Air-Sea CO₂ Fluxes: Climatology, Variability and Land-Ocean Links

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Quantifying the Sources and Sinks of Atmospheric CO₂ Keck Institute for Space Studies March 2, 2010

Overview

- pCO_2^{ocean} and air-sea CO_2 fluxes
- Climatological fluxes
- Interannual variability
- Trends in the CO₂ flux?
- Land-ocean linkages

Conclusions

- Mean flux for 1990's-early 2000's now known to ±0.3 PgC/yr
- Interannual variability ±0.5 PgC/yr
- Sink trends cannot be distinguished
- Land-water carbon transfers likely quantitatively significant at regional scale

Climatological air-sea CO₂ flux



Takahashi et al. 2009

Dominant flux control is surface ocean pCO₂

pCO₂^{ocean} is determined by

Solubility effects



WARM

COLD

Biological effects



Solubility effect of temperature



COLD

Cooling waters absorb CO₂ Warming waters release CO₂

Impact of Atmospheric pCO₂





Biological effect



Biological effect





Seasonal cycle due to convection and biology





(1) Cooling of northward flowing waters(2) High biological productivity



Upwelling drives return of cold and carbon-enriched deep waters to surface

Updating the Climatology

1995: 2.0 ± 1.2 PgC/yr



Takahashi et al. 2002

2000: 2.0 ± 1.0 PgC/yr



Takahashi et al. 2009



Data Density



Compare to ocean inversion



Gruber et al. 2009

Climatological flux 1990's-early 2000's

Paper (method)	PgC/yr
Gruber et al. 2009 (ocean inversion)	2.2 ± 0.3
Takahashi et al. 2009 (insitu pCO ₂)	2.0 ± 1.0

Variety of methods now agree within uncertainty

Variability in the air-sea CO₂ flux



Sarmiento and Gruber 2002

Interannual variability dominated by ENSO cycle



0. 1. 2. 3. 4. 5. 6. 7. 8.





-8. -7. -6. -5. -4. -3. -2. -1.

McKinley et al. 2004a

Forward models and inversion of Rodenbeck et al. (2003) agree



McKinley et al. 2004b

Trends?

Reduction in fraction stored in the ocean (Canadell et al. 2007)



Fig. 2. Fraction of the total emissions (F_{Foss} + F_{LUC}) that remains in the atmosphere (A), the land biosphere (B), and the ocean (C).

Increasing doubt about AF trends...

- "The hypothesis of a recent or secular trend in the AF cannot be supported on the basis of the available data and its accuracy." *Knorr 2009*
- "Suggestions that the carbon cycle is becoming less effective in removing CO₂ from the atmosphere can perhaps be true locally, but they do not apply globally..." Tans 2009



Tans 2009

Regional Trends in Ocean?



LeQuéré et al. 2009

Southern Ocean Trends?

S. Ocean (45S-90S)

Atmospheric inversion and forward ocean model



LeQuéré et al. 2007

But coarse forward models may overpredict increased outgassing of preindustrial CO_2 with increasing winds



North Atlantic Trends?



VOS datasets, linear pCO₂ trend 1990-2006 (Schuster et al. 2009)

Data of Corbiere et al. 2007 Shuster & Watson 2007 Bates 2007 Olsen et al. 2004 Santana-Casiano et al. 2007



0



W. Subpolar Gyre SURATLANT



Study	Years	Trend (µatm/yr)
	DATA	
Corbière et al. 07	93-03	2.8
Schuster et al. 09	93-05	4.0 ± 0.48
	MODELS	
Thomas et al. 08	95-04	3.0
Ullman et al. 09	92-06	0.9 ± 0.02

Inversion of Rodenbeck et al.'05 suggests increasing sink

Land – Ocean Linkages

Coastal CO₂ Flux Estimates in The First State of Carbon Cycle Report





Net efflux in North American coastal oceans: **+1.6 ± 35.6 Tg C y**⁻¹

Chavez et al. (2007)

Highly variable



SOCCR Fig 15.5

Lateral fluxes and processing in inland waters --- globally significant



Cole et al. (2007), Tranvik et al. (2009)

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