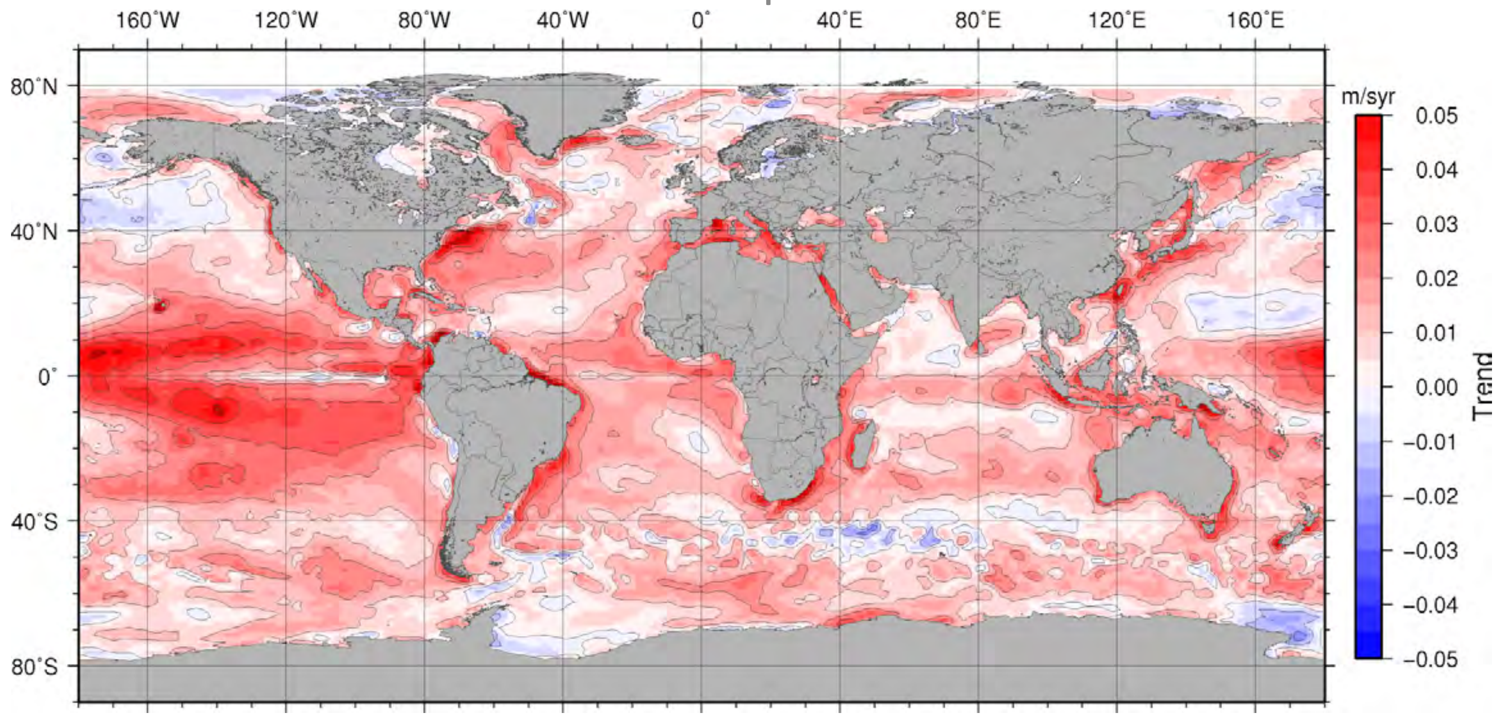
The Effect of Changing Wind Speeds on Global Air-Sea CO_2 Fluxes

Rik Wanninkhof, NOAA/AOML, Miami US.

Joaquin Trinanes, Univ. Santiago de Compostela, Santiago, Spain



Changes in wind speed 1987-2015 CCMP-2 winds

Motivation focused on the global carbon cycle

- ≈25 % of the anthropogenic CO_2 is sequestered [over time time periods] by the ocean
- Changes in Air-Sea CO_2 fluxes can have a profound effect on this uptake and estimates of future atmospheric CO_2 levels/climate mitigation policies (COP-21)
- Gas transfer can effectively be parameterized with wind over the ocean
- Using new quality wind product (CCMP-2) wind speed changes can be assessed at high resolution
- Overall increases in winds should lead to increases in air-sea CO_2 fluxes

Approach

Effect of wind alone, isolating it from the predominant effect of changes in ΔpCO_2

- $F = k\ s\ \Delta pCO_2$
- ΔpCO_2 monthly 4 by 5˚ climatology Takahashi centered on 2005 (unpublished) [not time varying]
- $k_{660} = 0.24 \langle U_{10}^2 \rangle$ or
- $k_{660} = 3 + 0.1 \langle U_{10} \rangle + 0.064 \langle U_{10}^2 \rangle + 0.011 \langle U_{10}^3 \rangle$ ["hybrid model"]

[Wanninkhof et al., 2009]

- CCMP-2 winds and moments monthly 1 by 1˚ from July 1987- July 2015

[www.remss.com/measurements/**ccmp**]

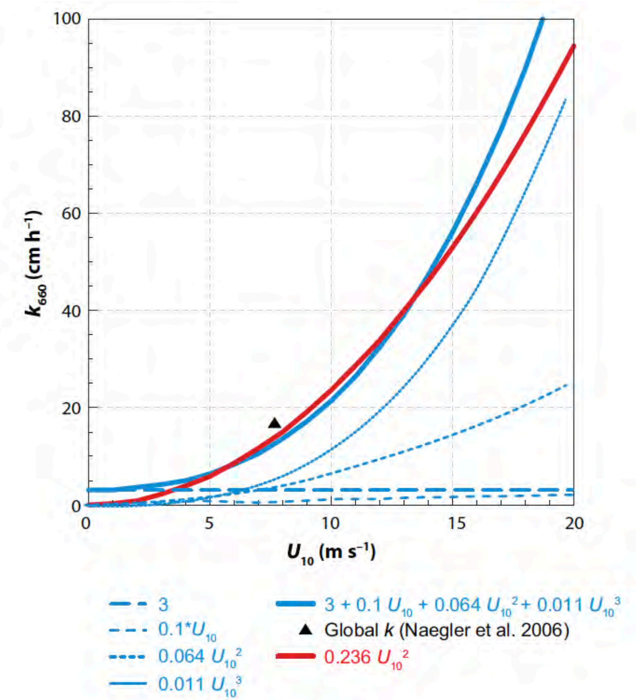
- Focus on long term trends (linear).
- Of note, Climatology shows [low] net uptake ≈1.3 Pg C /yr

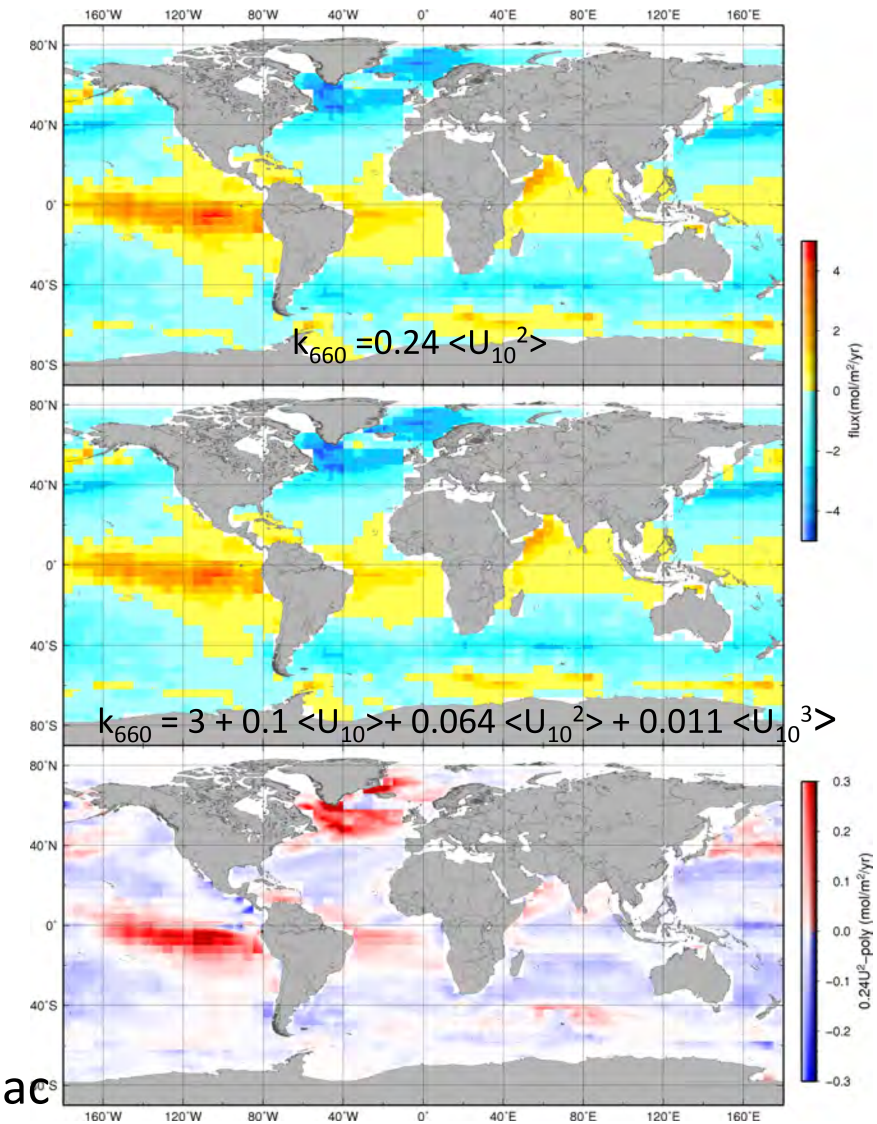
1988 **R. Wanninkhof et al.: Global ocean carbon uptake: magnitude, variability and trends**

Table 1. Summary of different components of the globally integrated sea–air CO_2 flux estimate including the sources and magnitude of the uncertainty.

	Year 2000 from Takahashi et al. (2009)			Updated estimate[a]	
	$Pg\,C\,yr^{-1}$	%	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$
Net flux	−1.38			−1.18	
ΔpCO_2		±13 %	±0.18		±0.18
k		±30 %	±0.42		±0.2
Wind (U)		±20 %	±0.28		±0.15
$< d(pCO_{2w})\,dt^{-1} >$[b]		±35 %	±0.5		±0.5
Total		±53 %	±0.7		
Undersampling[c]	−0.2			−0.2	
Riverine carbon[d]	0.4		±0.2	0.45	±0.2
Coastal area				−0.18	
Anthro CO_2 flux	−2.0		±0.8[e]	−2.0	±0.6

Background: Global Air-Sea CO_2 flux patterns





Difference: Net ≈0

Red: 0.24$<U_{10}^2>$ more release/less uptake

Blue: 0.24$<U_{10}^2>$ less release/more uptake

More uptake in Subtropics, more release Eq Pac

Background: Trends

Due to atmospheric CO_2 increase: -0.15 Pg C/yr/decade (increased uptake)

From data based approaches: + 0.2 Pg C/yr/decade (1991-2001);

-0.8 Pg C/yr/decade (2001-2011)

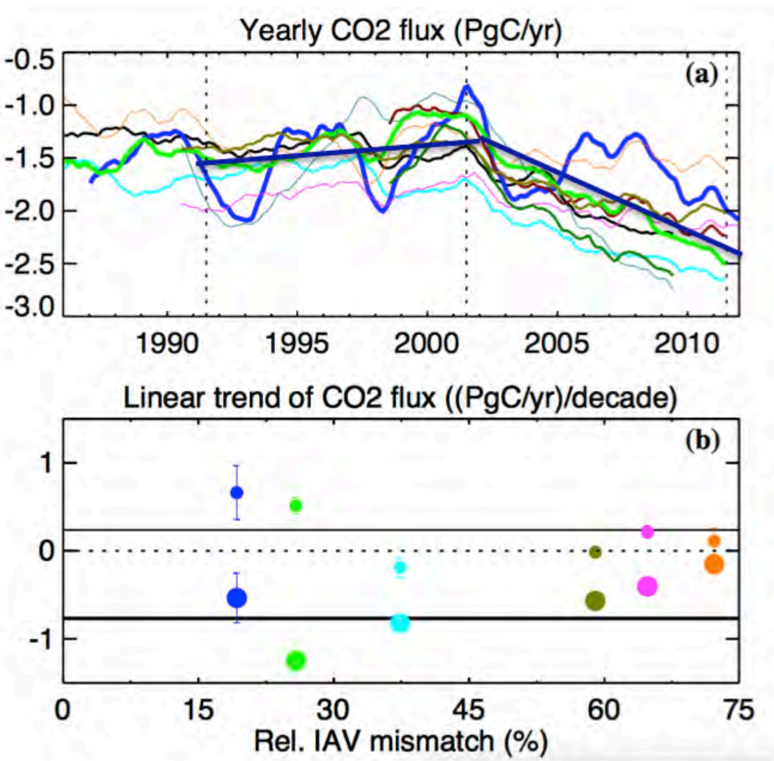
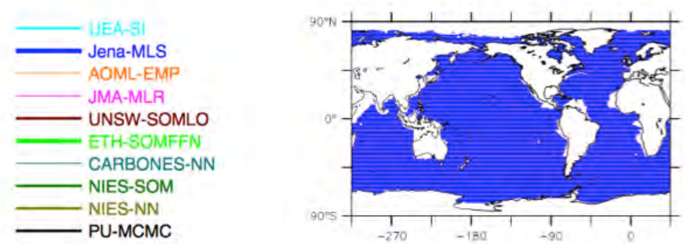


Table 3. Median sea–air anthropogenic CO_2 fluxes for the different approaches centered on year 2000.

Approach	Anthr. CO_2 flux	Uncertainty	IAV[e]	SAV[f]	Trend
	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$	$Pg\,C\,yr^{-1}$		$(Pg\,C\,yr^{-1})\ decade^{-1}$
Empirical	−2.0	±0.6[a]	0.20	0.61	−0.15
OBGCM	−1.9	±0.3[b]	0.16	0.38	−0.14
Atm. Inversion	−2.1	±0.3[c]	0.40	0.41	−0.13
Ocean Inversion	−2.4	±0.3[d]			−0.5[j]
Interior (Green function)[g]	−2.2	±0.5	–	–	−0.35
O_2/N_2[h]	−2.2	±0.6			

R. Wanninkhof et al.: Global ocean carbon uptake: magnitude, variability and trends

Biogeosciences, 10, 1983–2000, 2013 www.biogeosciences.net/10/1983/2013/



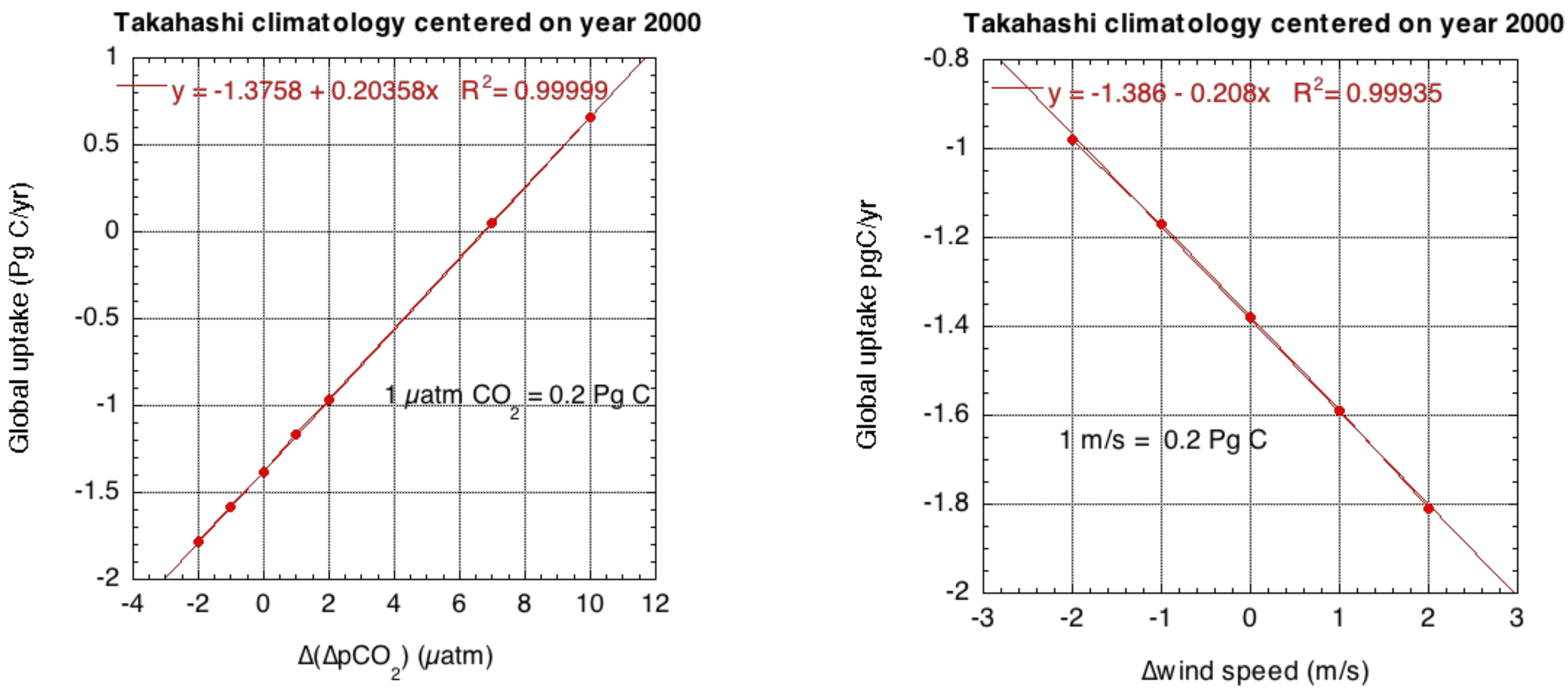
C. Rödenbeck et al.: An ensemble of $p$$CO_2$-based sea–air CO_2 flux estimates

Biogeosciences, 12, 7251–7278, 2015 www.biogeosciences.net/12/7251/2015/

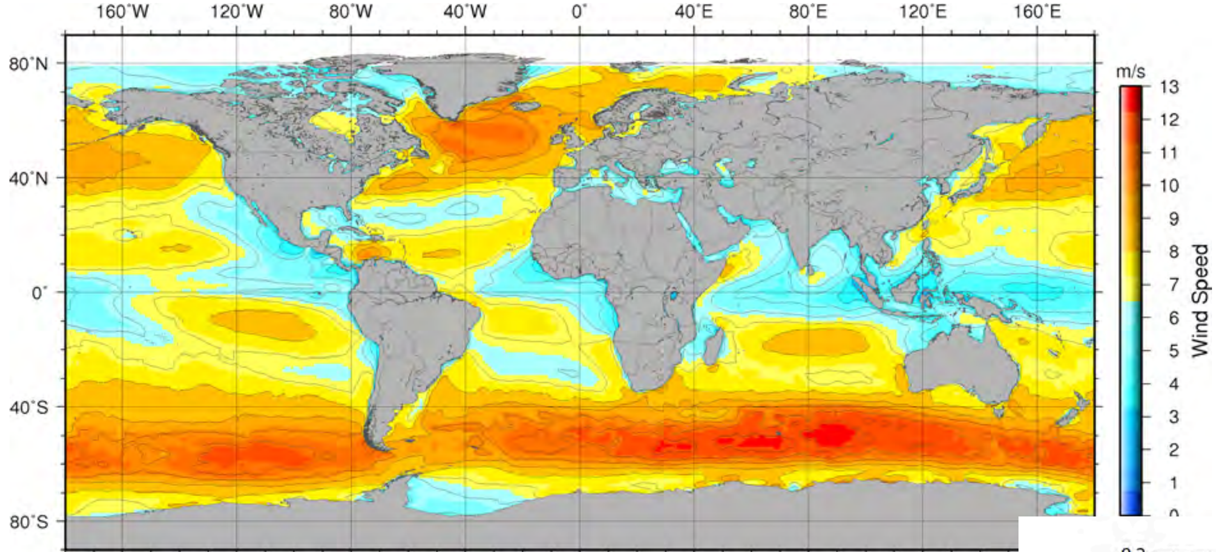
Background: The 1: 1: 0.2 rule

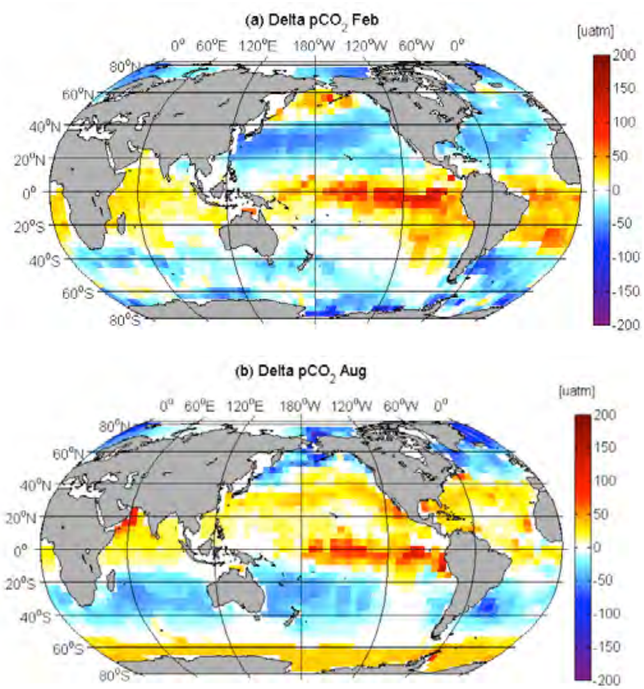
Changes due to changes in pCO_2 and wind

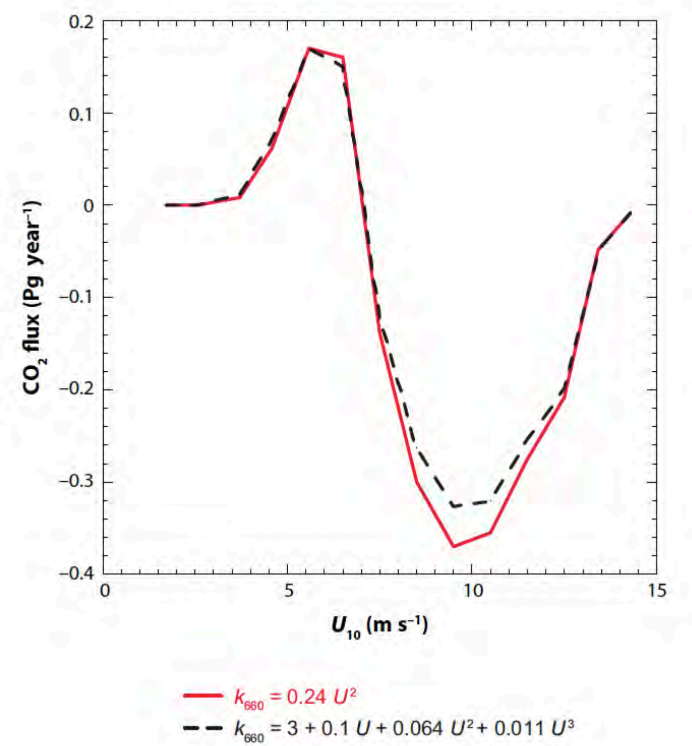
- 1 µatm increase in ΔpCO_2 will cause a 0.2 Pg C increase in global uptake (15 % of net global ocean CO_2 uptake)
- a 1 m/s increase in wind speed will increase the uptake by 0.2 Pg C as well



Global Wind patterns: Higher winds in regions of uptake

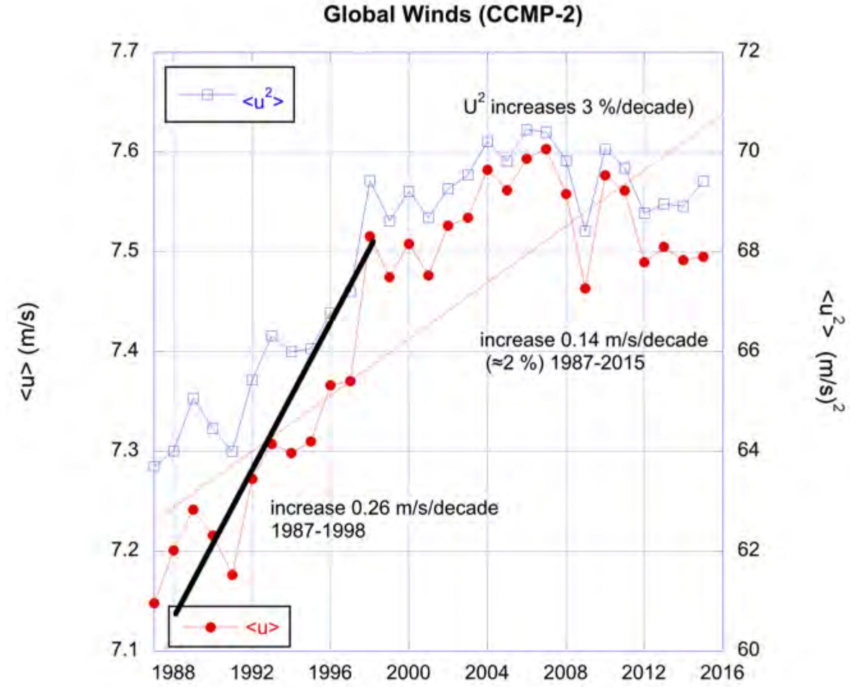




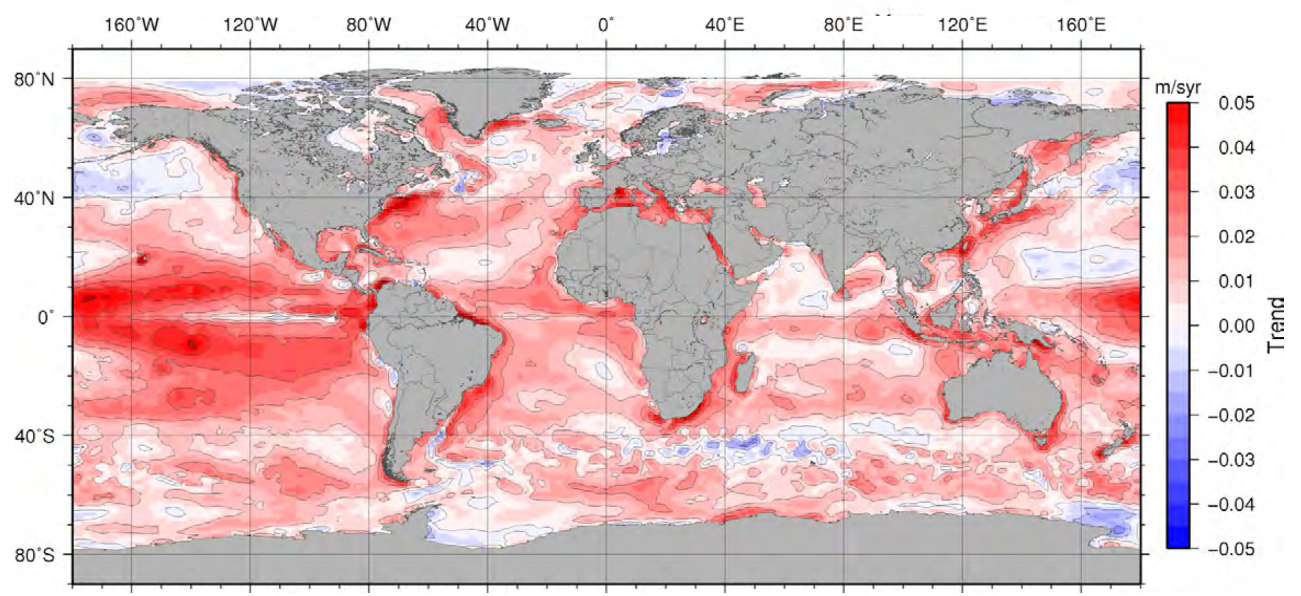


Trends: Global winds

Trend in global wind (1988-2014):
<u>: 0.14 m/s decade (≈2 %)
$<u^2>$: ≈ 3 % decade



If 1: 1: 0.2 "rule" holds:
0.05 Pg C: 1987-1998
0.08 Pg C 1987-2015



Quantitative assessment: the gas exchange coefficient, (k s)

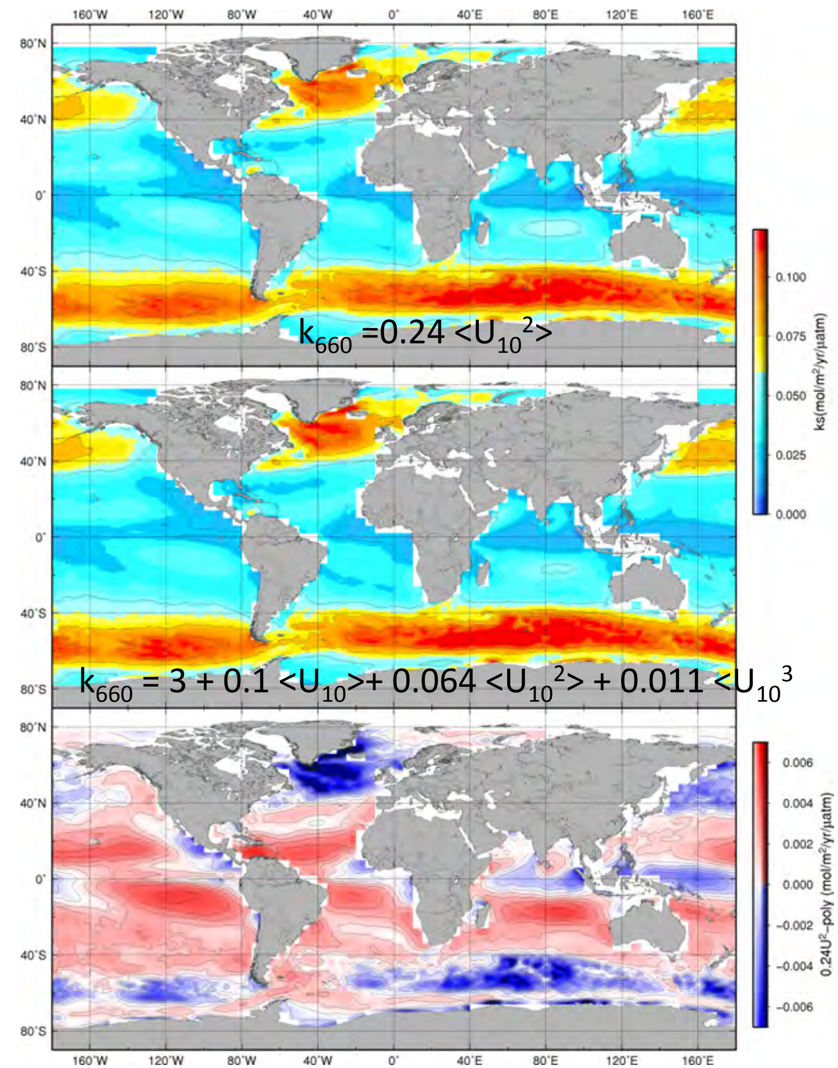
$F = k\ s\ pCO_2$

k & s are (opposing) functions of SST through solubility and Schmidt number

$k*s = mol/m^2/yr/uatm$ (Also called gas transfer coefficient (Takahashi et al. 2009))

Absolute magnitude of ks

Fourfold range over global ocean



Red: $0.24\langle U_{10}^2\rangle$ larger ks than hybrid

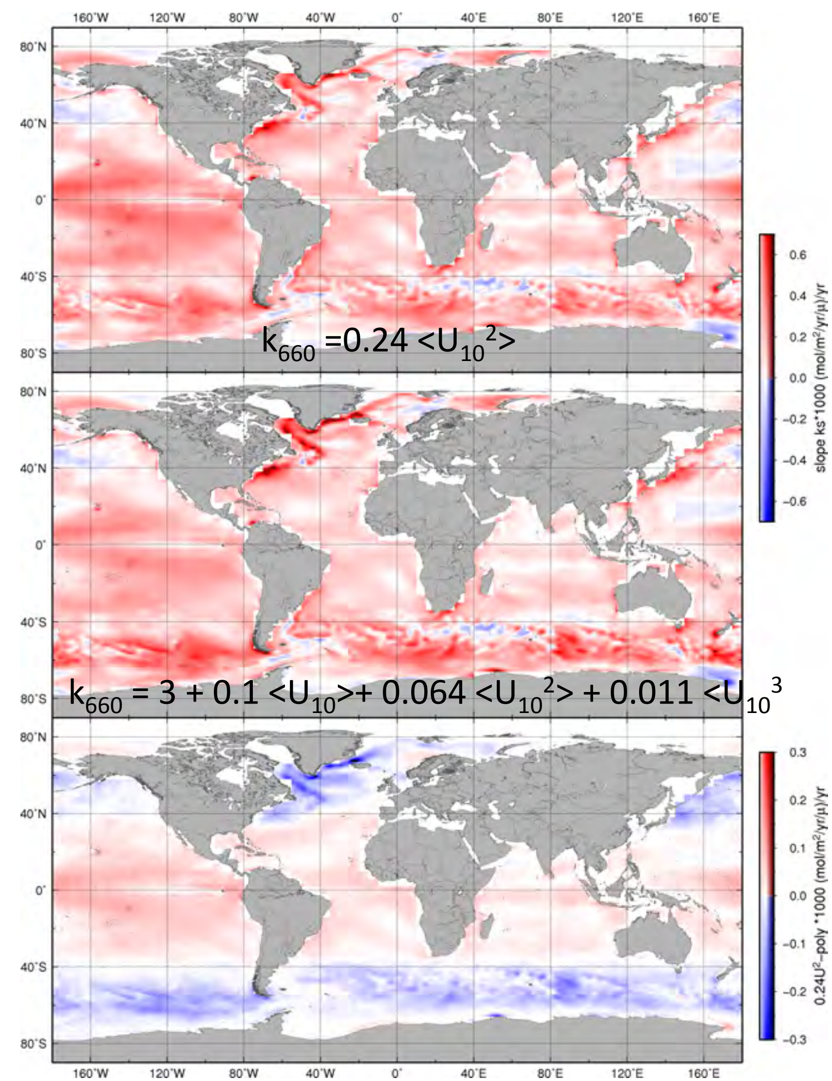
Blue : $0.24\langle U_{10}^2\rangle$ smaller ks than hybrid

Trends: the gas exchange coefficient, k s

Greatest trend :
Equatorial Pacific
40 ˚S in Southern Ocean
Western boundary currents

Largest difference in trends:
Equatorial Region: quadratic larger trend in ks
Southern Ocean: hybrid larger trned in ks

Red: $0.24\langle U_{10}^2\rangle$ larger trend than hybrid
Blue : $0.24\langle U_{10}^2\rangle$ smaller trend than uptake



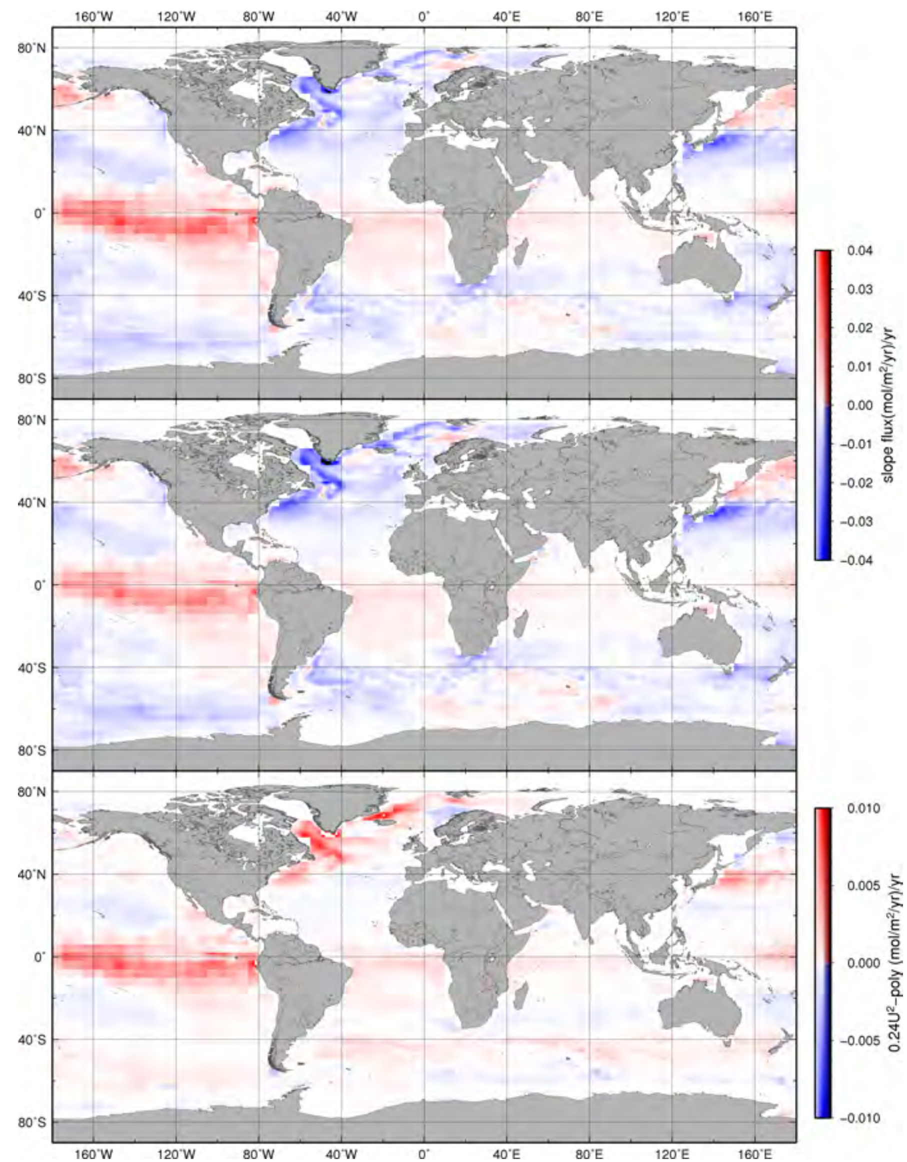
Trends: Global Sea- Air CO_2 Fluxes (Spatial distribution)

Areas of efflux: more release over time
Areas of uptake: more sequestration

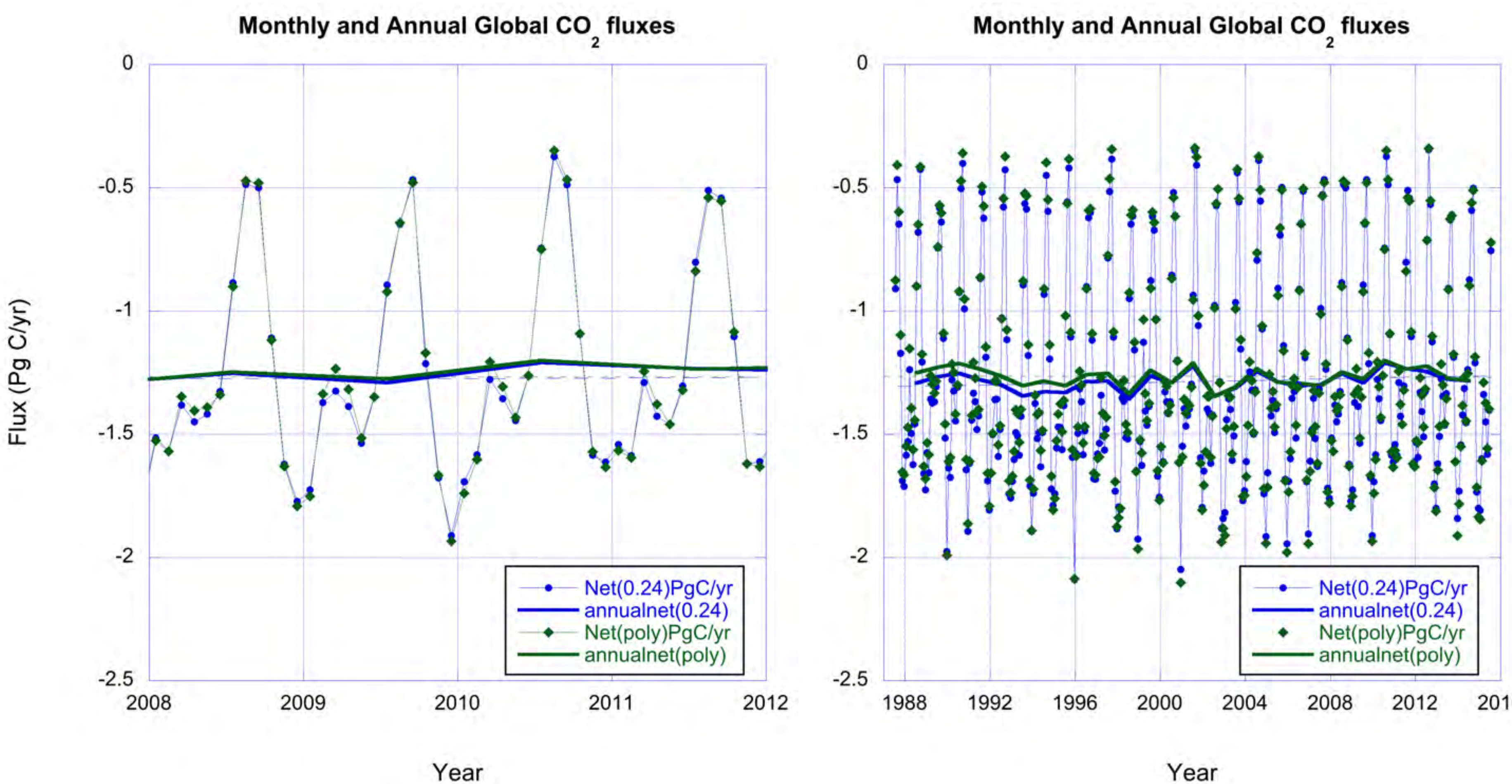
Trend in Sea-Air CO_2 Flux: $0.24\langle U_{10}^2\rangle$

Trend in Sea-Air CO_2 Flux: Polynomial

Red: $0.24\langle U_{10}^2\rangle$ more release/less uptake
Blue : $0.24\langle U_{10}^2\rangle$ less release/more uptake

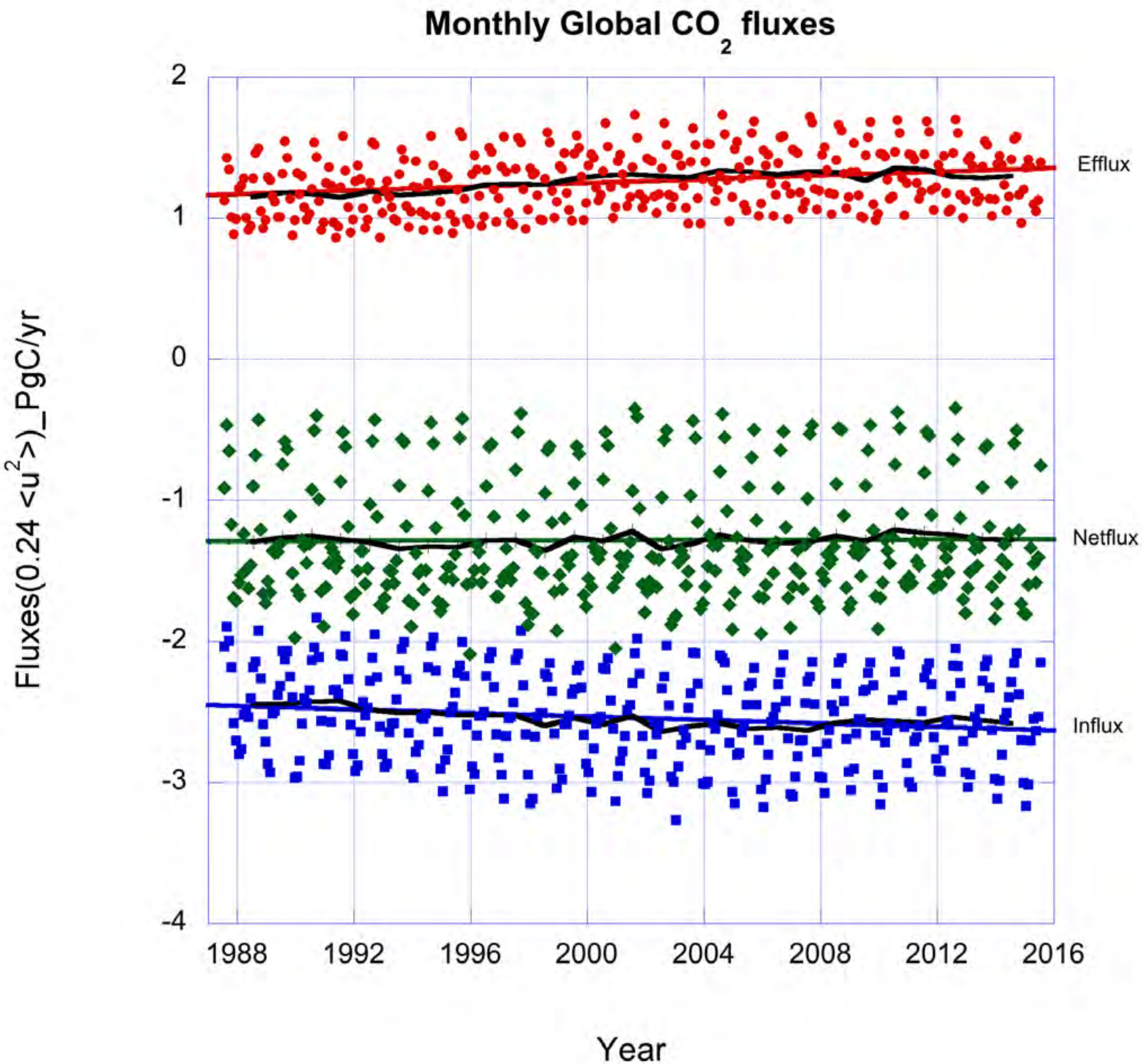


Changes: global sea-air CO_2 fluxes by year



Global Ocean Trend in Sea-Air CO_2 fluxes due to changes in winds: 0.015 ±0.009 Pg C decade (slightly less uptake)

Cause of small trend: Balance of effluxes and influxes

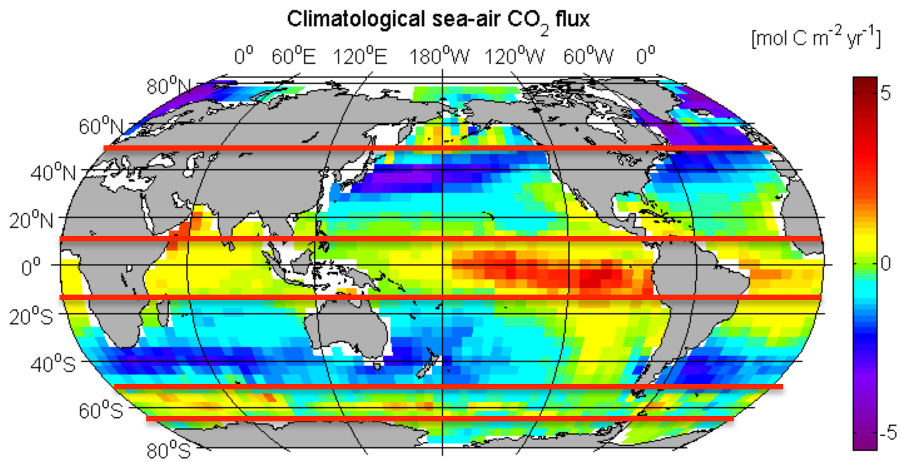


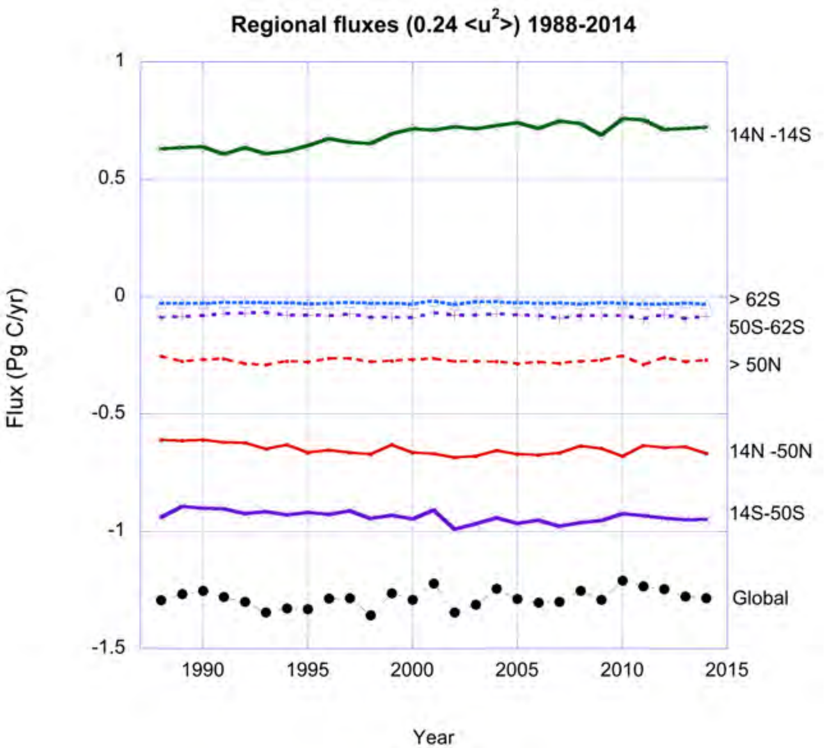
Efflux: 0.071 ±0.009 Pg C decade

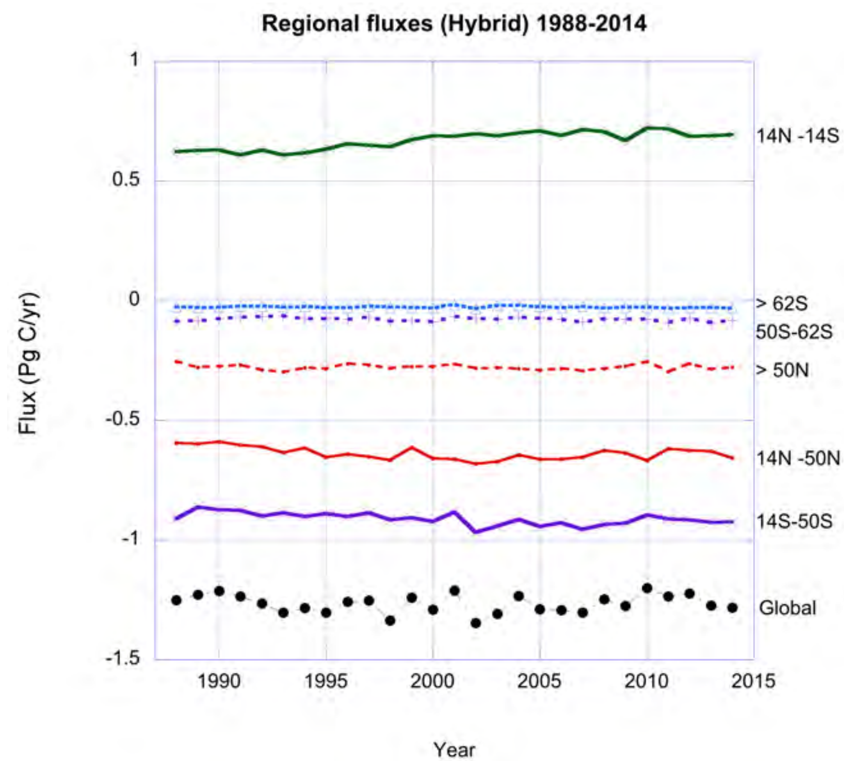
Net Flux: 0.015 ±0.009 Pg C decade

Influx: -0.05 ±0.01 Pg C decade

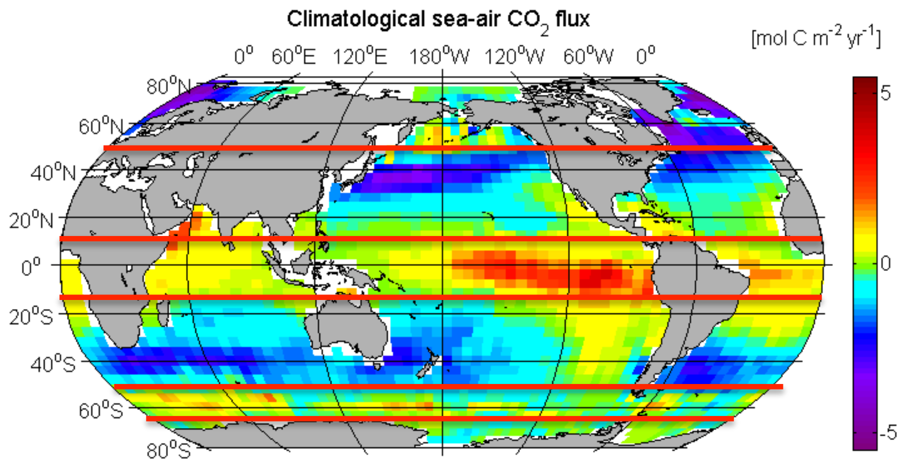
Patterns of Trends: Zonal distribution of Fluxes

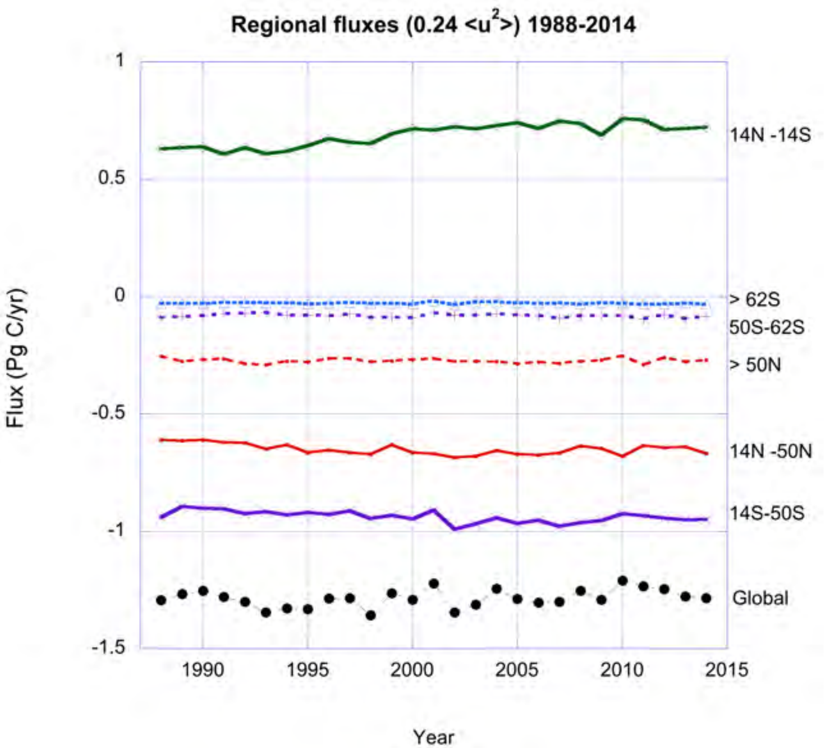


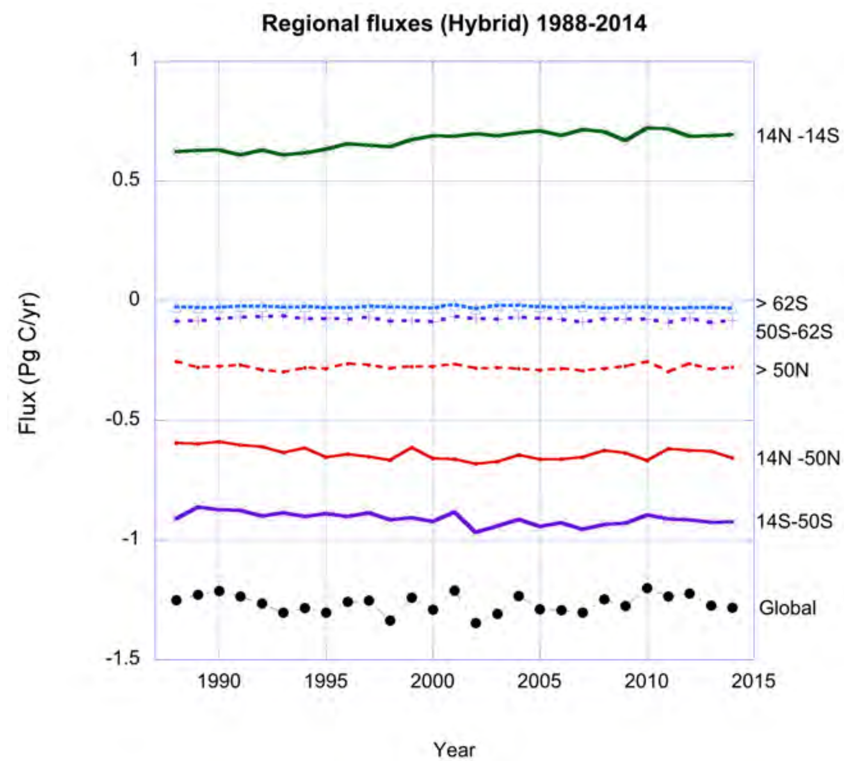




Patterns of Trends: Zonal distribution of Fluxes

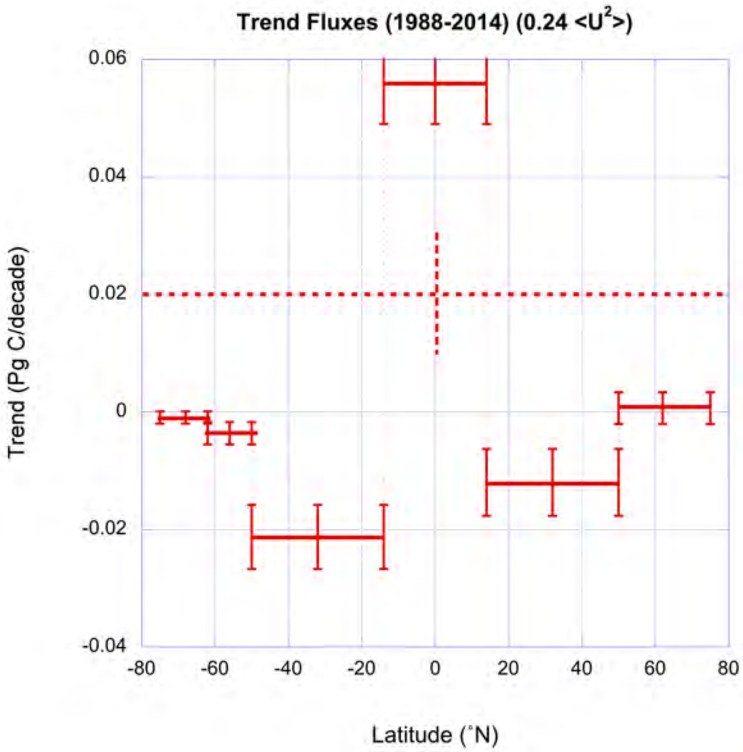




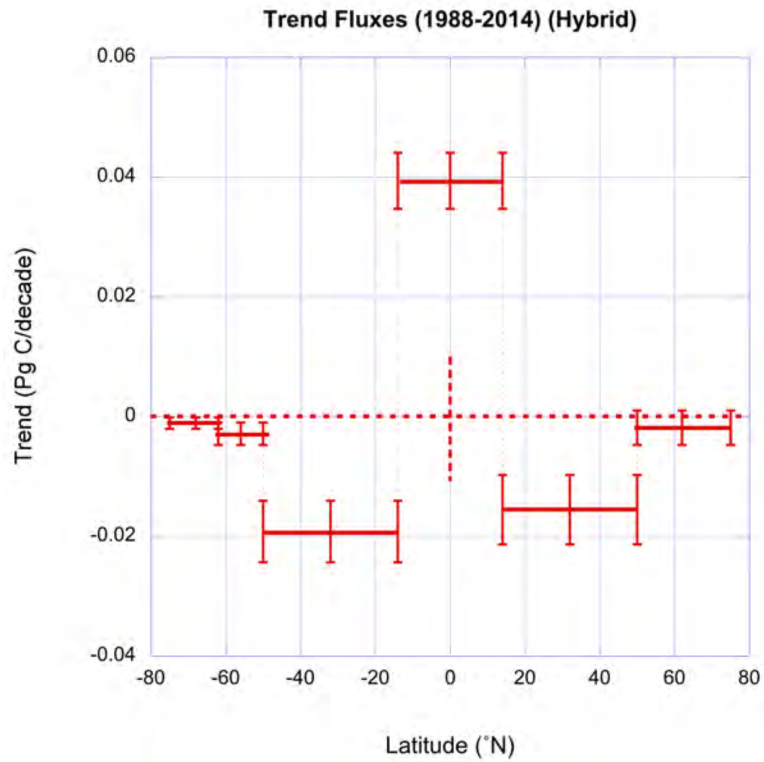


Patterns: Zonal distribution of annual trends in Fluxes

$k_{660} = 0.24 <u_{10}^2>$



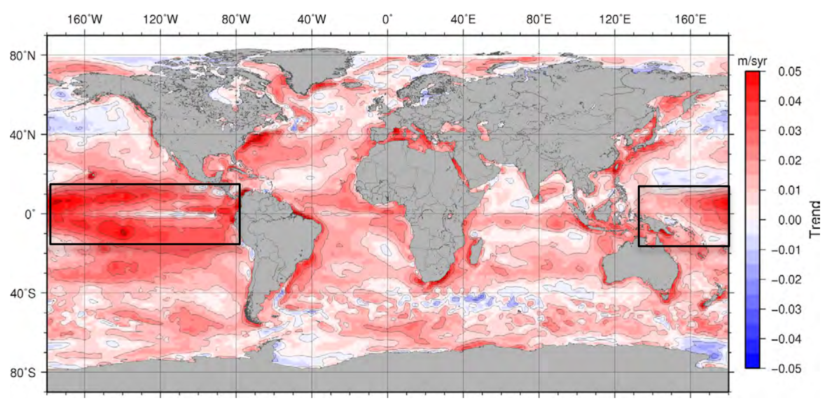
$k_{660} = 3 + 0.1 <u_{10}> + 0.064 <u_{10}^2> + 0.011 <u_{10}^3>$

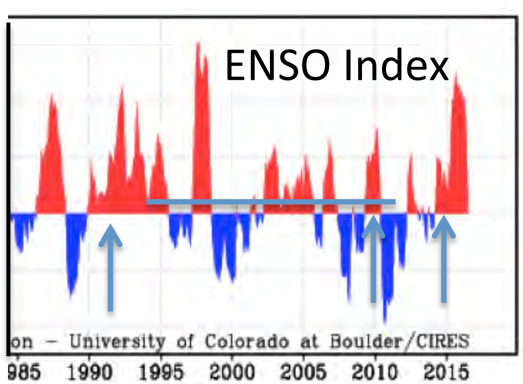


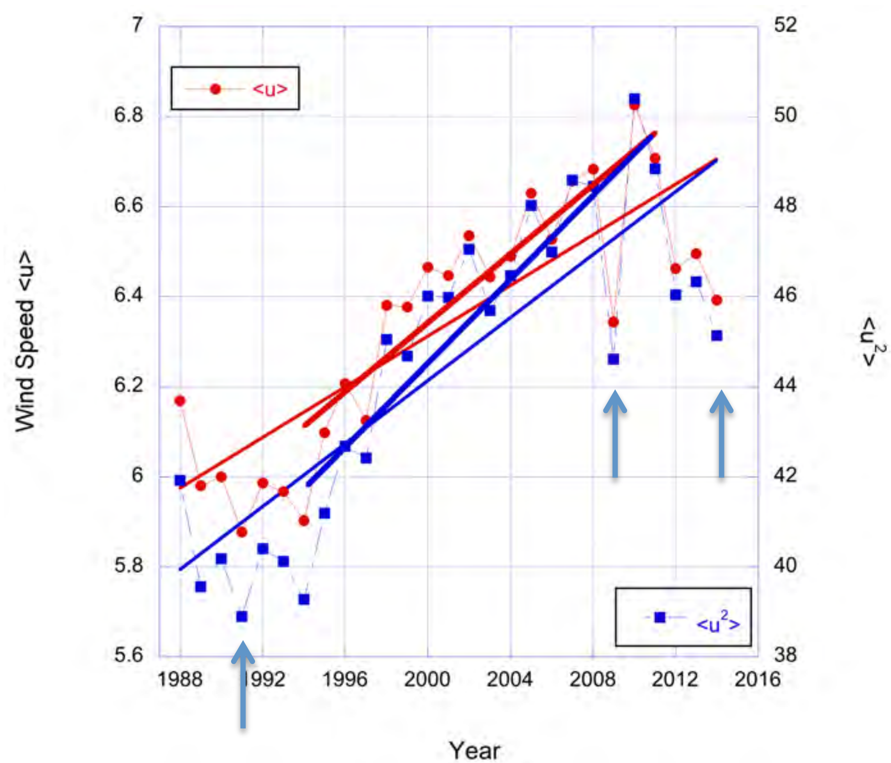
Trends: winds for the Equatorial Pacific
(14 ˚N-14 ˚S , 130 ˚E, 80 ˚W)

Changes in <u>
1988-2014: 0.28 m/s/decade (4.5 %/decade)
1993-2011: 0.38 m/s/decade (6.1 %/decade)

Changes in $\langle u^2 \rangle$
1988-2014: 3.5 $(m/s)^2$/decade (7.7%/decade)
1993-2011: 4.6 $(m/s)^2$/decade (10%/decade)





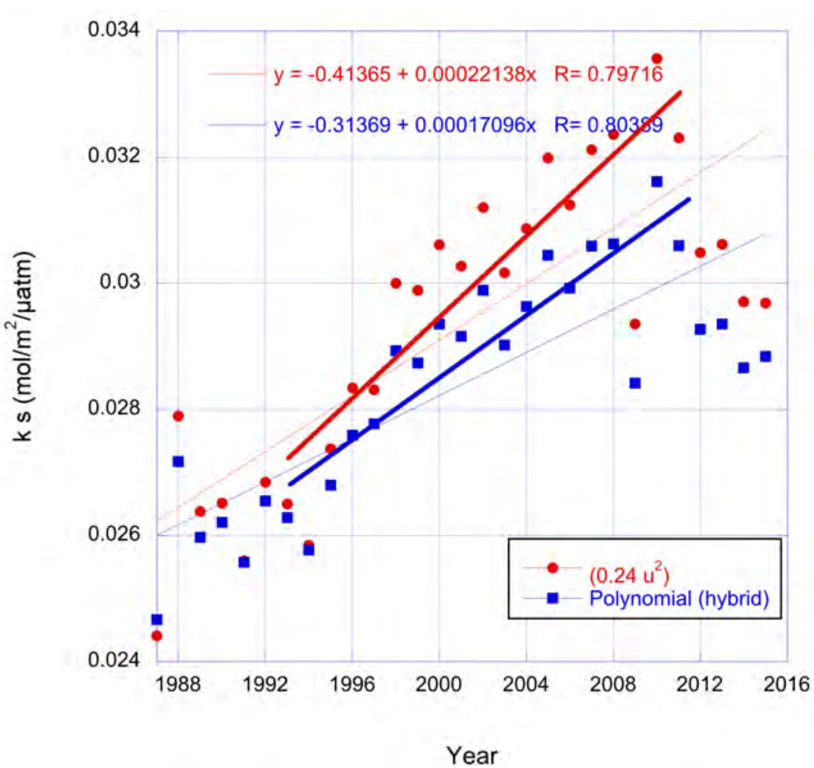


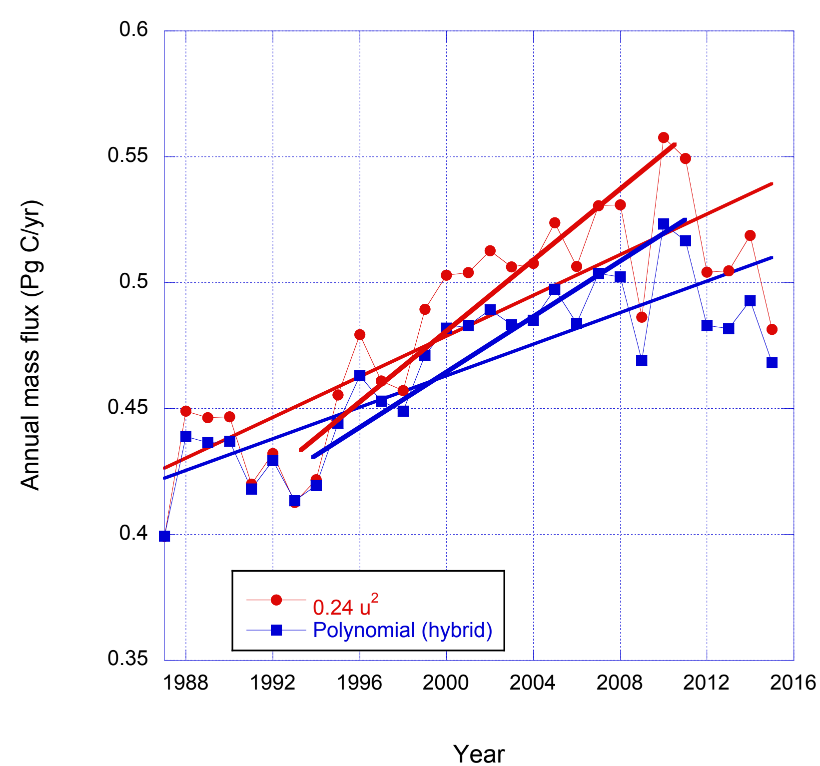
Trends: Fluxes and ks from the Equatorial Pacific

(14N-14S , 130 E, 80 W)

Changes in ks
1988-2014 (quadratic)≈ 7% decade
1993-2011 ≈ 11% decade
Hybrid: changes 29 % less

Changes in Flux
1988-2014 (quadratic)≈ 8% decade
1993-2011 ≈ 12% decade
Hybrid changes: 31 % less

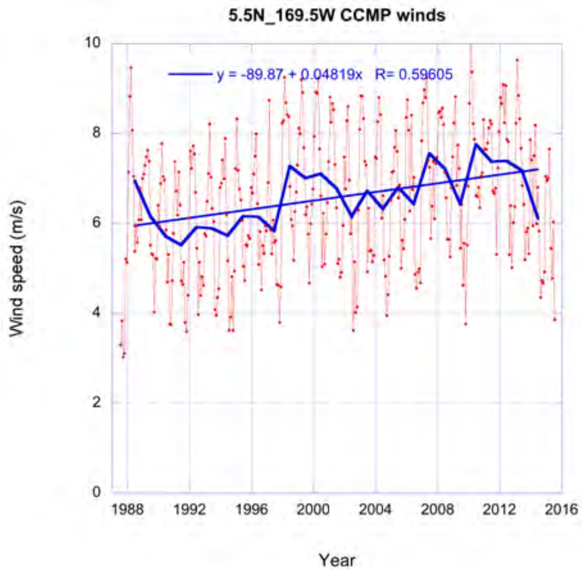




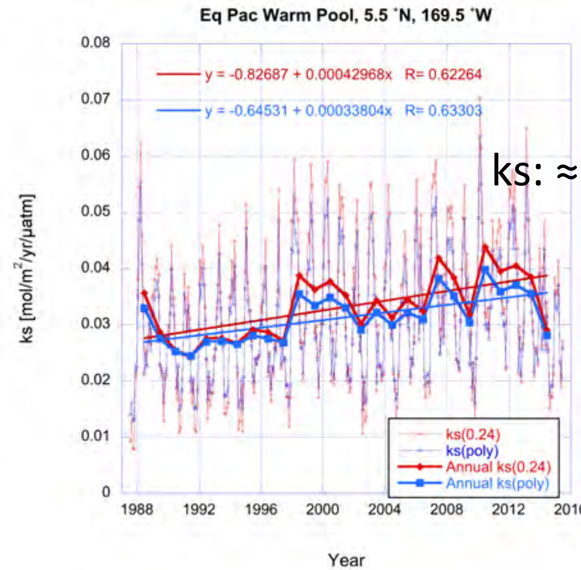
Trends: Effluxes from the Equatorial Pacific (Local)

Tropics (169.5 W, 5.5.N)

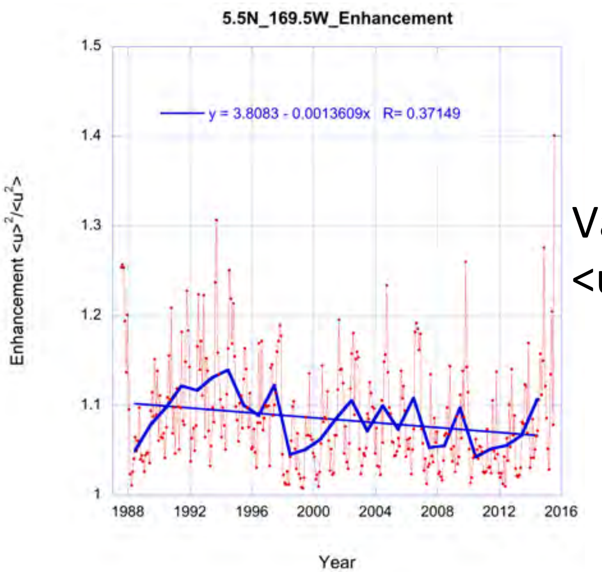
Eq Pac Warm Pool



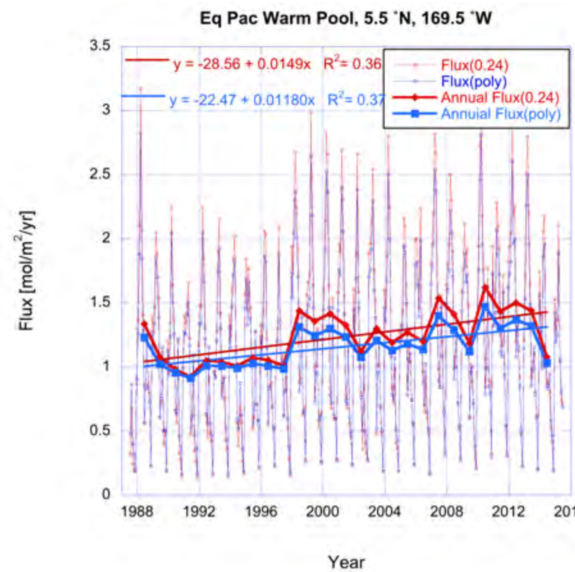
Wind speed increase: 0.5 (m/s)/decade



ks: ≈ 10%/decade



Variability Decrease $\langle u^2\rangle/\langle u\rangle^2 \approx 1$ % decade)



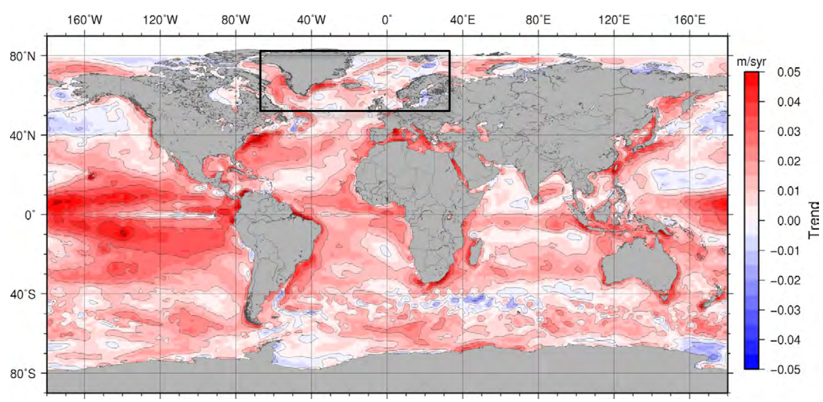
Flux: 9%/ decade

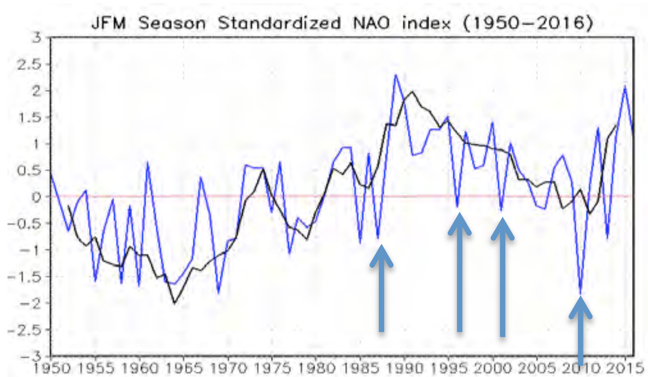
Quadratic 25 % greater change than hybrid

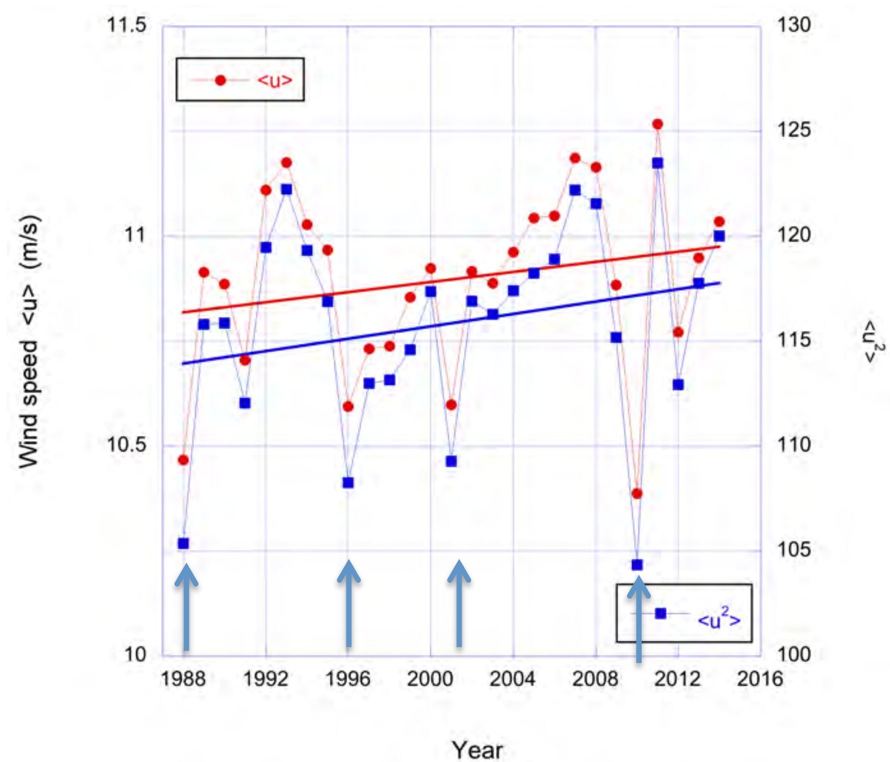
Trends: Changes in winds for the North Atlantic (> 50 ˚N)

Changes in <u>
1988-2014: 0.06 m/s/decade (0.5 %/decade)

Changes in $\langle u^2 \rangle$
1988-2014: 1.4 $(m/s)^2$/decade (1 %/decade)





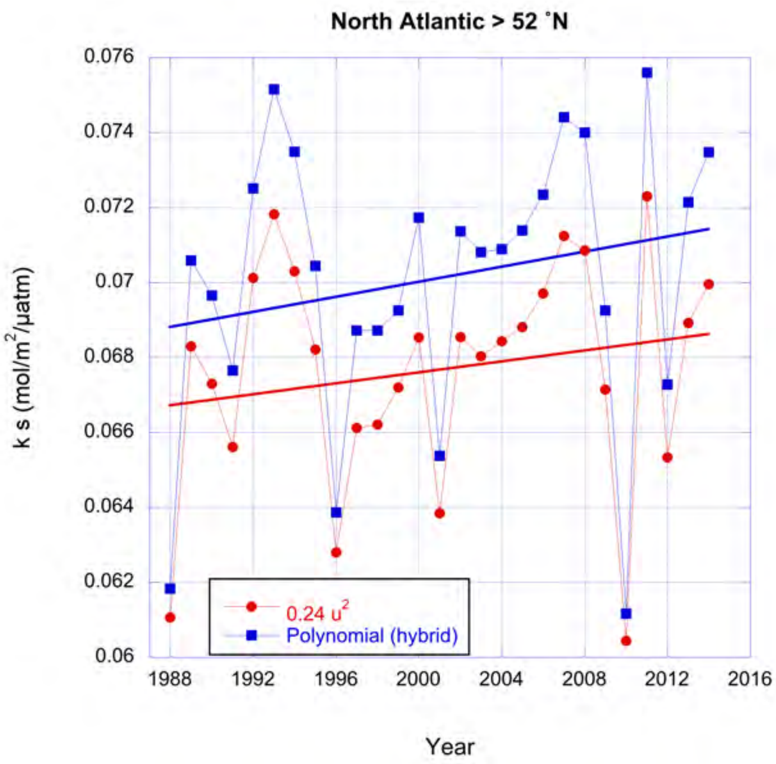


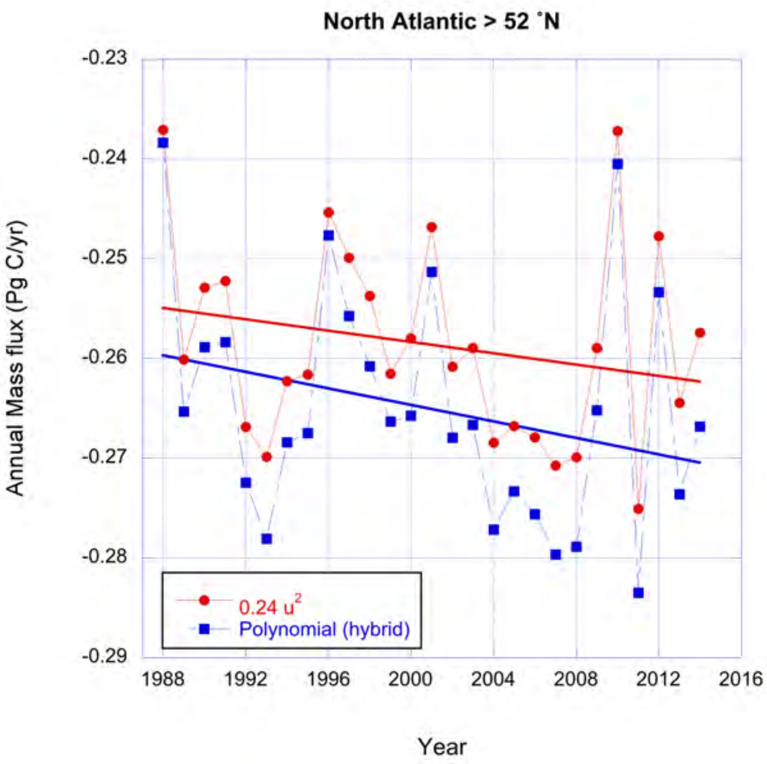
No significant decadal changes in wind

CO_2 Influx into the North Atlantic
(> 50 ˚N)

Changes in ks
1988-2014 (quadratic)≈ 1% decade
(Hybrid) ≈ 1.5 % decade
Hybrid changes: 46 % greater

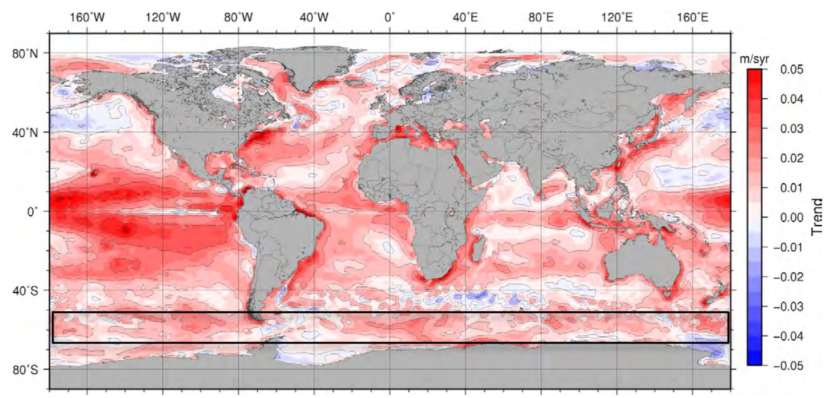
Changes in Flux (greater uptake)
1988-2014 (quadratic)≈ -1% decade
(Hybrid) ≈ -1.6 % decade
Hybrid changes: 46 % greater

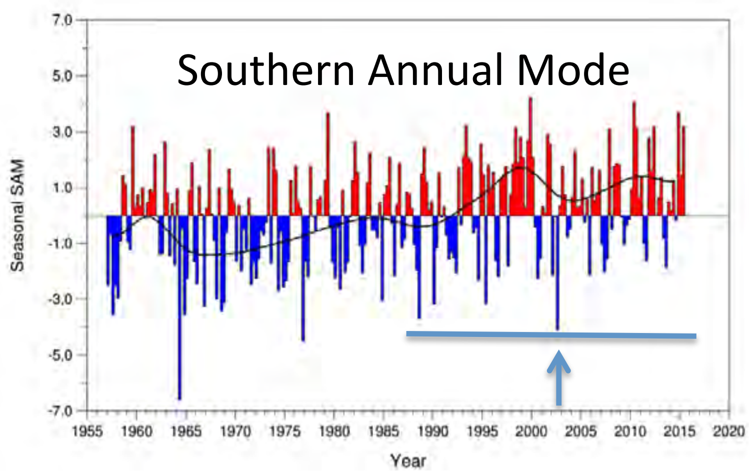




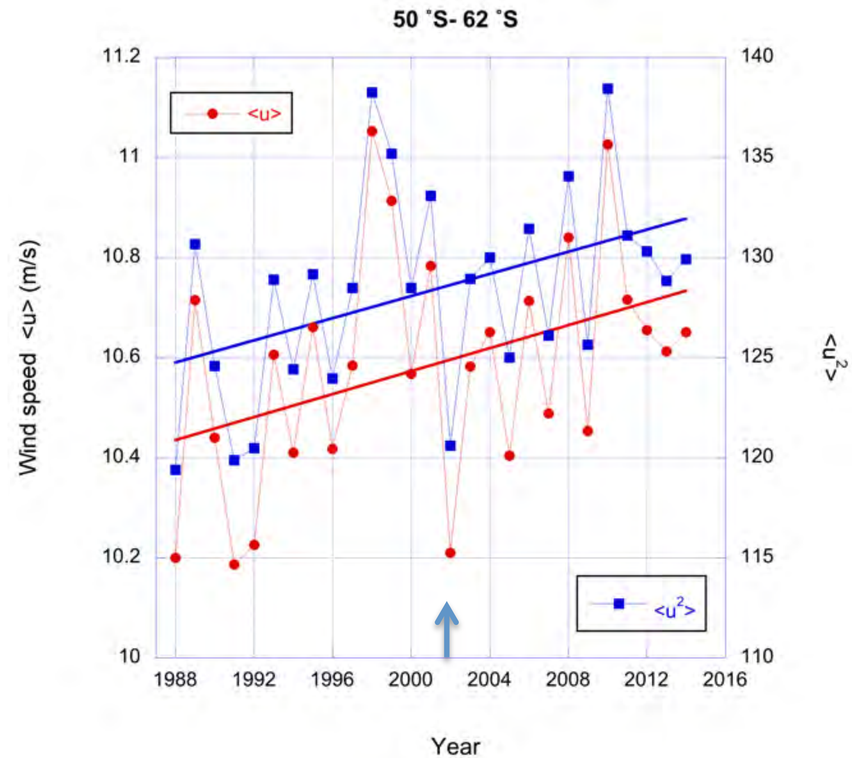
Trends: Changes in winds for the Southern Ocean (50 ˚S- 62 ˚S)

Changes in <u>
1988-2014: 0.1 m/s/decade (1 %/decade)





Changes in <u^2>
1988-2014: 2.7 (m/s)^2/decade (2 %/decade)

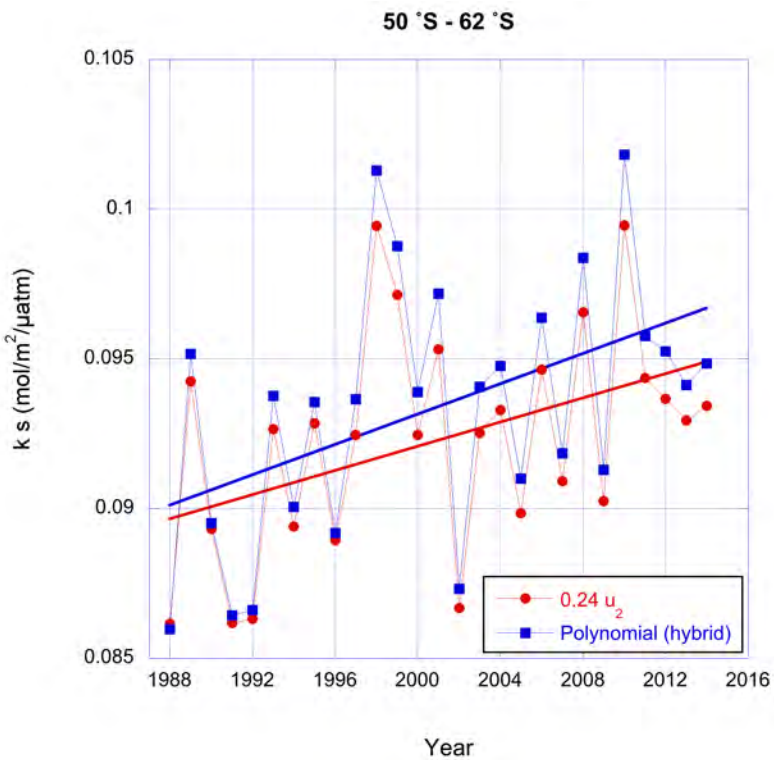


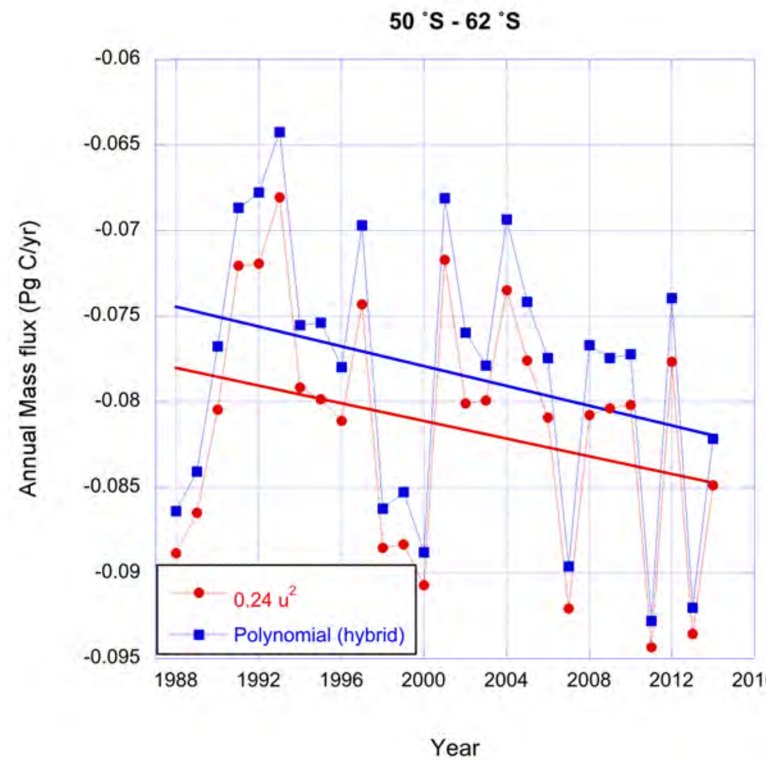
CO_2 Influx into the Southern Ocean

(50 ˚S – 62 ˚S)

Changes in ks
1988-2014 (quadratic)≈ 2% decade
(Hybrid) ≈ 2.7 % decade
Hybrid changes: 36 % greater

Changes in Flux (greater uptake)
1988-2014 (quadratic)≈ -3% decade
(Hybrid) ≈ -3.7 % decade
Hybrid changes: 25 % greater





Southern Ocean (50-62 ˚S: significant trends, small magnitude of fluxes

Conclusions

The effect of changing winds using a constant monthly pCO_2 climatology

- Global winds in the CCMP-2 product have increased by about 0.4 m/s over 26 years (1988-2014)
- Largest regional change is in the Equatorial Pacific with an increase of 0.7 m/s
- Change in global air-sea CO_2 fluxes relatively small due to compensation of increases with decreases
- Difference in quadratic and polynomial parameterizations has a small effect on trend in global scale fluxes with quadratic showing an increase in efflux and hybrid model showing no trend
- Effect of changes in wind is generally much smaller than impacts of changing ΔpCO_2 on fluxes with the direction of the trend (≈0.015 Pg C/decade being opposite and much smaller than the trend caused by changes of ΔpCO_2 (-0.15- 0.35 Pg C decade)