Constraining Fluxes at the Top:
Advances in Quantifying Air-Sea Carbon Dioxide Fluxes during the JGOFS Decade

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Outline:
- New techniques for determining gas transfer velocity
- Parameterization of pCO$_2$ from SST, SSS, Chl and nutrients
- Estimation of global CO$_2$ air-sea fluxes

\[ F_{av} = (k s \Delta pCO_2)_{av} \]

**Gas transfer velocity**
- Function of:
  - Surface turbulence (wind speed)
  - Physical properties of gas and water

**Thermodynamic component**
- Function of:
  - Temperature, Salinity, TCO$_2$
  - Biology (photosynthesis/respiration)
  - Transport (horizontal/vertical)

(Takahashi et al. 2002)
**CO₂ transfer velocity & exchange coefficient (K-ks):**

Monitoring using satellite wind speed (Geosat, SSM/I, ERS, QSCAT... 1985-2002)

K over Global ocean (k-U Wanninkhof (1992) relationship)

**Gas Transfer Velocity: Wind Speed and Mean Square Slope Dependence**

Data from 1997 NSF CoOP Coastal Air-Sea Exchange Experiment [Frew et al., 2003]

N. Frew / D. Glover WHOI 2003
CO₂ gas transfer velocity: summary and issues

- Monitoring of k using satellite wind speed (Geosat, SSM/I, ERS, QSCAT…) 1985-present
  and a given k-U relationship: Strong k variability (including interannual)

  **Issue:** Need for intercalibration of U retrieved from various instruments

- K deduced from various k-U relationships differ (Boutin et al., GRL, 2002):

  **Issue:** Calibration of k-U relationships still needed

- Use of altimeter measurements and k-MSS relationship (Glover et al., 2002)

  k-MSS estimates close to k-U Liss and Merlivat estimates (k-altimeter relationship calibrated with laboratory (wind/wave tank) measurements).

  **Issue:** Calibration of k-MSS relationships still needed
Joint Global Ocean Flux Program

Major scientific question for the JGOFS program:

1. How much carbon is sequestered by the open-oceans?

Takahashi et al. CO₂ Air-sea Flux Climatology based on a 40-yr database of over 1,400,000 measurements of surface seawater pCO₂

Global Oceanic Uptake

\[-1.5 \pm 0.4 \text{ Pg C yr}^{-1}\]

JGOFS Open Science Conference

pCO₂ versus Temperature in the Equatorial Pacific
89 Data Sets Collected Between March 1992 and July 2001

Cosca et al., (in press)
Large-Scale Observational Results: 1992-2002

El Niño: 0.2-0.4 Pg C year⁻¹
Non El Niño: 0.7-0.9 Pg C year⁻¹
La Niña: 0.8-1.0 Pg C year⁻¹
Average: 0.6 ± 0.2 Pg C year⁻¹

from Feely et al. JGR (submitted)

Influence of Chl and SST on pCO₂ observed during AESOPS and Astrolabe campaigns

see POSTER Session 1 Theme 2, Boutin et al.: Air-sea CO2 fluxes in the Southern Ocean inferred from satellite data

Boutin, Etcheto et al., JGOFS 2003
Air sea flux from CARIOCA pCO₂, atmospheric pCO₂ derived from atmospheric pressure measured onboard the buoy, satellite (QSCAT) wind speed and K-U Wanninkhof relationship.

From January to July 2002:
Mean $\Delta P = -12.6$ $\mu$atm
Mean Air-sea flux = -3.8 mmol m$^{-2}$ day$^{-1}$

PLOT: CARIOCA $\Delta$CO₂ and $\Delta$CO₂ Flux deduced from QSCAT winds and K-U Wanninkhof relationship.

$\Delta$PCO₂ (µatm)

Flux (mmol m$^{-2}$ day$^{-1}$)

pCO₂ regressions South of Tasmania and New Zealand

pCO₂ versus Chl in high Chl area

pCO₂ versus SST in low Chl area by seasons

see POSTER Session 1 Theme 2, Boutin et al.: Air-sea CO₂ fluxes in the Southern Ocean inferred from satellite data
MLR Regression $pCO_2$ versus SST, SSS, Chla, NO3 and SiO4 in the Equatorial Pacific using 89 Data Sets Collected Between March 1992 and July 2001

Cosca et al. (in press)

Global map of existing and planned near-surface $pCO_2$ measurements
Current Satellite Sensors

Wind speed: (2 scatterometers in the air)
- Scatterometer: QSCAT 1999-TBD
  Seawinds on ADEOS2 2003-TBD

Sea Surface Temperature:
- Visible/IR radiometer: AVHRR 1982-TBD
  GOES - TBD
  Meteosat 2nd generation 2002
- Microwave radiometer: TMI (40S-40N) 1997-TBD
  AMSR-E on AQUA 2002-TBD
  AMSR on ADEOS2 2002-TBD

Ocean Color: (6 radiometers in the air)
- Visible/IR radiometer: SeaWIFS 1997-2003
  MODIS on Terra 2001-2005
  MERIS on ENVISAT 2002-2007
  MODIS on AQUA 2002-2007
  POLDER 2 & GLI on ADEOS2 2003-TBD

Sea Surface Height anomalies: (3 altimeters)
- Altimeter: Topex-Poseidon 1992-TBD
  Jason 1998-TBD
  RA on ENVISAT 2005-TBD

Conclusions

- Remote sensing can be a powerful tool to monitor time and space variations of several parameters influencing CO₂ distribution and air-sea fluxes (wind speed, SSH, SST, Chl).
  - Remote sensing can help interpret and extend in space and time in situ measurements
  - Remote sensing can provide constraints for biogeochemical modelling

- In situ measurements are essential to:
  - Validate remotely sensed and parameters derived from remote sensing measurements covering various oceanographic provinces at various time scales.
  - Determine the processes controlling variations of parameters observed by remote sensing: measurements of parameters not accessible from space.