

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 $p\text{CO}_2$ from SST, SSS, Chl and nutrients**
- **Estimation of global CO_2 air-sea fluxes**

$$F_{av} = (k s \Delta p \text{CO}_2)_{av}$$

Gas transfer velocity

Function of:

Surface turbulence (wind speed)

Physical properties of gas and water

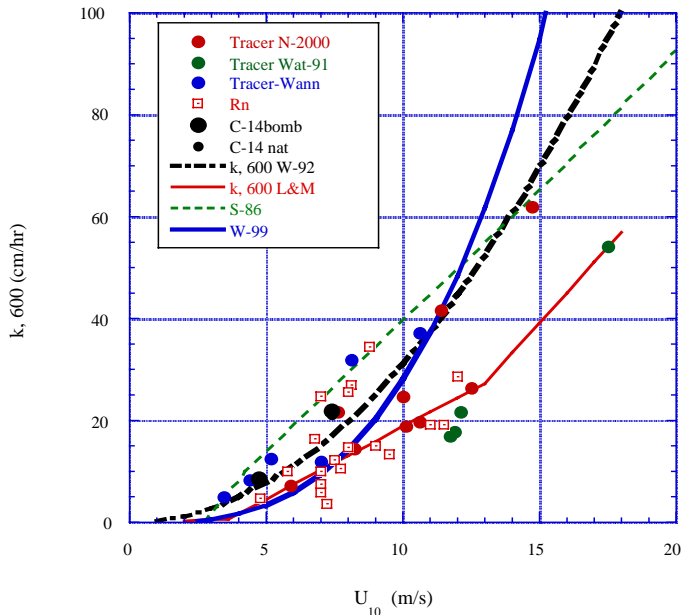
Thermodynamic component

Function of:

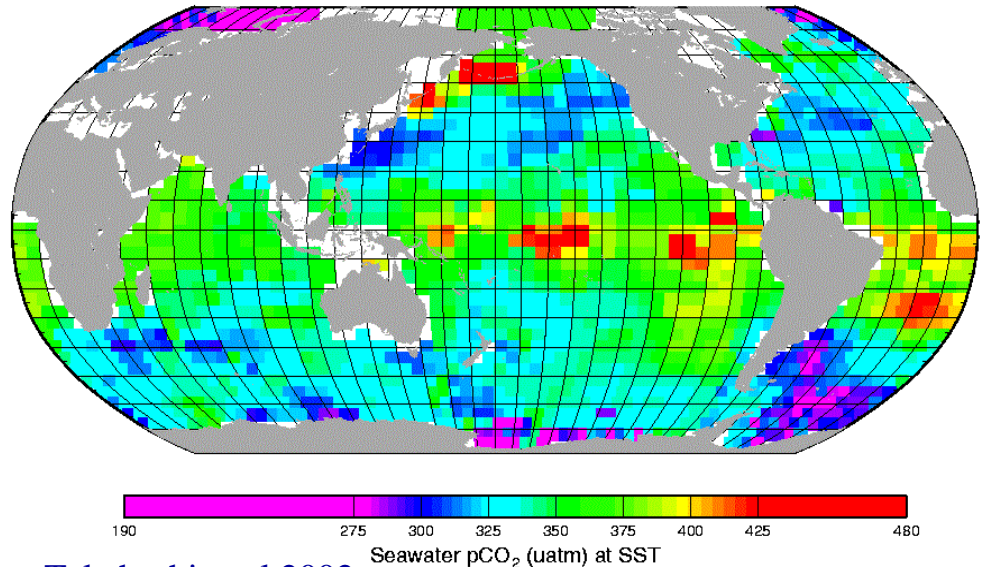
Temperature, Salinity, TCO₂

Biology (photosynthesis/respiration)

Transport (horizontal/vertical)



(B) Climatological pCO₂ in Surface Water for February 1995

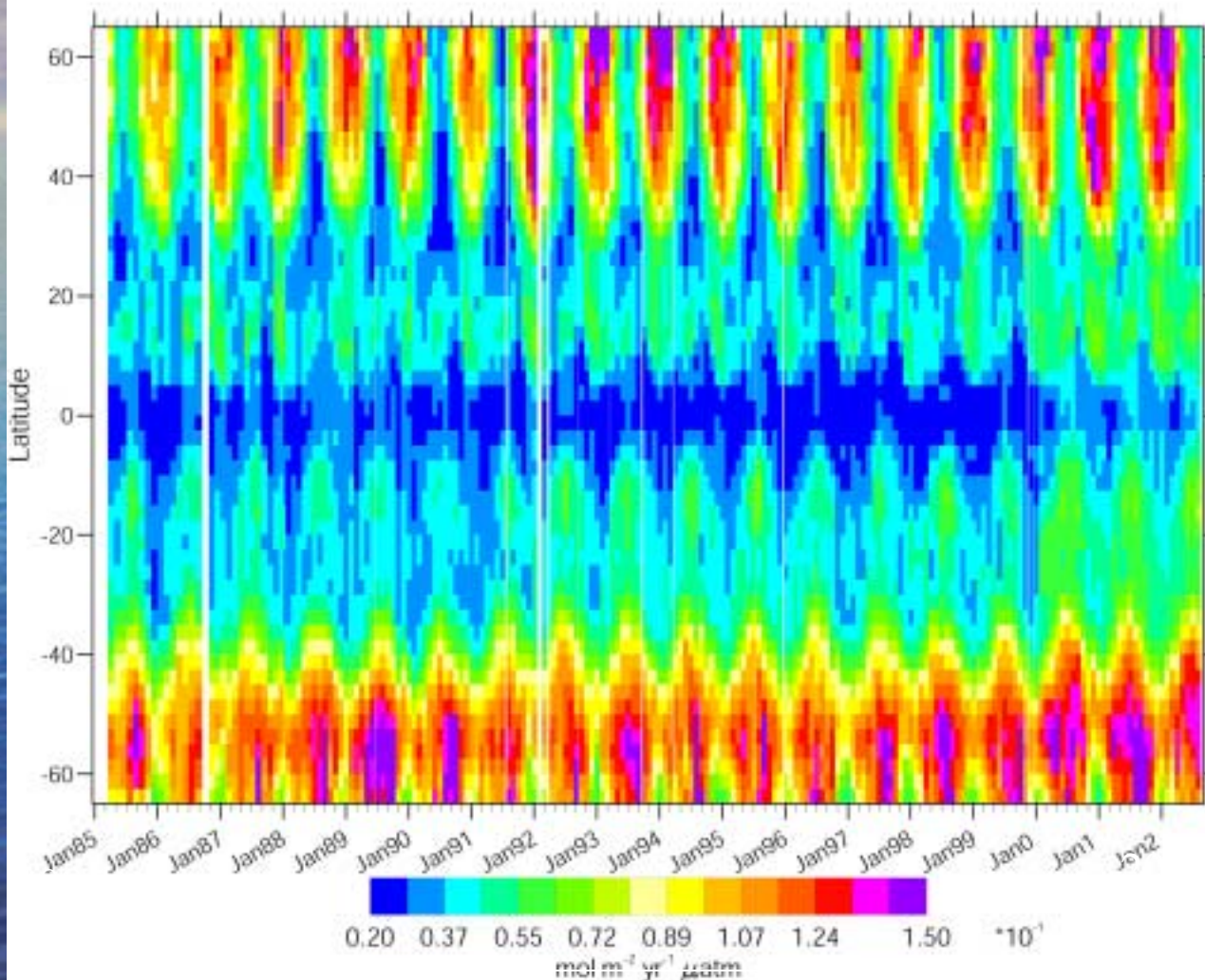


Takahashi et al 2002

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)



Geosat
altimeter

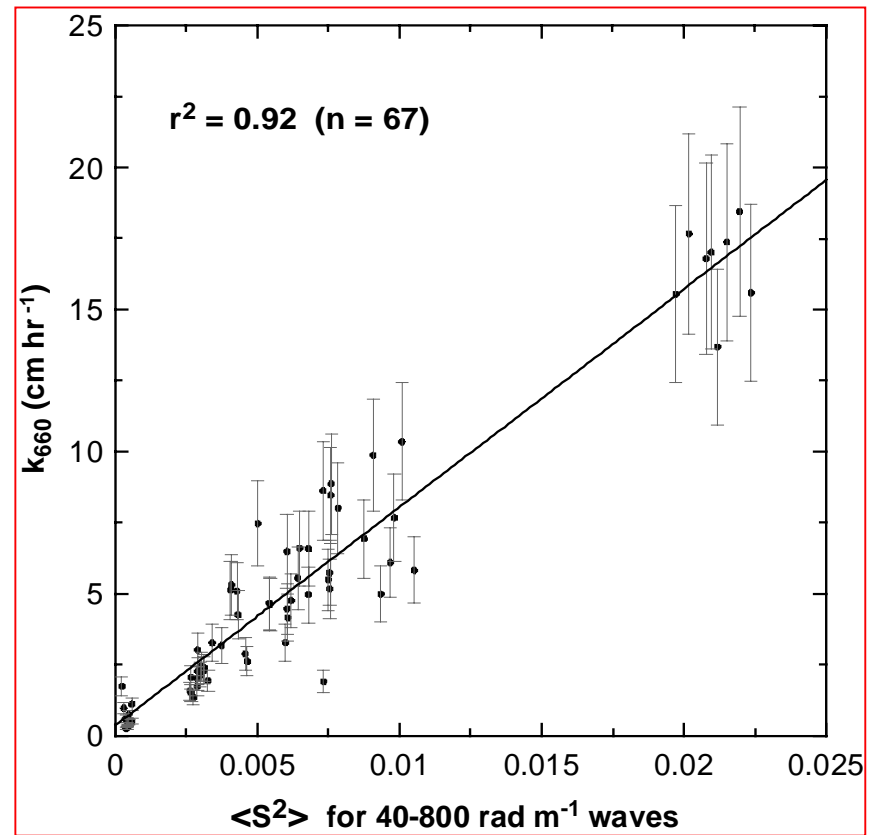
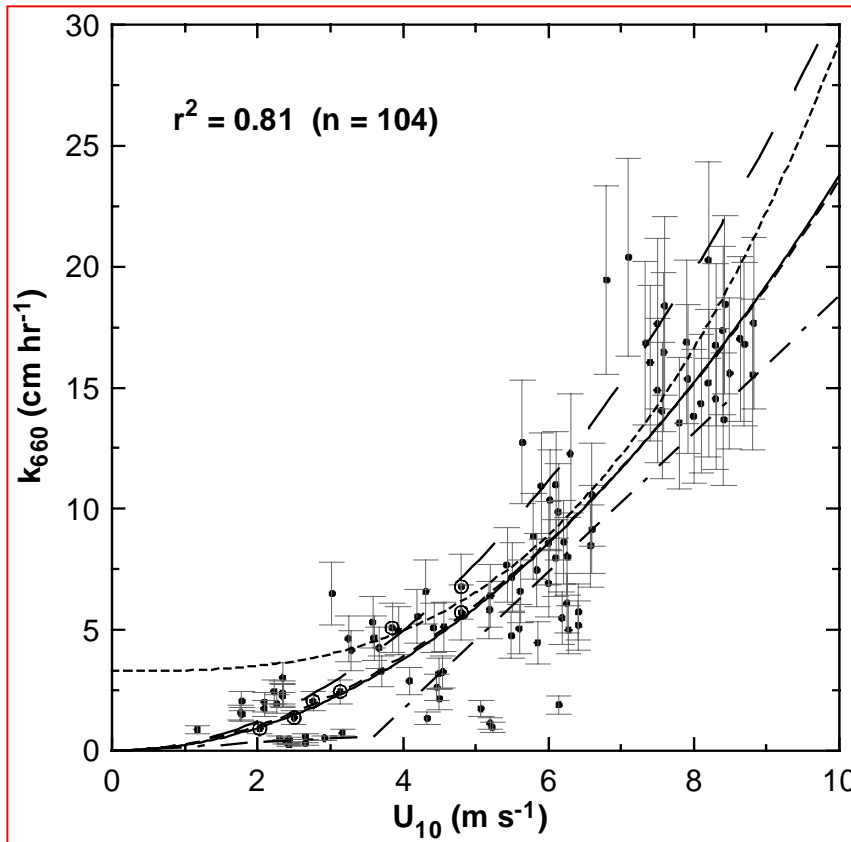
SSM/I
Microwave
radiometer

ERS1 and ERS2
scatterometer

QSCAT
scatterometer

(Boutin et al., 2003)

Gas Transfer Velocity: Wind Speed and Mean Square Slope Dependence

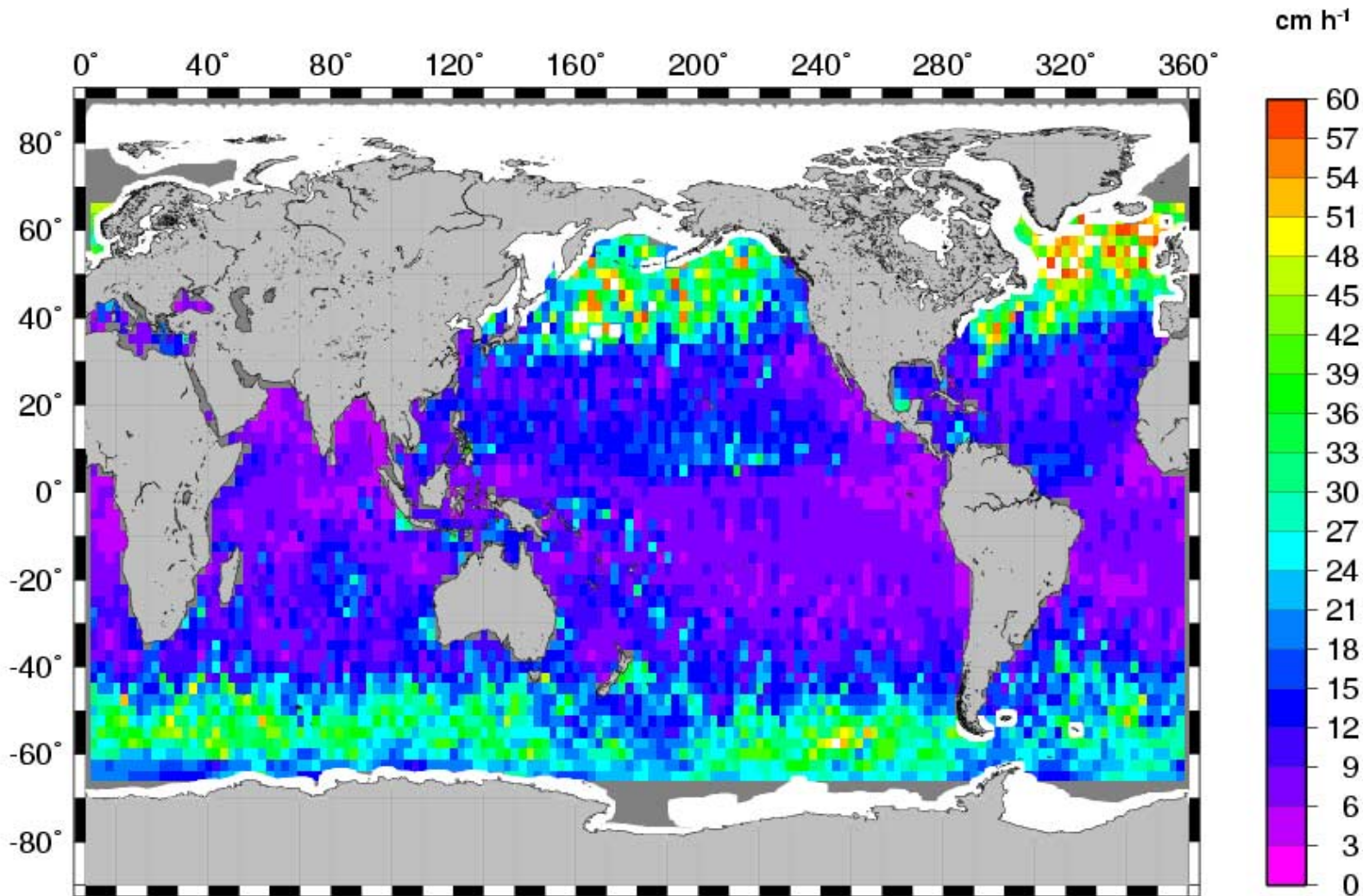


Data from 1997 NSF CoOP Coastal Air-Sea Exchange Experiment [Frew et al., 2003]



Jason-1 Altimeter Product

Gas Transfer Velocity, Feb 2002
From Jason1 Altimeter Backscatter and NSIDC Ice Masks



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).

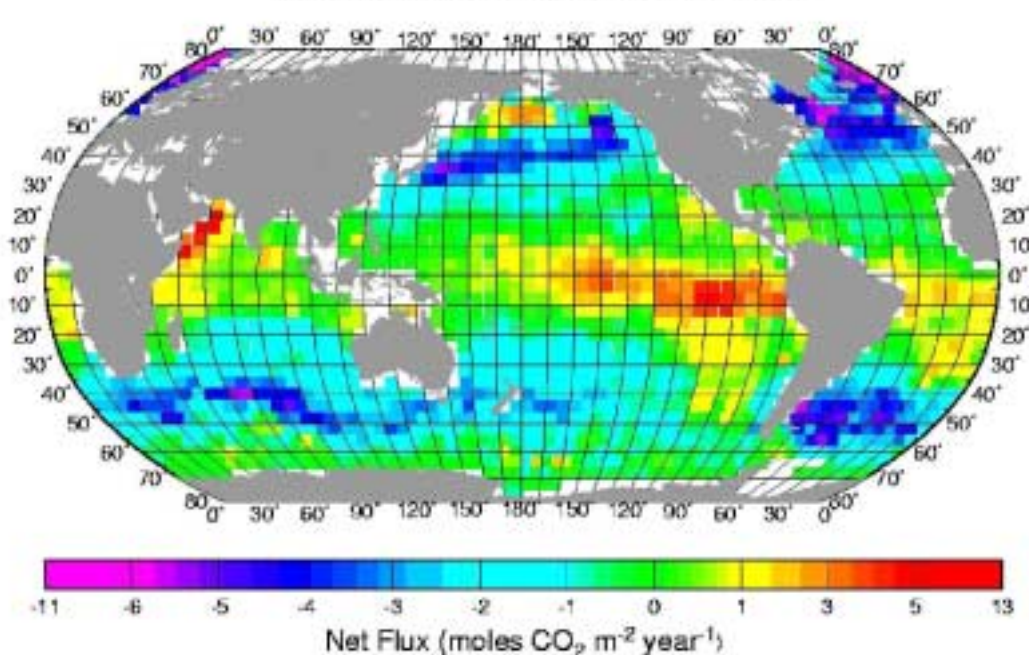
Issue: Calibration of k -MSS relationships still needed

Joint Global Ocean Flux Program

Major scientific question for the JGOFS program:

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

Mean Annual Air-Sea Flux for 1995



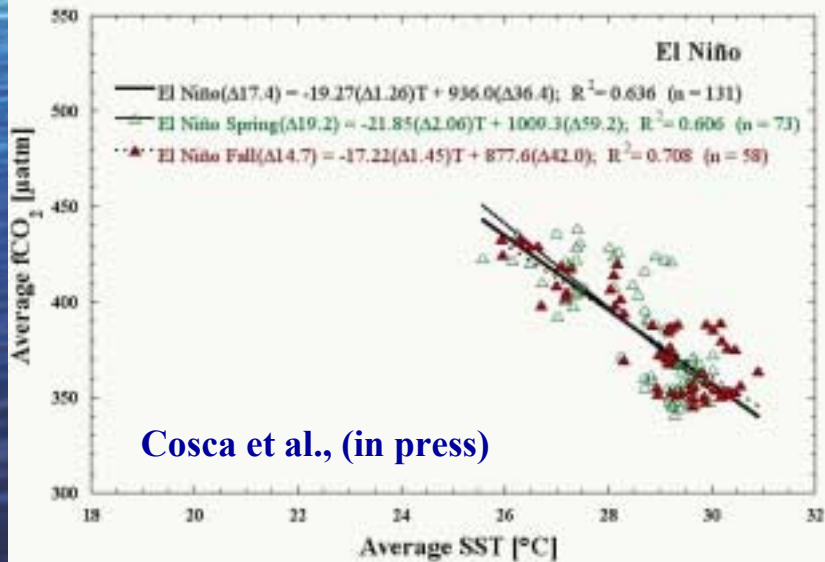
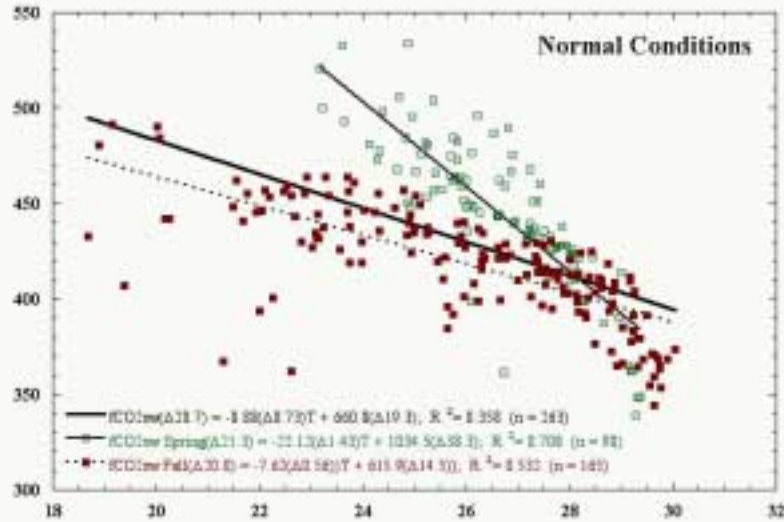
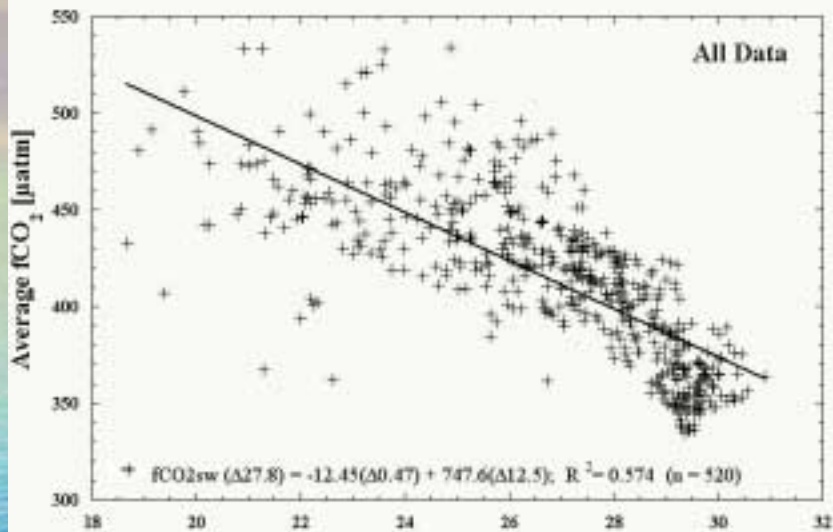
Takahashi et al. CO₂ Air-sea Flux Climatology based on a 40-yr database of over 1,400,000 measurements of surface seawater pCO₂

Global Oceanic Uptake

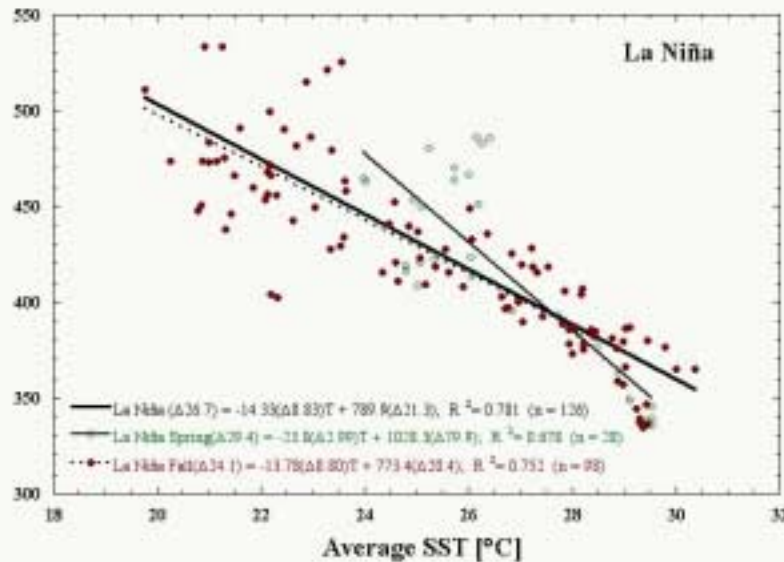
-1.5 ± 0.4 Pg C yr⁻¹

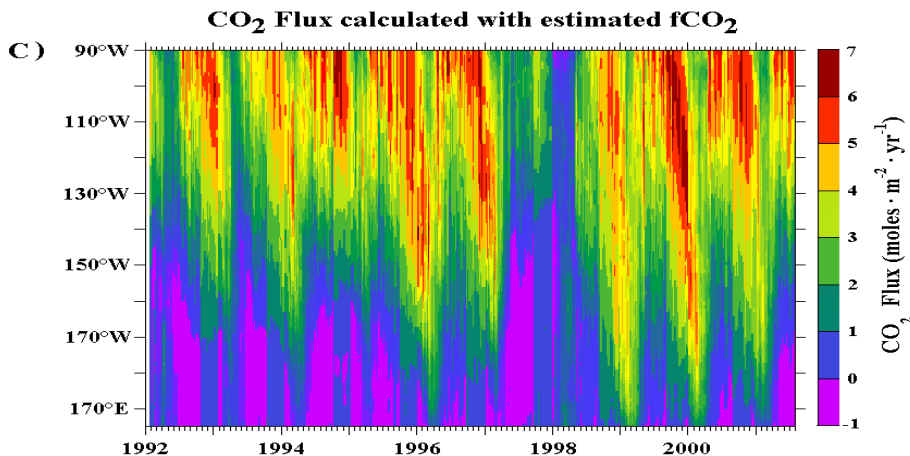
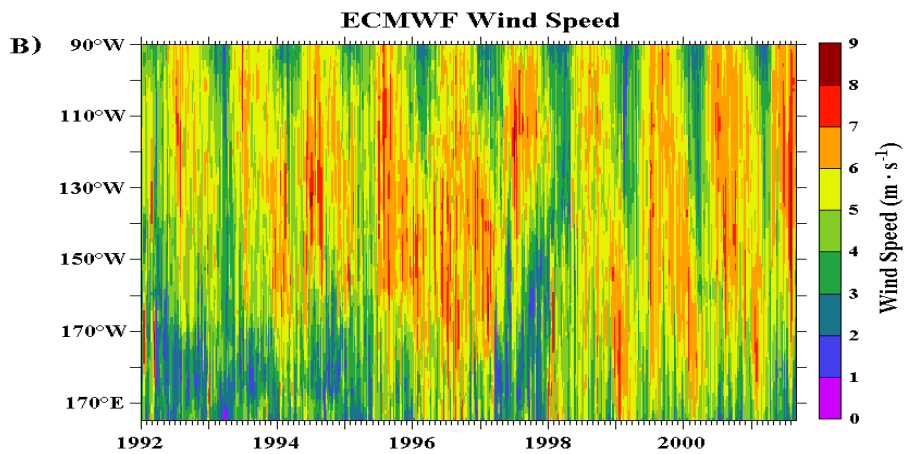
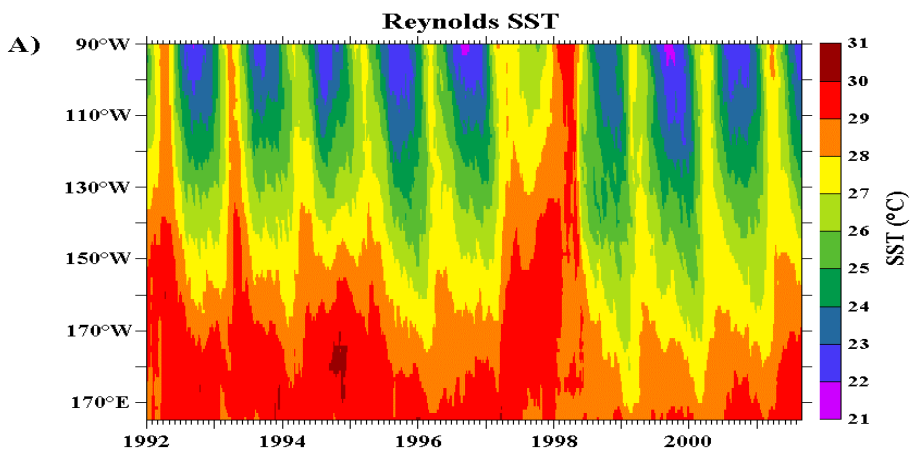
pCO₂ versus Temperature in the Equatorial Pacific

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

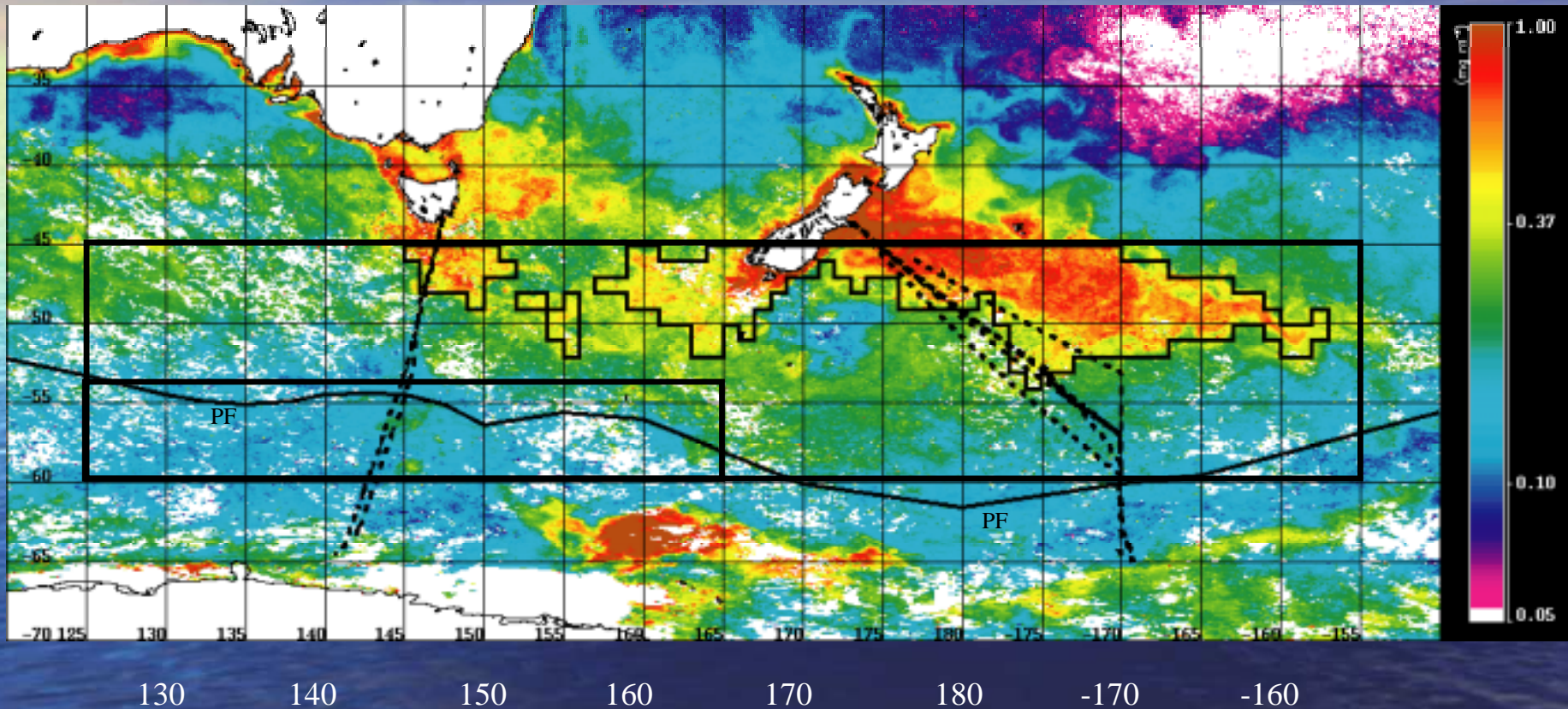
La Niña: 0.8-1.0 Pg C year⁻¹

Average: 0.6 ± 0.2 Pg C year⁻¹

from Feely et al. JGR (submitted)

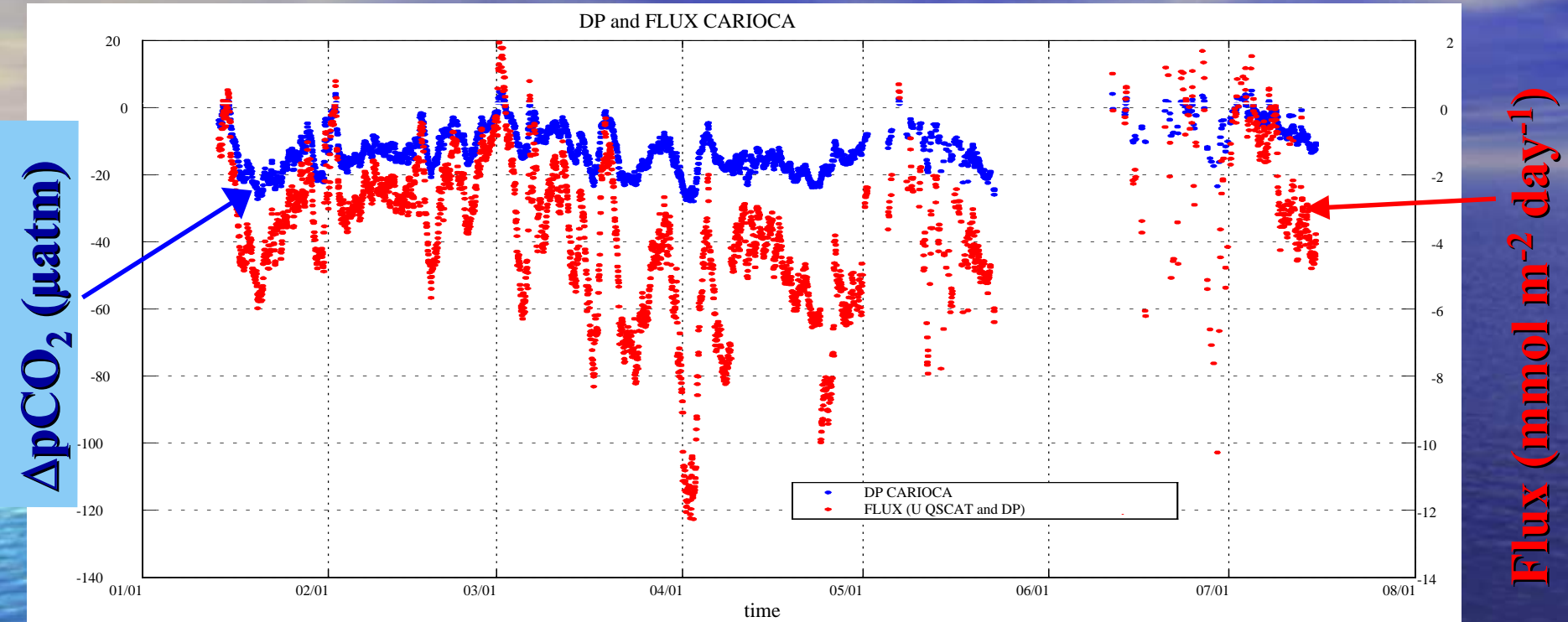
Influence of Chl and SST on pCO₂ observed during AESOPS and Astrolabe campaigns

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)

CARIOCA $\Delta p\text{CO}_2$ and CO_2 Flux deduced from QSCAT winds and K-U Wanninkhof (1992) relationship



Air sea flux from CARIOCA $p\text{CO}_2$, atmospheric $p\text{CO}_2$ derived from atmospheric pressure measured onboard the buoy, satellite (QSCAT) wind speed and K-U Wanninkhof relationship.

From January to July 2002:

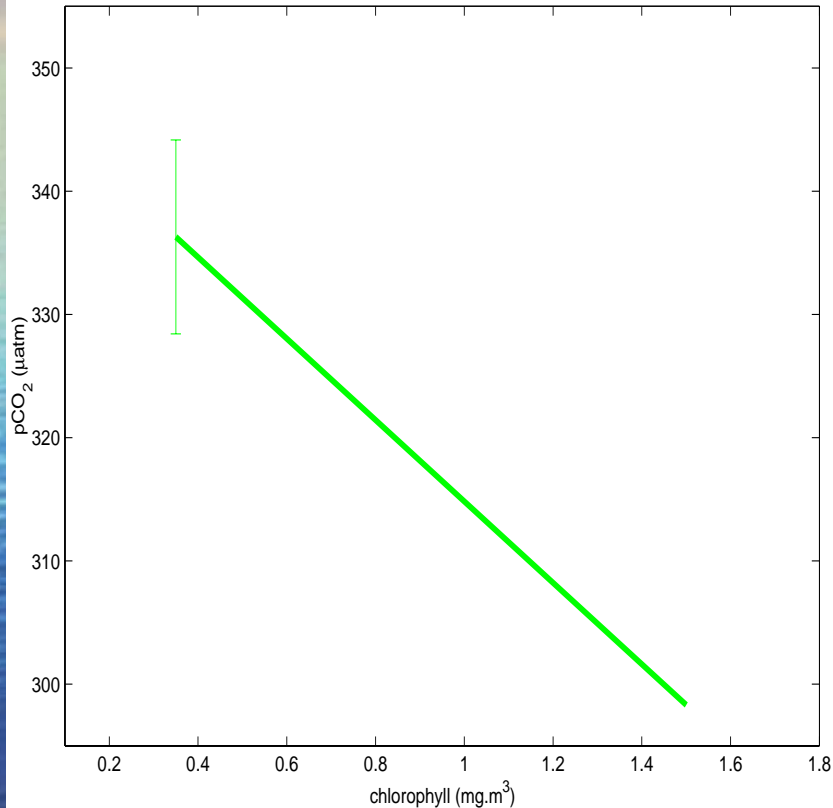
Mean $\Delta P = -12.6 \mu\text{atm}$

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

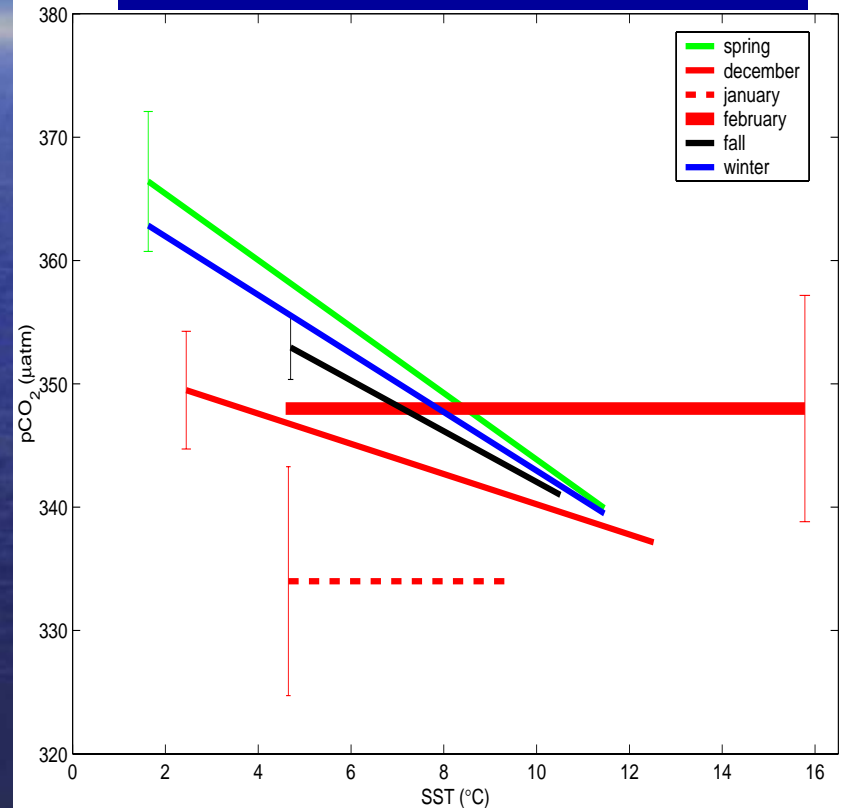


pCO₂ regressions South of Tasmania and New Zealand

pCO₂ versus Chl in high Chl area



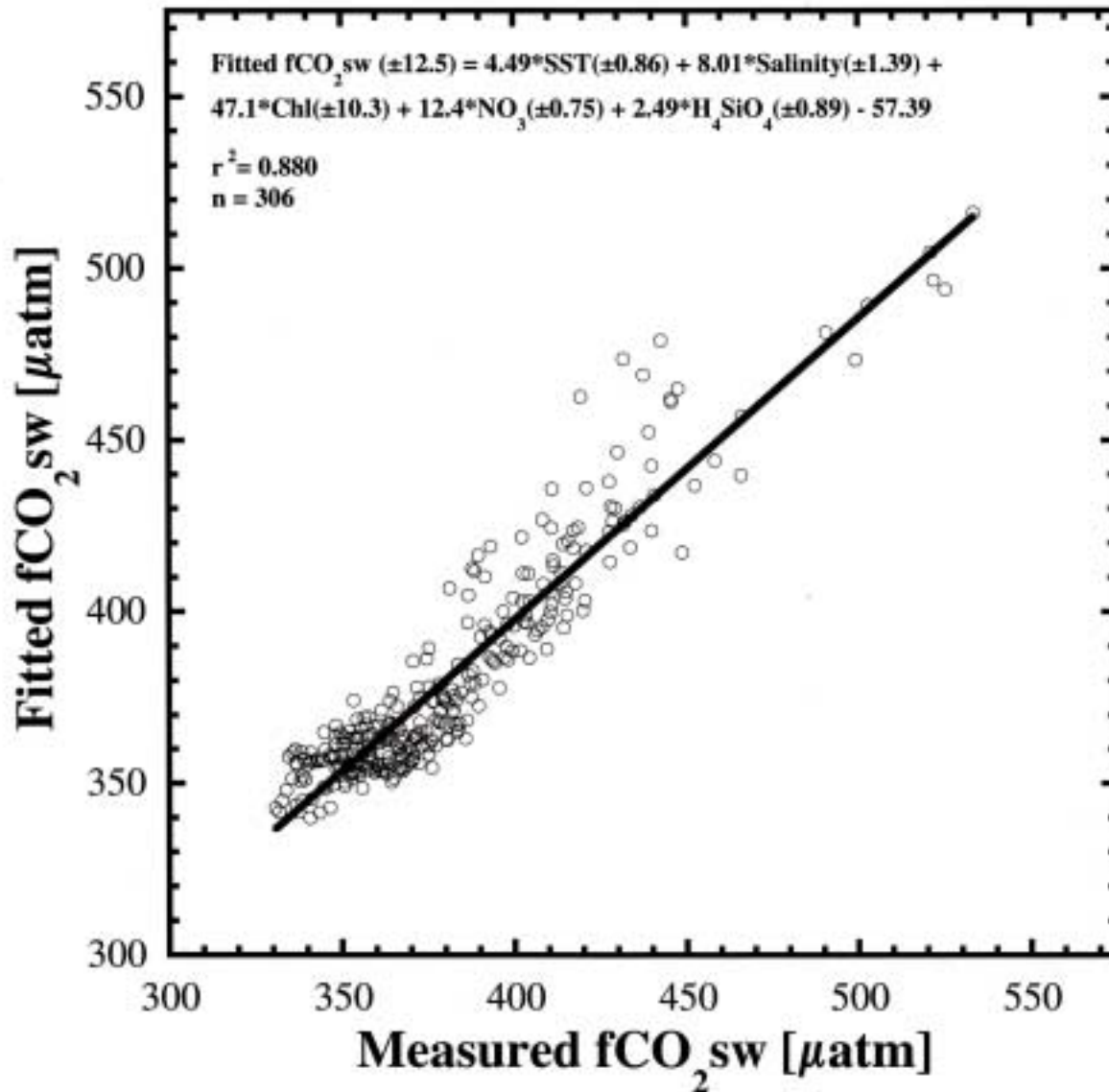
pCO₂ versus SST in low Chl area by seasons



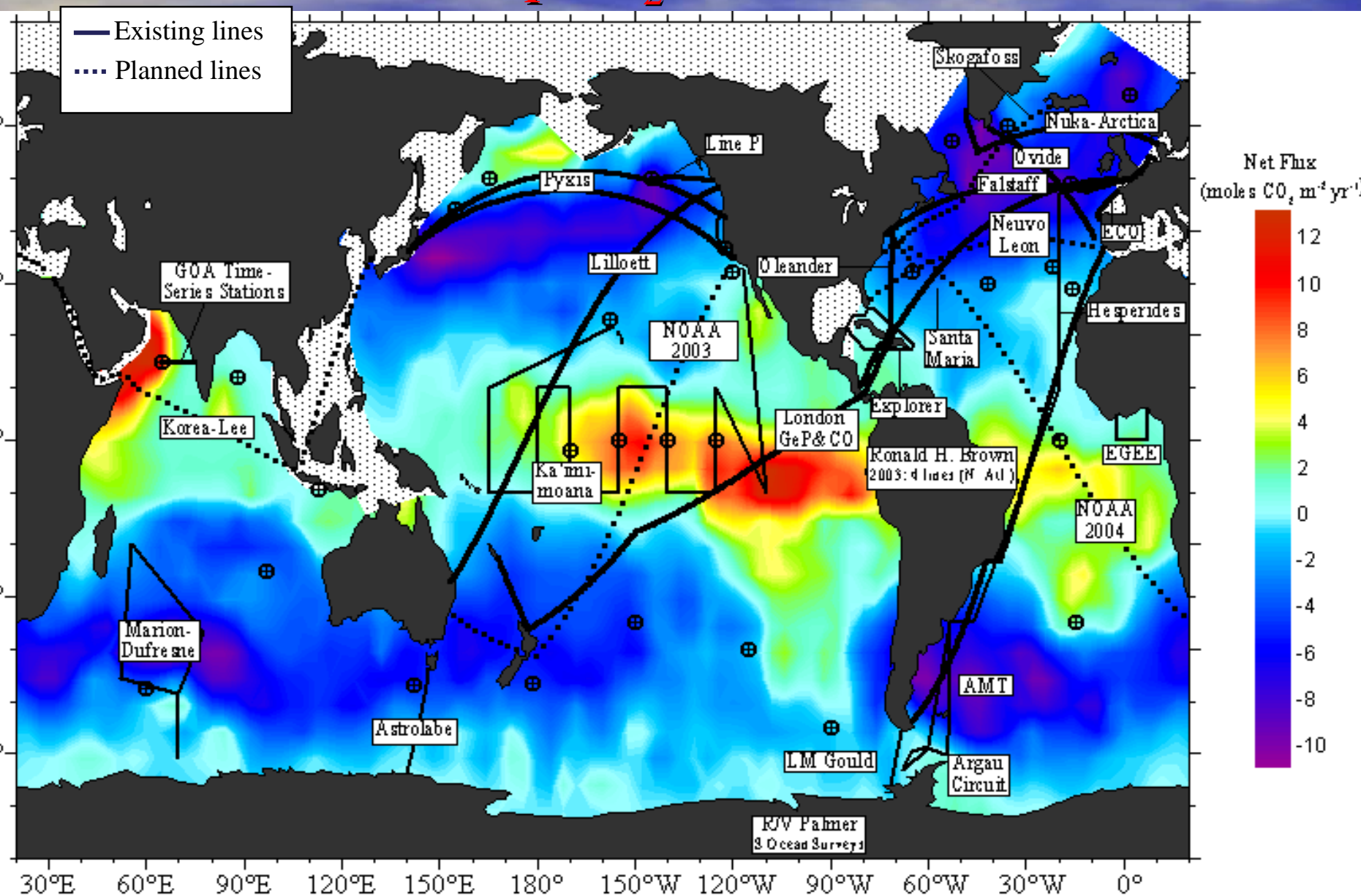
see POSTER Session 1 Theme 2, Boutin et al.: Air-sea CO₂ fluxes in the Southern Ocean inferred from satellite data)

MLR Regression $p\text{CO}_2$ versus SST, SSS, Chla, NO_3 and SiO_4 in the Equatorial Pacific using 89 Data Sets Collected Between March 1992 and July 2001

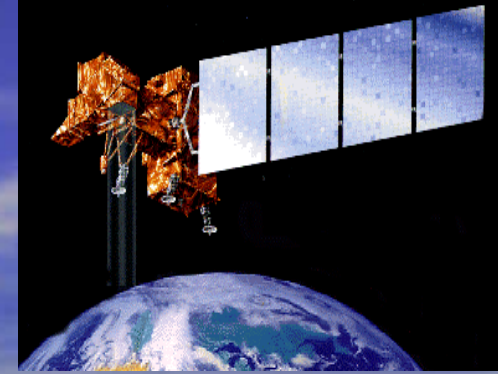
Cosca et al. (in press)



Global map of existing and planned near-surface pCO₂ 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 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.