Climatological Net Sea-Air CO_2 Flux over the Global Oceans
"the 2005 edition"

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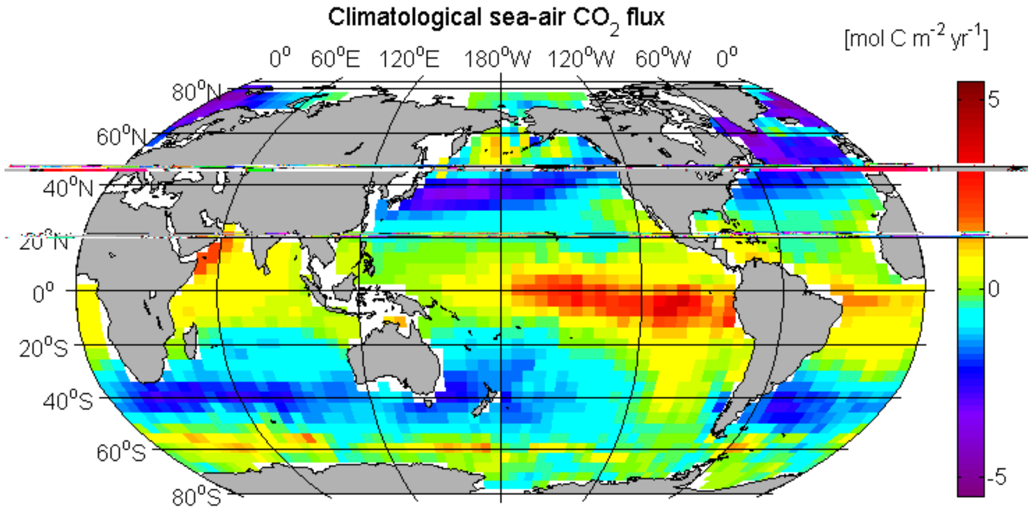

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<u>Outline</u>

- Describe rationale of Takahashi et al. global surface water pCO_2 data base
- Provide a description of conversion of data to sea-air CO_2 flux climatology
- The 2005 results
- Differences with the 2000 climatology
- Derived products from the Takahashi climatology (variability & trends, OA products)

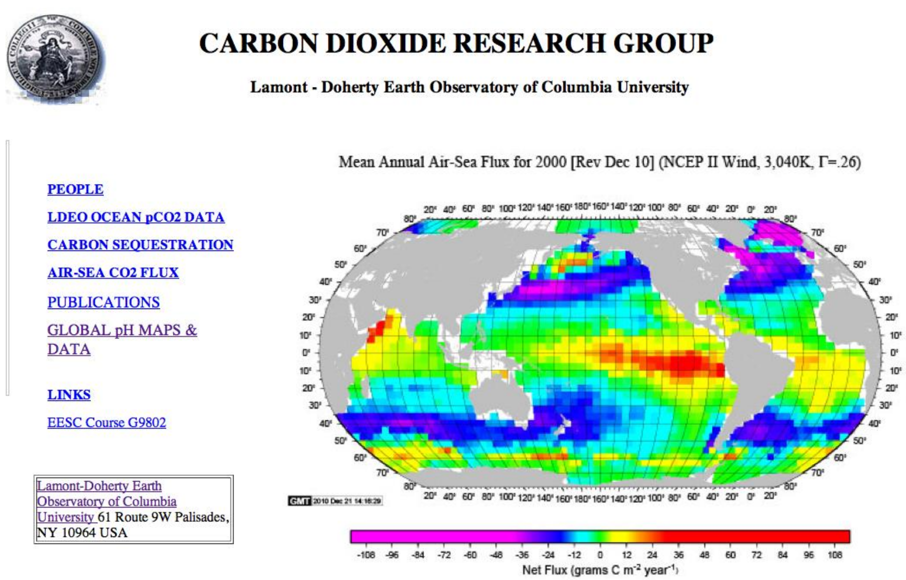
Data Access: A. http://cdiac.ornl.gov/oceans/LDEO_Underway_Database/

*LDEO Database V2012 NDP-088(V2012) (metadata)

*LDEO Database V2012 Files

* WAVES: LDEO Database V2012 Search

B. http://www.ldeo.columbia.edu/res/pi/CO2/

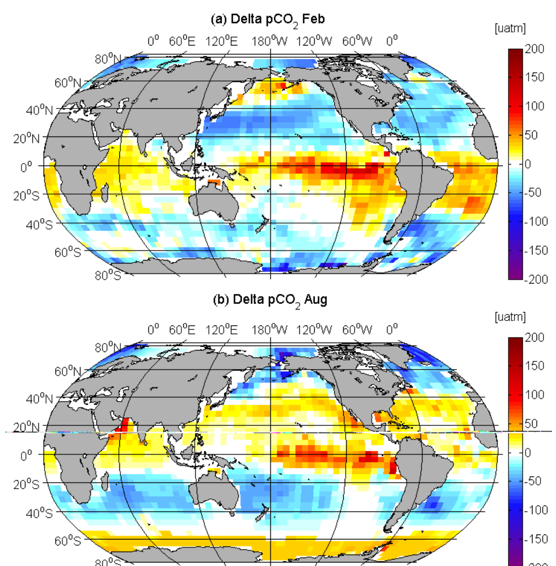


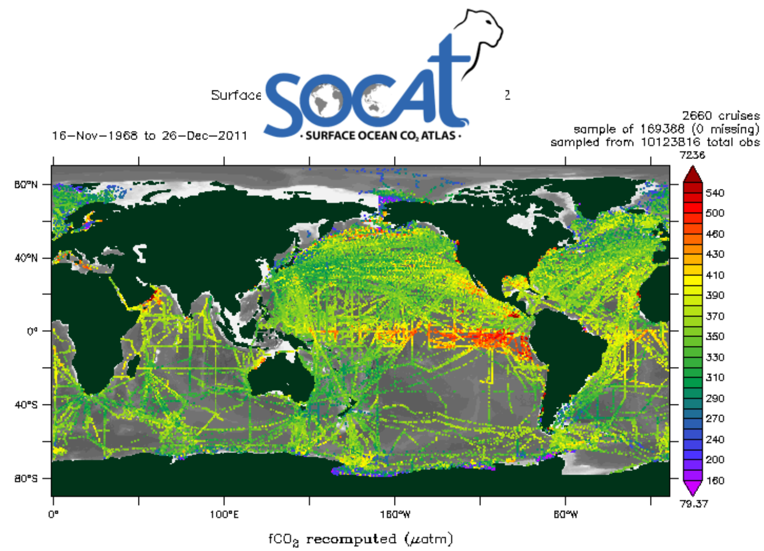
- *pCO_2 climatology is public*
- *Sea-Air flux climatology is in preparation*

Rationale behind the Takahashi effort

(and differences with SOCAT)

1. Primary purpose is to create a climatology
2. Data is obtained from direct contact with PI and through CDIAC
3. Data acceptance/rejection based on personal criteria
4. Data assembly and QC is done by a (very) small group
5. Initial data release was done at request of community
6. Limited traceability of data- it is expected that PI or CDIAC serves original data and metadata
7. Original data used is XCO_2 (@Teq), $SST_{in\ situ}$
8. Remotely sensed winds, pressure, and SST

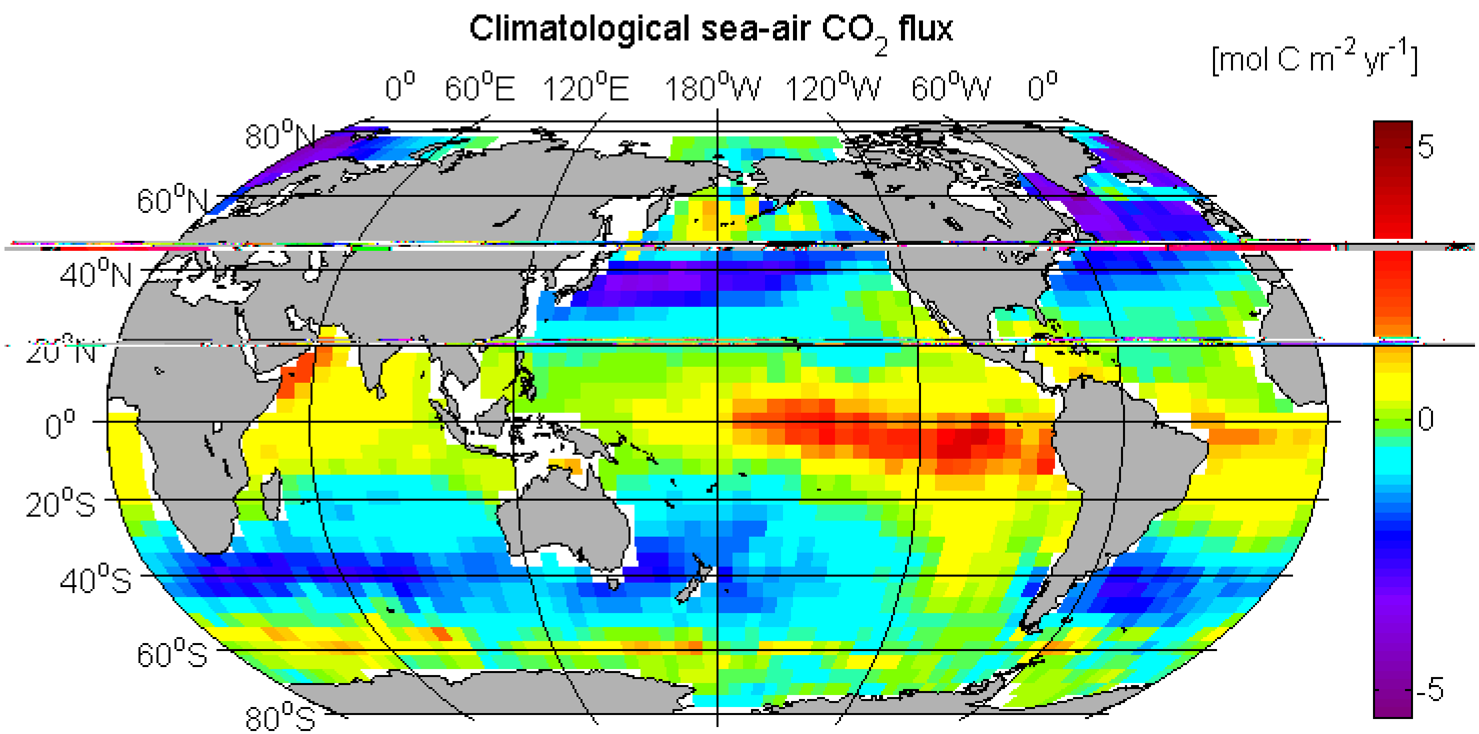




2005 CO_2 Flux

2005 Climatological Sea-Air CO_2 fluxes

Using interpolated 2005 CCMP WS



Data treatment 2005 climatology

- > 10 million data points

- Obtain daily mean pCO_2 value within a box, and correct the observed values to a single reference year of 2005. A global ocean mean rate of increase is taken to be 1.5 µatm to correct pre-2000 measurements to the reference year 2005, and 1.8 µatm/yr to correct the post-2000 measurements
- Values adjusted to Day in 2005 are averaged and centered in each 4˚ x 5˚ box
- The values ware interpolated using the advection-diffusion equation by solving it iteratively with one day as a time step.
- The one-day time step is needed for obtaining stable iterative solutions.
- Because large size of boxes and variability in boxes. A mean monthly pCO_2 value for 4˚ x 5˚ box is the best representation of real ocean climatology

Data Distribution

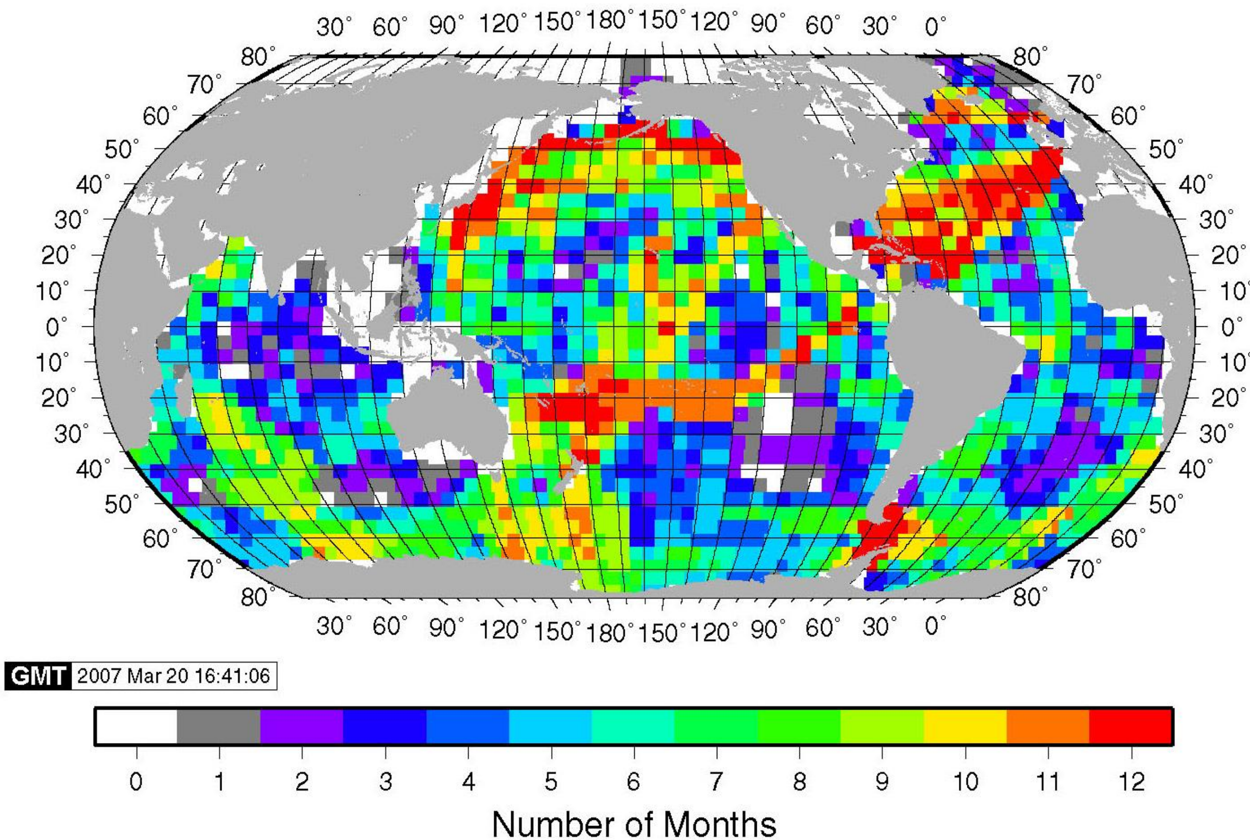
Data limitation remains an important issue for the climatology

(6-10 observation per year per 10 ˚)

A Large-Scale CO2 Observing Plan: In Situ Oceans and Atmosphere (LSCOP). Bender et al., 2002

Number of Months With at Least One Observation

2000 climatology

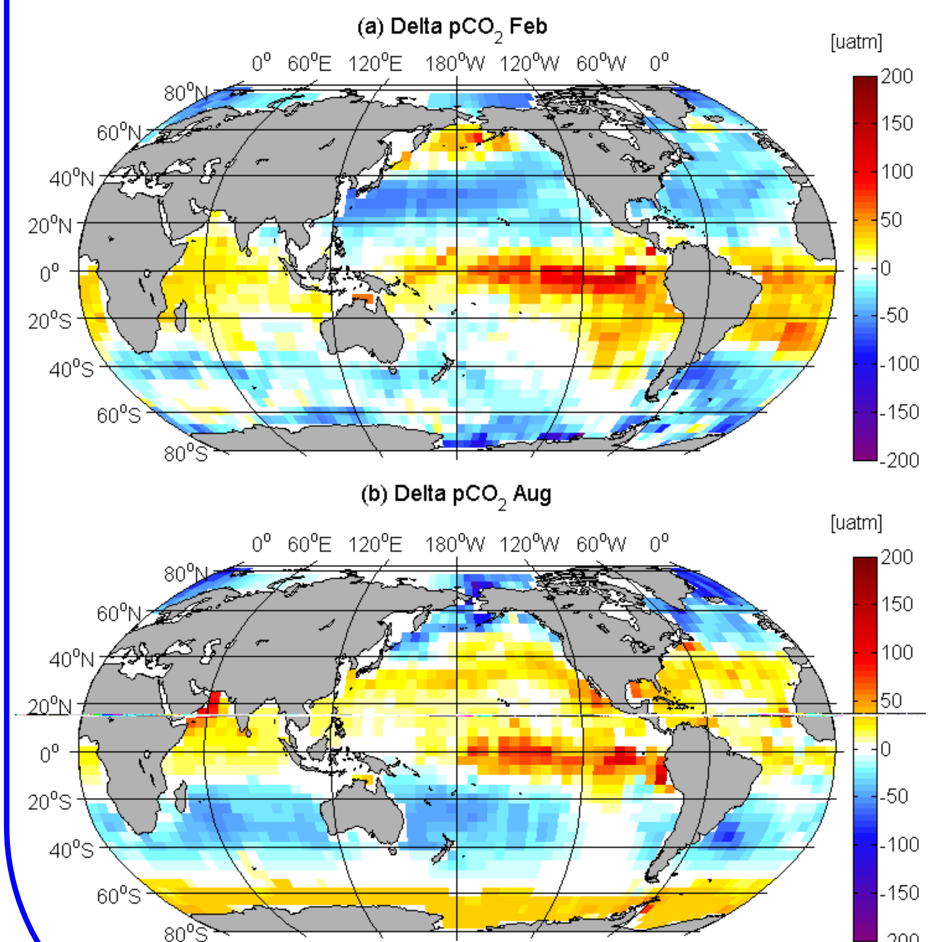


2005 CO_2 Flux

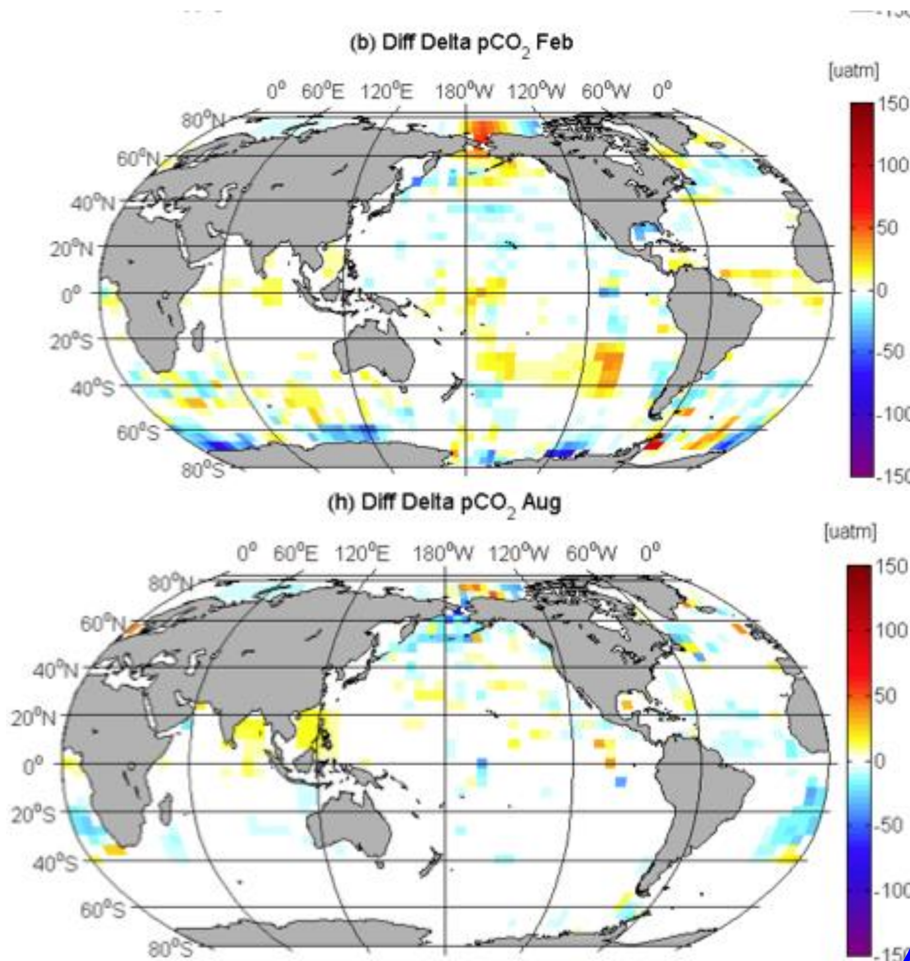
ΔpCO_2 maps, 2005 climatology

Differences due the data coverage and not (necessarily) due to natural trends

2005 ΔpCO_2 climatology



2005-2000 climatologies



Calculation of Sea-Air CO_2 Flux

$$\text{Flux} = K_0 \quad \Delta pCO_2 \quad 0.251 \quad \langle U^2 \rangle \quad (Sc/660)^{-0.5}$$

- XCO_2 air values are from the NOAA Greenhouse Gas Boundary Layer Reference (http://www.esrl.noaa.gov/gmd/ccgg/mbl/index.html). Because the GLOBALVIEW does not provide 2-dimensional matrix (time versus latitude) of CO2 values anymore.

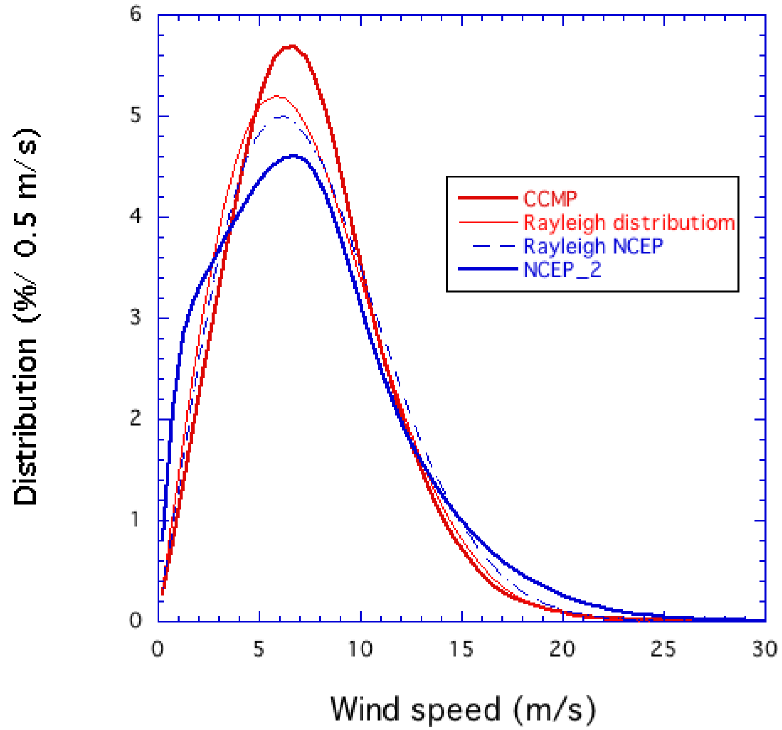
- Sea-ice coverage: 2005 NCEP/DOE reanalysis 2 surface ice concentration fields

- Wind speed (WS) is the 6-hour (4 times a day) 0.25˚ Cross Calibrated Multi-Platform (CCMP) that is squared and then averaged over 1 months and 4˚ by 5˚ to obtain $\langle U^2 \rangle$ (2^{nd} moment of winds)

Global wind product

Cross-Calibrated multi-platform (CCMP) 0.25 ˚ 6-hr product (*Atlas et al, 2011*)
http://podaac.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L3_OW_L2_5_SSMI_F14_WIND_VECTORS_FLK

The CCMP data set includes cross-calibrated satellite winds derived from SSM/I, SSMIS, AMSR-E, TRMM TMI, QuikSCAT, SeaWinds, WindSat and other satellite instruments as they become available from Remote Sensing Systems REMSS.
There is a strong correspondence with the ECMWF winds

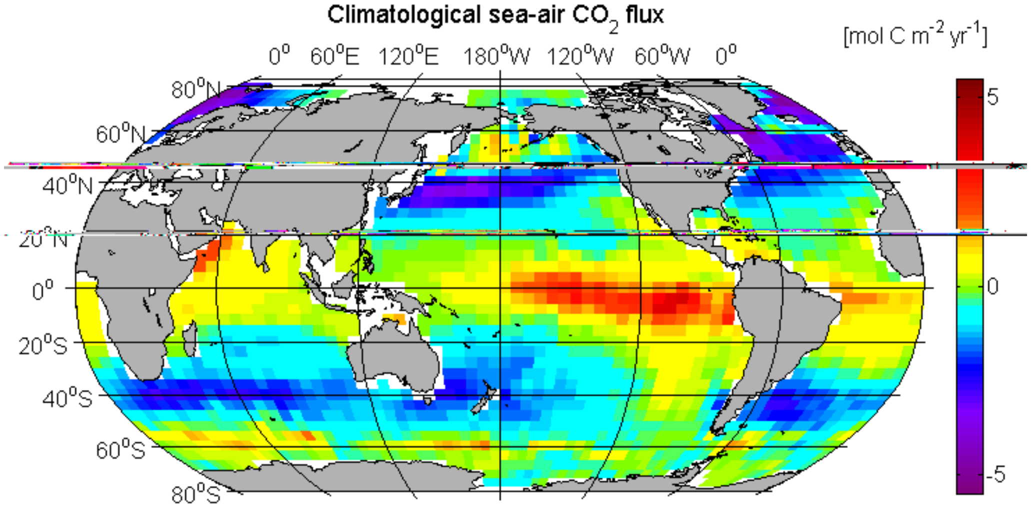


Current record 1990-2009

2005 Climatological Net CO_2 fluxes

Using interpolated 2005 CCMP WS

-1.3 Pg C yr^{-1}



Flux calculation Pg C yr^{-1} *(G.-H. Park, KIOST)*

Wind Speed product	2005 ΔpCO_2 Clim	2000 ΔpCO_2 Clim
Interpolated 2005 CCMP <U^2>	-1.33	-1.22
2005 CCMP <U^2>	-1.33	-1.23
Interpolated 20-year mean CCMP <U^2> (1990-2009)	-1.31	-1.20
20-year mean <U^2> (1990-2009)	-1.32	-1.21
Diff 2005-2000 flux	-0.10	

Anthropogenic Sea-Air CO_2 Fluxes

(including coastal ocean area)

Summary of different components of the global-integrated sea-air flux estimate including their uncertainty

	Year 2000 (Takahashi et al., 2009)			Year 2000 Updated estimate		
	Pg C yr^{-1}	%	Pg C yr^{-1}	Pg C yr^{-1}		
Net Flux	-1.42			-1.18		
ΔpCO_2		±13%	±0.18		±0.18	
k		± 30%	±0.42		±0.2	
Wind (U) (NCEP-R2)		± 20%	±0.28	(CCMP)	±0.15	
$<d(pCO_{2w})\ dt^{-1}>$[b]		± 35%	±0.5		±0.5	
Under-sampling[c]	-0.2			-0.2		
Pre-industrial flux	0.4		± 0.2	0.45	± 0.2	
Coastal area				-0.18		
Anthro CO_2 flux	-2.0	± 40 %	± 0.8[d]	**-2.0**	**± 0.6**	± 30%

For non El-Niño year 2000 (adapted from section 6, T-09).

[a]Details on the updated estimate are provided in text

[b]$<d(pCO_{2w})\ dt^{-1}>$ represents the error due to uncertainty in the mean rate of pCO_{2w} change (1.5 ± 0.2 µatm yr^{-1}) used for correcting observed values measured in different years to reference year 2000.

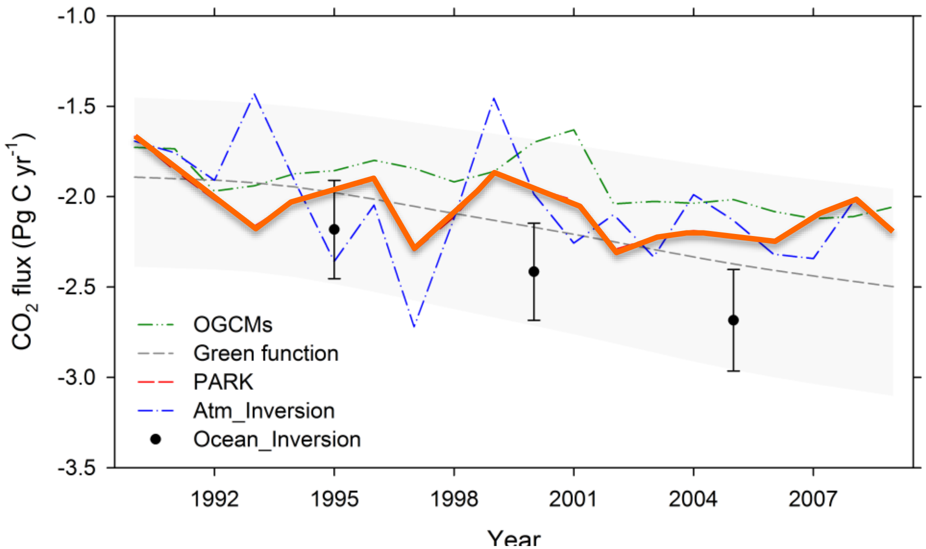
[c]The bias due to spatial undersampling is determined by using the temperature bias of 0.08 ˚C between the measured SST in the data used in the T-09 climatology and a comprehensive independent global SST climatology. For an iso-chemical temperature dependence of 4.2 % ˚C^{-1} for pCO_{2w}, this translates into a pCO_{2w} bias of 1.3 µatm that in turn leads to a bias in global-integrated flux of -0.2 Pg C yr^{-1}.

[d]Listed as ± 1.0 in T-09

Wanninkhof et al. BG 2013

Applications: Variability and trends

Trend estimates based on climatology and local sub-annual SST-pCO_2 relationships created from the climatology.



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			
O_2/N_2^i	−2.5	±0.7			

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2005 CO_2 Flux

Applications: Ocean Acidification Parameters

Derived products using other inorganic carbon parameters, S, T

Aragonite Saturation State (indicator of overall health of calcifying organisms)

$\Omega_{Ar} = [Ca^{2+}]\ [CO_3^{2-}]/K_{sp}$

$K_{sp} = f(T,P)$

$[Ca^{2+}] = f(S) \approx 10{,}000\ \mu mol$

$[CO_3^{2-}] = f(DIC, pCO_2) \approx (CA\text{-}DIC) \approx 200\ \mu mol.$

Takahashi and Sutherland, submitted