Uncertainties in CO_2 fluxes from EO-derived climatologies

David Woolf

Susanne Fangohr

Peter Challenor

Helen Kettle

Chris Merchant

Three things to do with uncertainties

- Reduce
- Quantify
- Explore

To estimate the air-sea flux

Regional and local air-sea fluxes are most successfully estimated via a bulk formula:

$$F = \alpha\, k\, \Delta p\mathrm{CO_2}$$

α solubility of CO_2 in seawater $\alpha(T,S)$

$\Delta p\mathrm{CO_2}$
difference in CO_2 partial pressure on either side of the air-sea interface [μatm]

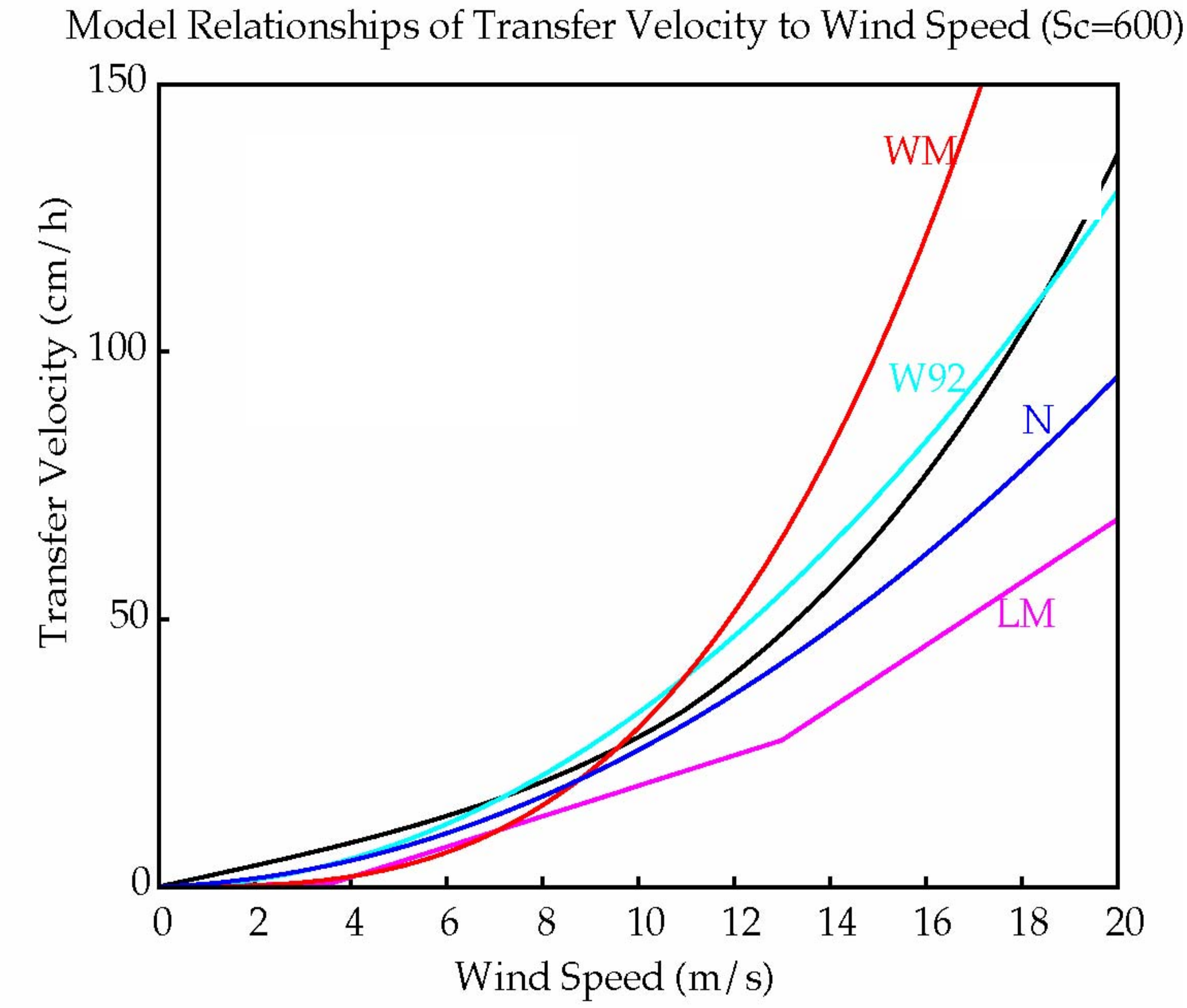
k gas transfer velocity [cm/h] $k(u,\ldots)$

Gas transfer velocity [cm/h] is a measure of the rate of turbulent transfer across the marine boundary layers

Where are the EO uncertainties?

- α
  - T well measured by EO
  - S in situ and climatology …
- k
  - Wind estimate errors
    - Different sensors, methods, definitions, gustiness …
  - Physics / parameterisations
    - K-u relationship, bubbles / sea state, free convection …
- ΔpCO_2 mainly water side
    - Under-sampled measurements
    - Unexplained variance w.r.t. T and Chl
- Co-variation & non-linearity

Well-known k-u relationships



Wanninkof & McGillis, 99

Wanninkof, 92

Nightingale

Liss and Merlivat

The Sea Surface

A rough surface with bubbles

Physical Basis of Gas Transfer

Boundary layer transfer: K should scale with u_*

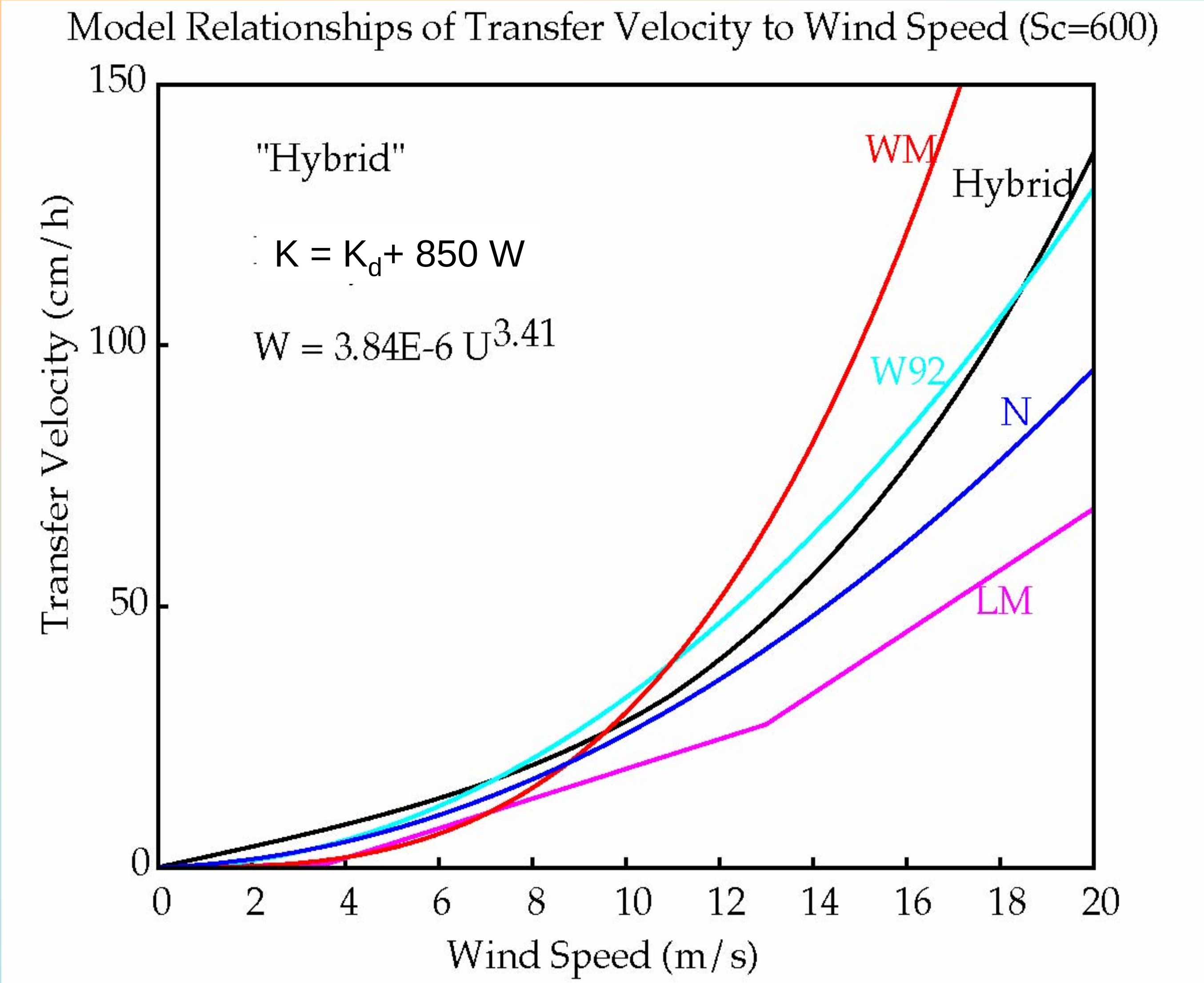
e.g., $K_d = 1.57E\text{-}4\ u_*\ (600/Sc)^{1/2}$ [Jähne *et al.* 1987]

Bubble mediated: scale with whitecap coverage, W

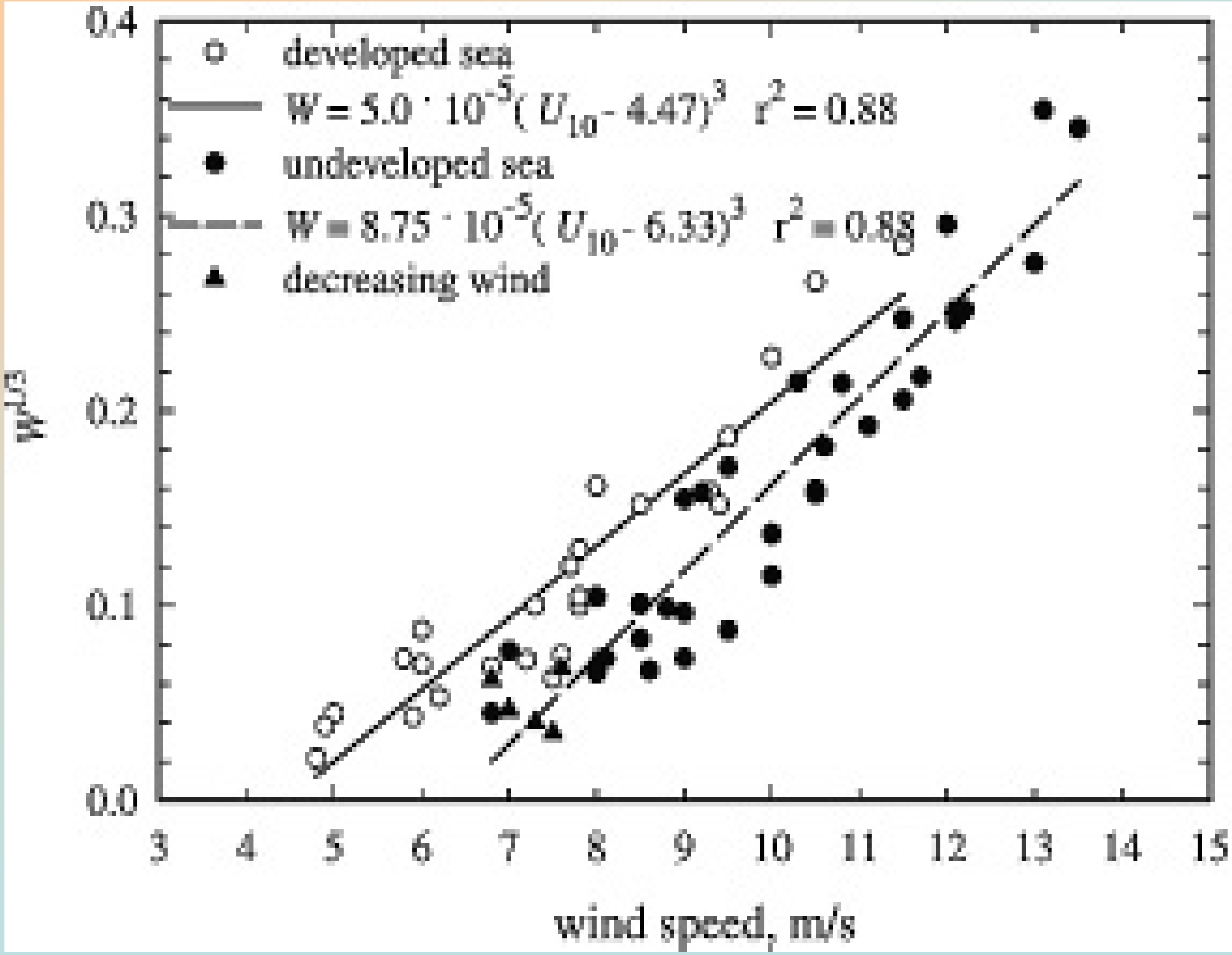
e.g., $K_b = (850\ \text{cm/h})\ W$ [Woolf, 1997]

$K_T = K_d + K_b$ "The Hybrid Model" [Woolf, 1997]

Hybrid K model

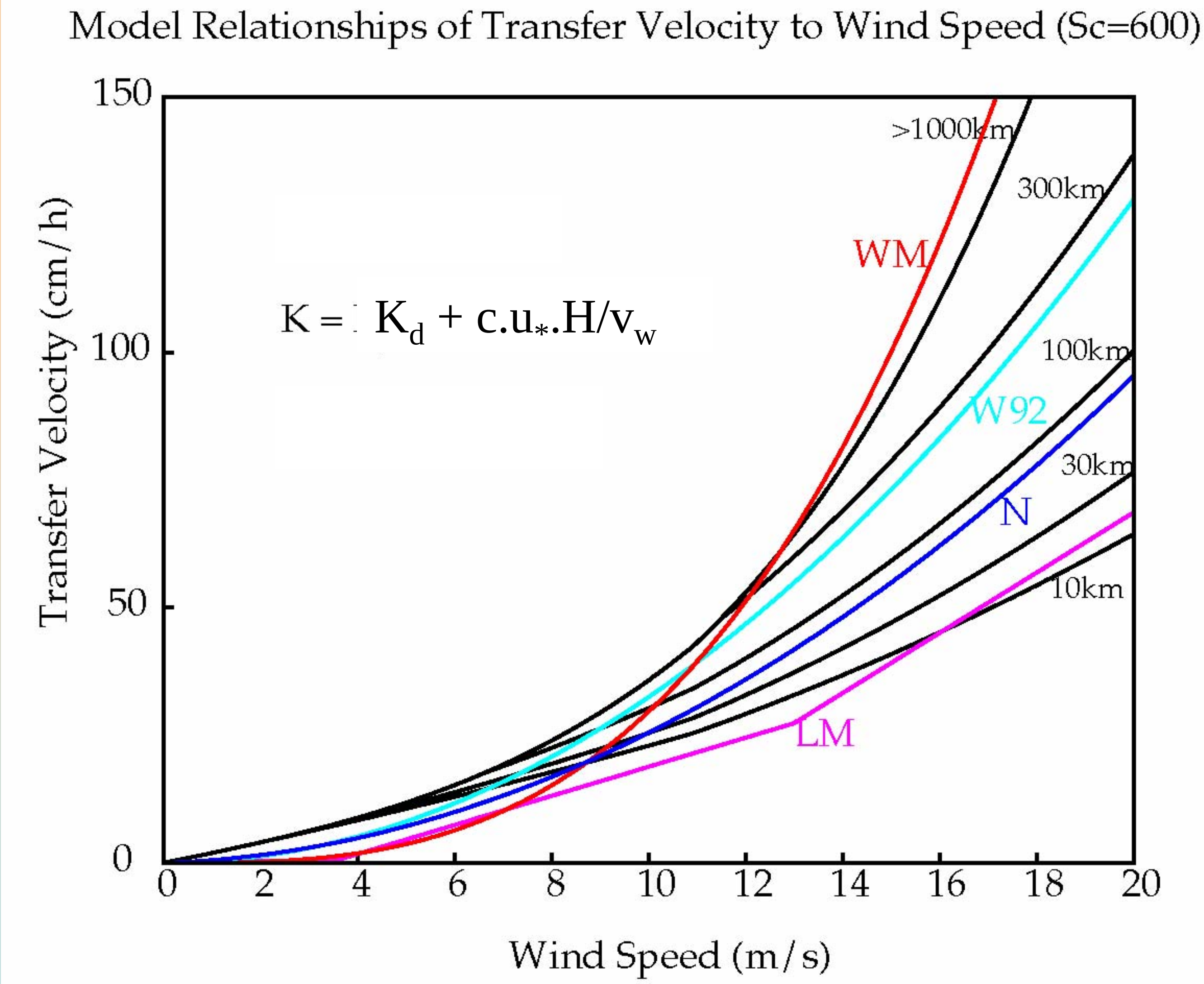


… but gas transfer at moderate and high wind speed depends on wave breaking and this depends not only on wind speed but wave development.



Stramska and Petelski, 2003

Incorporate sea-state dependence of wave breaking



Woolf, D.K. (2005),
Tellus, 57B, 87-94

Altimeter-based algorithms

- Based on Woolf (2005)

$$k = \underbrace{k_d}_{\text{non-breaking contribution}} + \underbrace{k_b}_{\text{whitecapping contribution}}$$

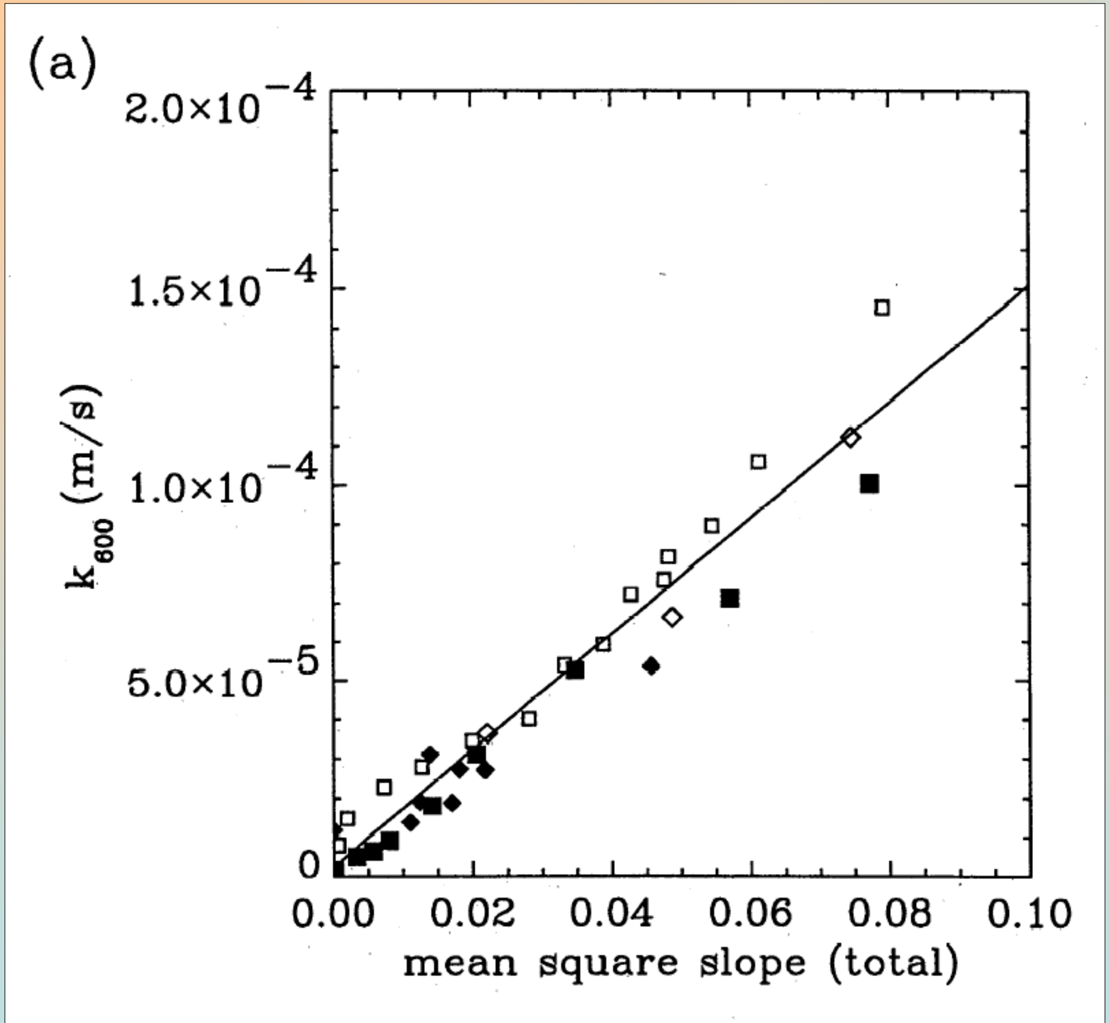
- $k_J = a.\mathrm{MSS} + b$
- $k_B = c.u_* H_s / v_w$

Best understanding $k_J : k_B = 3:1$ "ALT1"

dominant direct transfer

"ALT2" similar but $k_J : k_B = 1:3$

Dependence on surface roughness



Total mean square slope yields

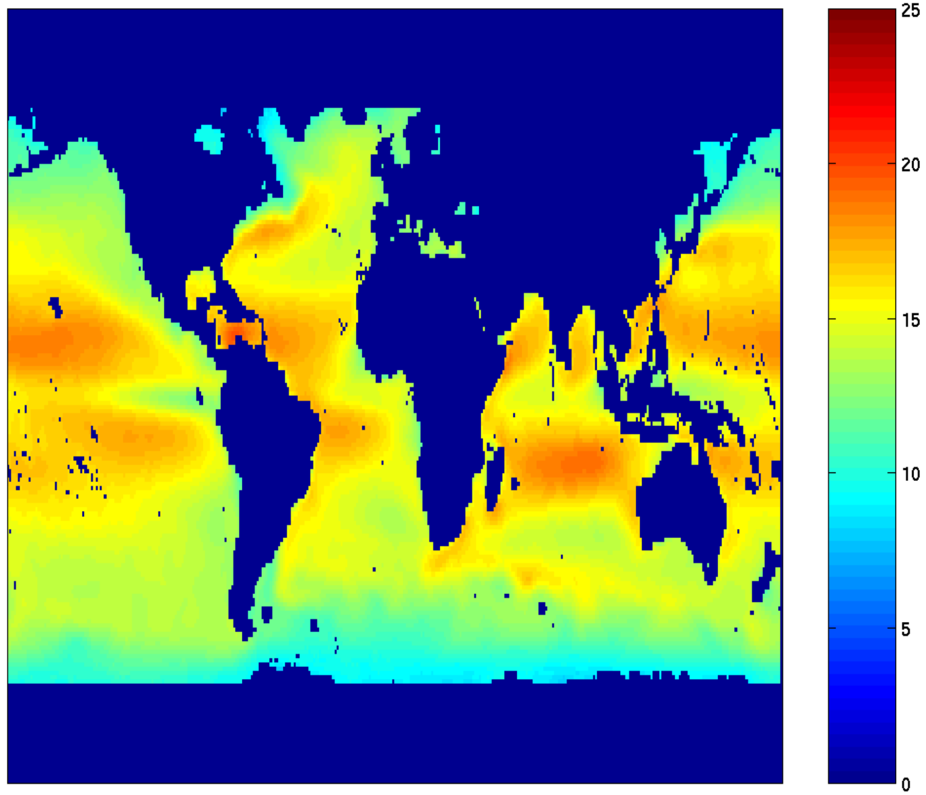
k_d = a.MSS + b

Related to Altimeter Backscatter, therefore can be calculated for ~15 years

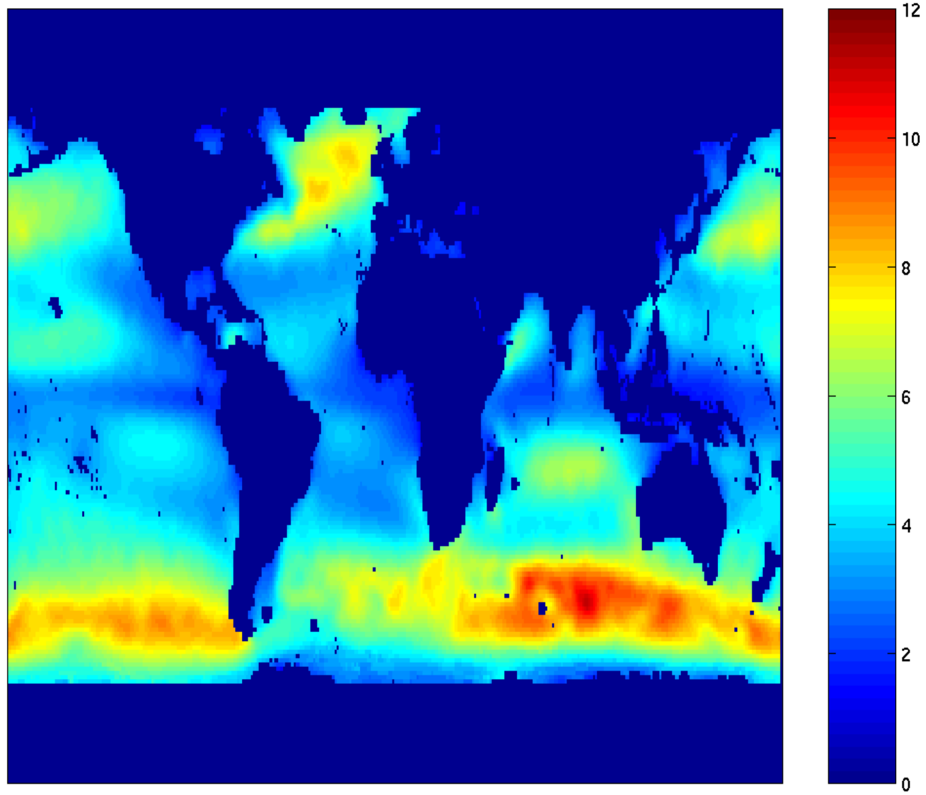
Relationship to mean square slope is robust with respect to surface films

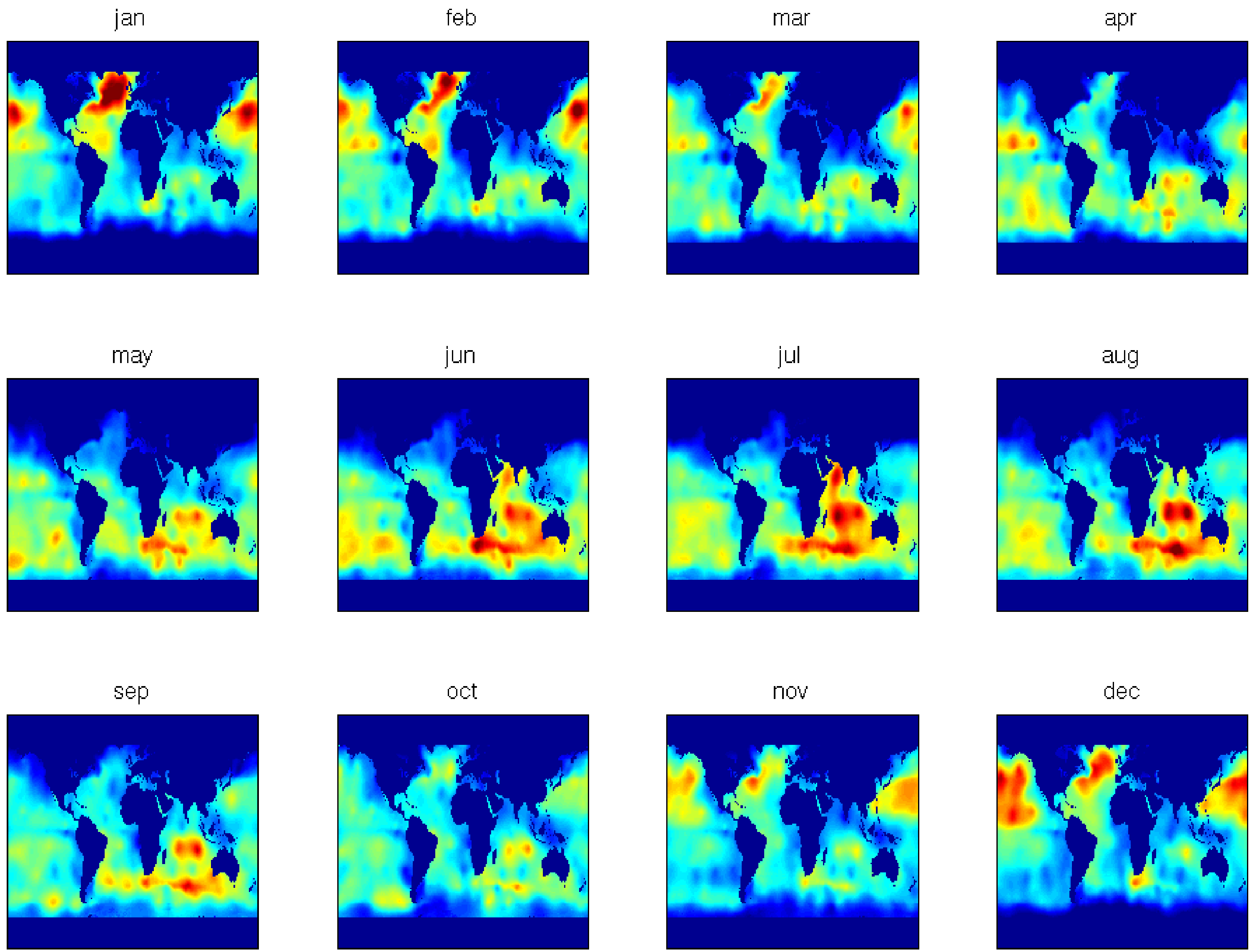
from Bock *et al.*, JGR 1999.

Average k_d from TOPEX



Average k_b from TOPEX

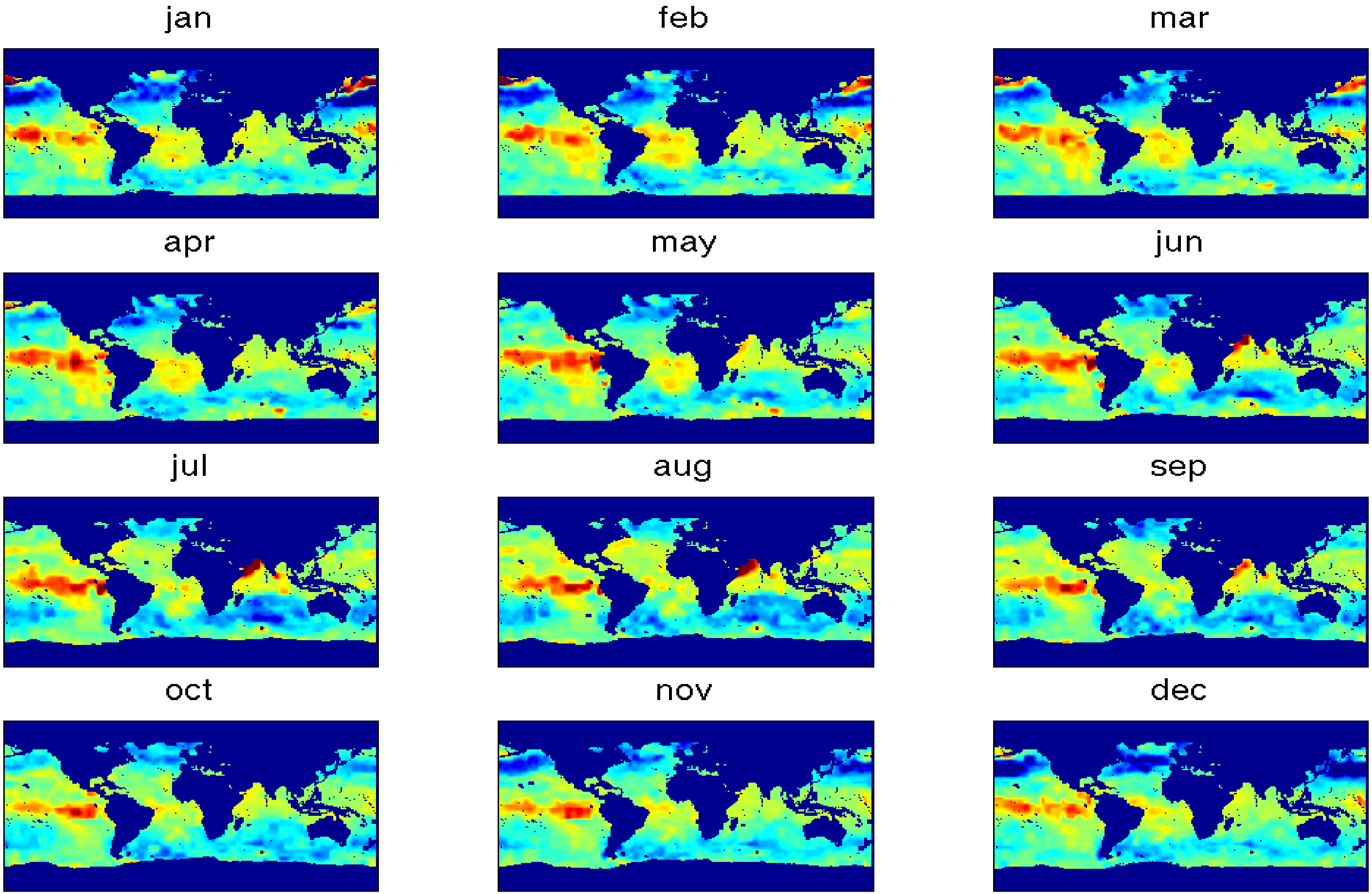




DARK BLUE: 12 cm/h

DEEP RED: 28 cm/h

CO_2 flux: k climatology + Takahashi

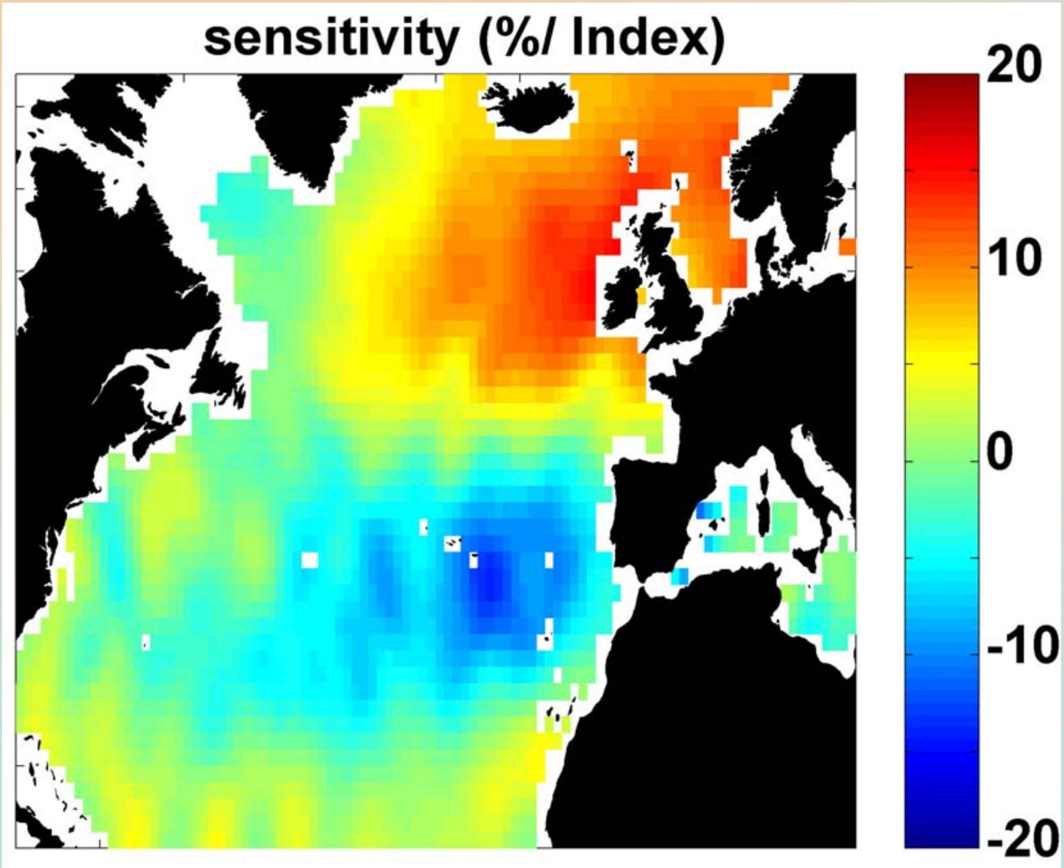


Global comparison

Mean transfer velocities and net carbon fluxes calculated using transfer velocity parameterizations by Wanninkhof (1992) (W92), Wanninkhof and McGillis (1999) (WG99), ALT1 and ALT2

	Zonal coverage	Mean transfer velocity [cm/h]	Net sink [Gt C/yr]
W92	±90° (±66°)	17.8 (17.9)	1.63 (1.53)
WG99	±90° (±66°)	16.4 (16.4)	2.15 (2.05)
ALT1	±66°	18.4	1.00
ALT2	±66°	18.4	1.72

Inter-annual variability



Sensitivity of whitecapping ($u_* H/\upsilon_w$) in the North Atlantic to the NAO Index.

Estimate pCO_{2water} from space?

- Use in situ data to derive relationship between pCO_{2water} and SST / ocean colour
- In situ data are more prevalent in North Atlantic
- Does any relationship vary with position? Biogeographical provinces
- Predictors: SST, Chl., lat, lon, day
- Linear modeling continues for EO version, NOCS

Co-variation effects: pCO_{2air} and wind

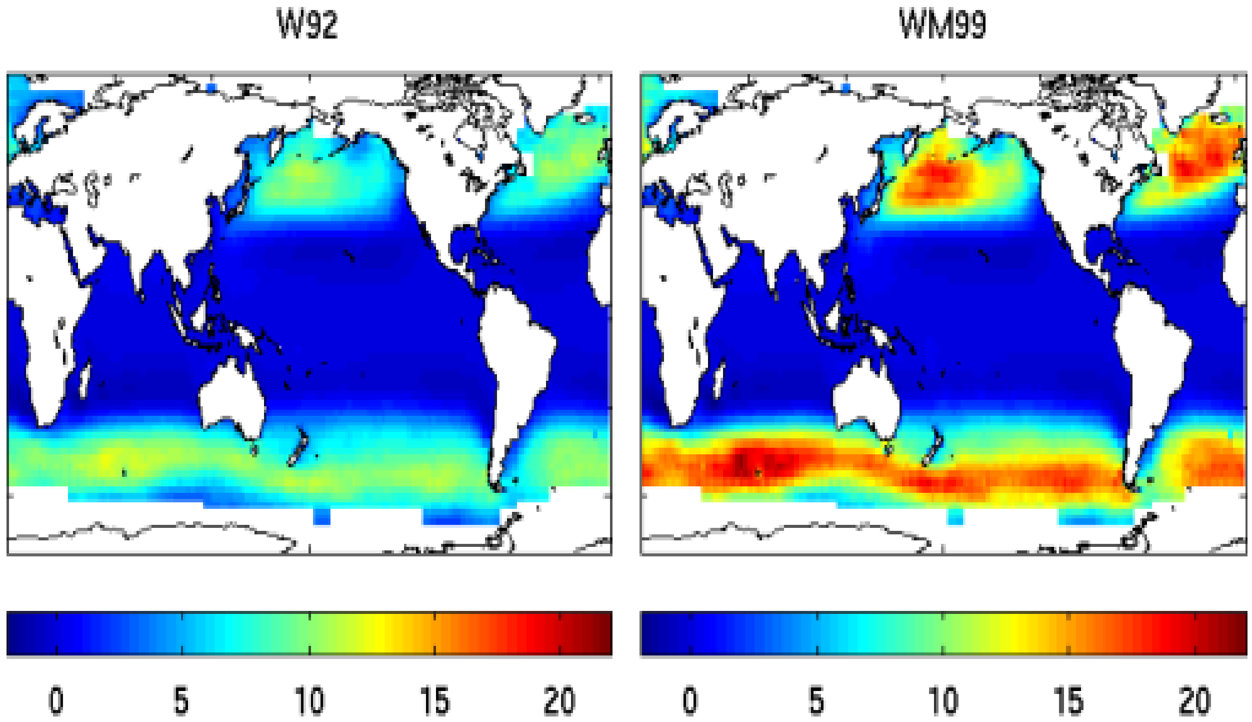
- ΔpCO_2 from Takahashi uses climatology surface pressure
- But surface pressure correlates with wind speed in the mid-latitudes

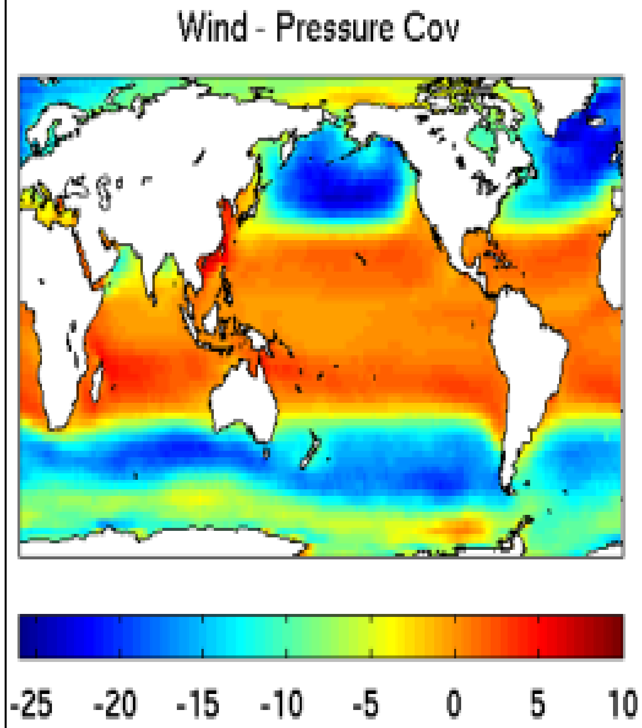
$$F = k(U)\ s\ [pCO_{2sea} - pCO_{2air}(P)]$$

- Using fixed, climatological or monthly averaged values for pCO_{2air} ignores this co-variation

Flux errors from monthly $pCO_{2\,air}$ (mol C m^{-2} yr^{-1})

Covariance (mb m s^{-1})





6hr – monthly fields

Cov(U,P) = <UP> - <U><P>

Over 10 years

Mean Global Mass Flux (Pg C/yr)

Averaging Period	**1990-1999**	
	W92	**WM99**
6 hourly	-1.60	-1.91
Monthly	-1.72	-2.08
Climatological	-1.74	-2.13
% Error (mon. av.)	7.2%	9.7 %
% Error (clim. av.)	8.6%	11.5%

Difference if co-variation included ~10%

Summary

- Transfer velocity
  - New formulation
  - Verification and tuning v. in situ in progress
  - Important radar-based k climatology
- pCO_2 difference
  - In situ exploration implies significant potential
    - Especially N Atlantic
  - Satellite SST-Chl predictors in progress at NOCS
  - Temporal co-variation u-p_{air} 10% effect