Utilizing Remotely Sensed Winds to Assess Global and Regional Air-Sea CO_2 Fluxes

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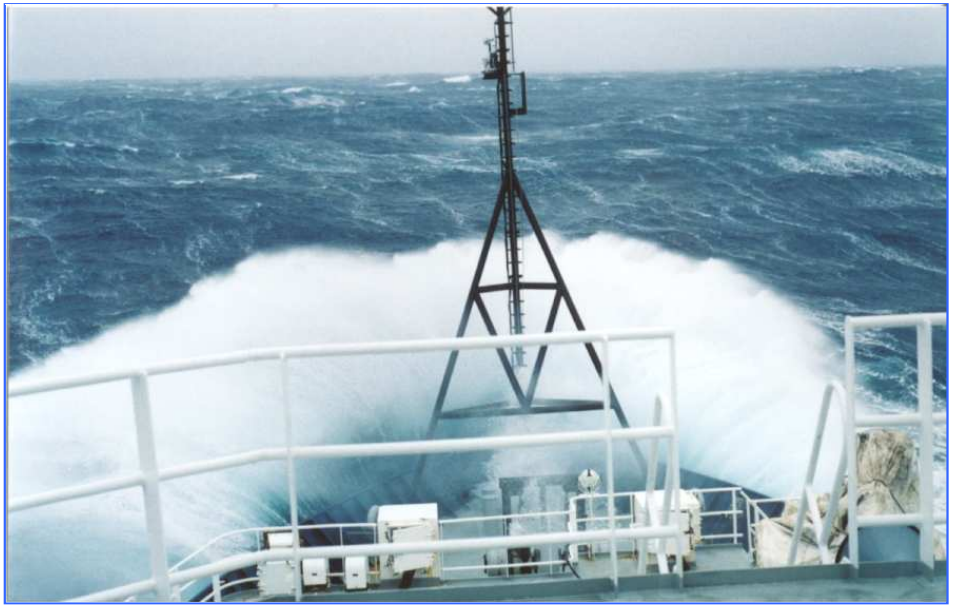


Courtesy K. Johnson, SoFex, 2001

Outline

- Determination of gas transfer & CO_2 fluxes
- Gas Transfer - wind speed relationships
  - -How they are determined
  - - Current uncertainties
- Recent estimates of global air-sea CO_2 fluxes
  - - Global climatology
  - - Interannual variability
- The impact of different wind speed products (NCEPII vs. “Atlas” winds)
  - - Global biases
  - - Variability
- The effect of different parameterization of gas tansfer

The Gas Transfer Velocity

The gas transfer velocity is a proportionality factor or kinetic driving force relating air water concentration differences of a gas to air-water fluxes:

$$F = k \Delta CO_2 = k K_o \Delta pCO_2$$

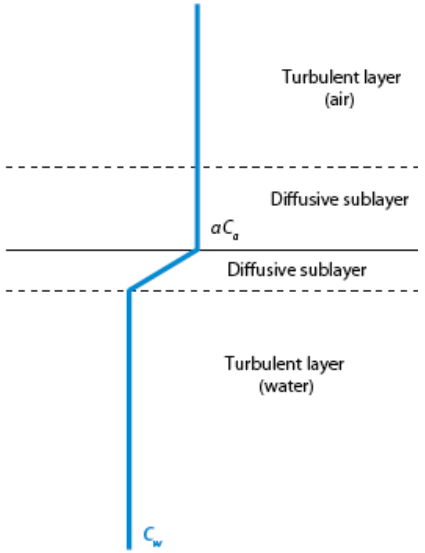
k = [length time^{-1}] *obtained from a relationship between gas transfer and wind*

ΔpCO_2: from measurements and interpolation

interpolations aided by empirical relationships of factors affecting pCO_2: SST, productivity, eddies, mixed layer depth

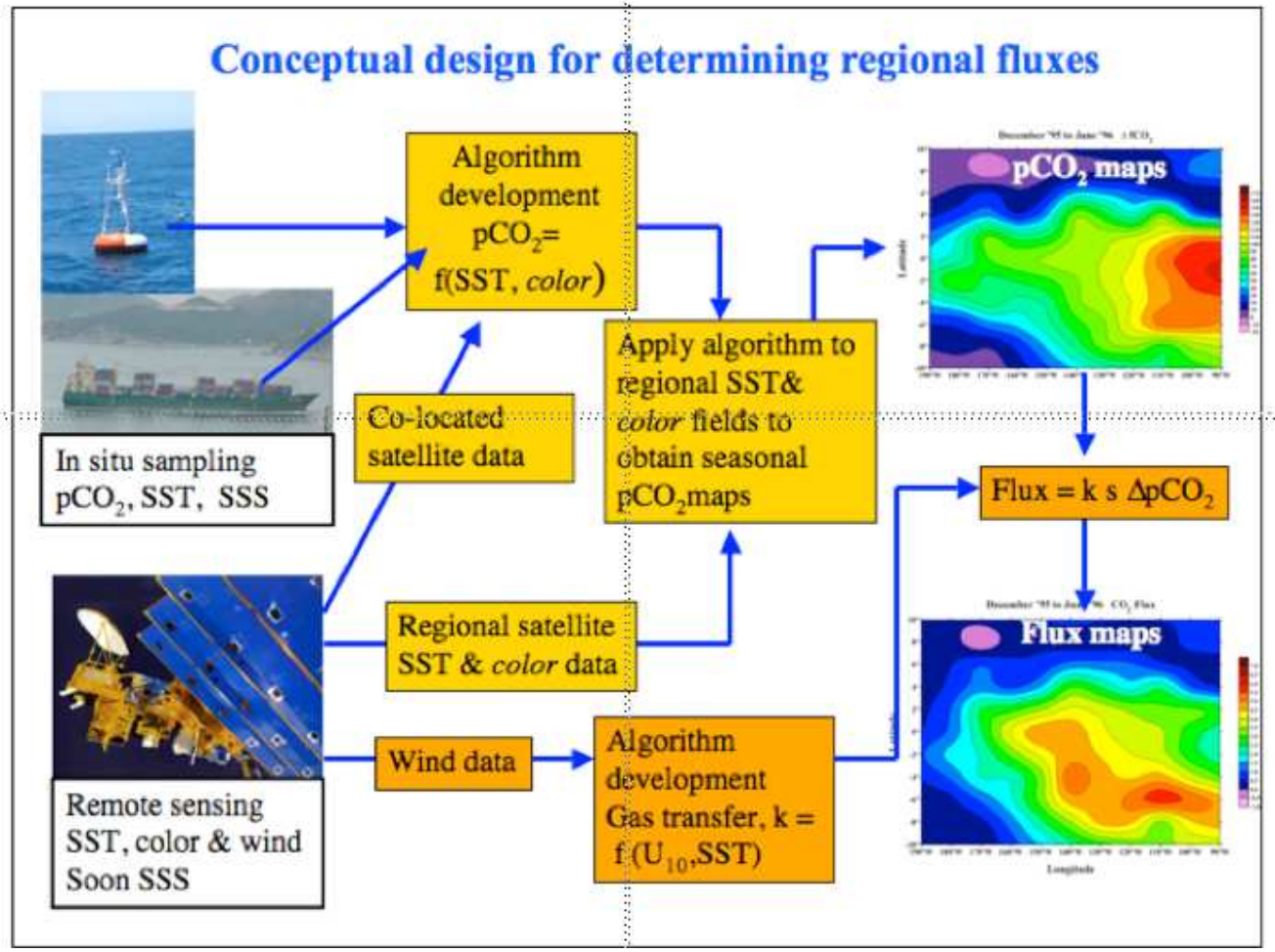
models

self-organizing maps



k is also referred to as:

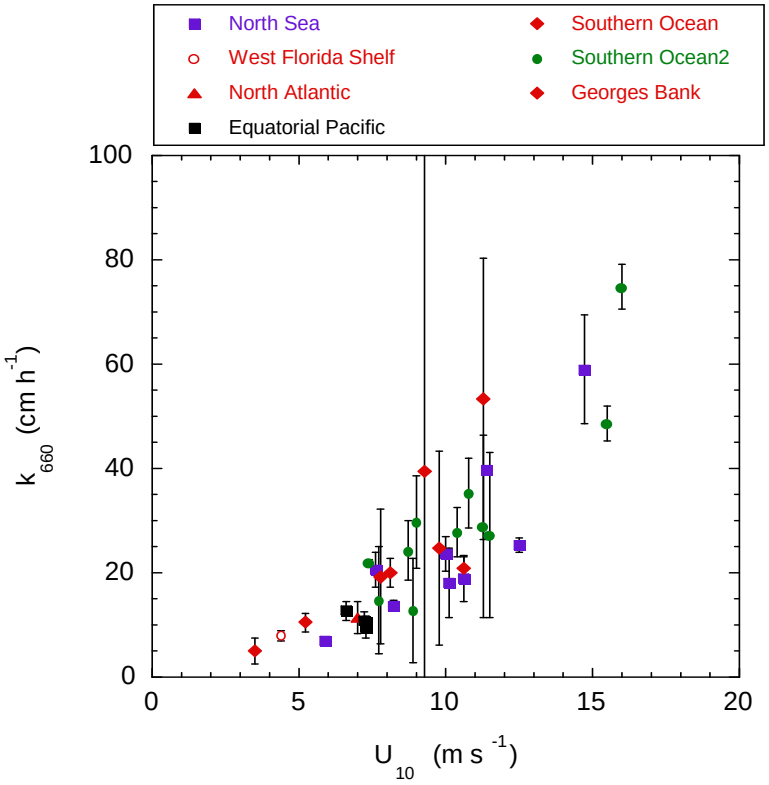
Piston velocity
Gas exchange coefficient
Gas transfer coefficient


Conceptual design for determining regional fluxes
Algorithm development pCO_2= f(SST, *color*)
pCO_2 maps
In situ sampling pCO_2, SST, SSS
Co-located satellite data
Apply algorithm to regional SST& *color* fields to obtain seasonal pCO_2maps
Flux = k s ΔpCO_2
Regional satellite SST & *color* data
Flux maps
Wind data
Algorithm development Gas transfer, k = f (U_{10},SST)
Remote sensing SST, color & wind Soon SSS

How is the relationship between k and U_{10} determined ?

1. Local studies using natural or purposeful gaseous tracers

(response time ≈ day, scale ≈ 10^2 km))



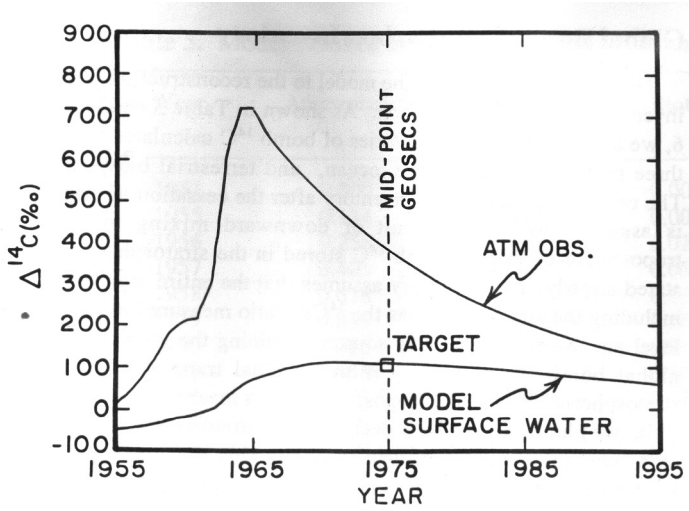
Summary of dual deliberate tracer experiments

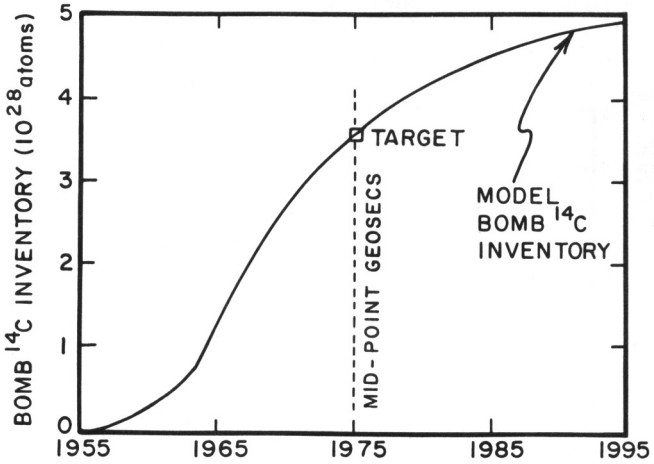
2. Micro-meteorological methods (co-variance, gradient)

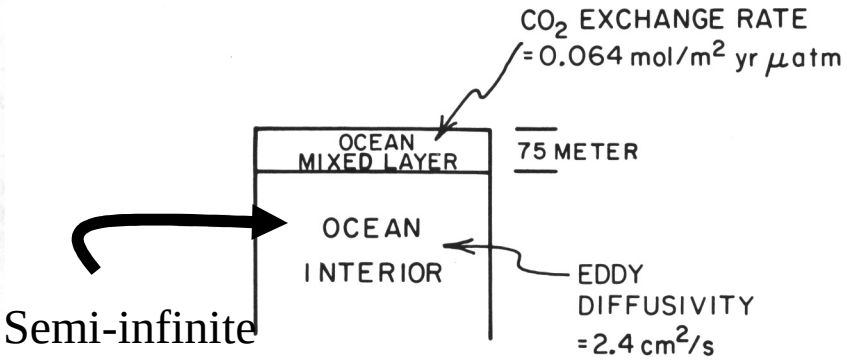
(response time ≈ hour, scale ≈ 1 km)

How is k determined? (cont)

Global Bomb ^{14}C constraint







Semi-infinite Half space

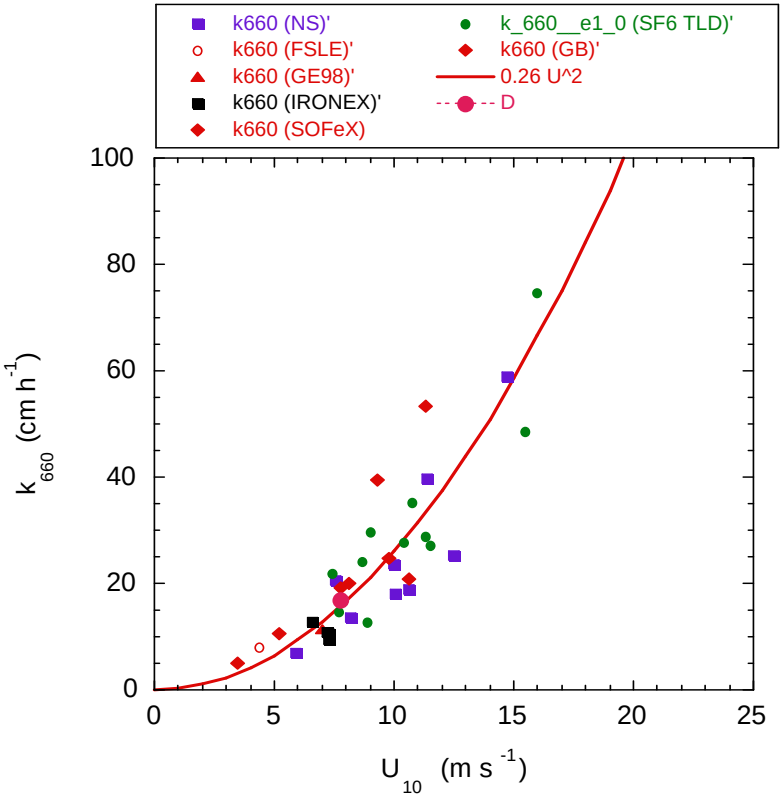
Broecker and Peng (1994)

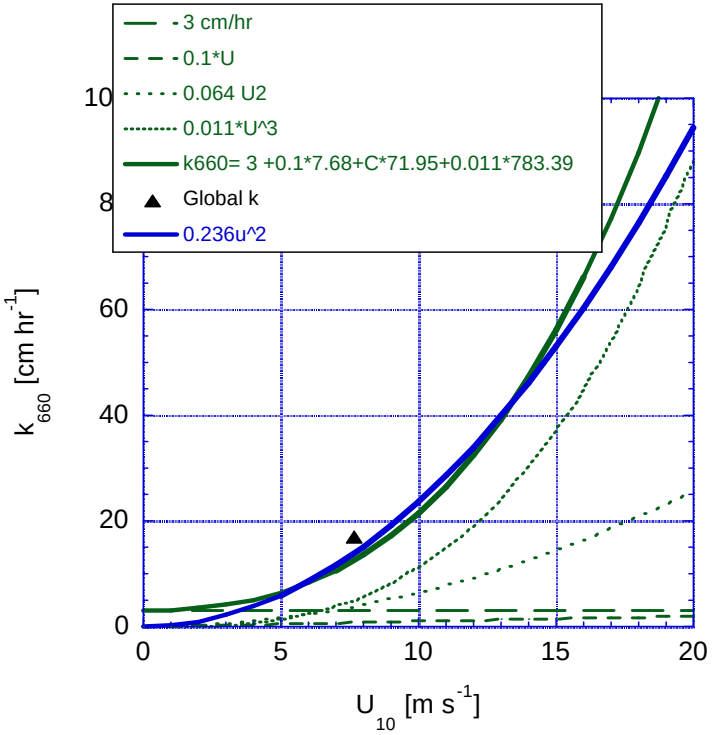
~~*Transfer velocity*~~
~~k_{av} = 22 cm/hr~~
~~U_{10} = 7.4 m/s~~

Transfer velocity
k_{av} = 17 cm/hr
U_{10} = 7.8 m/s

Adapted from Colm Sweeney

Empirical relationships with wind:





k is proportional to wind stress

$k_{660} = 0.26 \langle u^2 \rangle$

or: hybrid model

$k_{660} = 3 + 0.1 \langle u \rangle + 0.26 \langle u^2 \rangle + 0.011 \langle u^3 \rangle$

k_{global} is constrained:

$k_{global} = a \langle u^2 \rangle = \text{constant}$

so:

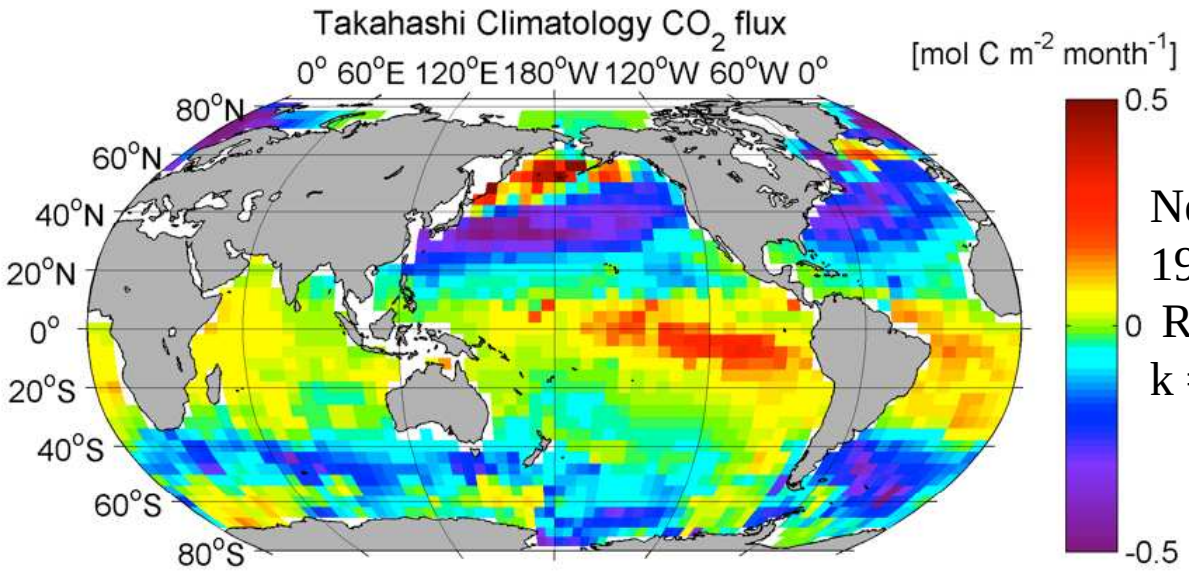
if $\langle u^2 \rangle$ changes so must "a"
higher resolution wind leads to smaller "a"

Table 1. Characteristics of the Five Wind Speed Climatologies Used in This Study: Global Annual Mean Wind Speeds Over the Ice-Free Ocean $\langle u \rangle$ and $\langle u^2 \rangle$, Resulting Gas Exchange Parameter a_q for Different Temporal and Spatial Resolutions, the Product $a_q \cdot \langle u^2 \rangle$, and the Global Annual Mean Piston Velocity k (Calculated According to Equation (2))[a]

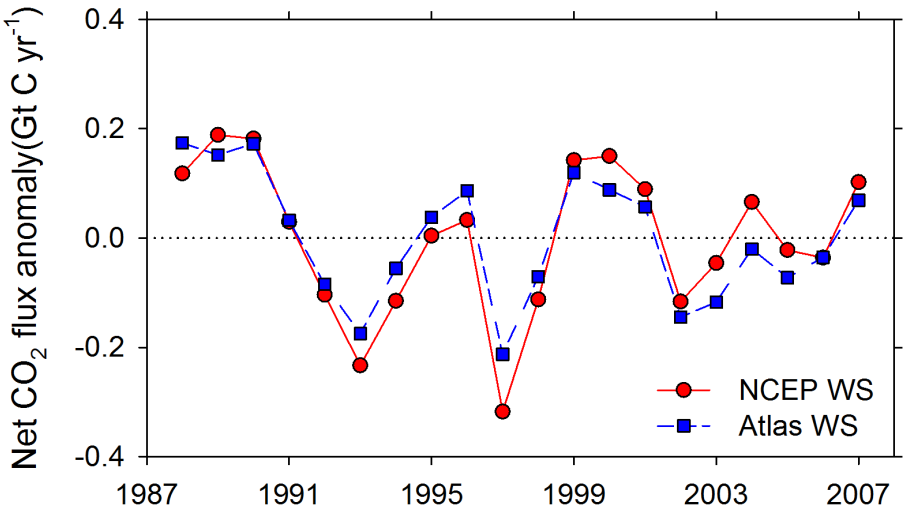
Parameter	Unit	NCEP	ECMWF	SSMI	QSCAT	ERS12	Mean ± σ	σ/Mean
$\langle u \rangle$	m/s	6.6	7.0	7.8	7.9	7.3	7.3 ± 0.6	0.08
$\langle u^2 \rangle$	$(m/s)^2$	46.9	53.1	65.0	66.4	57.1	57.7 ± 8.2	0.14
a_q (monthly winds, 5° ×4° grid)	$(cm/hr)/(m/s)^2$	0.40	0.35	0.29	0.29	0.34	0.33 ± 0.05	0.14
a_q (monthly winds, 1° ×1° grid)	$(cm/hr)/(m/s)^2$	0.39	0.34	0.28	0.27	0.32	0.32 ± 0.05	0.14
a_q (daily winds, 1° × 1° grid)	$(cm/hr)/(m/s)^2$	0.38	0.33	-	-	-	-	-
$a_q \cdot \langle u^2 \rangle$	cm/hr	18.1	17.9	18.2	18.1	18.4	18.1 ± 0.2	0.01
$\langle k \rangle$	cm/hr	16.6	16.2	16.4	17.3	16.9	16.7 ± 0.4	0.02

[a]Note that for the satellite wind speed data sets (SSM/I, QSCAT and ERS1/2), no daily resolution with full global coverage is available. $\langle u \rangle$, $\langle u^2 \rangle$, $a_q \cdot \langle u^2 \rangle$ and $\langle k \rangle$ are calculated from monthly winds on a 1° × 1° grid.

Current estimates of global air-sea CO_2 fluxes



Net flux into ocean = 1.6 Pg C yr^{-1}
1979-2005 NCEP-DOE AMIP-II
Reanalysis (R-2) wind
$k = 0.26 \langle u^2 \rangle$



Interannual variability
$\pm$ 0.14 Pg C yr^{-1}

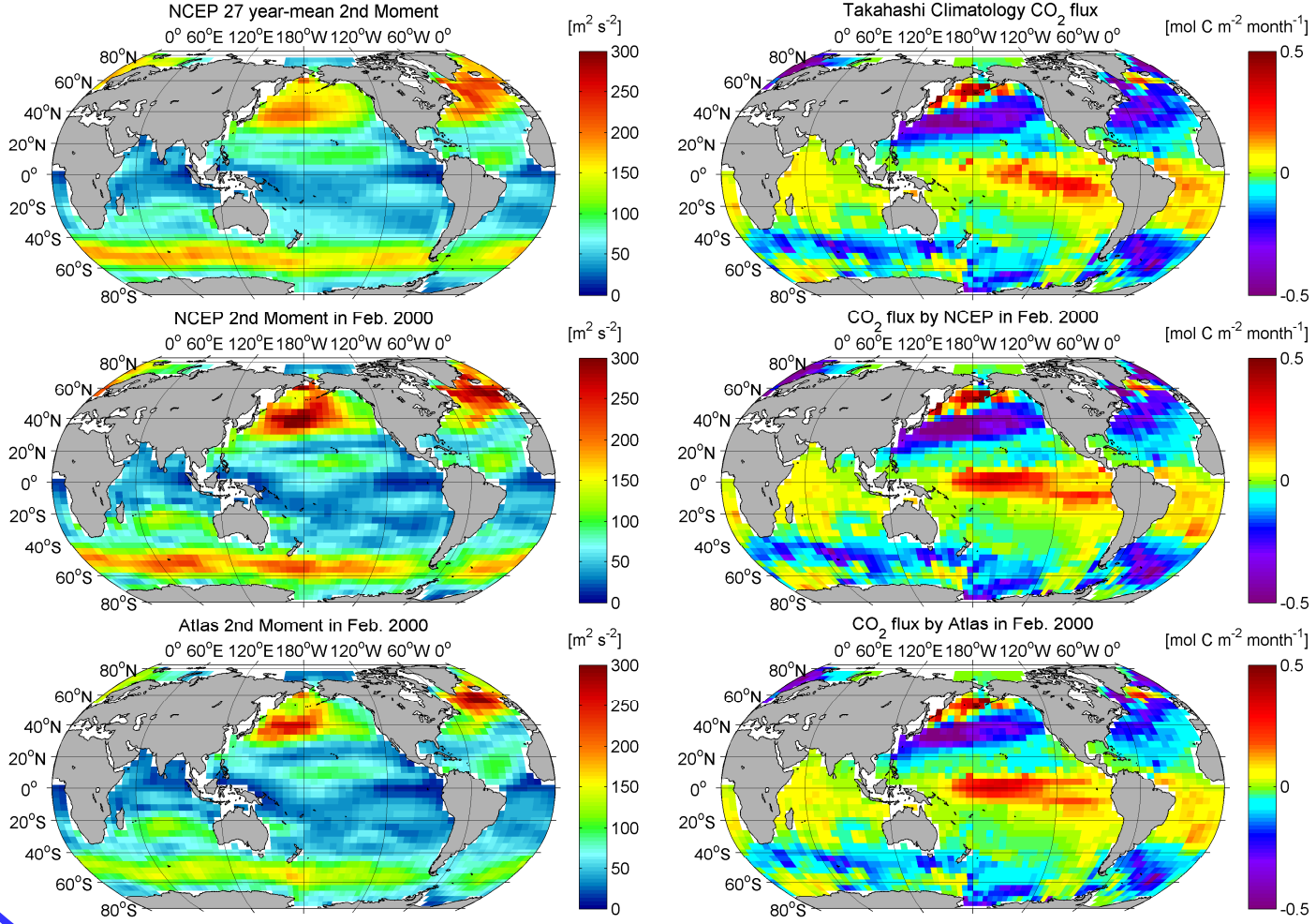
Impact of winds: NCEPII vs. "Atlas"

$\langle U^2 \rangle_{NCEPII} \approx 1.25 \langle U^2 \rangle_{Atlas}$

A cross-calibrated multiple platform ocean surface wind data set (Eos, vol. 90, #27, 7 July 2009)

Robert Atlas, Ross N. Hoffmann, Joseph Ardizzonec

National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Cwy., Miami, FL, USA 33149; Atmospheric and Environmental Research, Inc., 131 Hartwell Ave., Lexington, MA 02421-3126; SAIC NASA Goddard Space Flight Center, Greenbelt, MD USA 20771

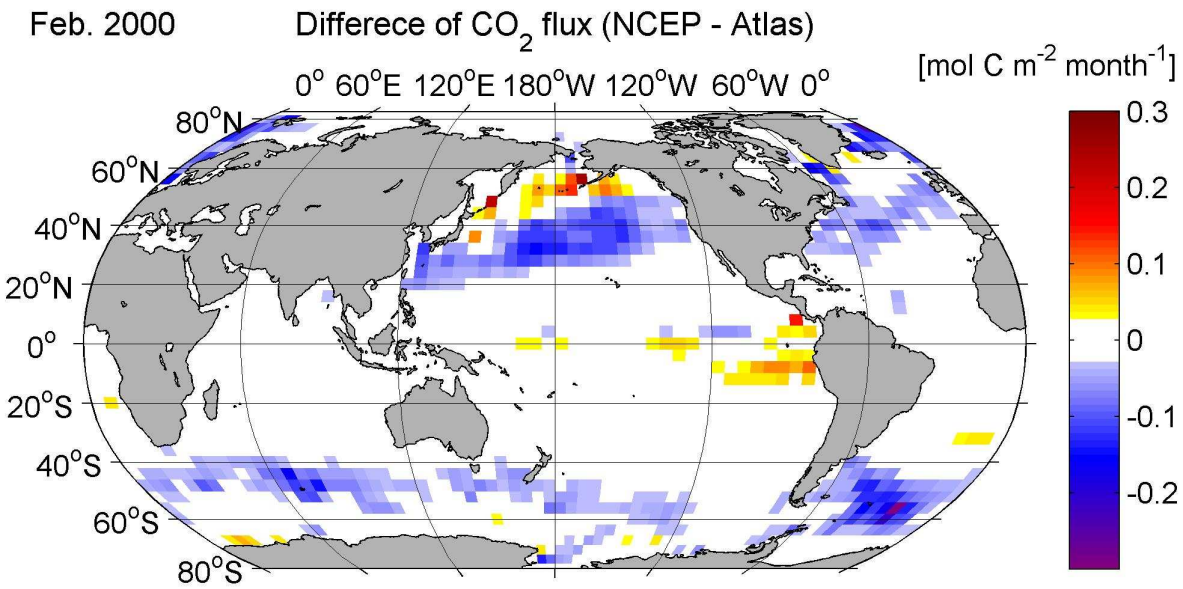


20 year-mean (1988-2007)
1.6 ± 0.7
Gt C yr^{-1}
$k = 0.26 \langle U \rangle^2$

NCEP II:
1.54 ± 0.14
Pg C yr^{-1}
$k = 0.217 \langle U^2 \rangle$

Atlas:
1.34 ± 0.14
Pg C yr^{-1}
$k = 0.27 \langle U^2 \rangle$

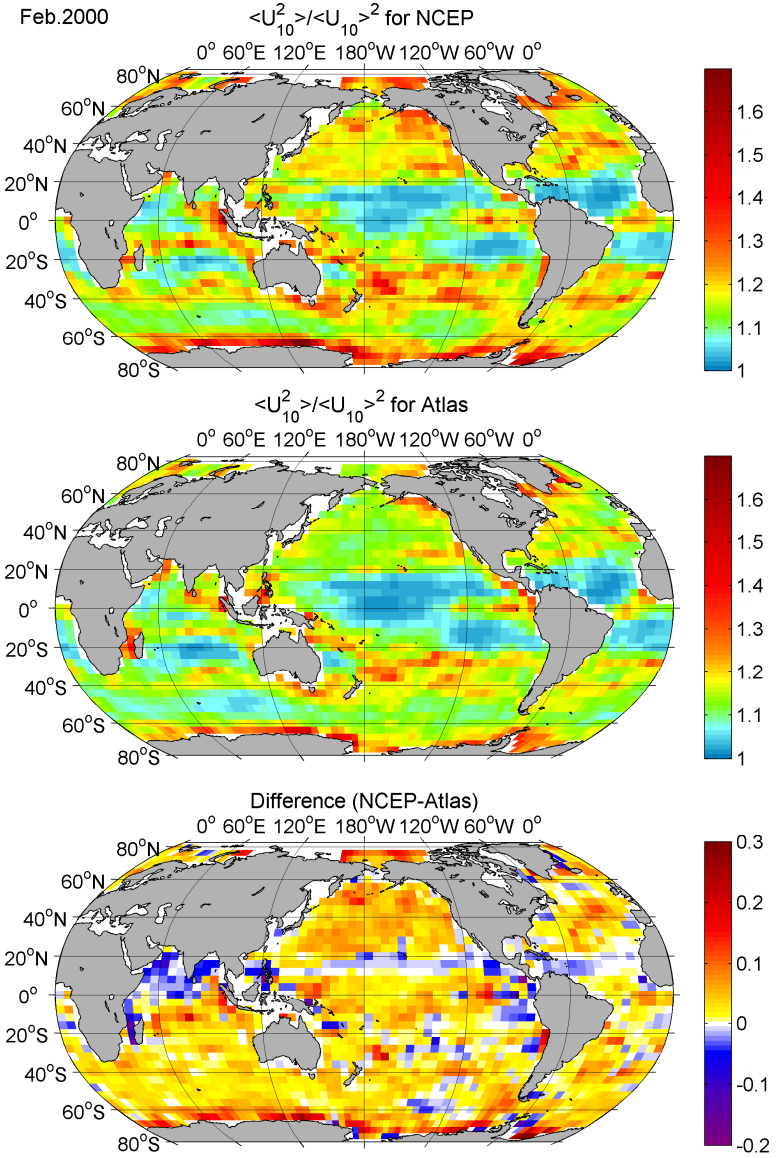
Patterns of wind speed biases



EqPac: NCEP- more evasion
High latitude: NCEP- more uptake
Two processes reinforce each other

Ratio of $<U_{10}^2>/<U_{10}>^2$

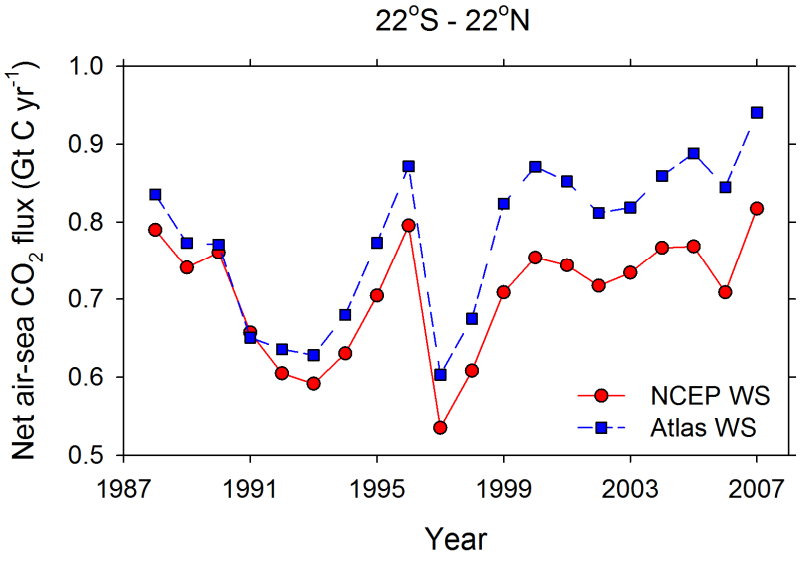
Example, February 2000



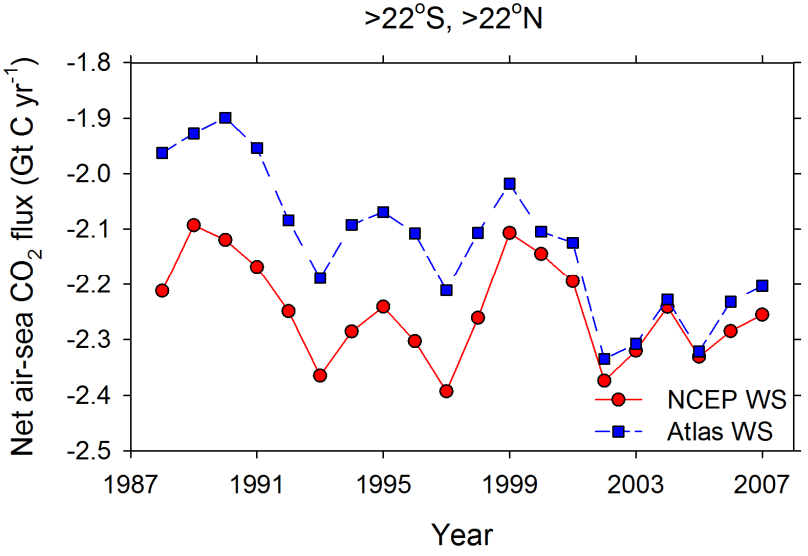
Mean ± S.D.
: 0.03 ± 0.05

Regional differences in fluxes for NCEP II and "Atlas"

- Tropical variability dominated by ENSO
- Greater efflux with Atlas winds

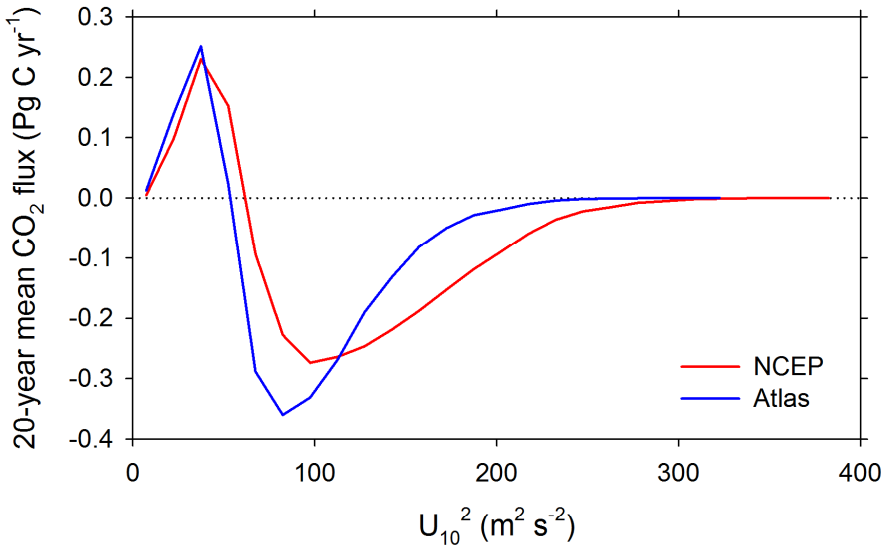


- Increasing uptake with time with "Atlas" winds
- Less uptake with "Atlas" winds

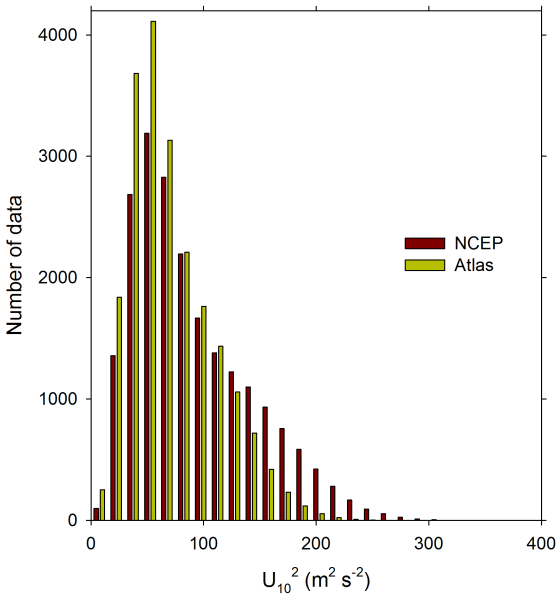


Air-Sea CO_2 fluxes versus wind speed

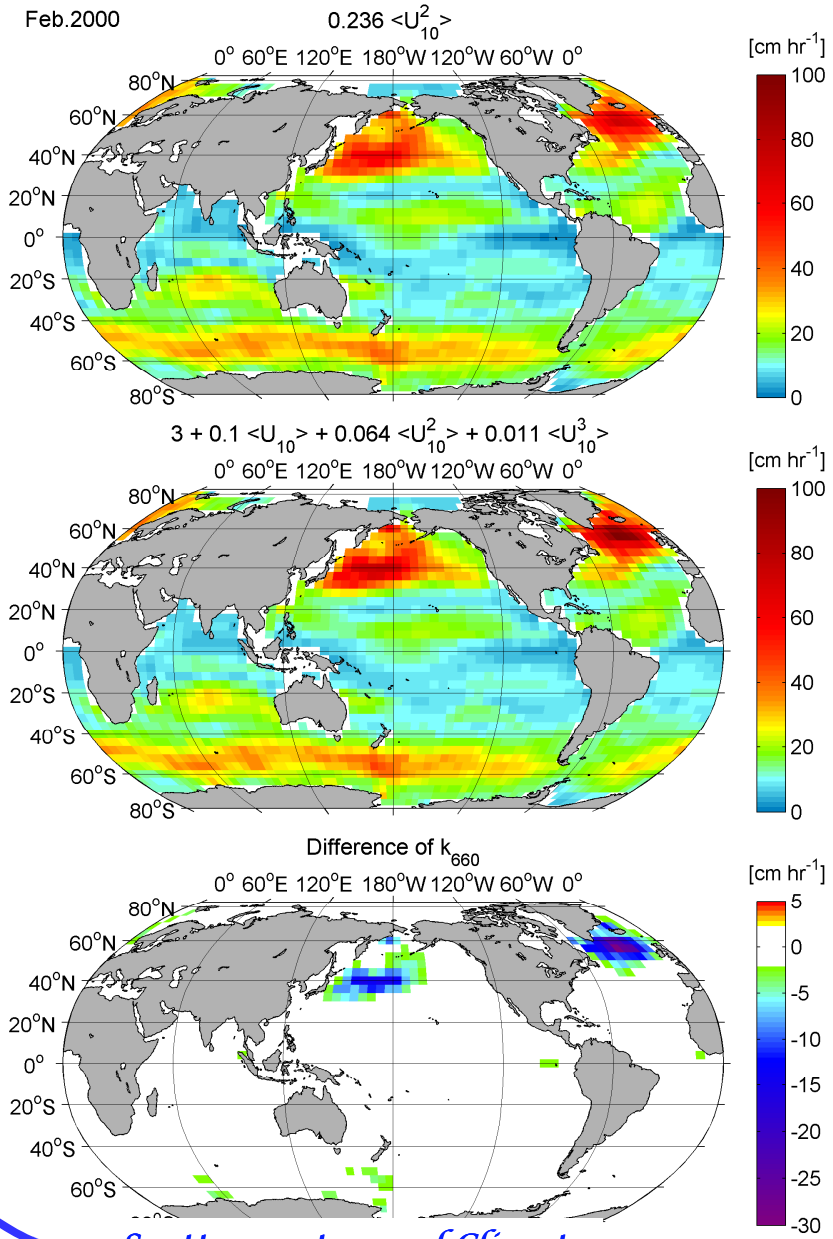
Efflux at low winds
Invasion at higher winds
Very high winds have
Limited impact due to limited frequency

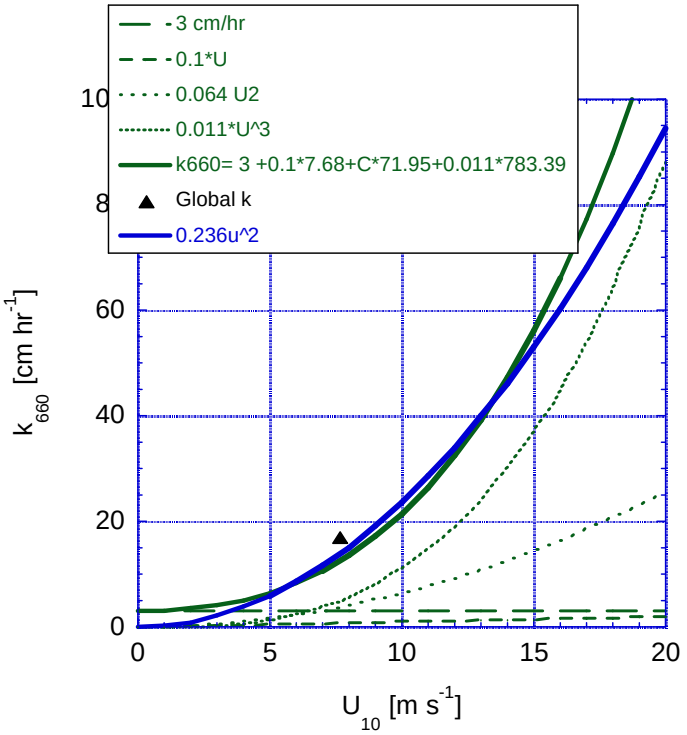


"Atlas" winds (2nd moment) significantly lower then NCEPII
The maximum invasion flux is at lower winds



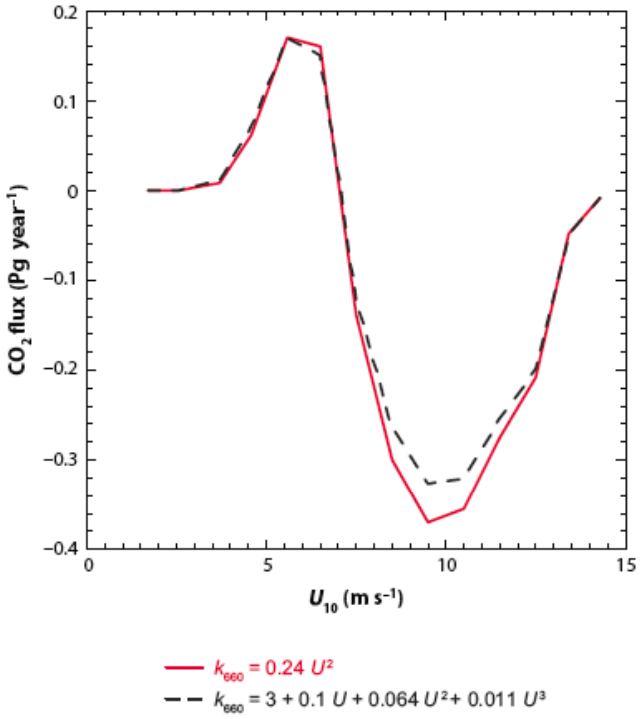
Difference in functionality





With Atlas wind speed
Mean difference
-0.38 ± 2.5 cm hr^{-1}

Small differences in functionality can lead to significant differences in global fluxes



k_{660} [cm hr^{-1}]= 3 + 0.1 U_{10} +0.064 U_{10}^2 + 0.011U_{10}^3 : 1.16 Pg C yr^{-1}

k_{660} [cm hr^{-1}]= 0.236 U_{10}^2 : 1.3 Pg C yr^{-1}

Conclusions

- For quadratic dependencies between gas transfer and wind, the 2nd moment of winds should be used ($<U^2>$) rather than the mean ($<U>$)

- Gas transfer velocities- wind speed relationships should be scaled to the global mean 2nd moment of the wind product used

- Global wind products show regional differences that will impact global CO_2 fluxes.

- Differences are accentuated by the regional distinct (and wind speed distinct) direction of fluxes