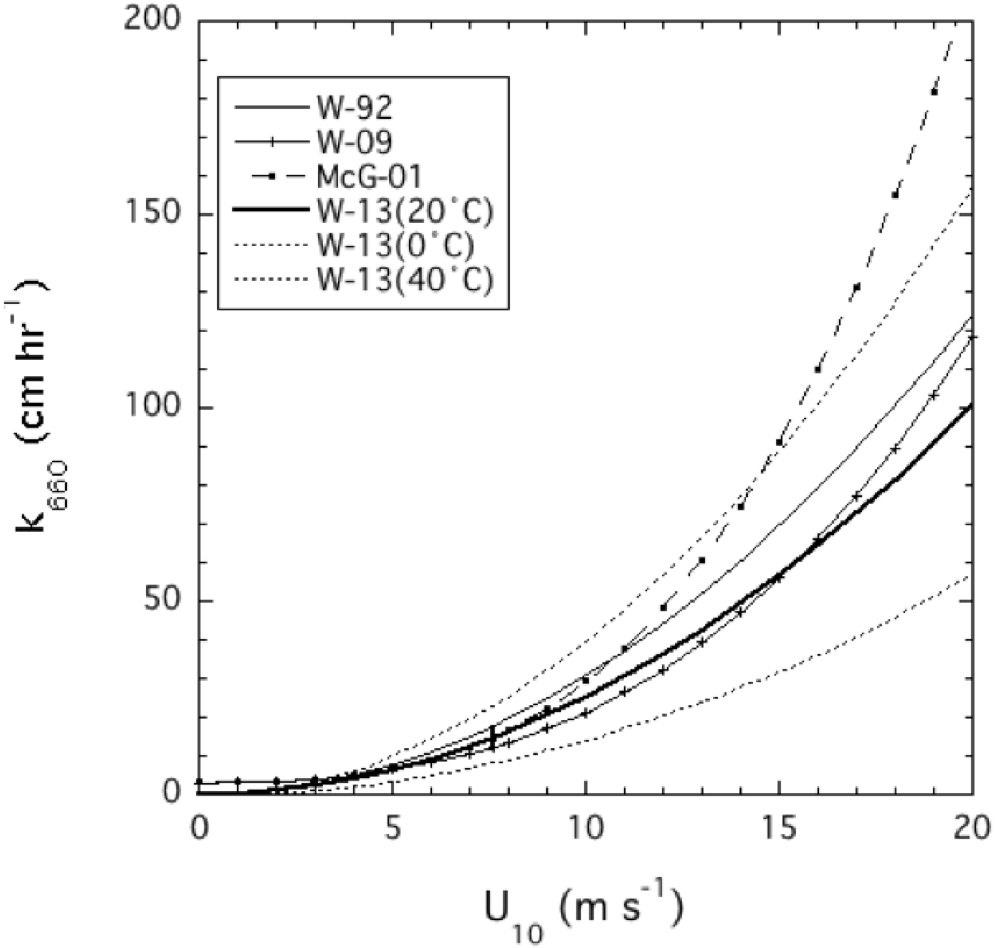
Relationship Between Wind Speed and Gas Exchange Over the Ocean, Revisited

$$k = 0.251 \langle U^2 \rangle (Sc/660)^{-0.5}$$



- A new coefficient
- Use of 2nd moment of wind

Relationship Between Wind Speed and Gas Exchange Over the Ocean, Revisited

Focus on CO_2 exchange

Basic assumptions

1. An assumed functionality between gas transfer and wind over the ocean ✓

1. Global constraint on gas exchange (k): ^{14}C - **Updated & Improved**

1. Link the global average k to a global average wind speed $<U_{10}>$ - **No**

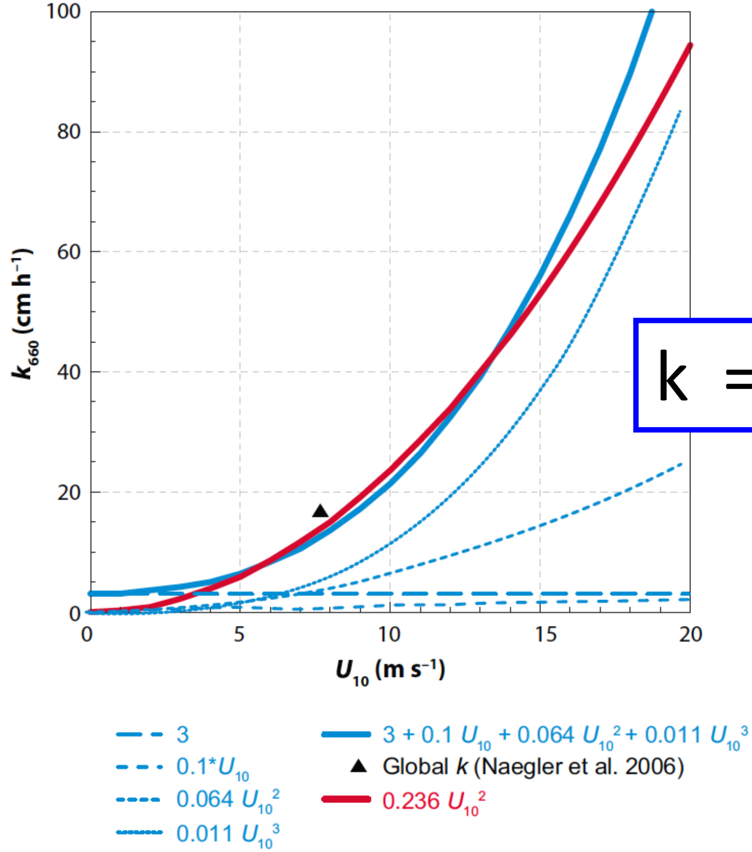
1. Normalization for temperature ✓ **Updated Schmidt numbers (-2 to 40 ˚C)**

1. Include the impact of variability of the wind on the average k **– No use local wind product (CCMP 0.25˚ 6-hr)**

An assumed functionality between gas transfer and wind over the ocean

While a multi-function l relationship ("hybrid model") more accurately represents the processes, it can be well approximated by a quadratic

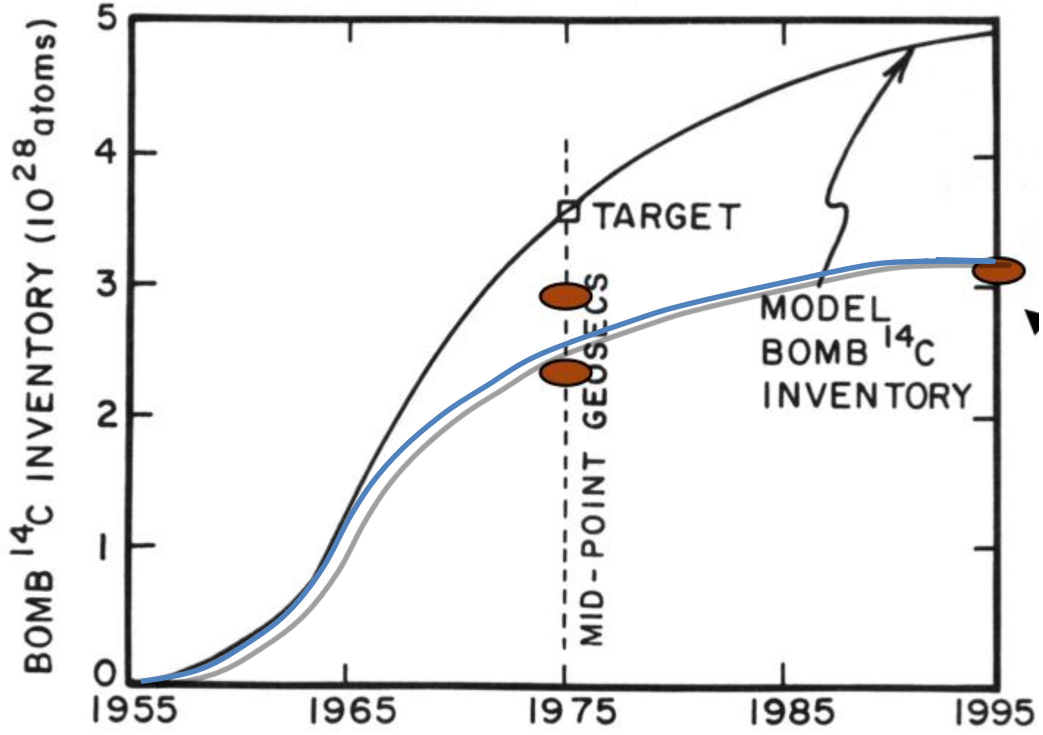
$$k = 3 + 0.1 \langle U \rangle + 0.064 \langle U^2 \rangle + 0.011 \langle U^3 \rangle$$



$$k = a\,(Sc/660)^{-1/2} \langle U^2 \rangle$$

Wanninkhof, R., Asher, W. E., Ho, D. T., Sweeney, C. S., and McGillis, W. R.: Advances in Quantifying Air-Sea Gas Exchange and Environmental Forcing, Annual Reviews Mar. Science, 1, 213-244, 101146/annurev.marine.010908.163742, 2009.

Global constraint on gas exchange (k): ^{14}C - **Updated & Improved**



k ≈22 cm hr^{-1}

k ≈16 cm hr^{-1}

ated Global bomb ^{14}C inventory : Suggests global gas transfer velocity ≈ 16 cm hr^{-1}
gler, 2009)

Link the global average k to a global average wind speed $\langle U_{10} \rangle$ - **No**

W-92:

$\langle U_{10} \rangle = 7.4\ m\ s^{-1}$ $\langle k \rangle = 21\ cm\ hr^{-1}$ **$\langle k \rangle = 0.39 \langle U_{10} \rangle^{2}$**

Improved: Much better estimates of wind over the ocean

$\langle U_{10} \rangle = 7.3\ m\ s^{-1}$ $\langle k \rangle = 16\ cm\ hr^{-1}$ **$\langle k \rangle = 0.30 \langle U_{10} \rangle^{2}$**

Updated bomb ^{14}C has the largest impact on the estimate of the coefficient

Normalization for temperature

Updated Schmidt numbers (-2 to 40 ˚C)

$$Sc = A + Bt + Ct^2 + dt^3 + Et^4 \qquad (T \text{ in } ^\circ C)$$

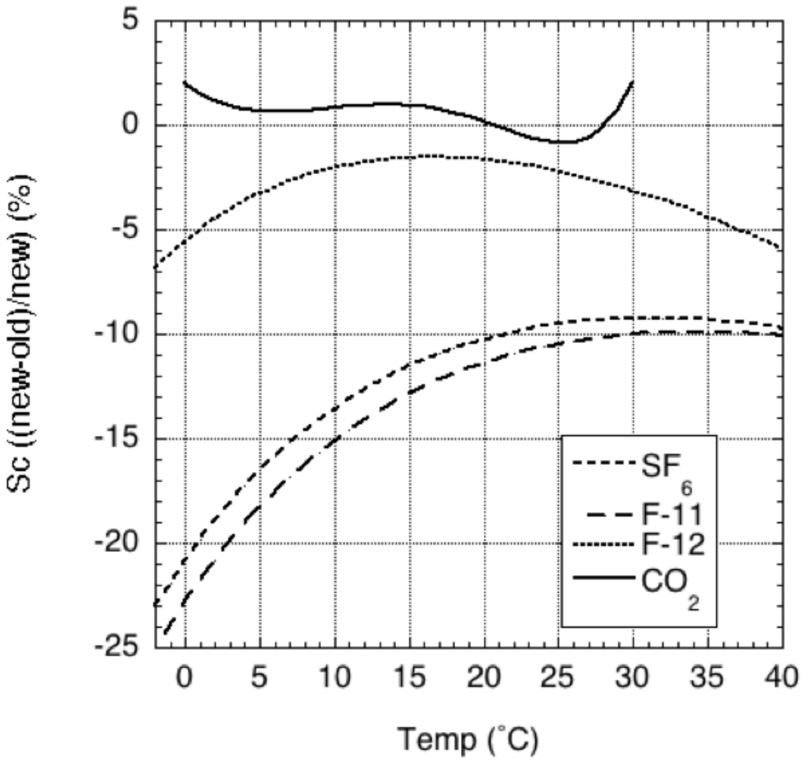
Table 1. Coefficients f… versus temperature for seawater (35 $^{o}/_{oo}$) for temperature from -2 ˚C to 40 ˚C.

Gas	A	B	C	D	E	Sc(20 ˚C)
Seawater						
^3He[a]	369.11	-19.485	0.60131	-0.011005	0.000087258	146
He[a]	416.36	-21.979	0.67828	-0.012413	0.000098427	165
Ne[a]	844.95	-48.305	1.5615	-0.029273	0.00023487	307
Ar[b]	2078.1	-146.74	5.6403	-0.11838	0.0010148	615
O_2[b]	1920.4	-135.6	5.2122	-0.10939	0.00093777	568
N_2[b]	2304.8	-162.75	6.2557	-0.13129	0.0011255	682
Kr[a]	2252	-147.33	5.1729	-0.10141	0.00083242	696
Xe[a]	2975.2	-201.06	7.2057	-0.14287	0.0011798	882
CH_4[a]	2101.2	-131.54	4.4931	-0.08676	0.00070663	687
CO_2[a]	2116.8	-136.25	4.7353	-0.092307	0.0007555	668
N_2O[b]	2356.2	-166.38	6.3952	-0.13422	0.0011506	697
Rn[a]	3489.6	-244.56	8.9713	-0.18022	0.0014985	985
SF_6[c]	3177.5	-200.57	6.8865	-0.13335	0.0010877	1028
DMS[d]	2855.7	-177.63	6.0438	-0.11645	0.00094743	941
F-12[e]	3828.1	-249.86	8.7603	-0.1716	0.001408	1188
F-11[e]	3579.2	-222.63	7.5749	-0.14595	0.0011874	1179
CH_3Br[f]	2181.8	-138.4	4.7663	-0.092448	0.0007547	701
CCl_4[b]	4398.7	-308.25	11.798	-0.24709	0.0021159	1315

Normalization for temperature

Updated Schmidt numbers (-2 to 40 ˚C)

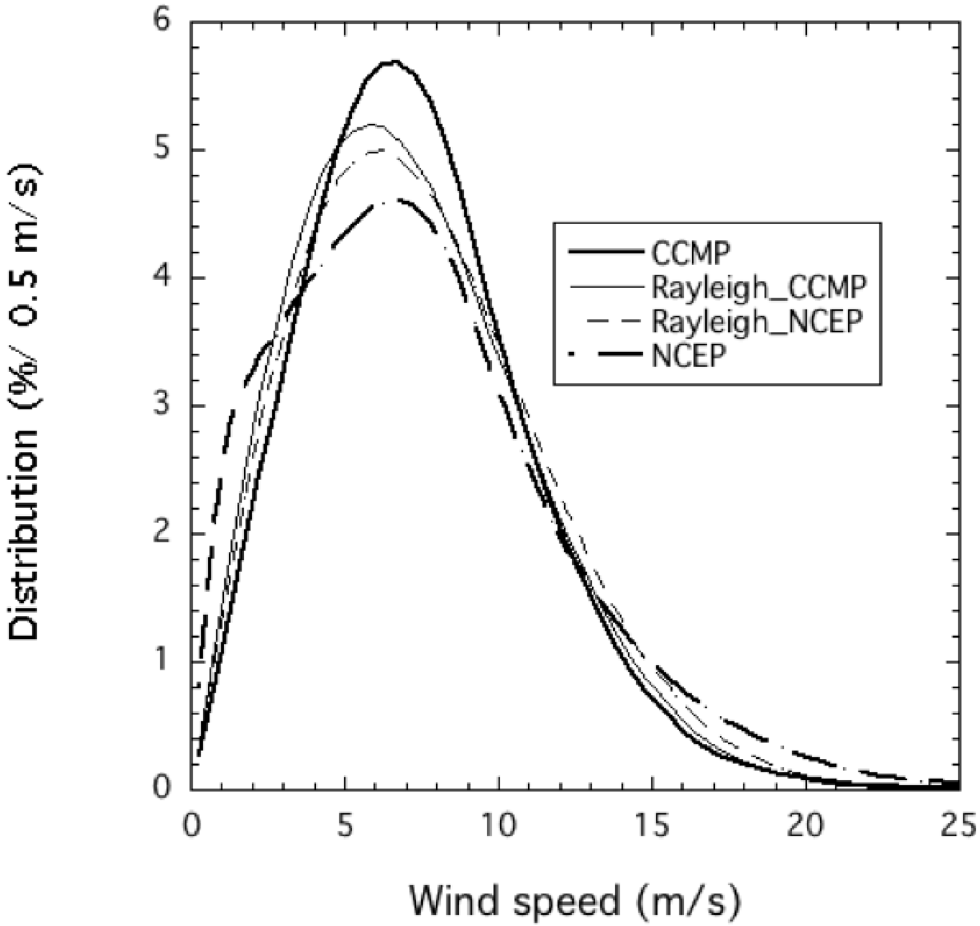
- Change in curve fit < 2 % uncertainty
- Measured vs estimated diffusion coefficient (D): up to 25 % difference
- Assume that fresh water D is 6 % greater than salt water D
- Saltzman's group saw no difference in diffusion coefficients using fresh water or a 35 g/l sodium chloride (NaCl) solution for, SF_6, CH_3Cl ,and F-11 but did see ≈ 4-7 % difference for CH_4 and F-12.



Include the impact of variability of the wind on the average k

No, use local wind product (CCMP 0.25˚ 6-hr)

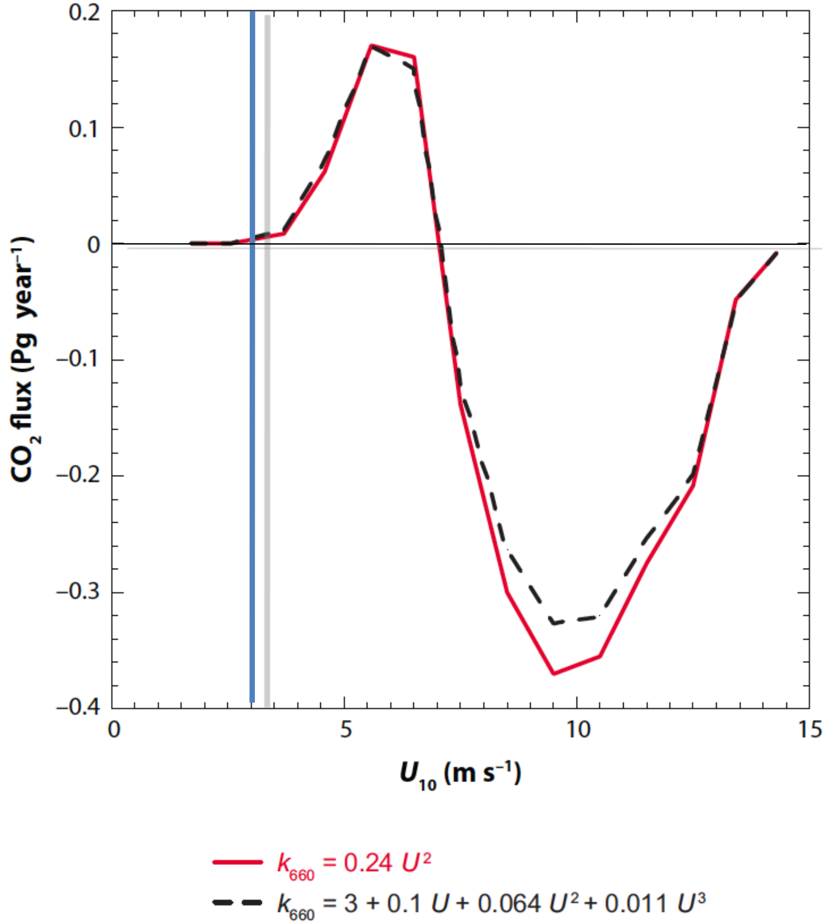
Wind products have appreciable differences and differences will contribute significantly to estimated flux



Include the impact of variability of the wind on the average k

No, use local wind product (CCMP 0.25˚ 6-hr)

Due to co-variation of wind speeds and ΔpCO_2 differing wind speed distribution leads to a 0.2 Pg C yr^{-1} (≈15 %) lower net CO_2 uptake by the ocean uptake for the CCMP winds compared to NCEP-2 winds even after accounting for differences in global mean wind by adjusting coefficient “a”



Low winds-outgassing
High winds- influx

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Uncertainty in k for CO_2 exchange

1. The coefficient (10 %- Ho et al.; Sweeney et al.; Nightingale et al.) for 3-12 m s^{-1}
2. Wind: 0.3 m s^{-1} at 7.3 m s^{-1} (4%)
3. Schmidt number: 5 %
4. Low wind ($k = 0.0251\ U^2$ vs. constant 3 cm hr^{-1} up to 3.5 m s^{-1})
5. High wind, additional 10 % uncertainty (> 12 m s^{-1})

$$\Delta k\ k^{-1} = 0.0251/0.251 + \Delta\langle U^2\rangle/\langle U^2\rangle + 0.5\ \Delta Sc/Sc + \Delta\ k\ k^{-1}_{(k=3,\ U10<3.5)} + \Delta\langle U^2\rangle/\langle U^2\rangle_{U10>12}$$

$$\Delta k\ k^{-1} = 0.1 + 0.04 + 0.025 + 0.01 + 0.02 = 0.20$$

$\Delta k \approx 20$ %

Relationship Between Wind Speed and Gas Exchange Over the Ocean, Revisited

Conclusion:

$$k = 0.251_{\pm 0.05} \langle U^2 \rangle (Sc/660)^{-0.5}$$

Acknowledgments:

This update on the manuscript “Relationship between wind speed and gas exchange over the ocean” was inspired by the recognition of the original work through the ALSO John Martin Award.

Thanks many colleagues who made the basic physical chemical measurements, improved the wind speed products, and those who performed experimental and theoretical studies on the controls of sea-air gas transfer (many who are in this room) .