# JGOFS Open Science Conference
# 5-8 May 2003
# Washington, D.C.

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

**Speaker: Rik Wanninkhof NOAA/AOML**
**Commentator: Richard A. Feely NOAA/PMEL**

**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**

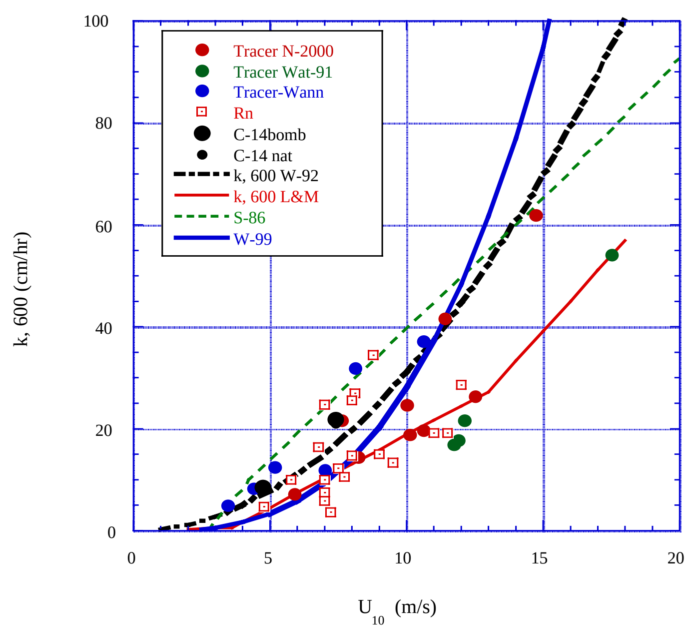
## Thermodynamic component

**Function of:**

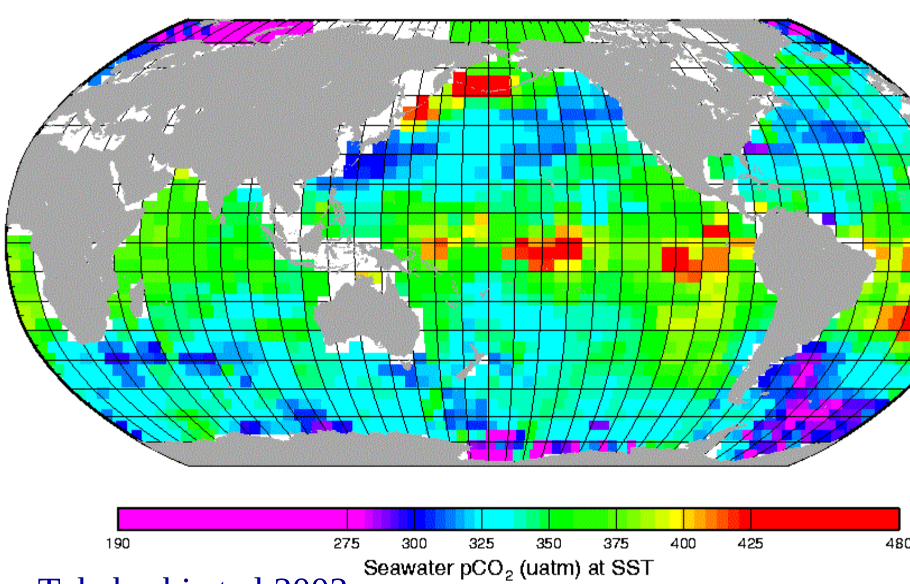
**Temperature, Salinity, $TCO_2$**

**Biology (photosynthesis/respiration)**

**Transport (horizontal/vertical)**




(B) Climatological $pCO_2$ in Surface Water for February 1995

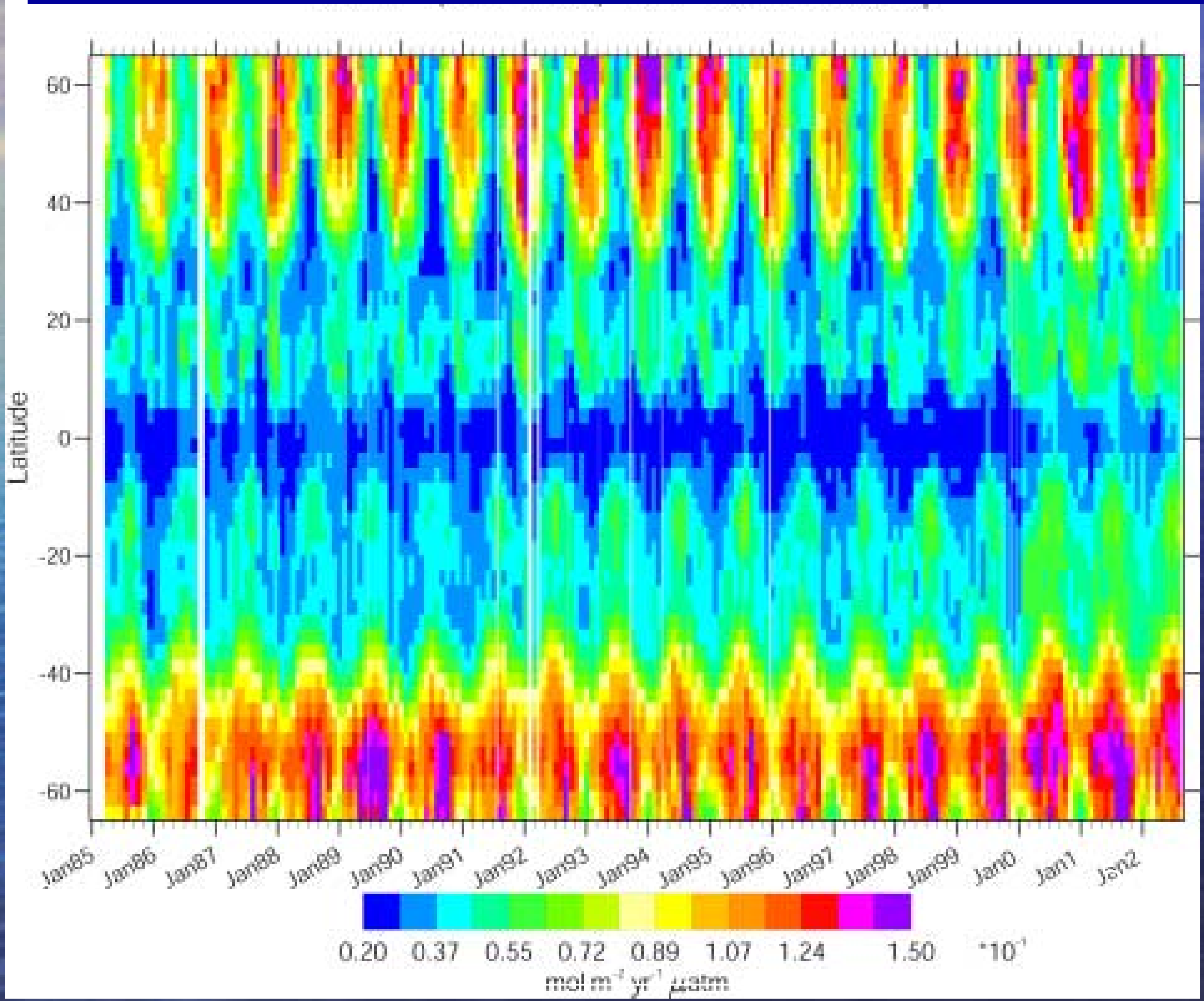



Takahashi et al 2002

# $CO_2$ 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)




**Geosat** altimeter

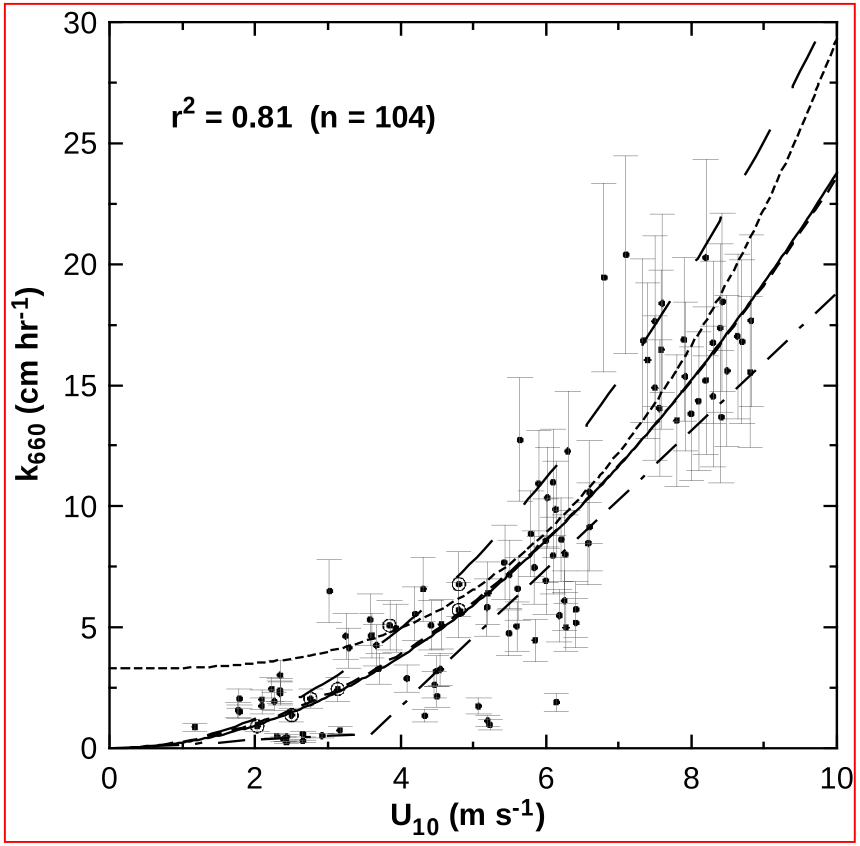
**SSMI** Microwave radiometer

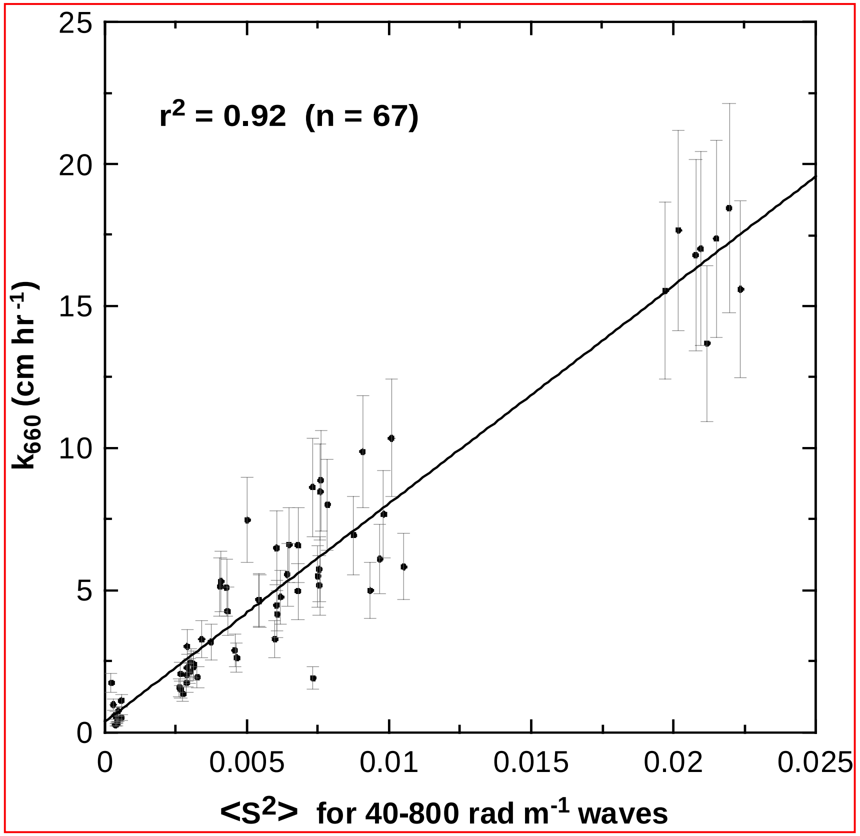
**ERS1 and ERS2** scatterometer

**QSCAT** scatterometer

*(Boutin et al., 2003)*

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




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

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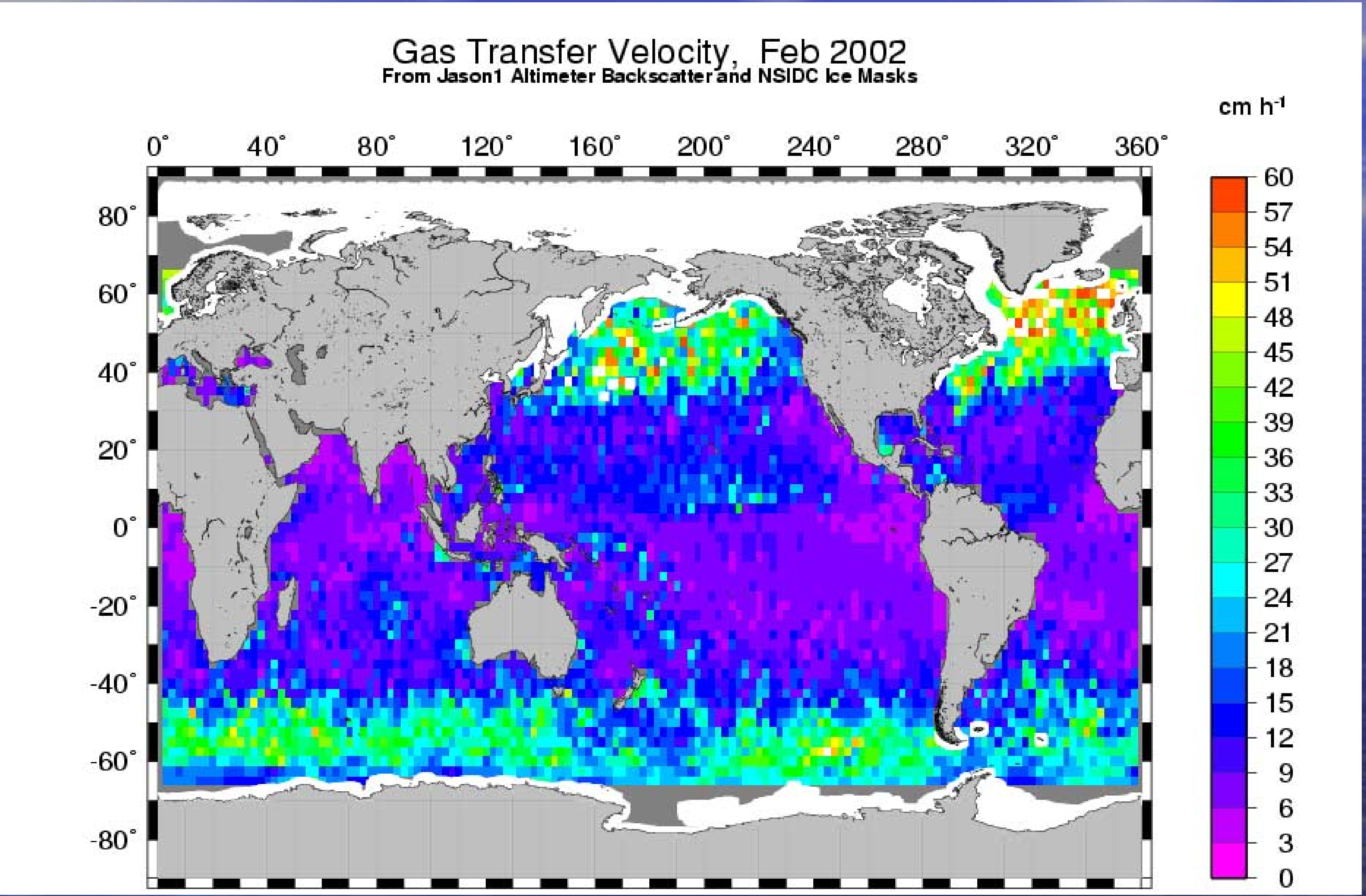
# Jason-1 Altimeter Product



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# $CO_2$ 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**

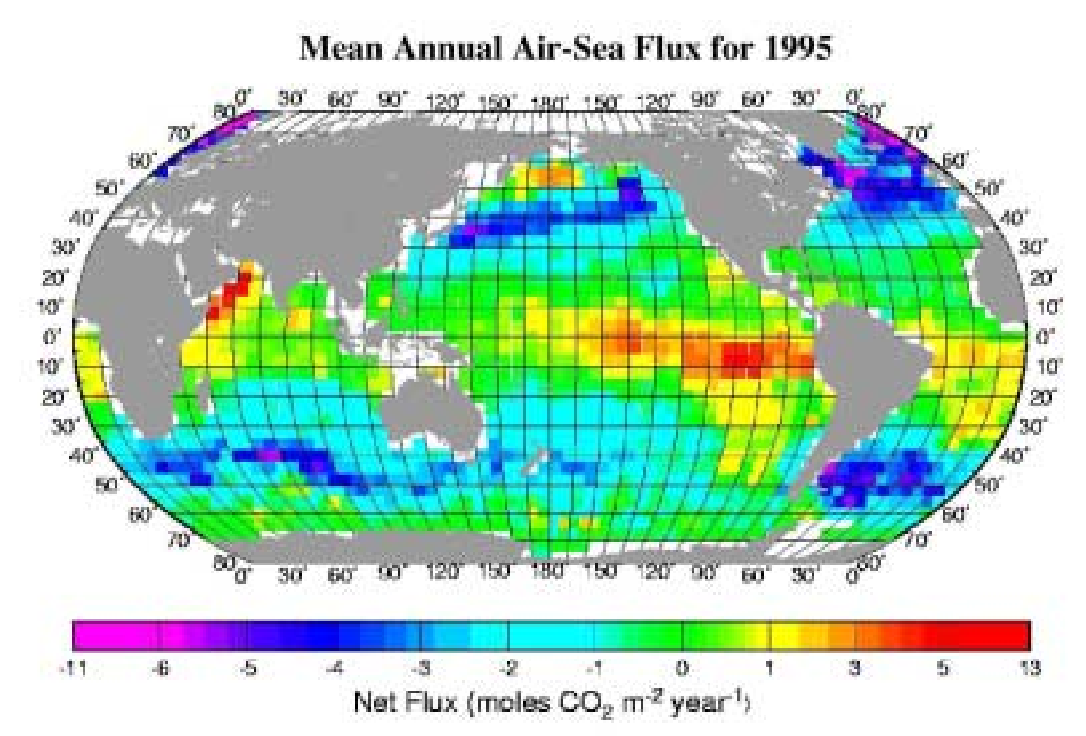


-Boutin, Etcheto et al., JGOFS 2003

# 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. $CO_2$ Air-sea Flux Climatology based on a 40-yr database of over 1,400,000 measurements of surface seawater $pCO_2$**

**<u>Global Oceanic Uptake</u>**

**$-1.5 \pm 0.4$ Pg C $yr^{-1}$**

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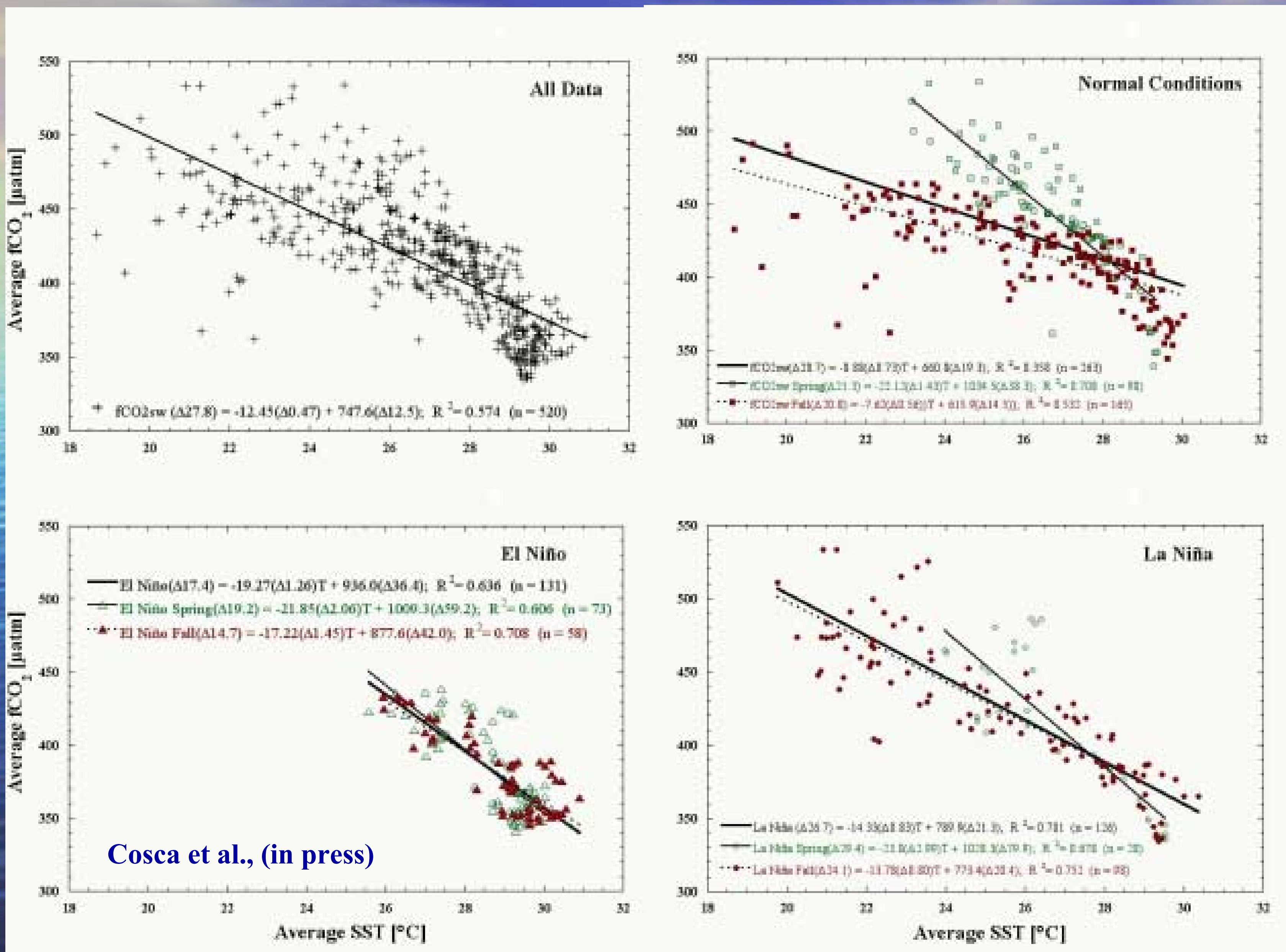
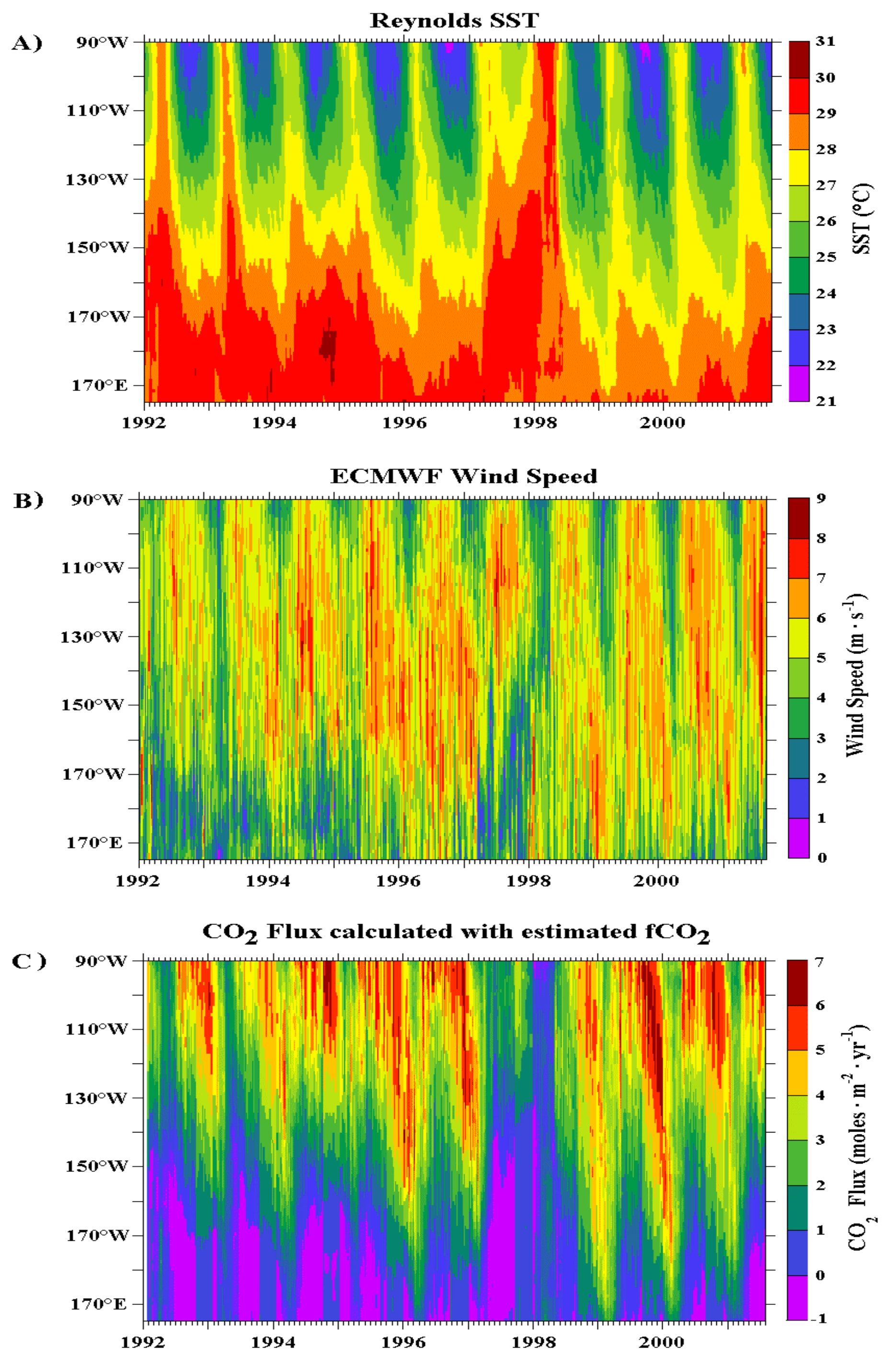
# $pCO_2$ versus Temperature in the Equatorial Pacific
# 89 Data Sets Collected Between March 1992 and July 2001






# 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$^{-1}$**

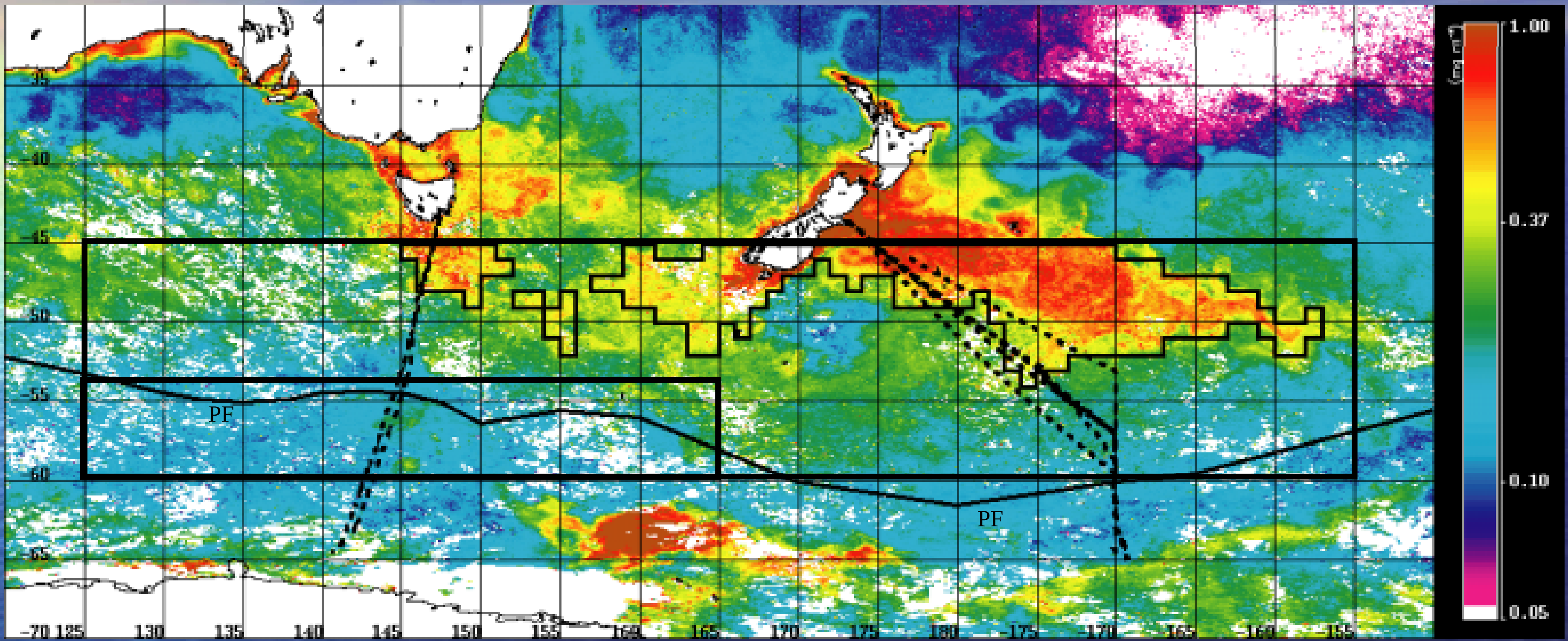
**La Niña: 0.8-1.0 Pg C year$^{-1}$**

**Average: 0.6 ± 0.2 Pg C year$^{-1}$**

**from Feely et al. JGR (submitted)**

# Influence of Chl and SST on $pCO_2$ observed during AESOPS and Astrolabe campaigns

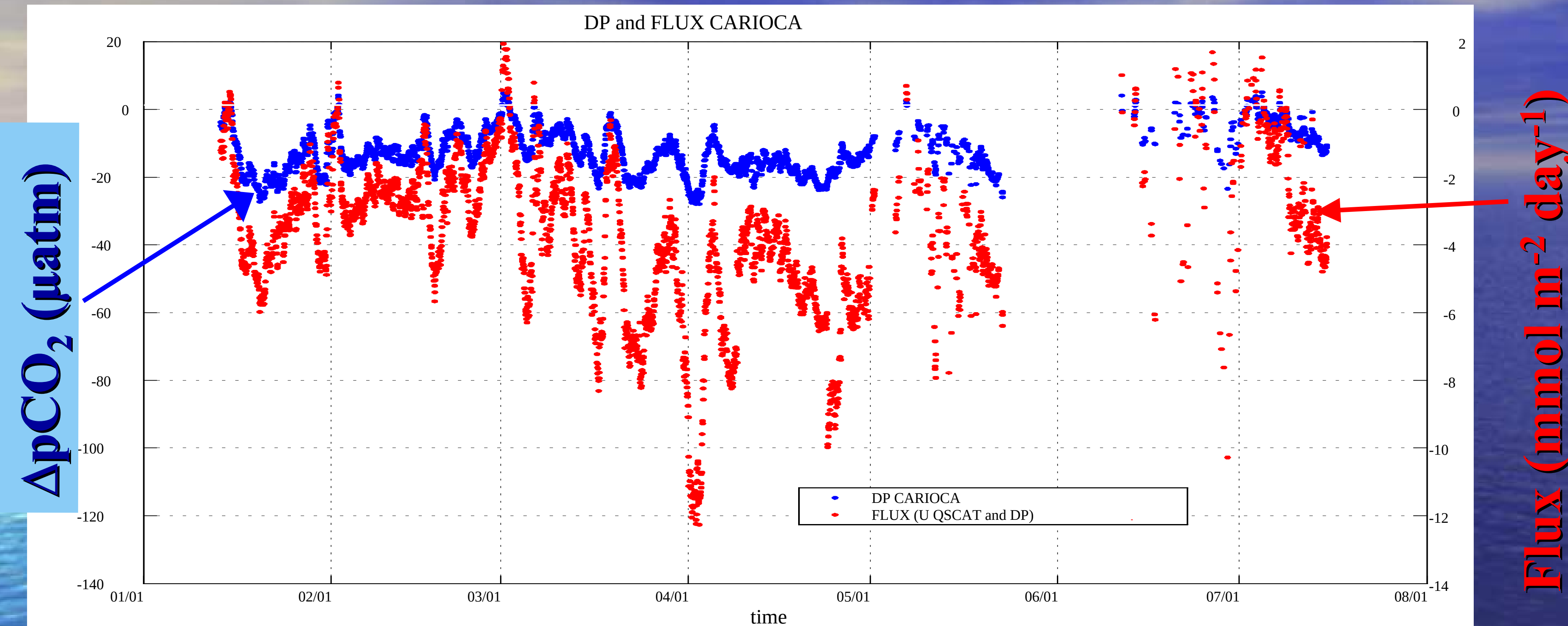
pCO2 campaigns (nov 97 to dec 99) - Seawifs chl a (mar 98)




***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

# CARIOCA $\Delta pCO_2$ and $CO_2$ Flux deduced from QSCAT winds and K-U Wanninkhof (1992) relationship




Air sea flux from CARIOCA $pCO_2$, atmospheric $pCO_2$ derived from atmospheric pressure measured onboard the buoy, satellite (QSCAT) wind speed and K-U Wanninkhof relationship.

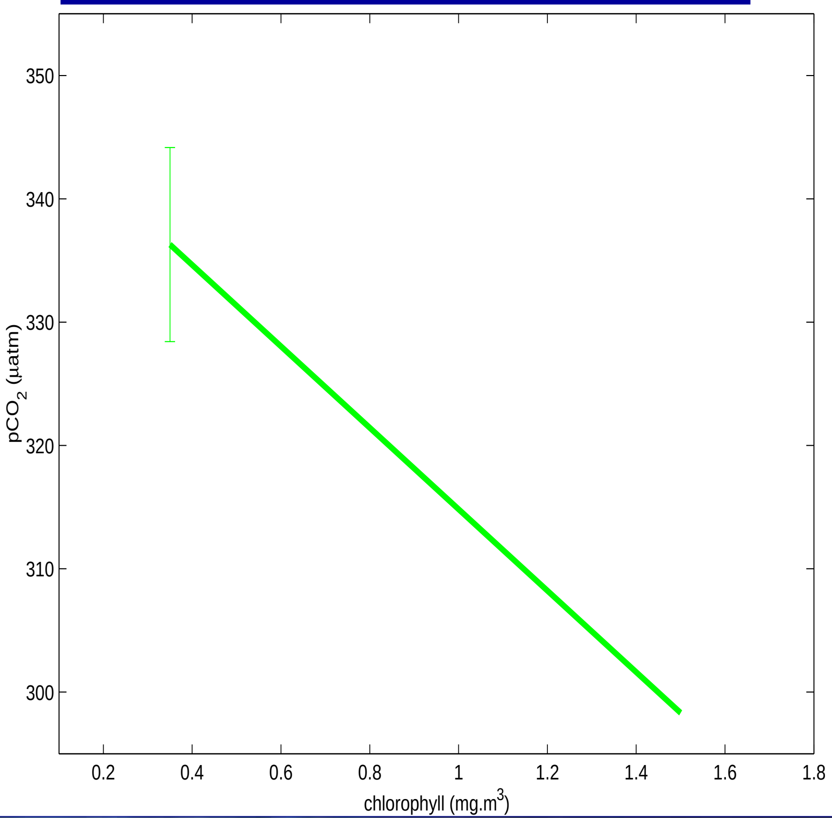
**From January to July 2002:**

**Mean ΔP = -12.6 µatm**

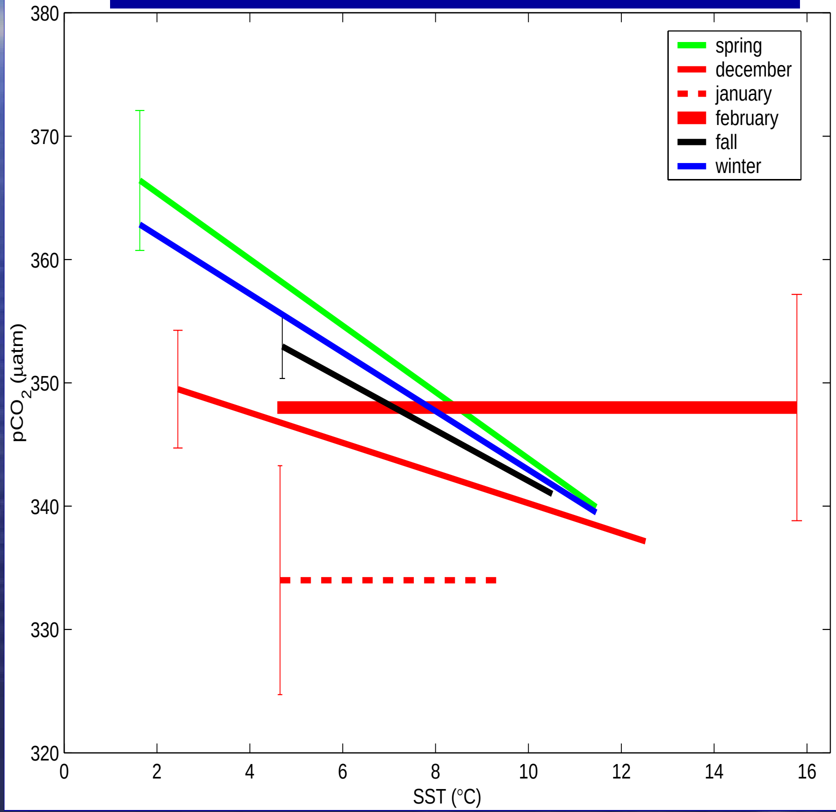
**Mean Air-sea flux = -3.8 mmol m$^{-2}$ day$^{-1}$**

# $pCO_2$ regressions South of Tasmania and New Zealand

pCO2 versus Chl in high Chl area




pCO2 versus SST in low Chl area by seasons

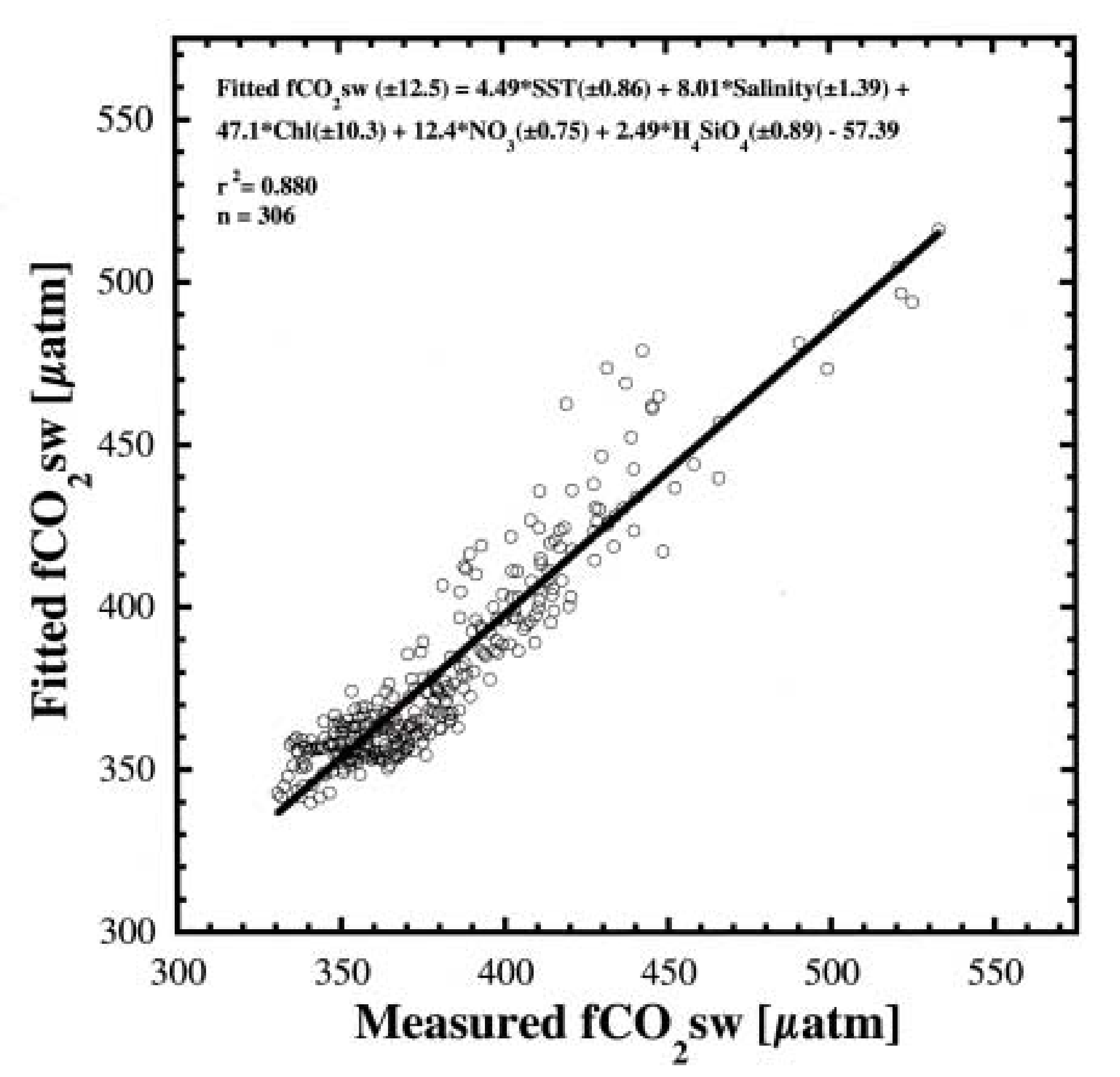



***see POSTER Session 1 Theme 2, Boutin et al.:*** *Air-sea $CO_2$ fluxes in the Southern Ocean inferred from satellite data )*

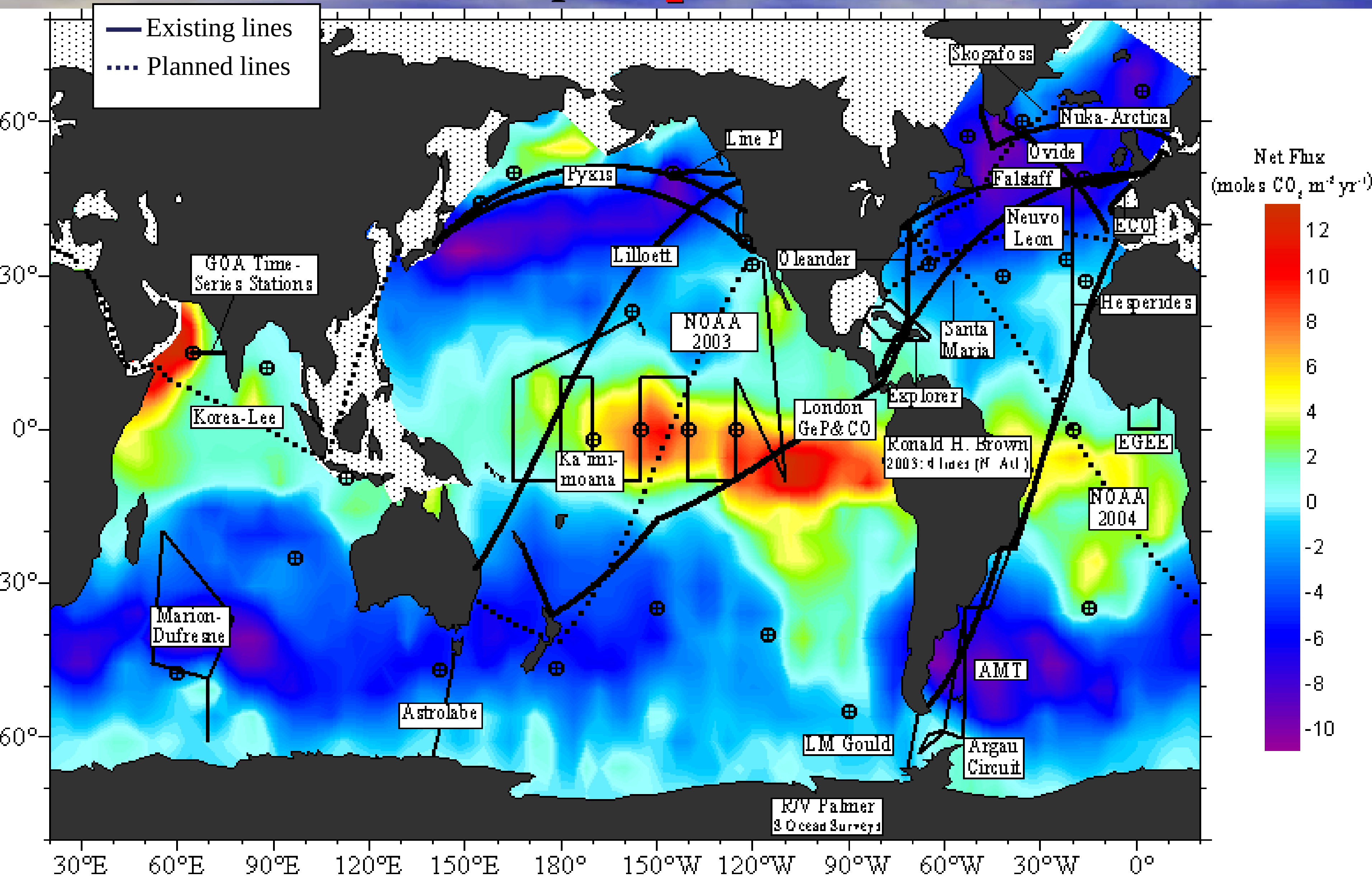
Boutin, Etcheto et al., JGOFS 2003

# 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

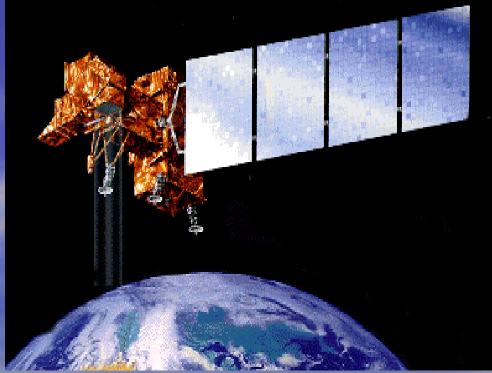
Cosca et al. (in press)



# 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 1991-TBD
RA on ENVISAT 2002-TBD

# Conclusions

- **Remote sensing can be a powerful tool to monitor time and space variations of several parameters influencing $CO_2$ 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 contolling variations of parameters observed by remote sensing: measurements of parameters not accessible from space.**