Decadal Changes in Pacific Ocean Inorganic Carbon

by

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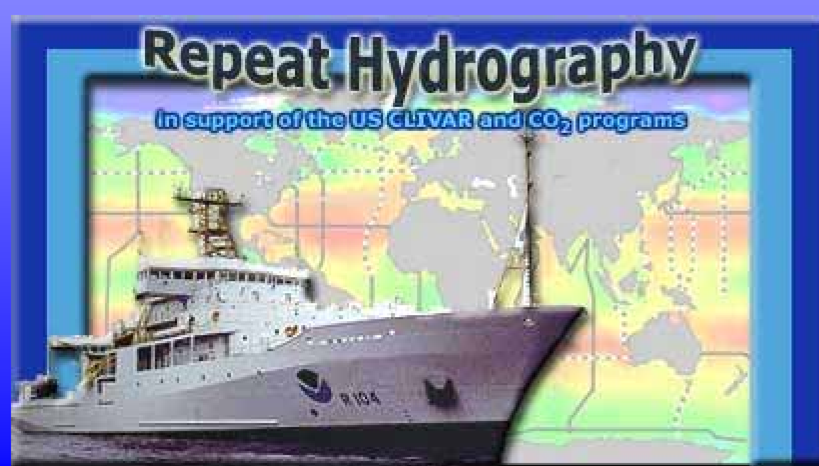
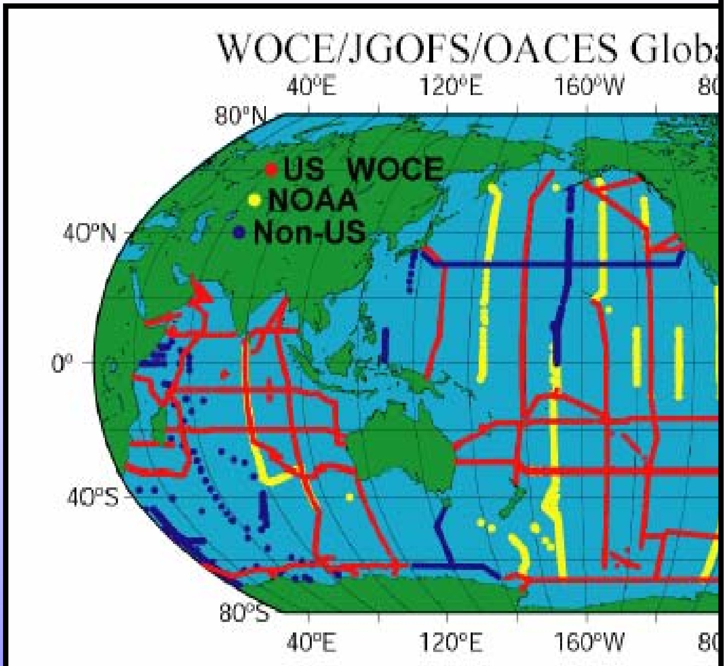
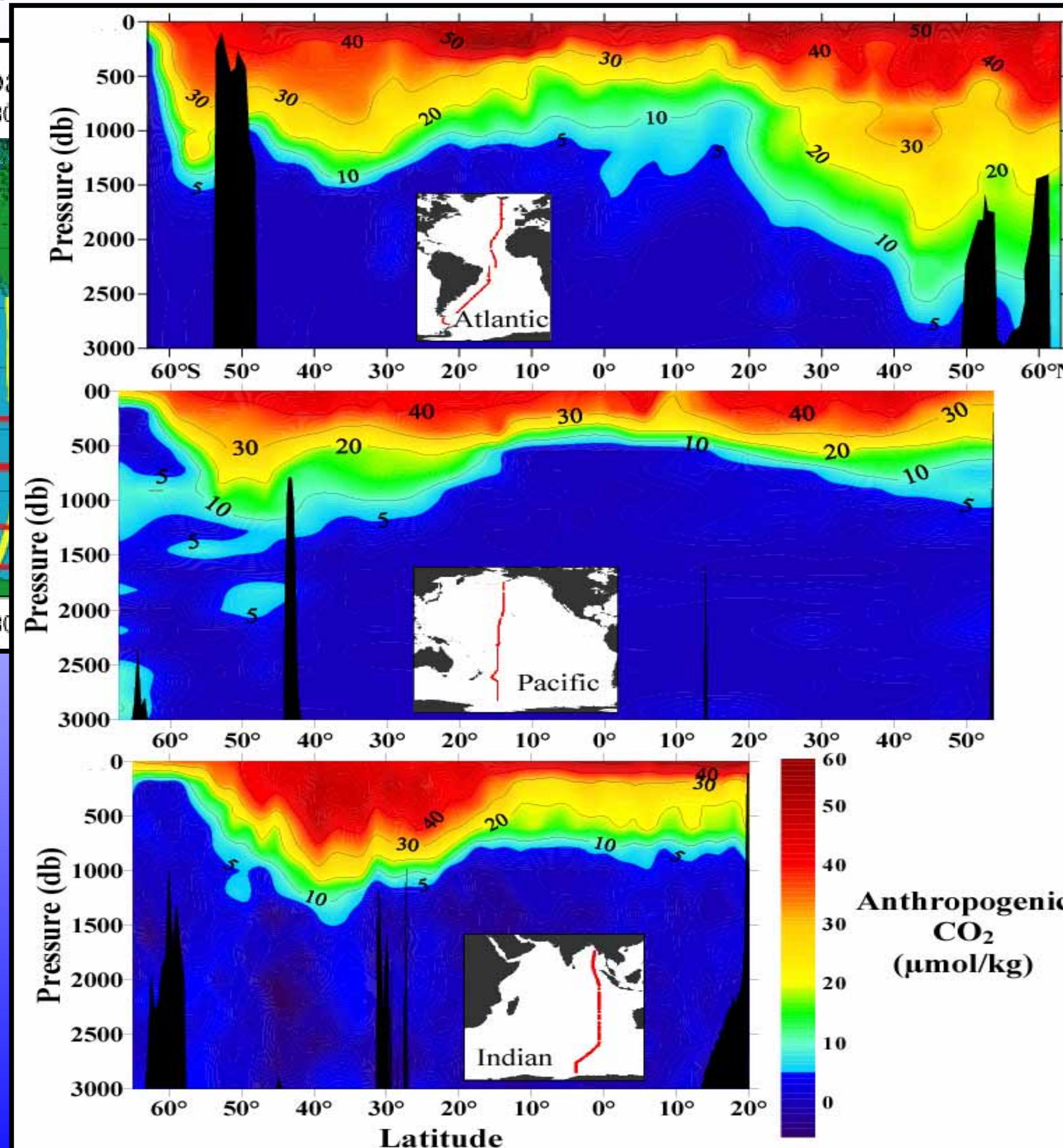


A first look at the distribution of anthropogenic CO_2 in the ocean was based on the WOCE/JGOFS/OACES global survey of carbon conducted in the 1990s.





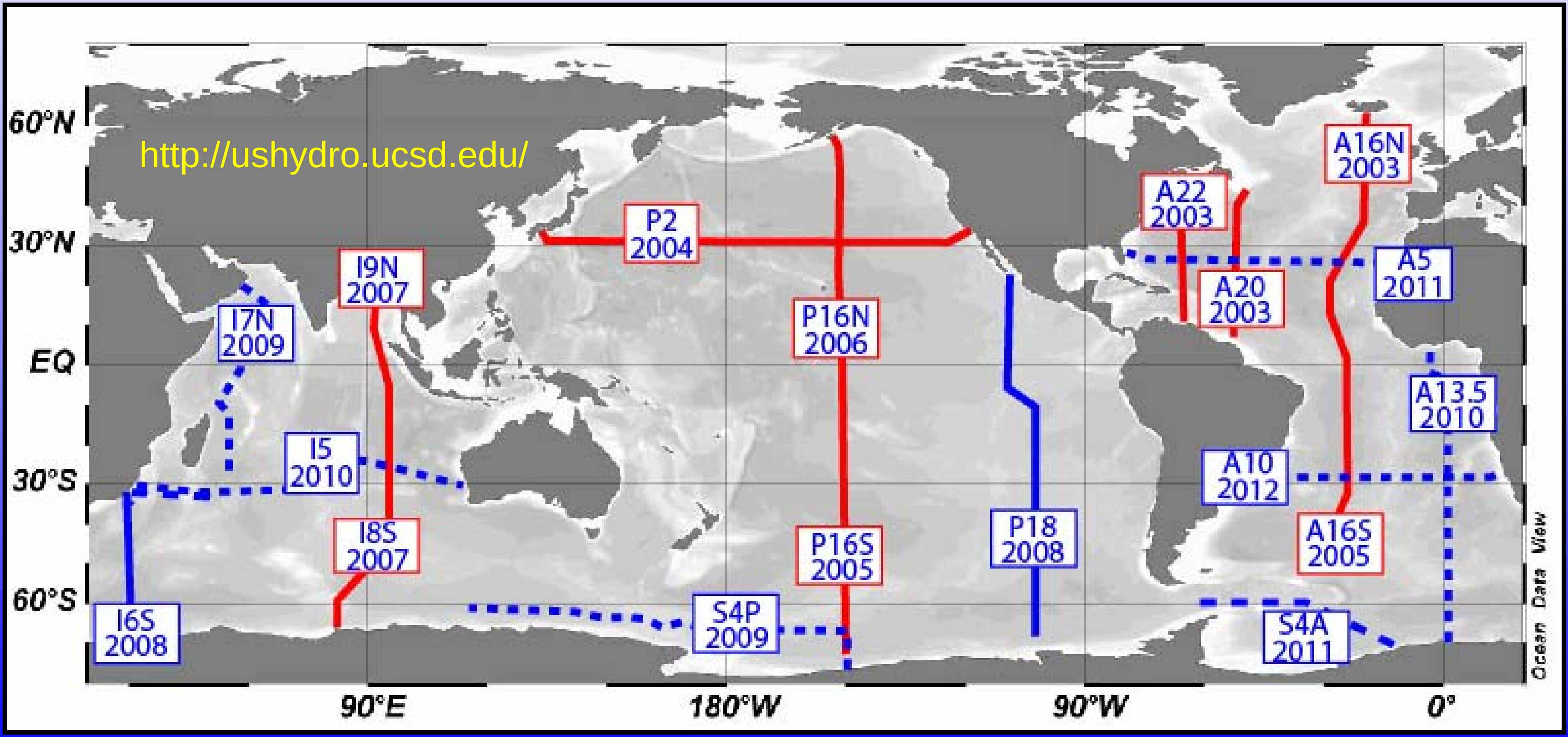
Pacific shows very little penetration in high latitude S.O., deeper penetration in southern subtropics and relatively shallow penetration in tropics

CLIVAR/CO_2 Repeat Hydrography

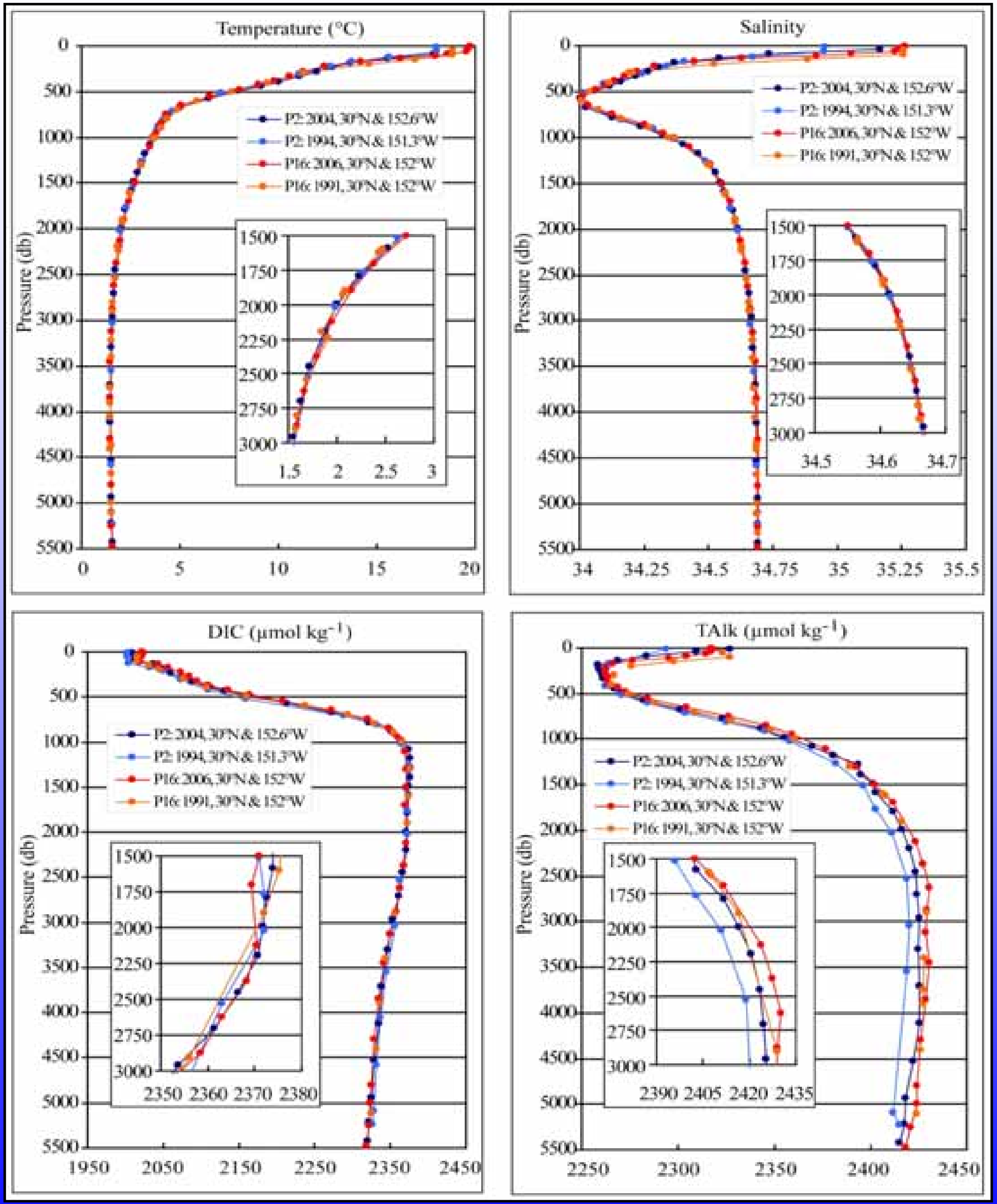
Goal: To quantify decadal changes in the inventory and transport of heat, fresh water, carbon dioxide (CO_2), chlorofluorocarbon tracers and related parameters in the oceans.

Approach: The sequence and timing of the U.S. CLIVAR/CO_2 Repeat Hydrography cruises have been selected so that there is roughly a decade between them and the WOCE/JGOFS global survey.

Achievements: The U.S. CLIVAR/CO_2 Repeat Hydrography Program has completed 9 of 18 lines and is on schedule to complete global survey by 2012.



Comparison of profiles from stations near the intersection of P2 and P16N.



Repeat Hydrography Data Are Very High Quality

P02 along 30°N
Japan to San Diego, CA
June-August 2004

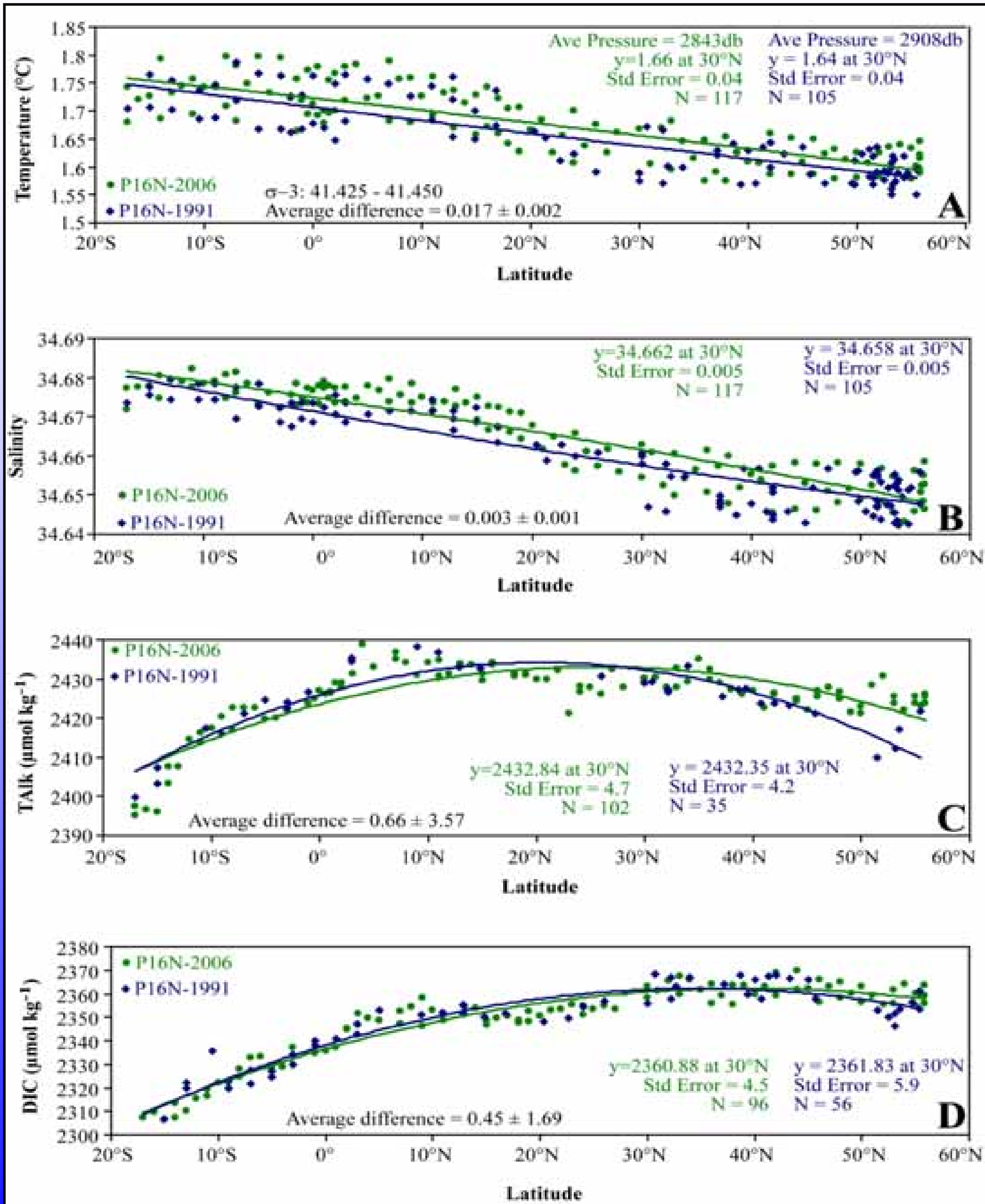
P16S along 150°W
Tahiti to New Zealand
Jan. - Feb. 2005

P16N along 152°W
Tahiti to Kodiak, AK
Feb.-March 2006

Comparison of crossover and overlap stations indicate the DIC data are good to +/- 1 μmol kg^{-1} and alkalinity data are good to +/- 2 μmol kg^{-1}

Repeat Hydrography Data Agree Well With Historical Data

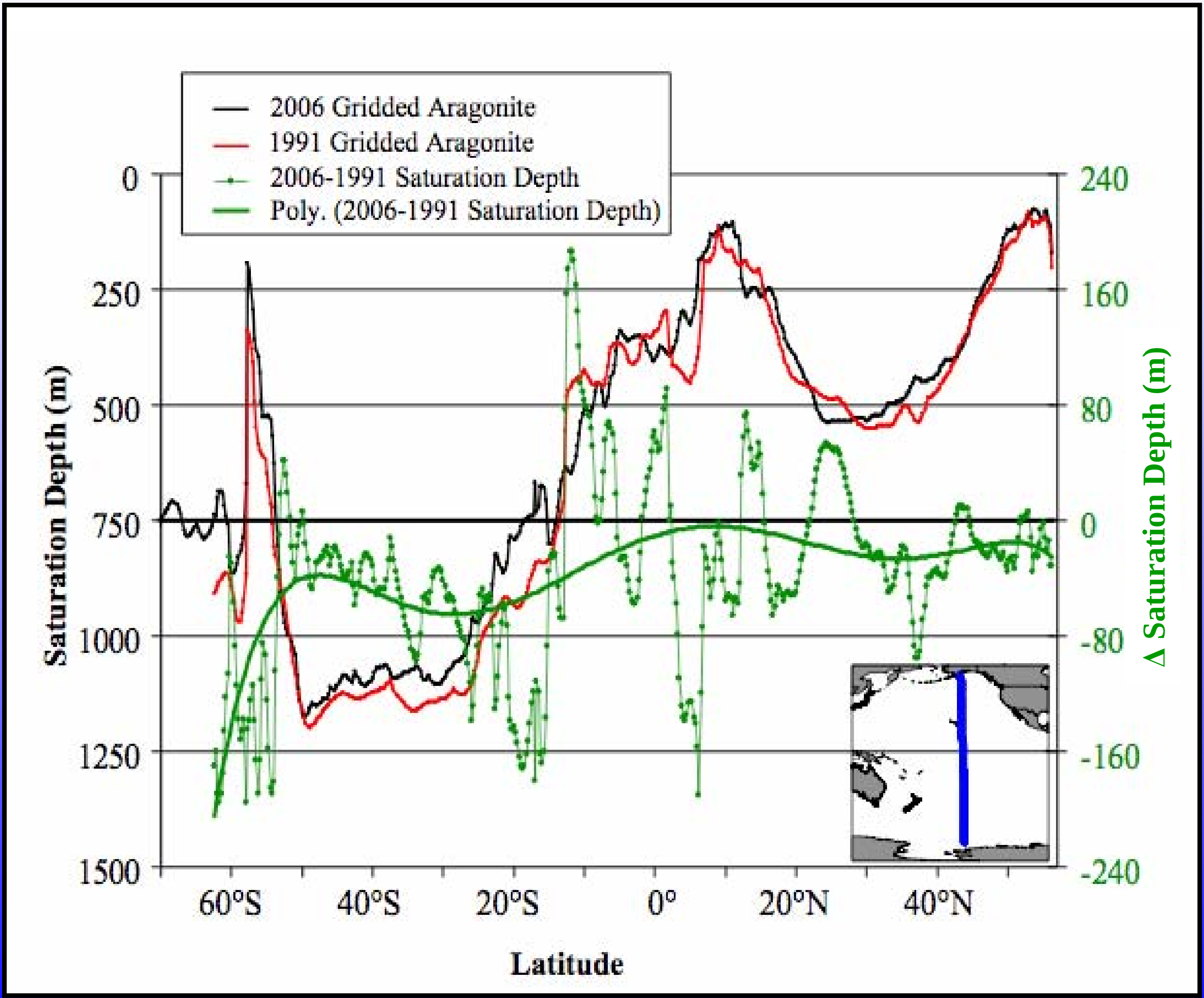
Comparison of 1991 P16N data with 2006 P16N data along 41.425-41.450 σ_3 isopycnal surface.



These cruises repeat WOCE lines
P02 occupied in 1994 (10 yr diff.)
P16S/P16A in 1991/2 (14 yr diff.)
P16C/P16N in 1991 (15 yr diff.)

Comparison of deep waters on isopycnal surfaces show no significant offsets between Repeat Hydrography and WOCE cruises.

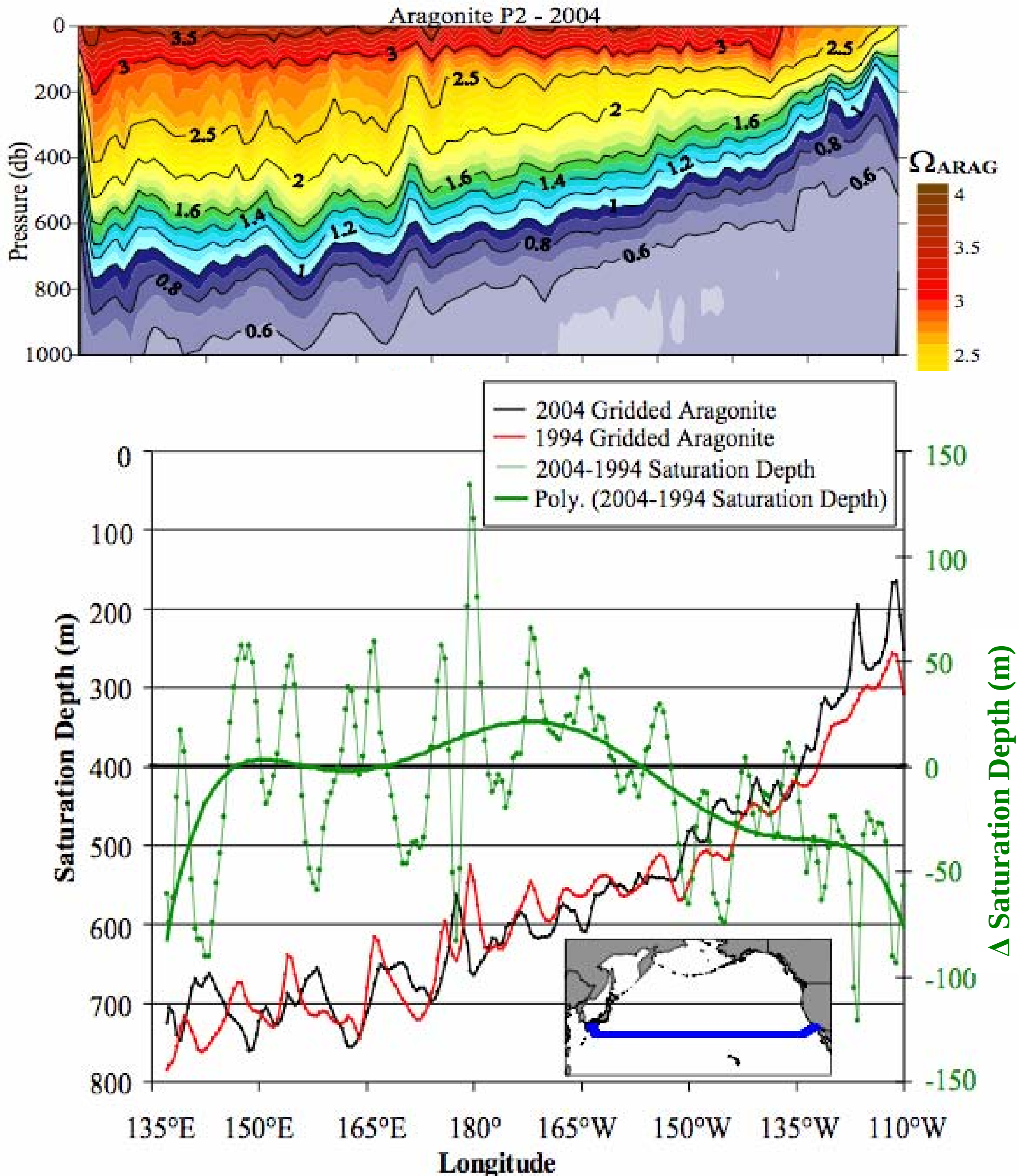
Shoaling of aragonite saturation horizon of ~1-2 m yr^{-1}



Decreases of aragonite saturation depths in the upper 1000m

Shoaling of aragonite saturation horizon of ~1-2 m yr^{-1}

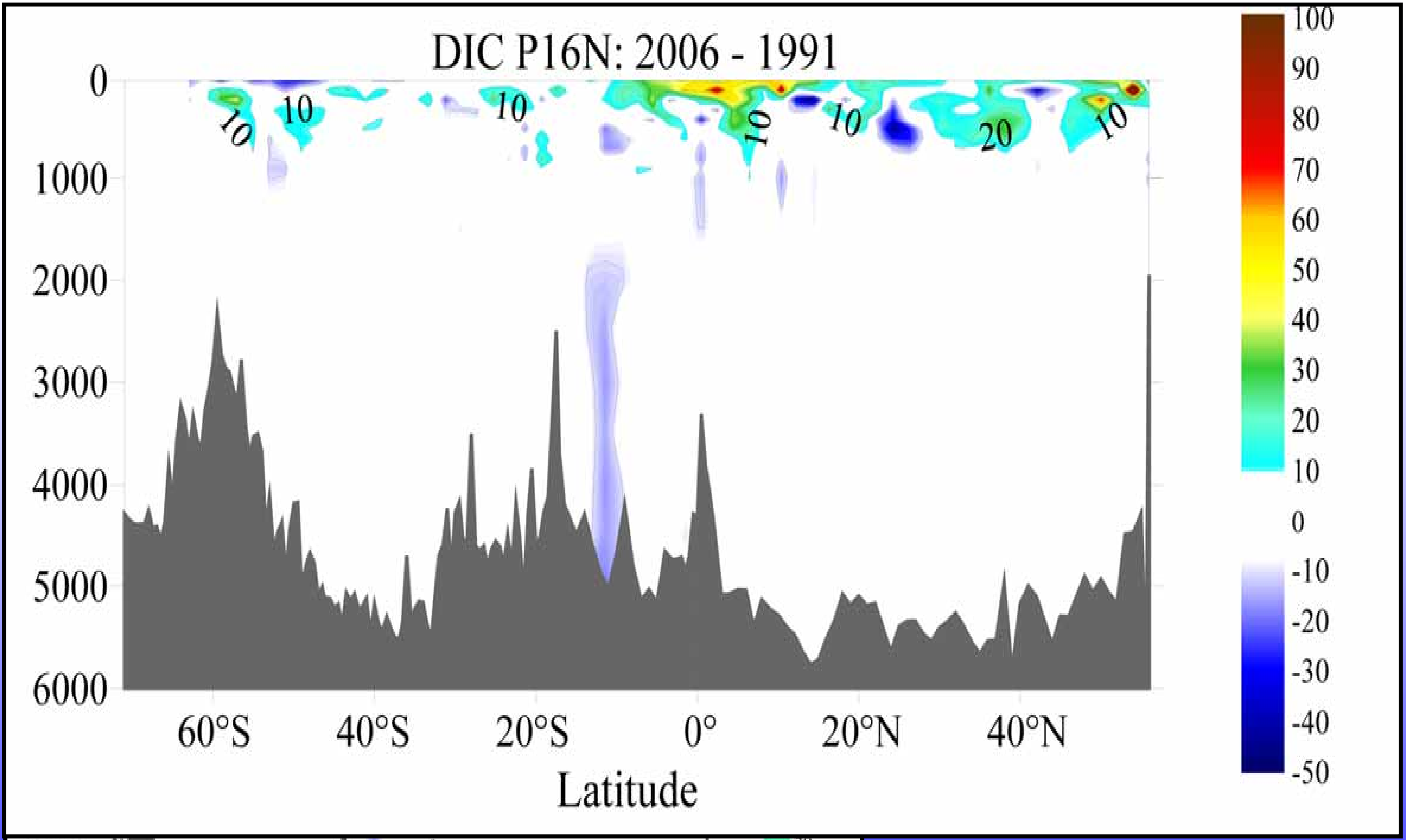
Feely et al. (in prep)

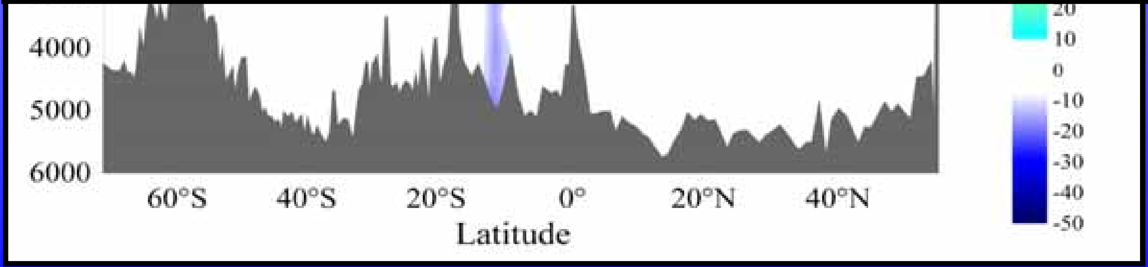


Major shoaling of aragonite saturation in the eastern Pacific

How do circulation changes affect decadal carbon chemistry signals?

Feely et al. (in prep)





But the changes are very patchy and do not show consistent trends.

Use a Multiple Linear Regression Approach to Identify Changes

Wallace (1995, OOSDP Report #5) first recognized that empirical relationships between carbon and other hydrographic properties could be used to isolate the CO_2 uptake in the ocean.

Approach:

1) Fit carbon data from older cruise with properties that should not be affected by rising atmospheric CO_2,
2) Use empirical fit of older cruise together with hydrographic data from new cruise to predict carbon distributions on the new cruise,
3) The difference between the measured carbon values on the new cruise and the predicted values is a measure of the additional carbon taken up from the atmosphere.

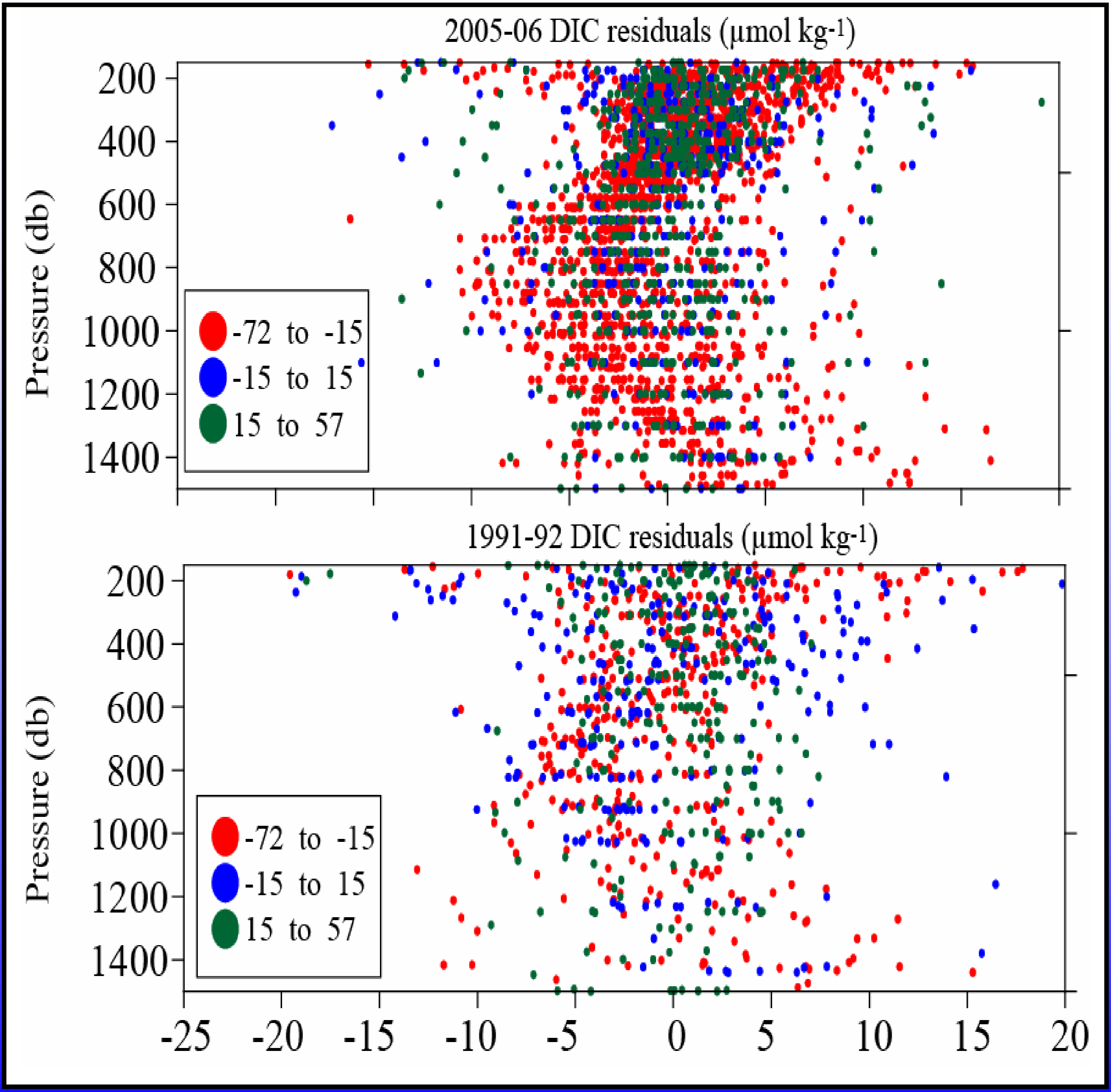
Friis et al. (2005, Deep Sea Res.) refined this approach with the extended MLR where both cruises are fit and take difference in fits.

$$DIC_{(1991)} = a*\sigma_\theta + b*\theta + c*S + d*Si + e*P + f$$

$$DIC_{(2006)} = A*\sigma_\theta + B*\theta + C*S + D*Si + E*P + F$$

$$\Delta DIC_{(06\text{-}91)} = A\text{-}a*\sigma_\theta + B\text{-}b*\theta + C\text{-}c*S + D\text{-}d*Si + E\text{-}e*P + F\text{-}f$$

Use a Multiple Linear Regression Approach to Identify Changes



DIC=f(σ_θ, θ, S, Si, P)

P16 2005/6:

72°S-15°S R^2=0.994, Std err.=4.7, n=1552

15°S-15°N R^2=0.994, Std err.=4.4, n=392

15°N-57°N R^2=0.999, Std err.=4.1, n=575

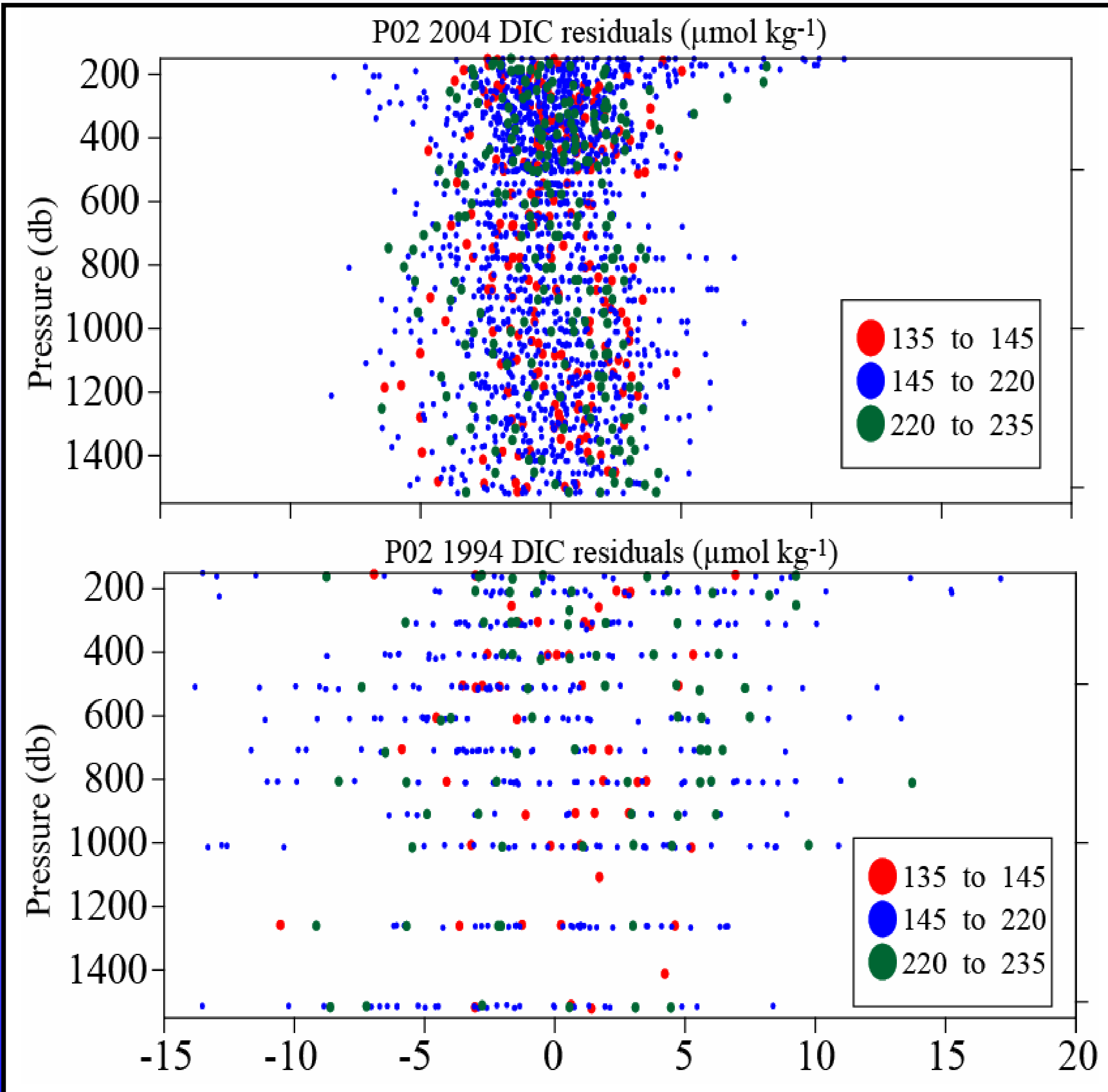
P16 1991/2:

72°S-15°S R^2=0.992, Std err.=5.3, n=418

15°S-15°N R^2=0.989, Std err.=6.6, n=253

15°N-57°N R^2=0.999, Std err.=3.8, n=250

Use a Multiple Linear Regression Approach to Identify Changes



$DIC=f(\sigma_\theta, \theta, S, Si, P)$

P2 2004:

135°E-145°E R^2=1.000, Std err.=2.2, n=199

145°E-140°W R^2=1.000, Std err.=2.5, n=1389

140°W-125°W R^2=0.999, Std err.=2.5, n=240

P2 1994:

135°E-145°E R^2=0.999, Std err.=3.6, n=50

145°E-140°W R^2=0.998, Std err.=5.8, n=353

140°W-125°W R^2=0.998, Std err.=5.8, n=82

Total Change in DIC Along P16 (150°W) 2005/6 – 1991/2

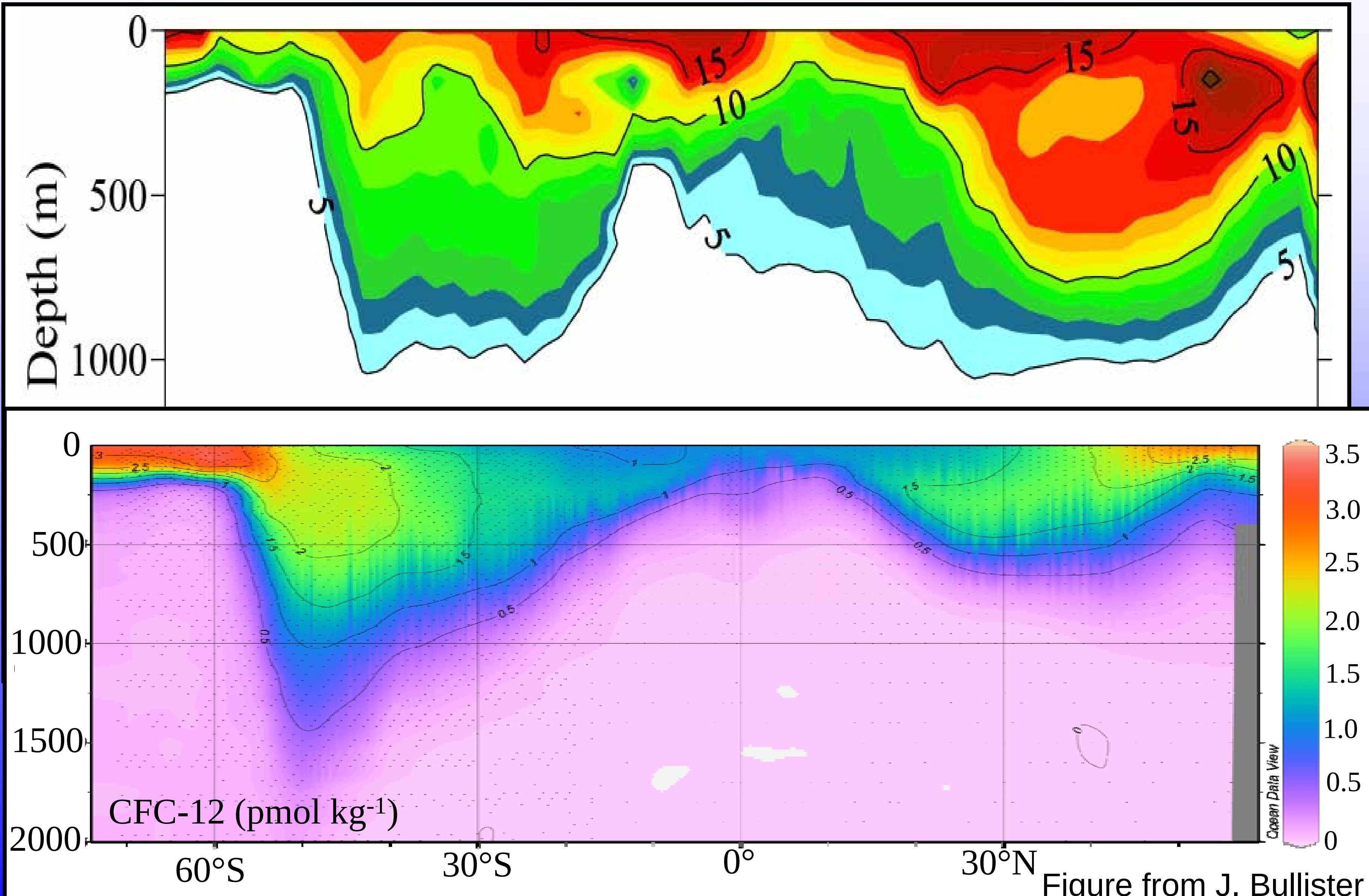
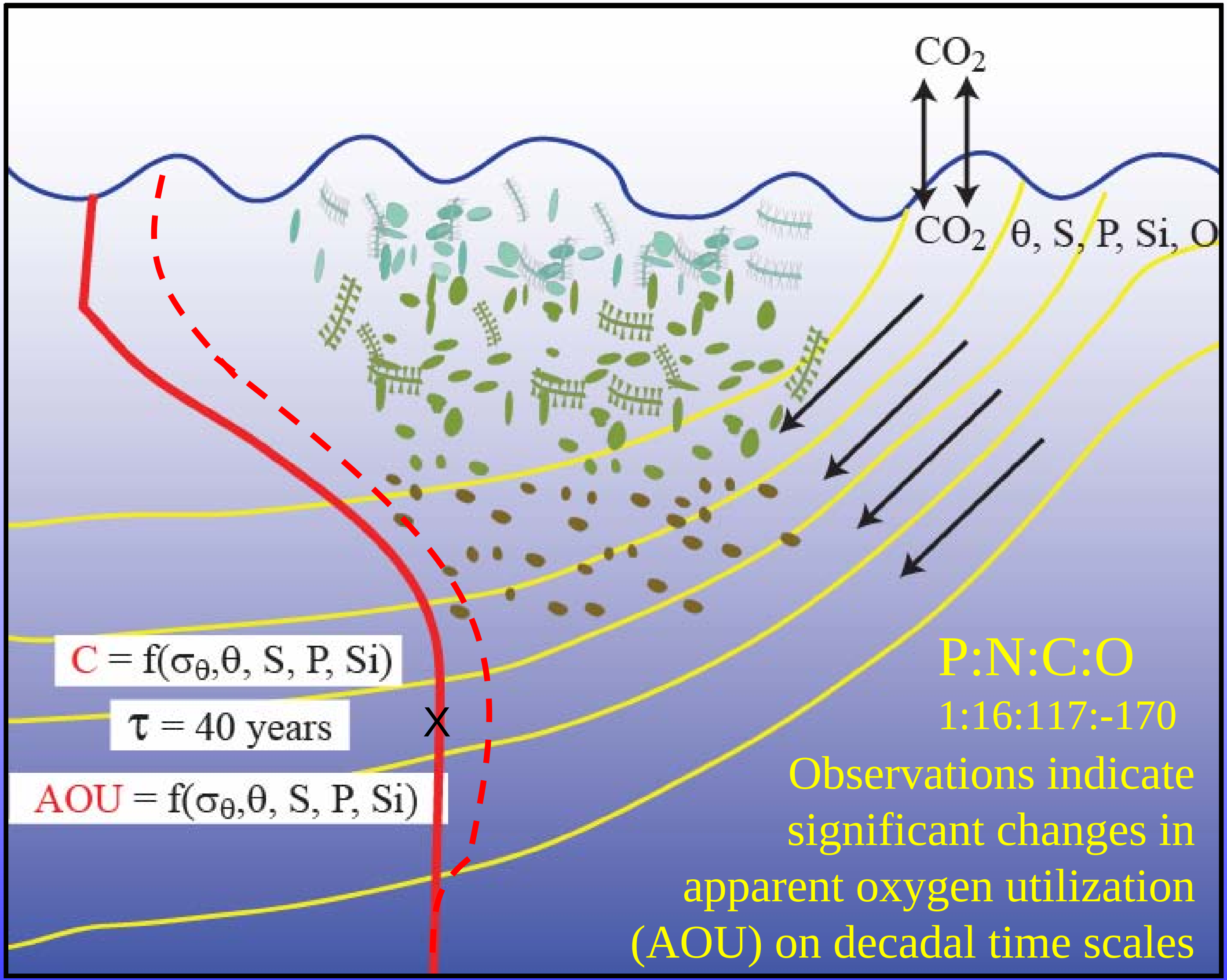


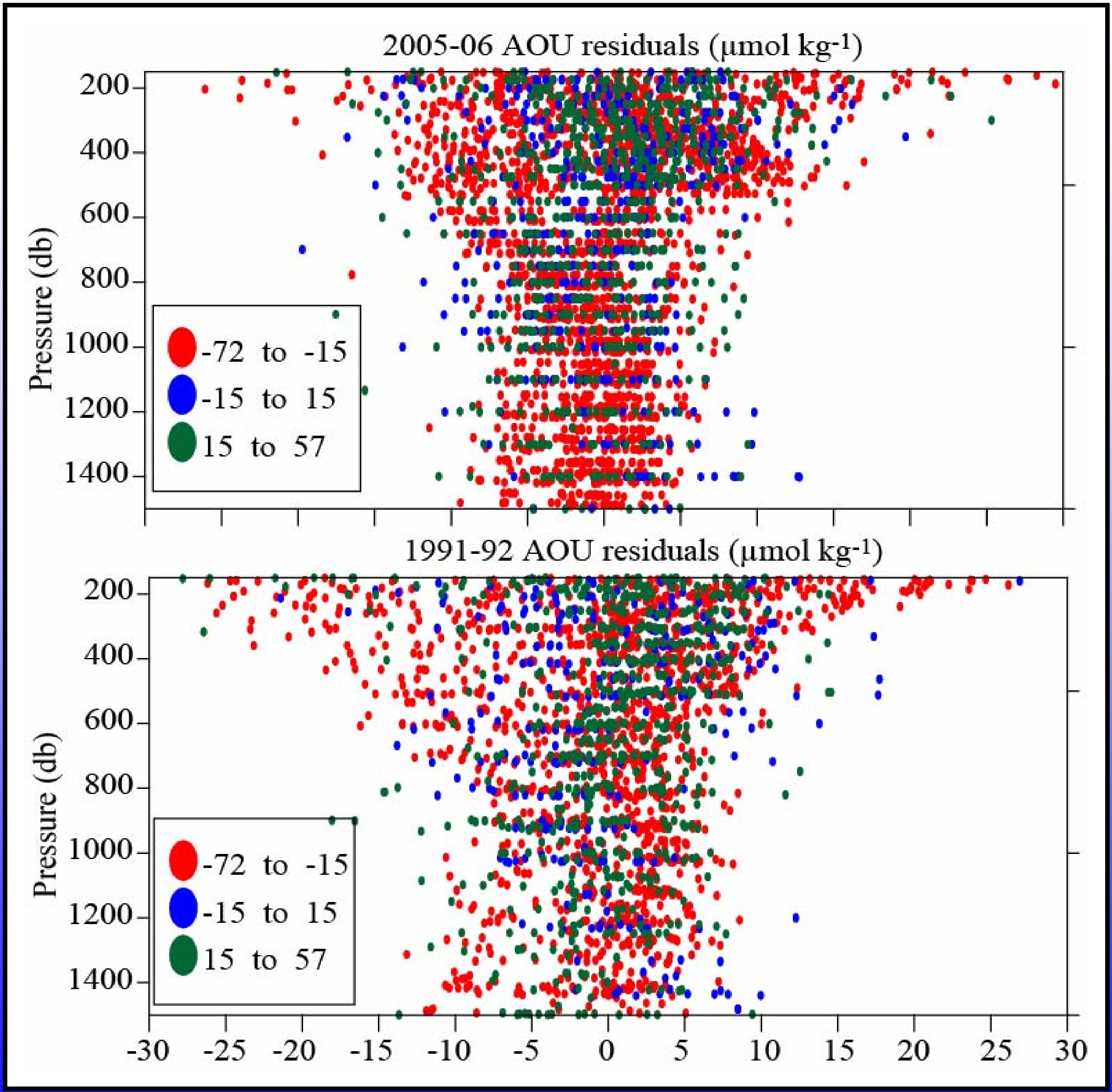
Figure from J. Bullister

What Does the MLR Tell us About Carbon Changes?



Changes in circulation or changes in export flux can alter the apparent remineralization rate affecting the carbon distributions relative to the other parameters - - use AOU to estimate this change

Use a Multiple Linear Regression Approach to Identify Changes



AOU=f(σ_θ, θ, S, Si, P)

P16 2005/6:

72°S-15°S R^2=0.984, Std err.=6.2, n=1829

15°S-15°N R^2=0.987, Std err.=6.0, n=446

15°N-57°N R^2=0.996, Std err.=6.1, n=653

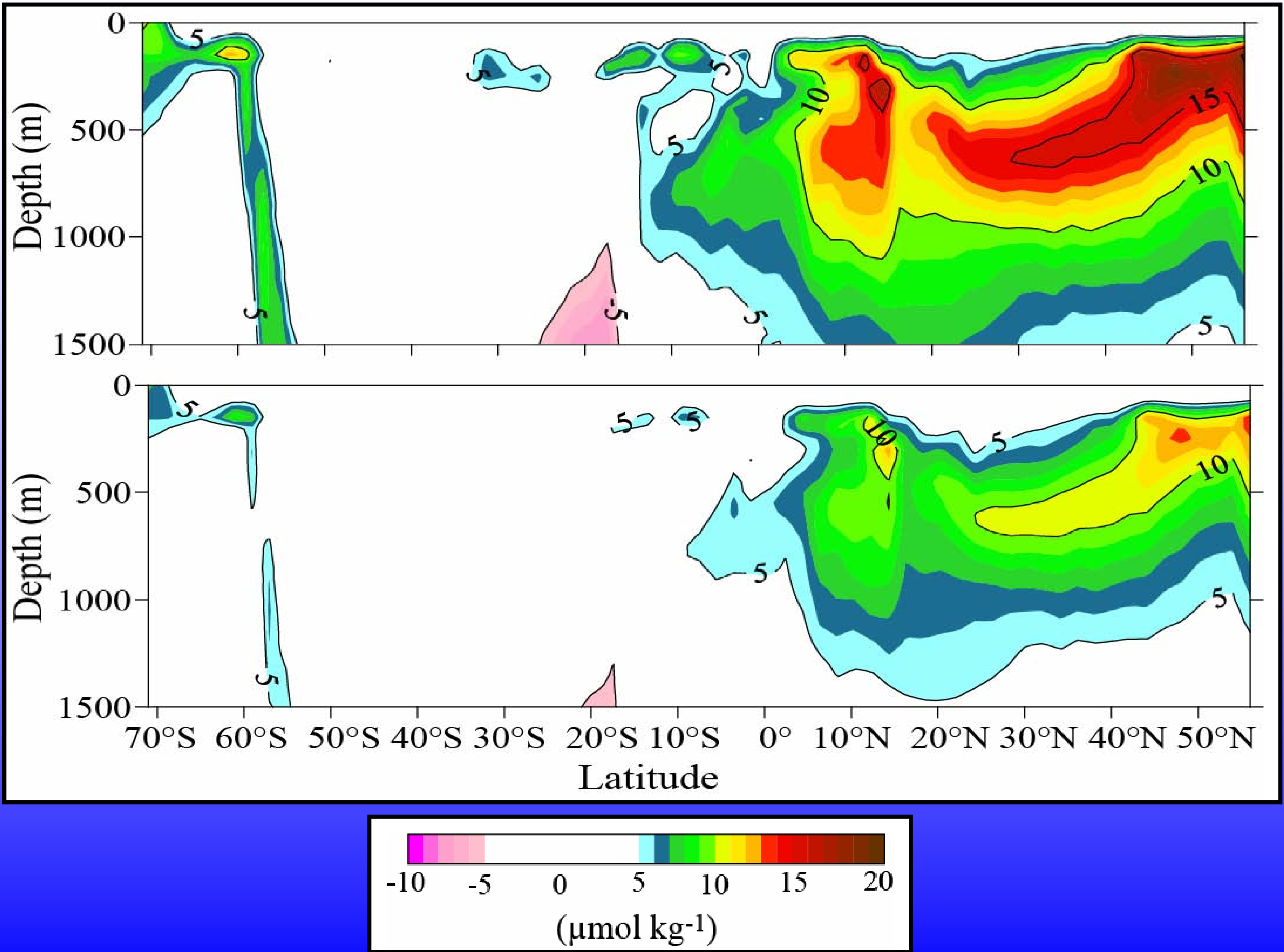
P16 1991/2:

72°S-15°S R^2=0.977, Std err.=7.4, n=1376

15°S-15°N R^2=0.986, Std err.=6.4, n=292

15°N-57°N R^2=0.995, Std err.=6.3, n=655

Change in AOU (top) And AOU Converted to C Using 117/170 Redfield Ratio (Bottom) Along P16 (150°W) 2005/6 – 1991/2



Total - AOU DIC Change Compares Well With CFC-12 Distributions Along P16 (150°W) 2005/6 – 1991/2

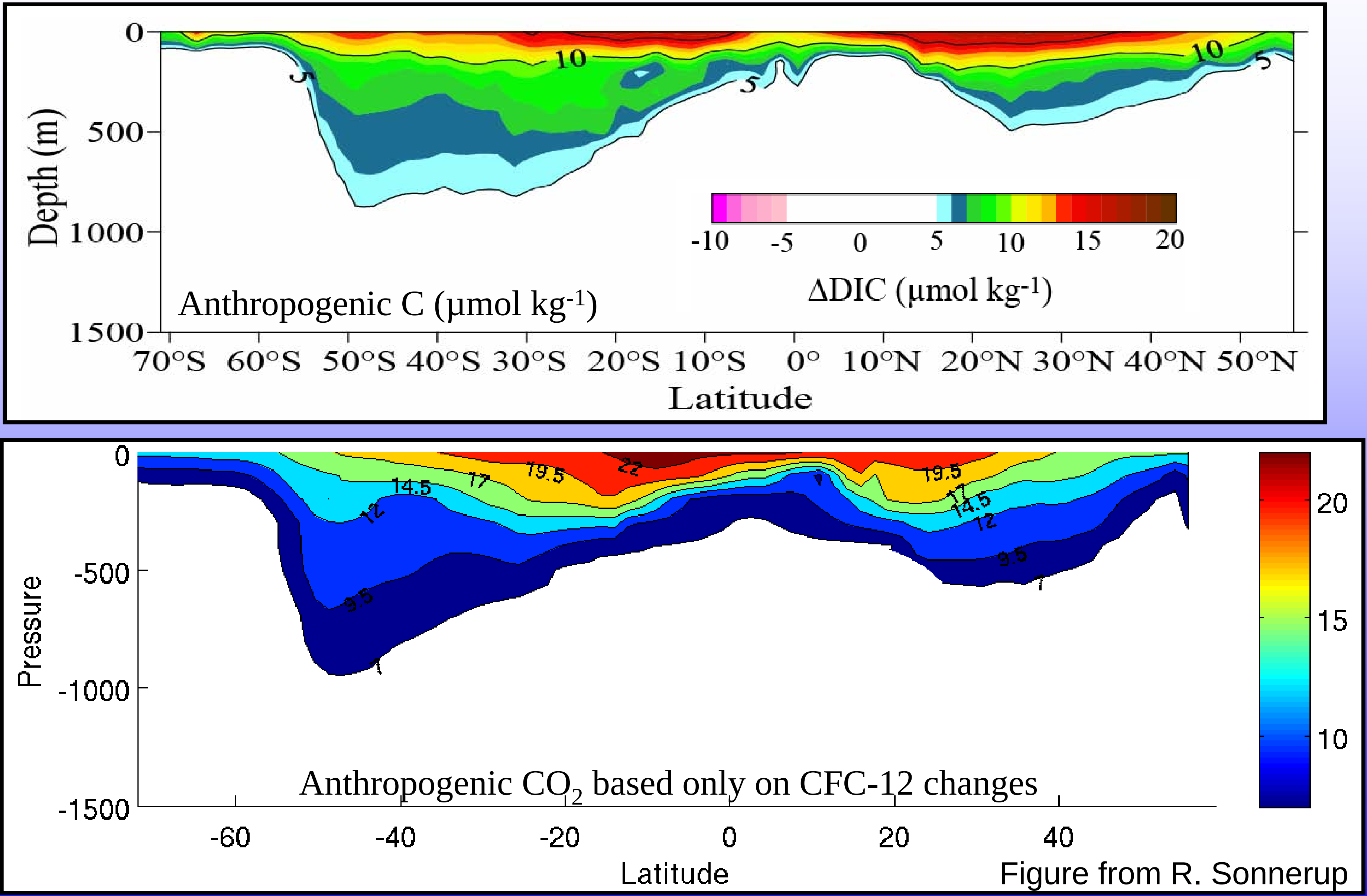
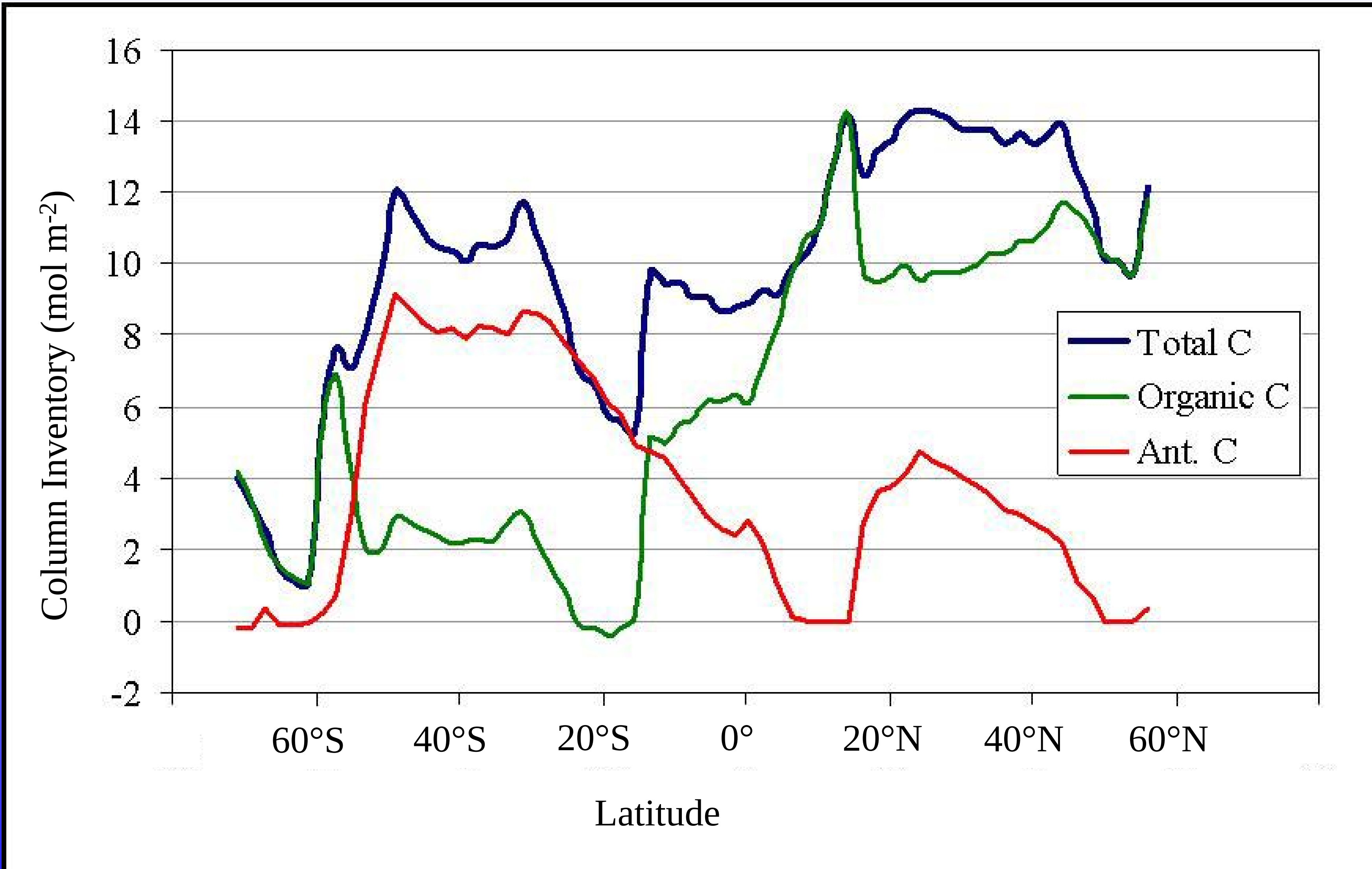
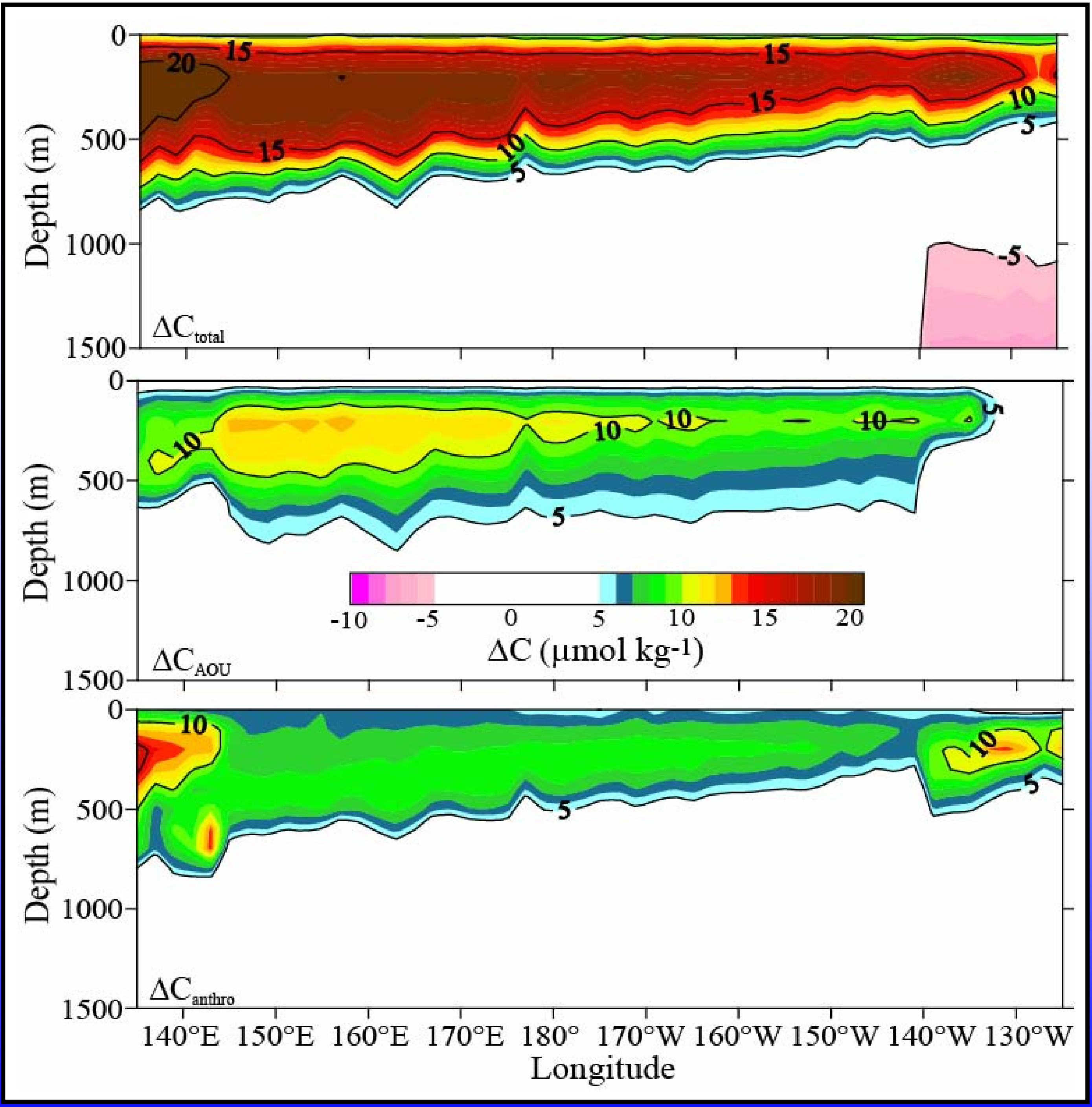


Figure from R. Sonnerup

Changes in P16 Carbon Inventory Over The Last 14 Years



P02 (30°N) Data 2004 - 1994



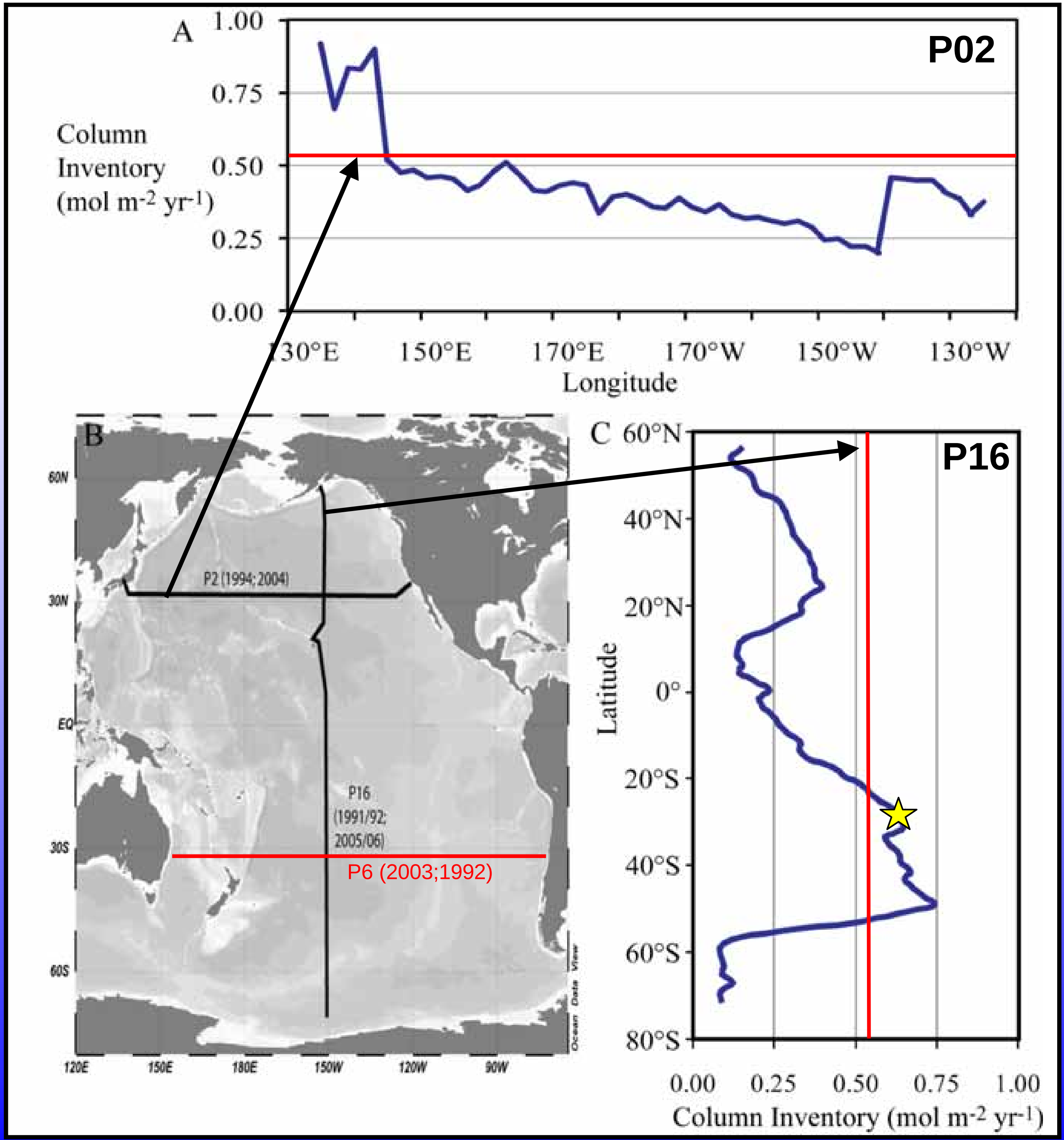
Total Carbon Change

AOU Change converted to C units

Anthropogenic Carbon Change

Average Global Growth Rate of Anthropogenic C is 0.55 mol m^{-2} yr^{-1} Based on uptake of 2.2 Pg C yr^{-1} over a global ocean area of 335.2 x 10^{9} km^{2}

Murata et al. (2007) From BEAGLE cruise isopycnal analysis 170-150°W

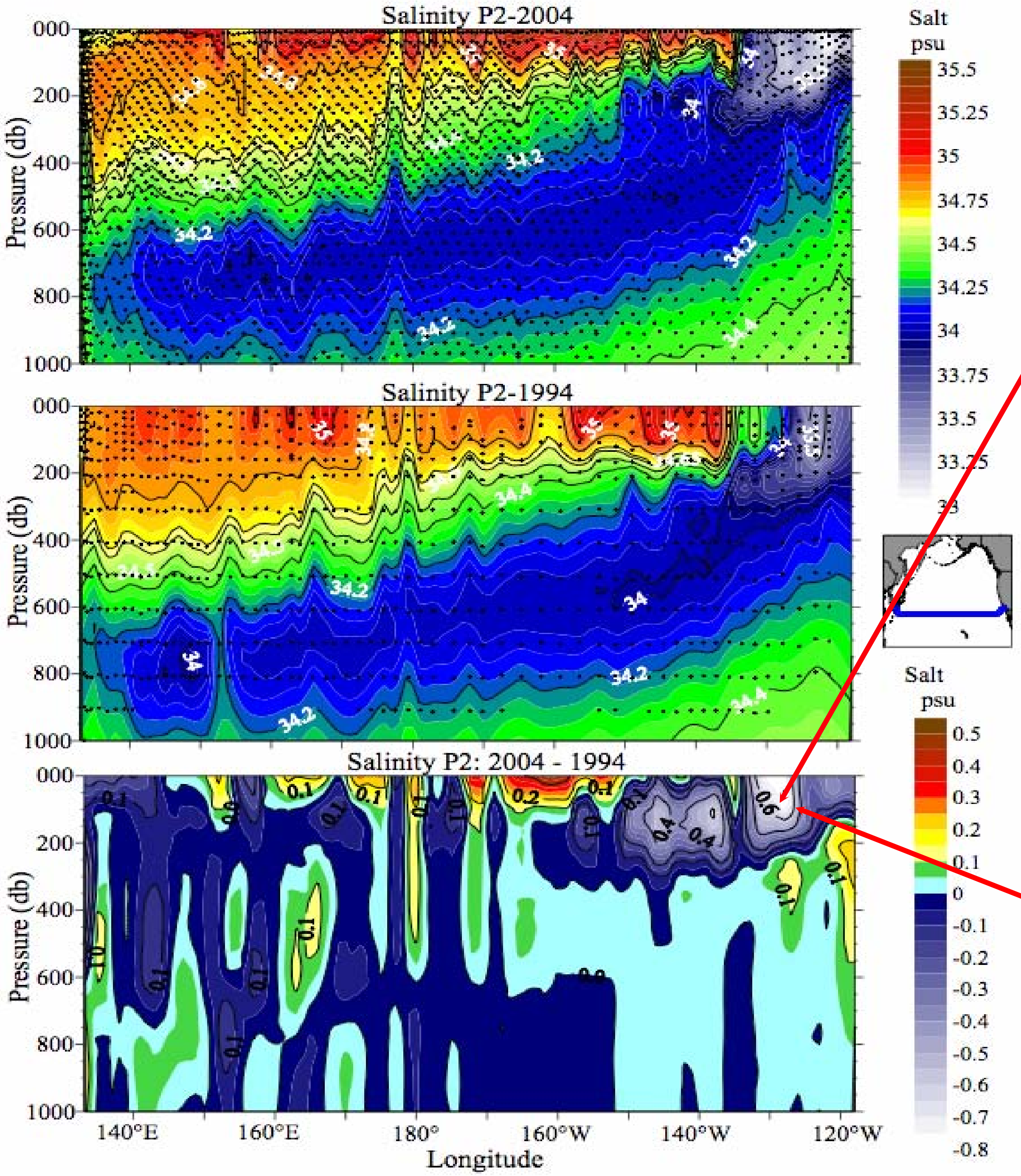


Conclusions

1) The Repeat Hydrography program is providing very high quality data
2) The observations reveal significant changes in carbon concentrations and aragonite saturation depths on decadal time scales
3) Changes in organic remineralization rates can have a significant impact on total carbon changes on decadal time scales
4) Both the anthropogenic and organic carbon changes show patterns of variability consistent with expected processes
5) Levels of anthropogenic carbon uptake in the Pacific are consistent with anticipated global average uptake

Thank you for your time!

The R/V Thomas G. Thompson arriving in Papeete, Tahiti
for the beginning of P16N February 2006



Significant freshening of the California Current in the eastern Pacific

Major decrease in salinity and temperature in the eastern Pacific due to a change in <u>circulation</u> after 1997

Feely et al. (in prep)