Using The World Ocean Database to Estimate Decadal-Scale Variability

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NOAA/NODC Ocean Climate Laboratory

http://www.nodc.noaa.gov/OCL/

Abrupt Climate Change: Mechanisms, Early Warning Signs, Impacts, and Economic Analyses
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OUTLINE

- The World Ocean Database 2005 (*WOD05*)

- Examples of variability and trends inferred from the WOD01+ (t, S, O_2)

OCL staff supporting WOD development

1) Sydney Levitus (Director, OCL & WDC)
2) Tim Boyer (Federal Employee)
3) Hernan Garcia, PhD (Federal Employee)
4) John Antonov, PhD (NCAR project scientist)
5) Ricardo Locarnini, PhD (contractor)
6) Michelle Levesque (contractor)
7) Alexey Mishonov, PhD (contractor)
8) Igor Smolyar, PhD (contractor)
9) Daphne Johnson (Federal Employee)

TECHNICIANS

10) Olga Baranova (contractor)
11) Carla Forgy (contractor)
12) Galyna Mishonova (contractor
13) Alexandra Grodsky (contractor)

WORLD DATA CENTER FOR OCEANOGRAPHY-SILVER SPRING

14) Bob Gelfeld (Federal Employee, WDC)
15) Charlotte Sazama (0.4 FTE; Federal Employee, WDC)

NODC OCL

With NOAA OGP & ESDIM support, the NODC Ocean Climate Laboratory (OCL) has been building global ocean profile databases to study the role of the ocean as part of the earth's climate system.

This includes:

1) Creating and distributing climatologies;

2) Creating anomaly fields of temperature, salinity, and oxygen by yearly or pentadal (5-year) averaging periods to study interannual-to-decadal variability;

3) Creating derived and integral fields from the above variables for studying changes in heat content, steric sea level, chemistry, etc.

This talk focuses on recent results that are a result of systematic investigations by the OCL that begin with large scales. I emphasize examples of the value of historical integrated databases to examine oceanic variability.

WOD Generalities

1) **Database development and maintenance is <u>labor–intensive</u>.**

2) **Nearly every data set we receive has some type of problem that requires (+/-) human intervention (*e.g.*, A research ship traveling at warp speeds between observations, a profiling float sampling on land, …).**

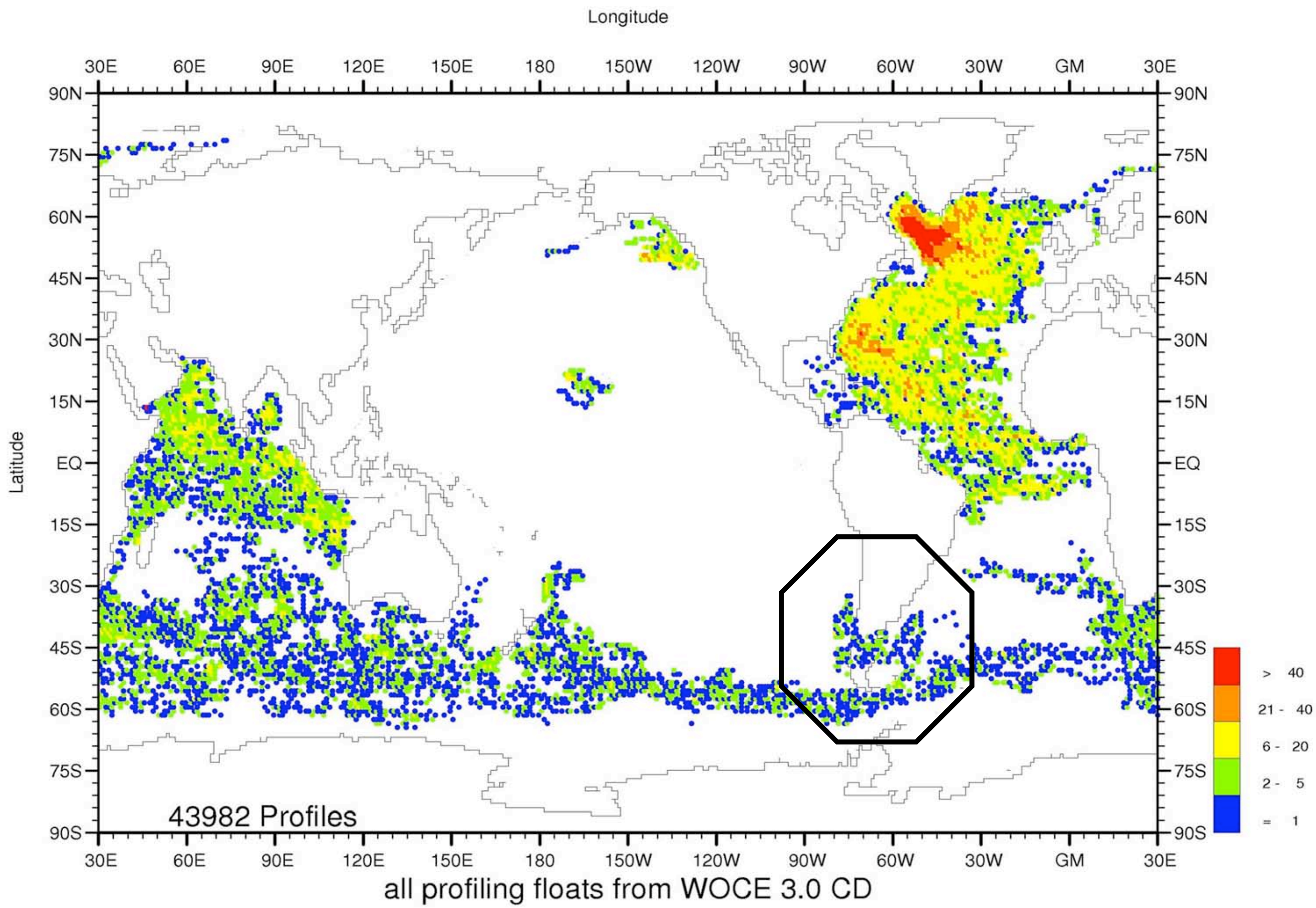
3) **We actively work with all data "operators" (providers) by providing feedback on problems we encounter.**

4) **We check our database to identify and correct errors. We provide data and metadata corrections and comments online monthly.**

The *WOD* is a work in progress

WOCE 3.0 CD-ROM: Profiling Floats

Floats on land in southern South America

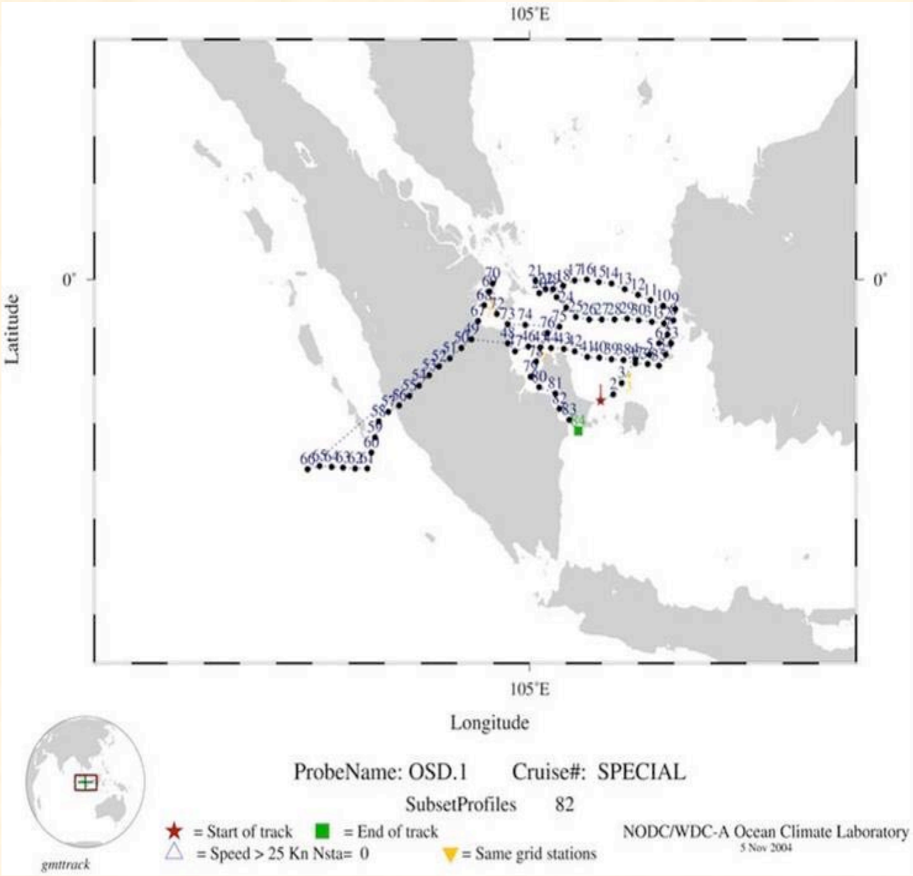


Example of data with incorrect hemisphere- UKHO card file

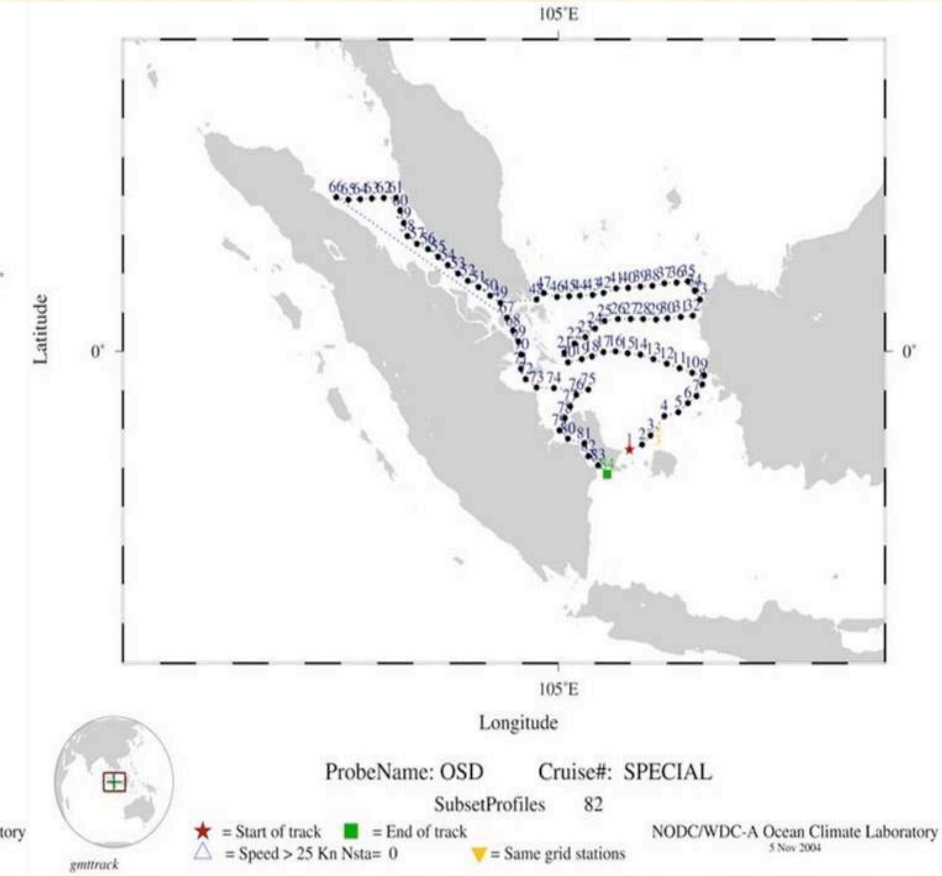
Accession # 0000450

Problem identified by CSIRO, Australia

Incorrect sign for latitude



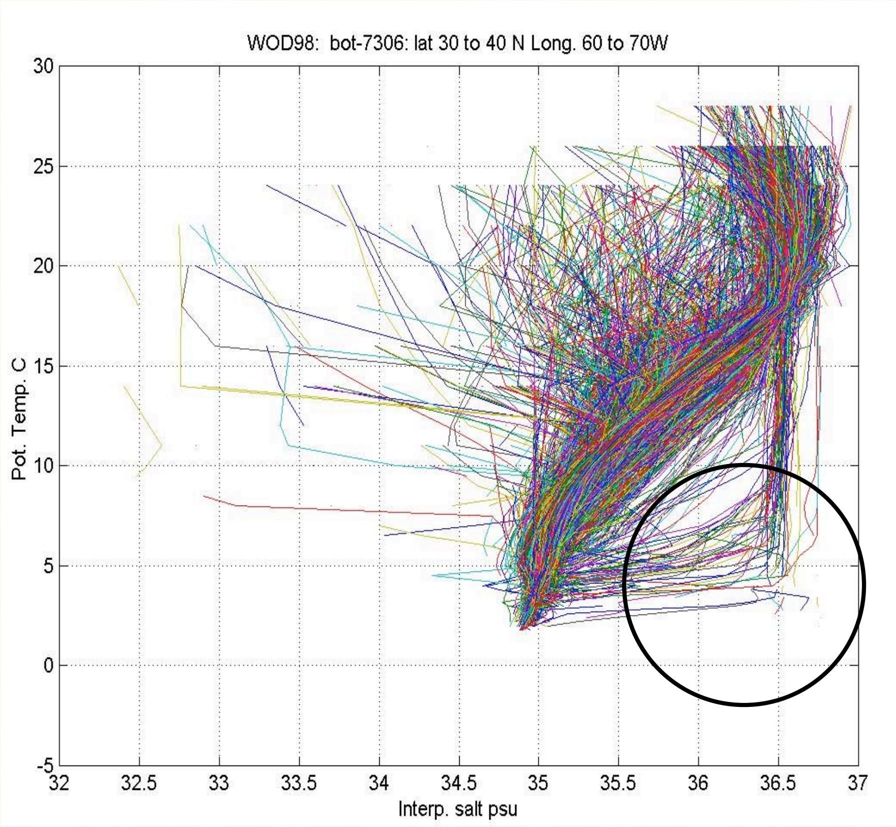
Correct sign for latitude



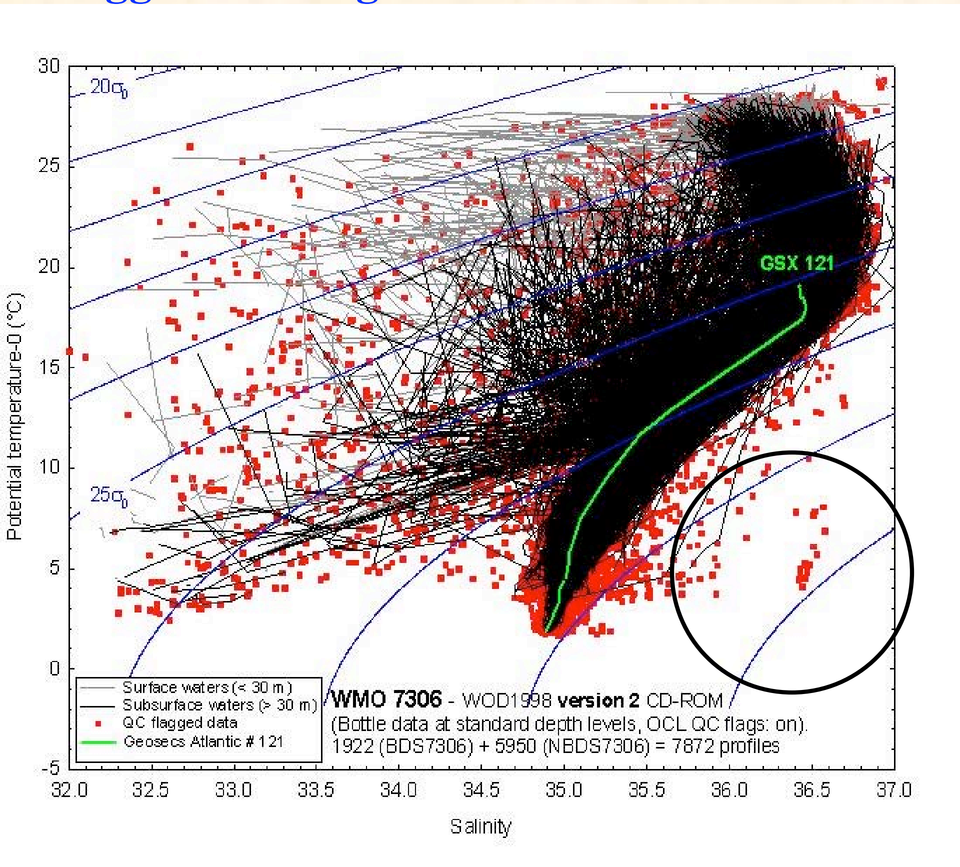
Example of data quality flags in WOD98 not being used

Bottle data for WMO Square7306: 30-40°N, 60-70°W

A user showed this T-S plot as an example of problems in WOD98. The vertical lines centered on S = 36.5 is not a "feature" of the ocean.

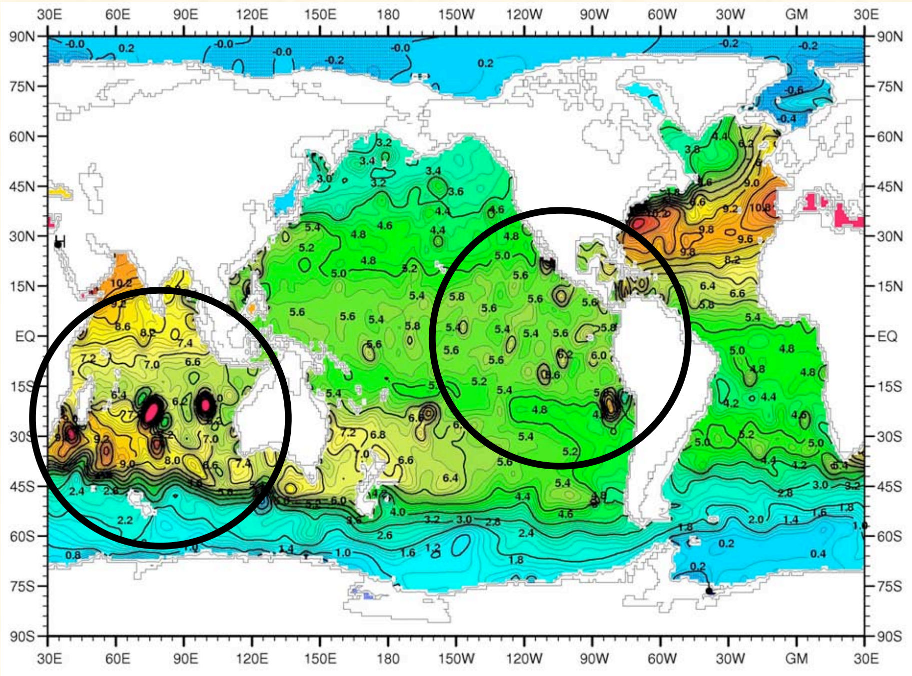


However, when we tried to reproduce the plot on the bottom left we found the user had included data that we had flagged as being erroneous.

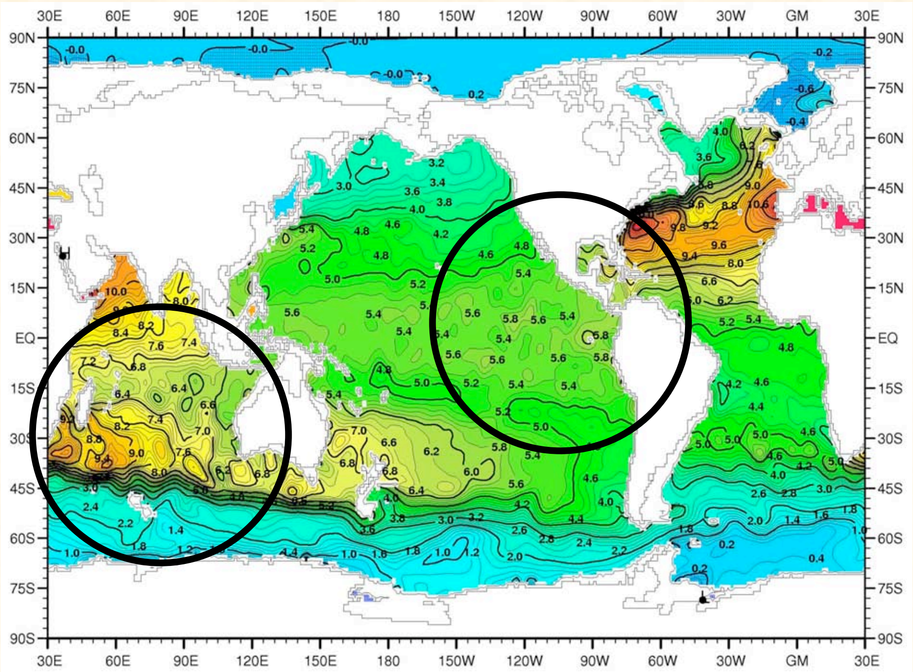


Impact of quality control on January, 800 m depth temperature climatology

January temperature climatology at 800 m depth, without "final, subjective " quality control.



January temperature climatology at 800 m depth, with quality control.



Automatic checks performed:

1) Standard deviation check
2) Range
3) Vertical gradient
4) Spike
5) Density inversion
6) Cruise speed

Did not identify these possible errors.

Data could be in error or could be "non-representative", *e.g.,* a mesoscale feature.

Permanent and semi-permanent representative features

Using data is one of the most important procedures for identifying errors or "non-representative" data (subjective checks).

What's New in *WOD* 2005

- More historical (GODAR), modern data, & metadata

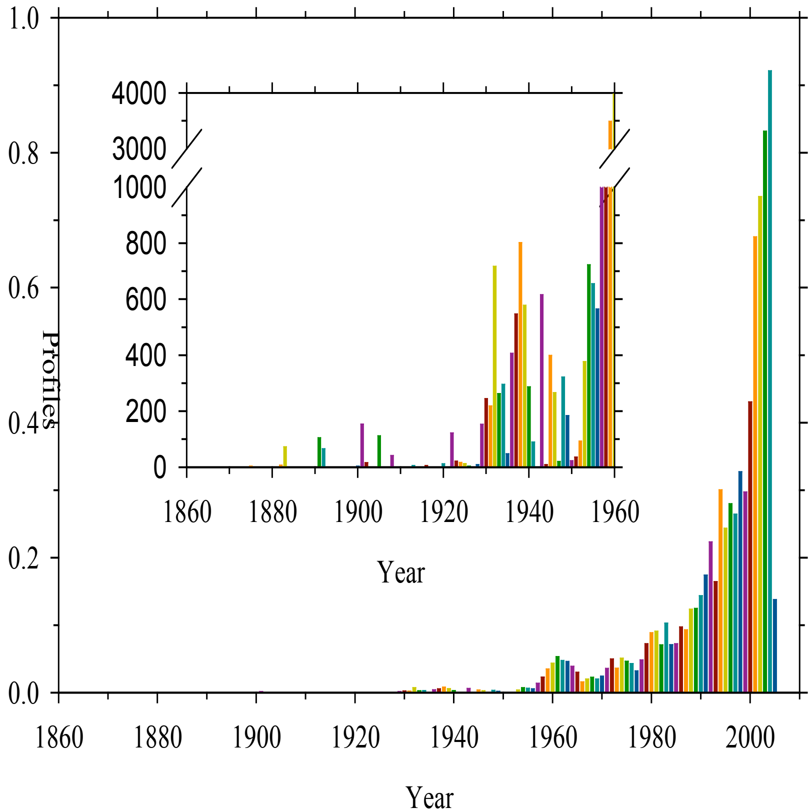
1) ~800,000 new temperature profiles
2) ~200,000 new salinity profiles
3) 216,842 replaced profiles (*e.g.*, moored buoy data from PMEL …)

***WOD*05 ~ 7,983,414 profiles (~10% increase from *WOD*01)**

- **New variables:** *e.g.*,Tritium, He, Ar, Ne, dHe3, dC14, dC13, Freons, dO18, beam attenuation coefficient, open to suggestions.

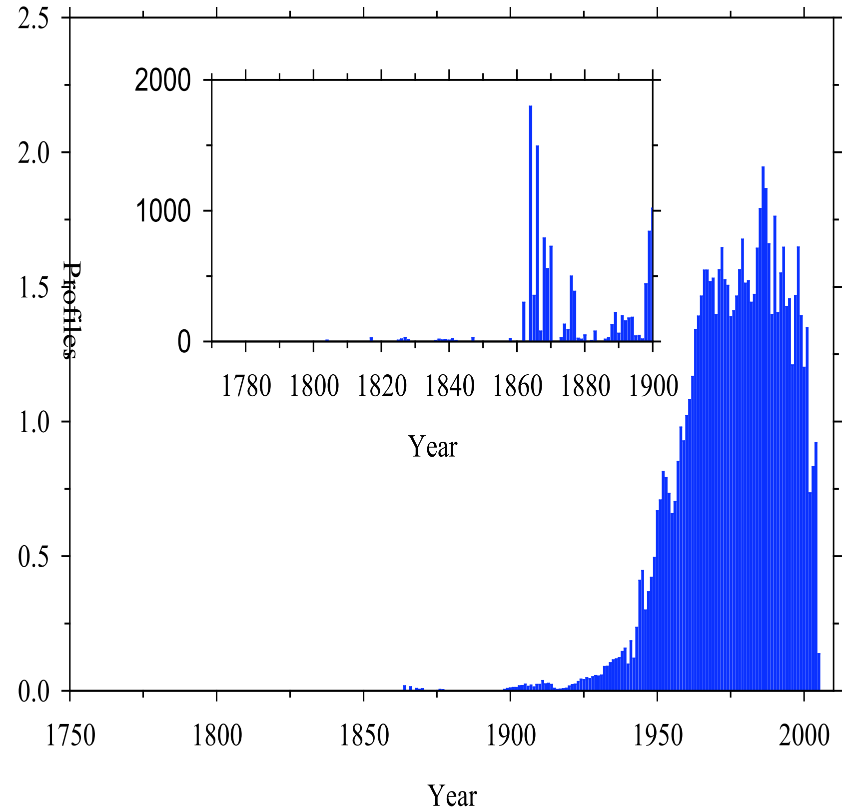
New data for *WOD*05

803,301 profiles (June 2005)

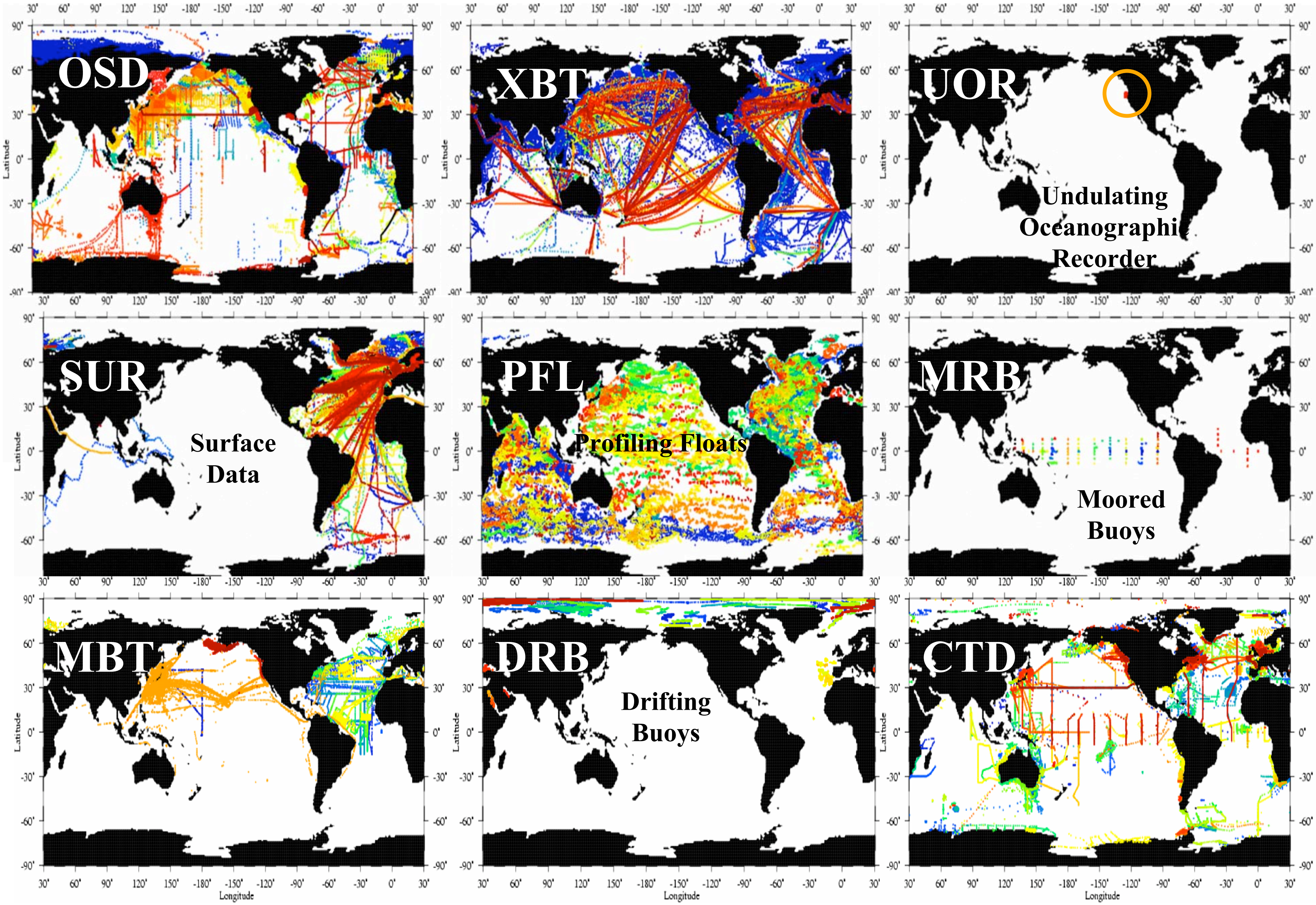


*WOD*05 final?

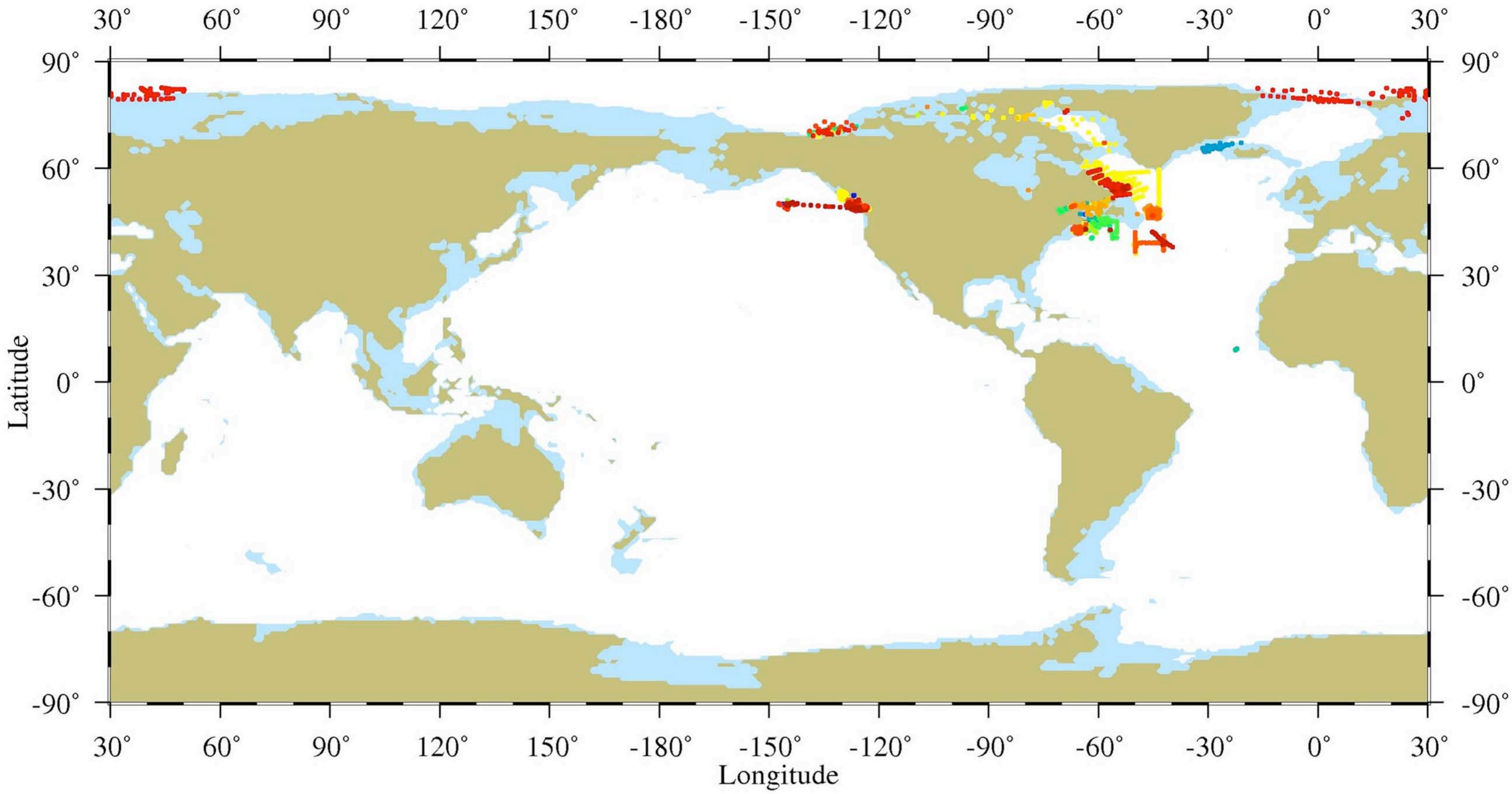
7,983,414 profiles



New WOD05 data by instrument type *as of June 2005*



MEDS CTD data 1966-1980 as of March 2005



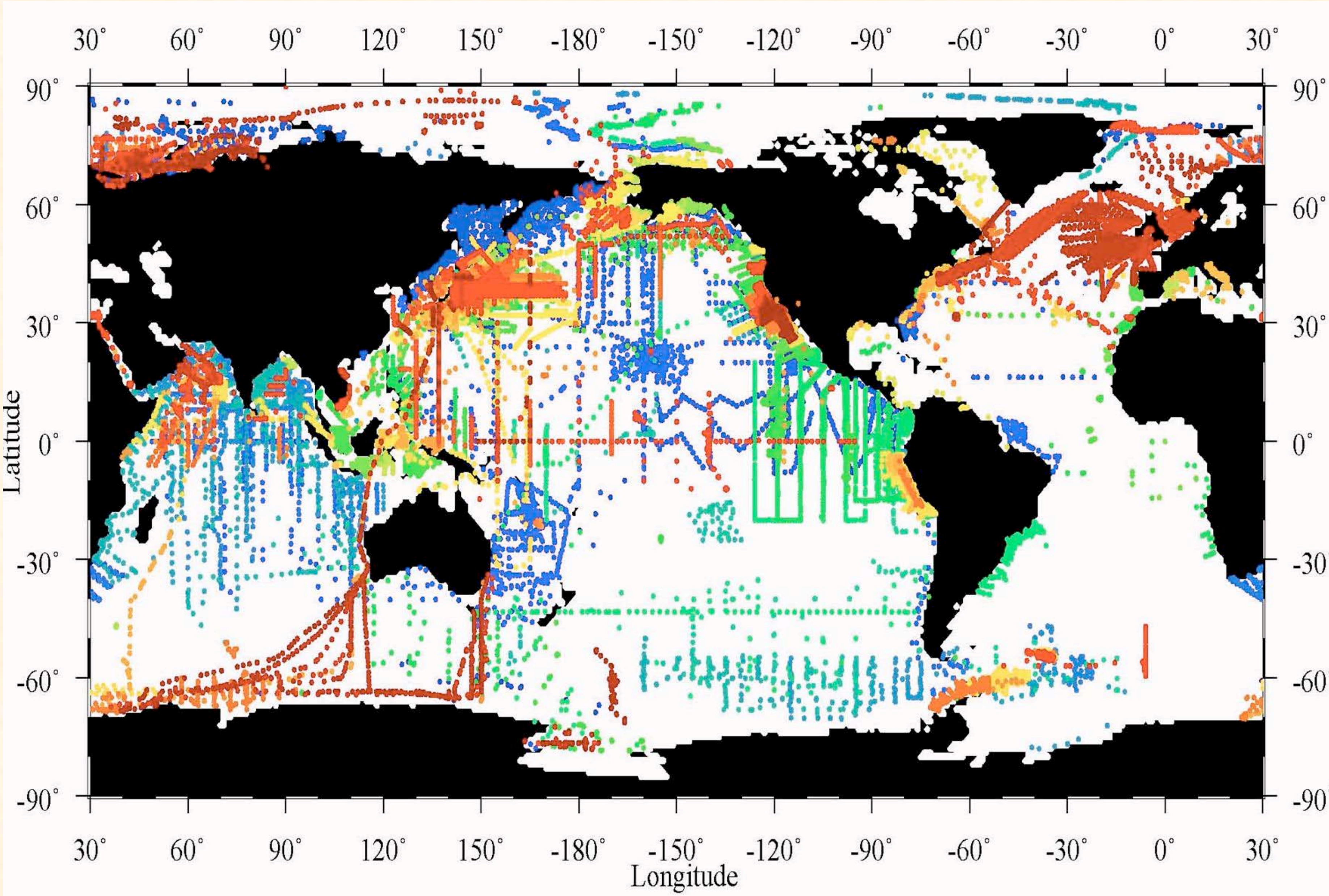
Accession 0002023, Marine Environmental Data Service (MEDS), Canada, CTD data 1966 - 1980 POSTMERGE

Ocean Climate Laboratory
chelle / 11 Jun 2005

Number of profiles= 11570 (243 cruises)

Additional data available…when to stop?

Distribution of plankton data in *WOD*01 from 1905 to 2000

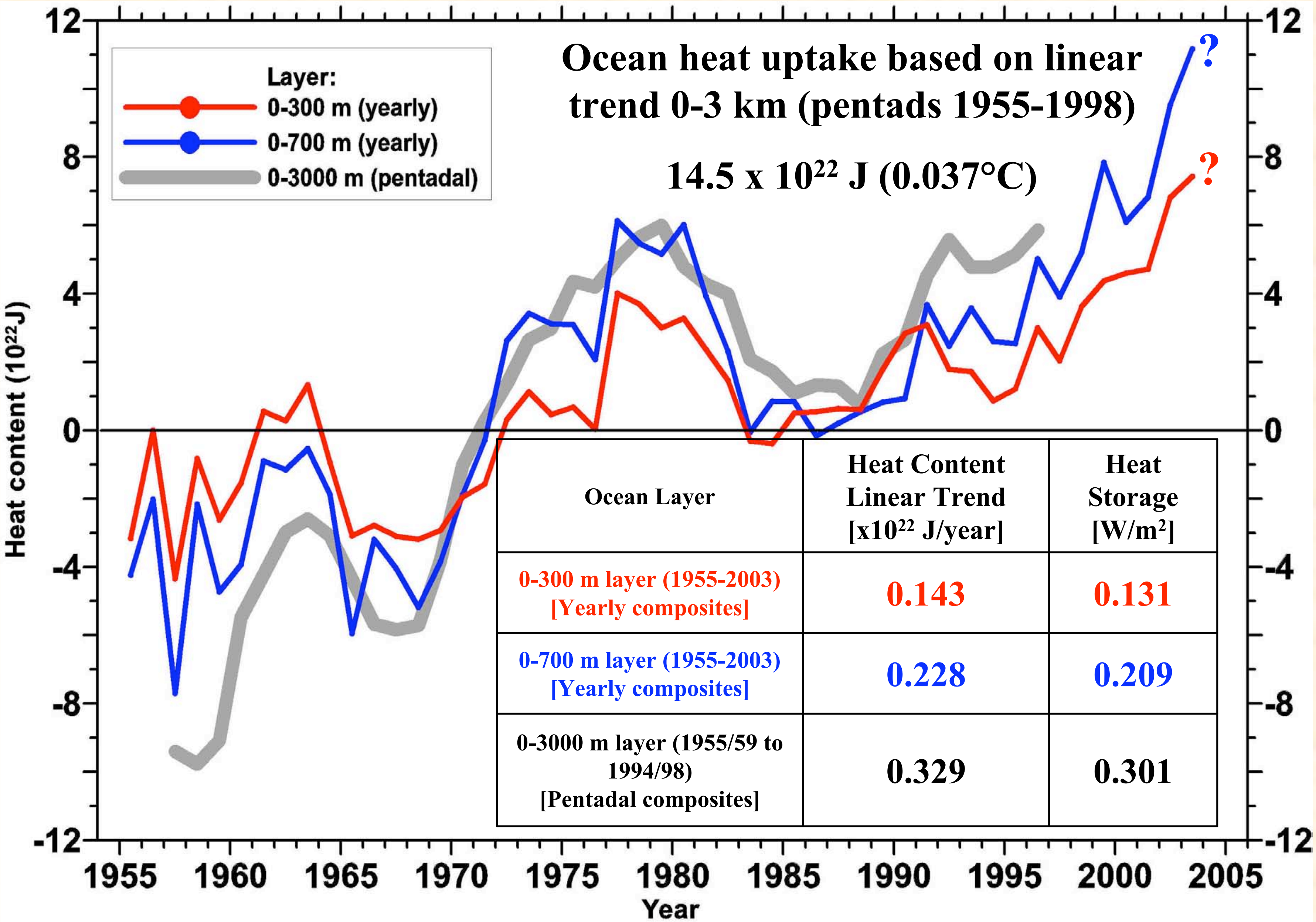


Variability in Ocean Heat Content & Thermosteric Sea Level

- **Levitus S., J. Antonov, and T. Boyer, 2005, Warming of the World Ocean, 1955-2003. *Geophys. Res. Lett., 32,* L02604, doi:10.1029/2004GL021592**

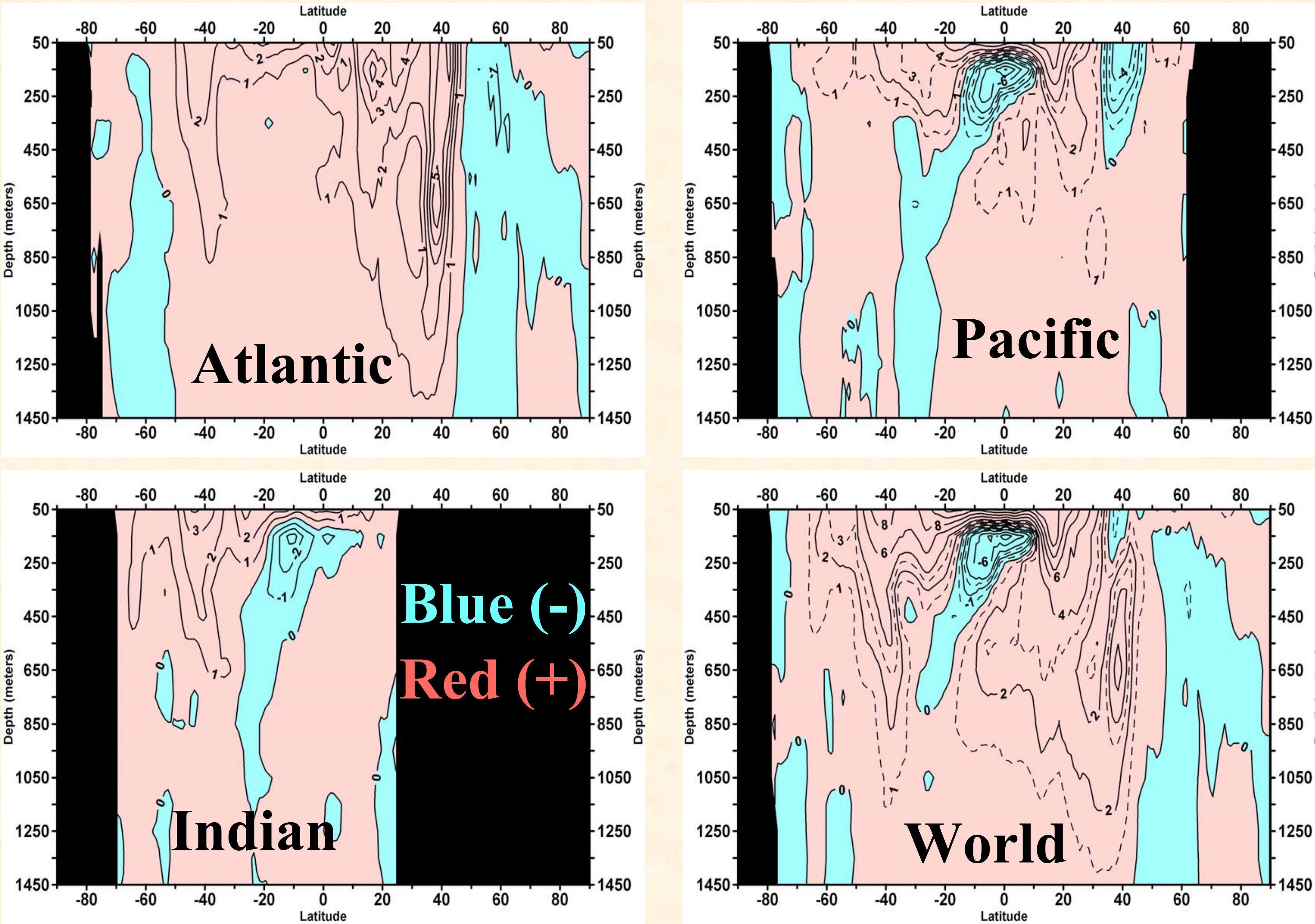
- **Antonov J.I., S. Levitus, T. P. Boyer, 2005, Thermosteric sea level rise, 1955-2003. *Geophys. Res. Lett.*, 32, L12602, doi:10.1029/2005GL023112**

Time series of ocean heat content (10^{22} J). Levitus *et al.*, 2005



Ocean Layer	Heat Content Linear Trend [x10^{22} J/year]	Heat Storage [W/m^2]
0-300 m layer (1955-2003) [Yearly composites]	0.143	0.131
0-700 m layer (1955-2003) [Yearly composites]	0.228	0.209
0-3000 m layer (1955/59 to 1994/98) [Pentadal composites]	0.329	0.301

Linear Trend of the zonally integrated heat content (x 10^{18} J/year) for 100 m thick layers (1955/59 to 1994/98). Levitus *et al.*, 2005]



Thermosteric Sea Level Variability (1955-2003). Antonov *et al.*, 2005

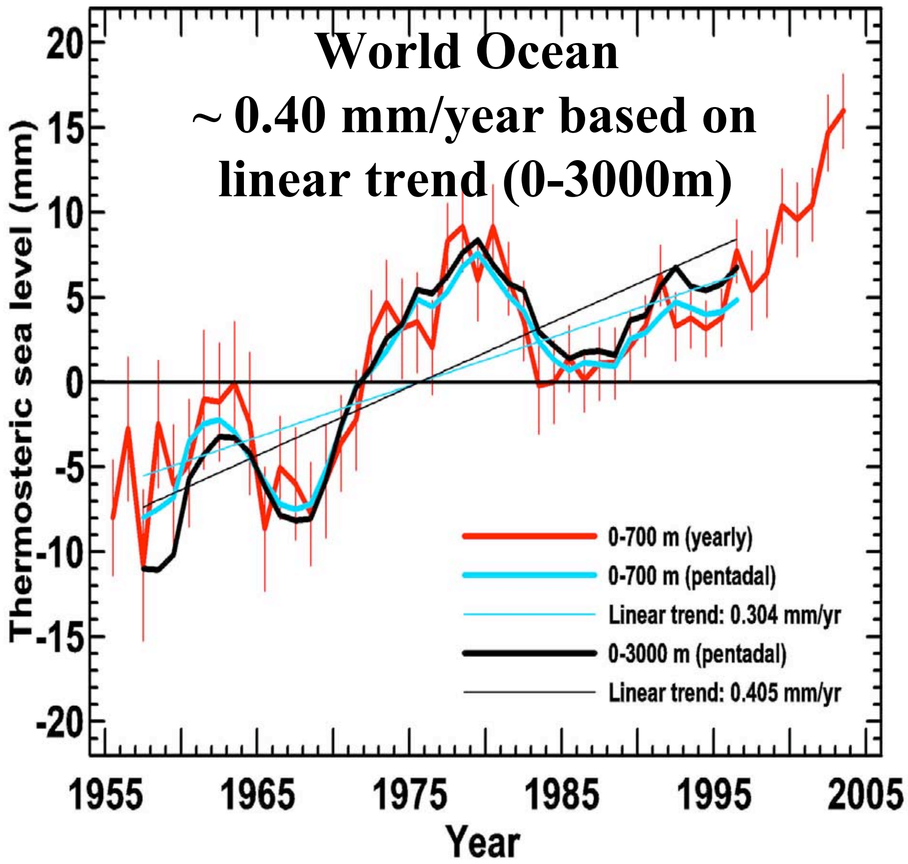


Figure 1. Time series of yearly thermosteric sea level (mm) for the 0-700 m layer (red curve) and pentadal (5-year running composites for 1955-59 through 1994-98) thermosteric sea level (mm) for the 0-700 m (blue curve) and 0-3000 m (black curve) layers. Vertical lines through each yearly estimate represent +/- 1 standard error. The linear trend for each pentadal series is plotted as a blue (black) line.

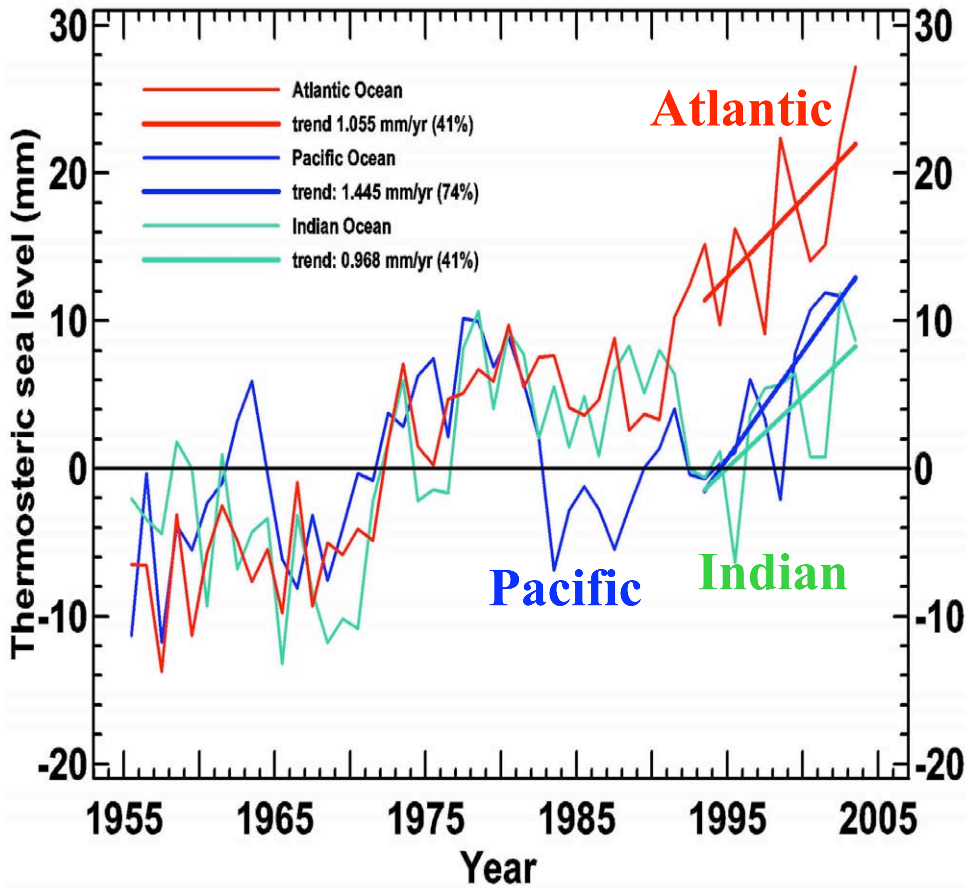


Figure A1. Time series of yearly thermosteric sea level (mm) for the 0-700 m layer for the Atlantic, Pacific, and Indian oceans. Each yearly value is plotted at the midpoint of the year. Reference period: 1957-1990. The linear trends for the 1993-2003 period are plotted as thick lines. Values given in parentheses are the percent variance accounted for by linear trend.

Partially supported by NASA Physical Oceanography Program

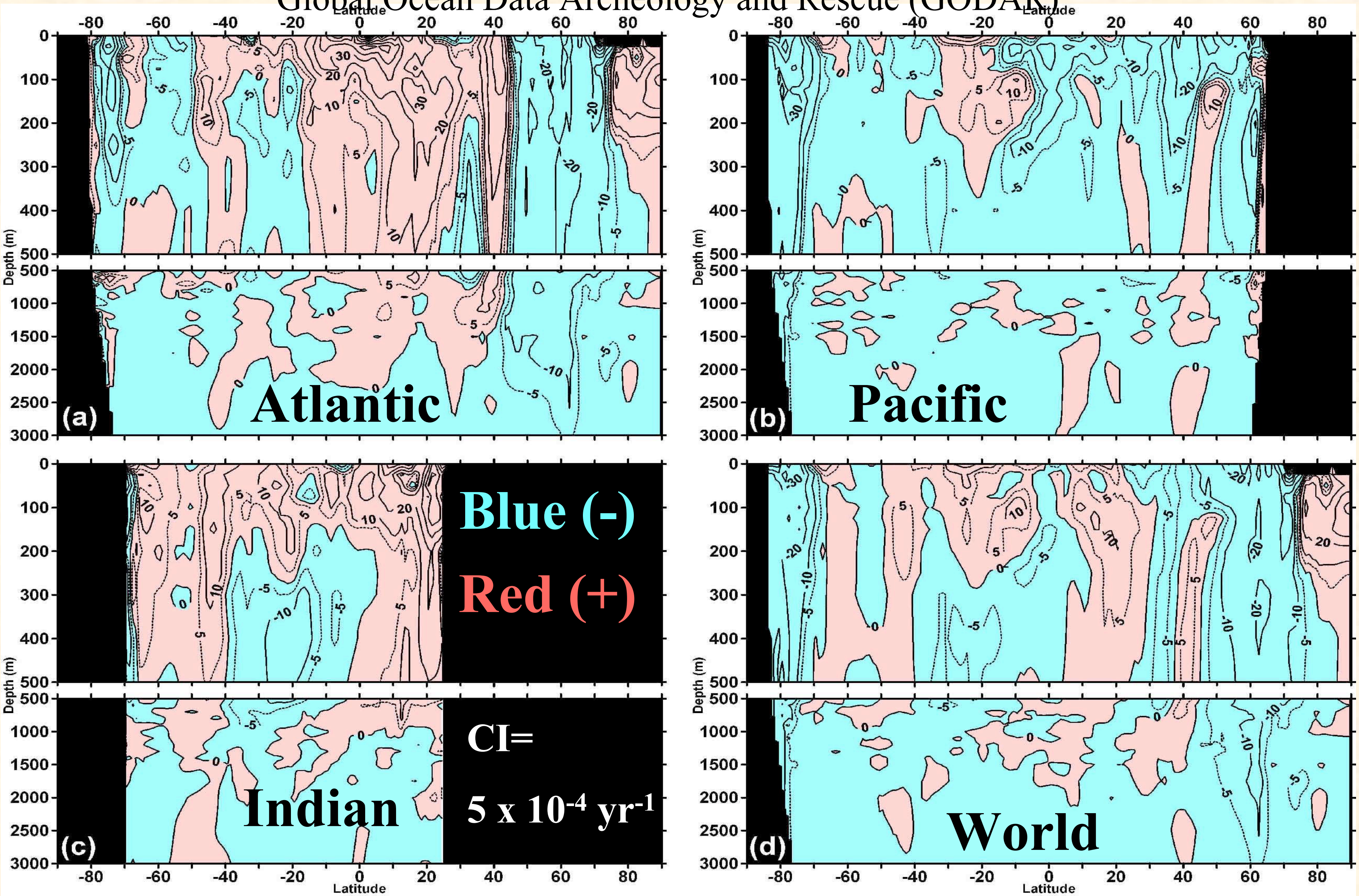
Variability in Ocean Salinity & Halosteric Sea Level

- Boyer, T.P., J. I. Antonov, S. Levitus, R. Locarnini, H. Garcia, 2005: Linear trends of salinity for the world ocean, 1955-1998. *Geophys. Res. Lett.*, 32, L01604, doi: 10.1029/2004GL021791

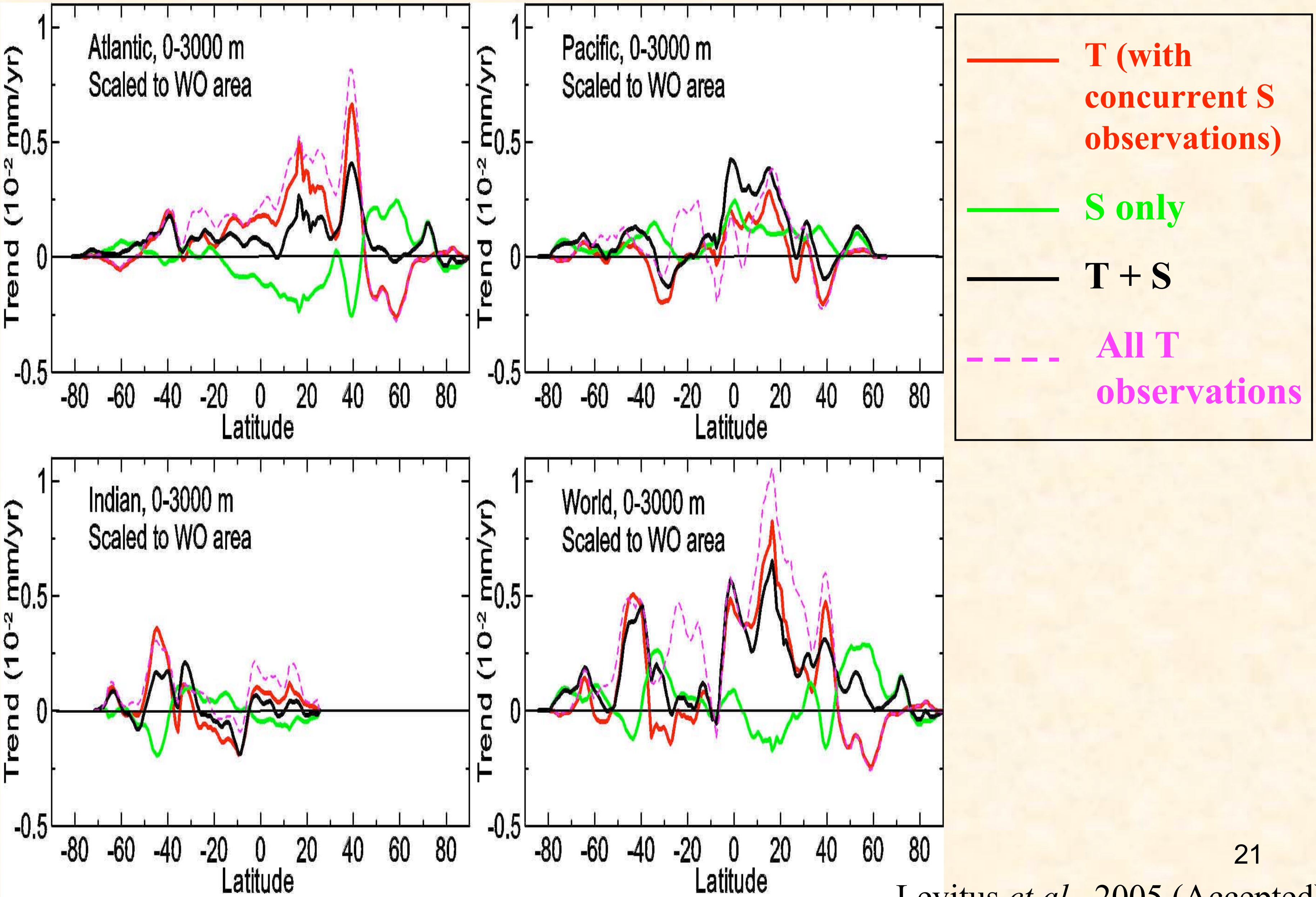
- Levitus S., J. Antonov, T. Boyer, H. Garcia, R. Locarnini, 2005, Linear Trends of Zonally Averaged Thermosteric, Halosteric, and Total Steric Sea Level for Individual Ocean Basin and the World Ocean, (1955-1959)-(1994-1998), *Accepted*

Linear Trend in Salinity (x 10^{-4} $year^{-1}$) of the zonally averaged pentadal salinity anomaly (1955/59 to 1994/98). Boyer *et al.,* 2005.

Global Ocean Data Archeology and Rescue (GODAR)



Linear trends of zonally averaged thermosteric & halosteric Sea Level Variability

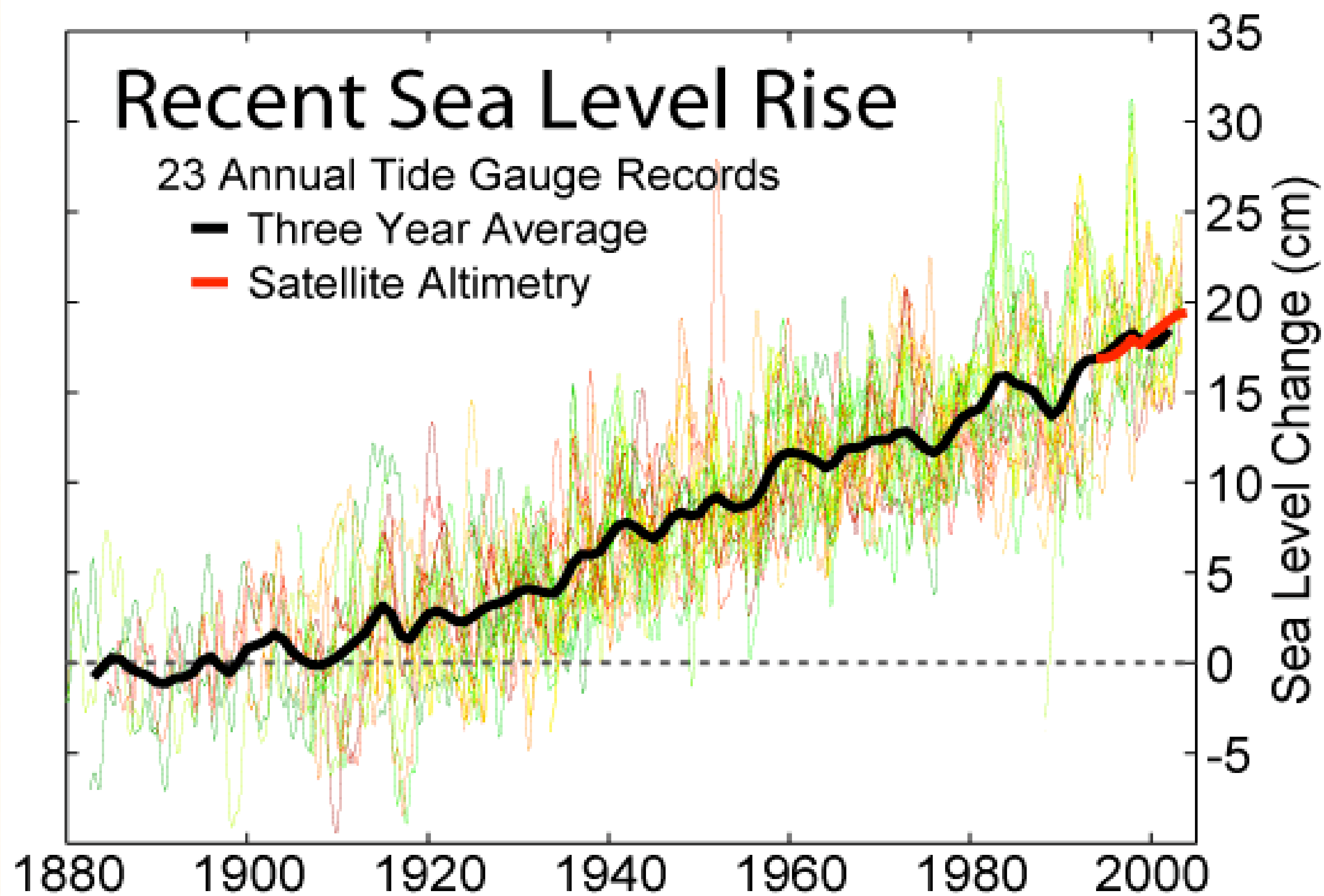


Levitus *et al*., 2005 (Accepted)

Linear Trends of Steric Sea Level Components (mm/year)

World Ocean, 1955/59-1994/98

	0-700 m	0-3000 m
Thermosteric *(2.3 million simultaneous T-S profiles)*	0.15	0.20
Halosteric *(2.3 million simultaneous T-S profiles)*	0.02	0.08
Steric *(2.3 million simultaneous T-S profiles)*	0.17	0.28
THERMOSTERIC (7.3 million temperature profiles, WOD01+)	0.30	0.40
Halosteric and **THERMOSTERIC (7.3 million temperature profiles, WOD01+)**	0.32	0.48

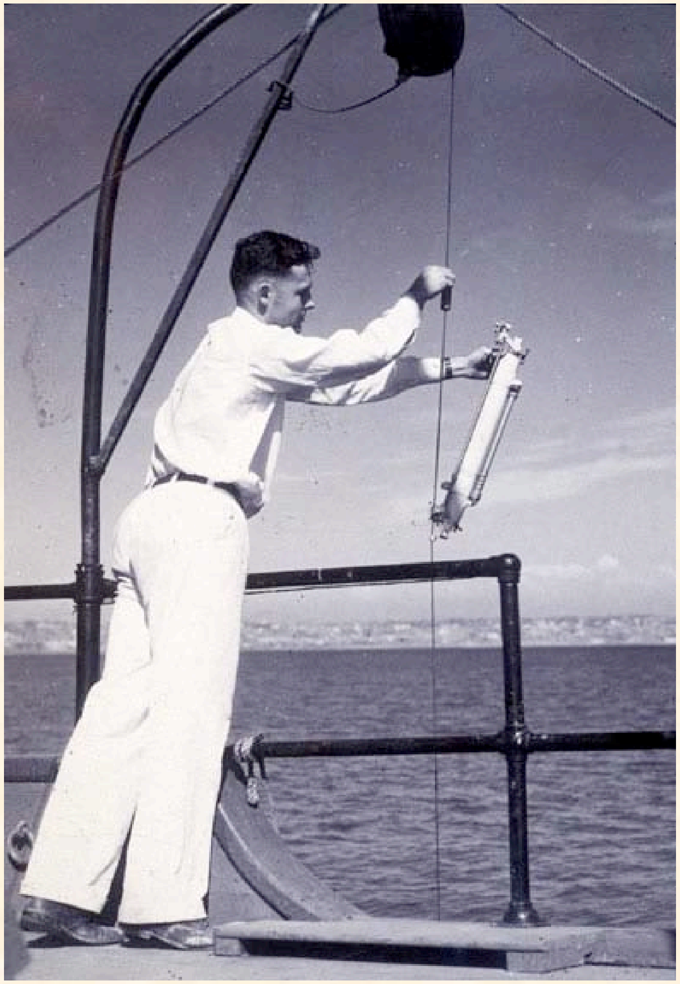


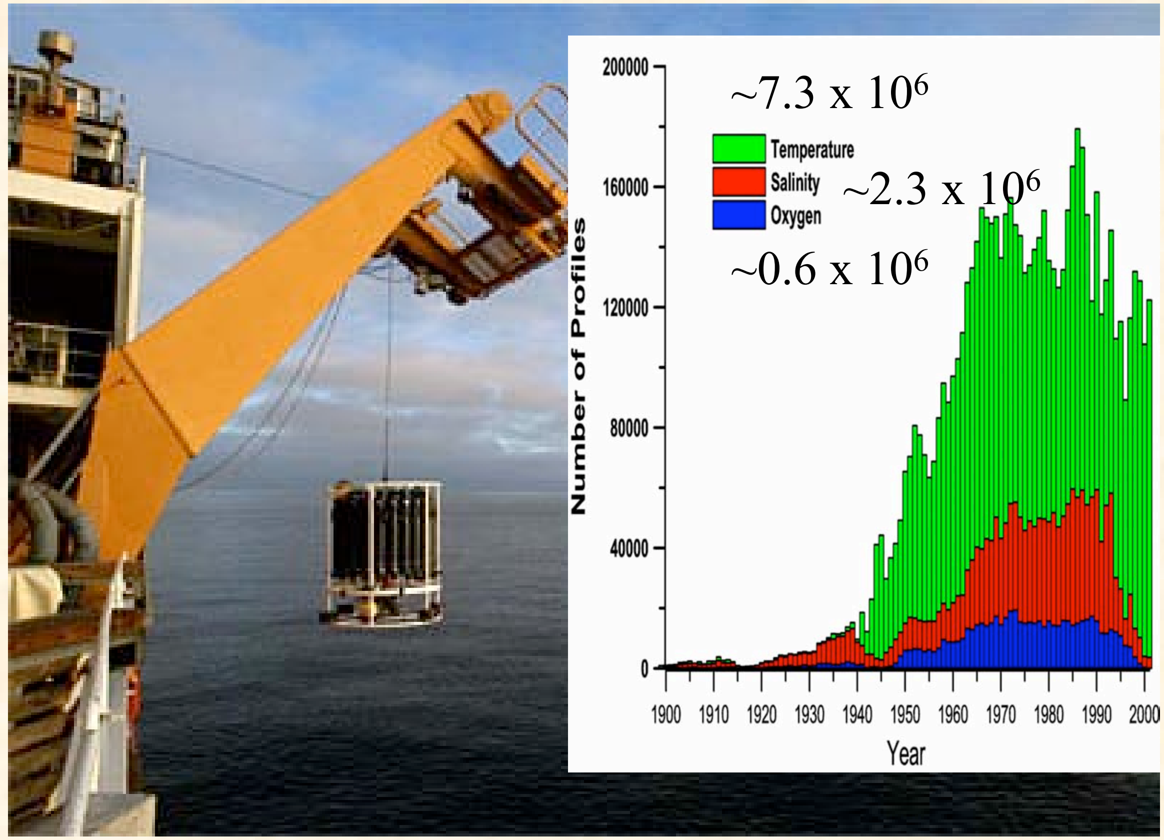
Douglas (1997, 2001): 1.8 mm/year based on tide gauge records (http://en.wikipedia.org)

Variability in Ocean Oxygen Content

•Garcia H., T. P. Boyer, S. Levitus, R. A. Locarnini, and J. I. Antonov, 2005a, On the variability of dissolved oxygen and apparent oxygen utilization content for the upper world ocean: 1955 to 1998, *Geophys. Res. Lett.,* 32, L09604, doi: 10.1029/2004GL022286.

•Garcia H., T. P. Boyer, S. Levitus, R. A. Locarnini, and J. I. Antonov, 2005b, Climatological annual cycle of upper ocean oxygen content anomaly. *Geophys. Res. Lett.* , V. 32, L09604, doi:10.1029/2004GL022286.





Manual methods:

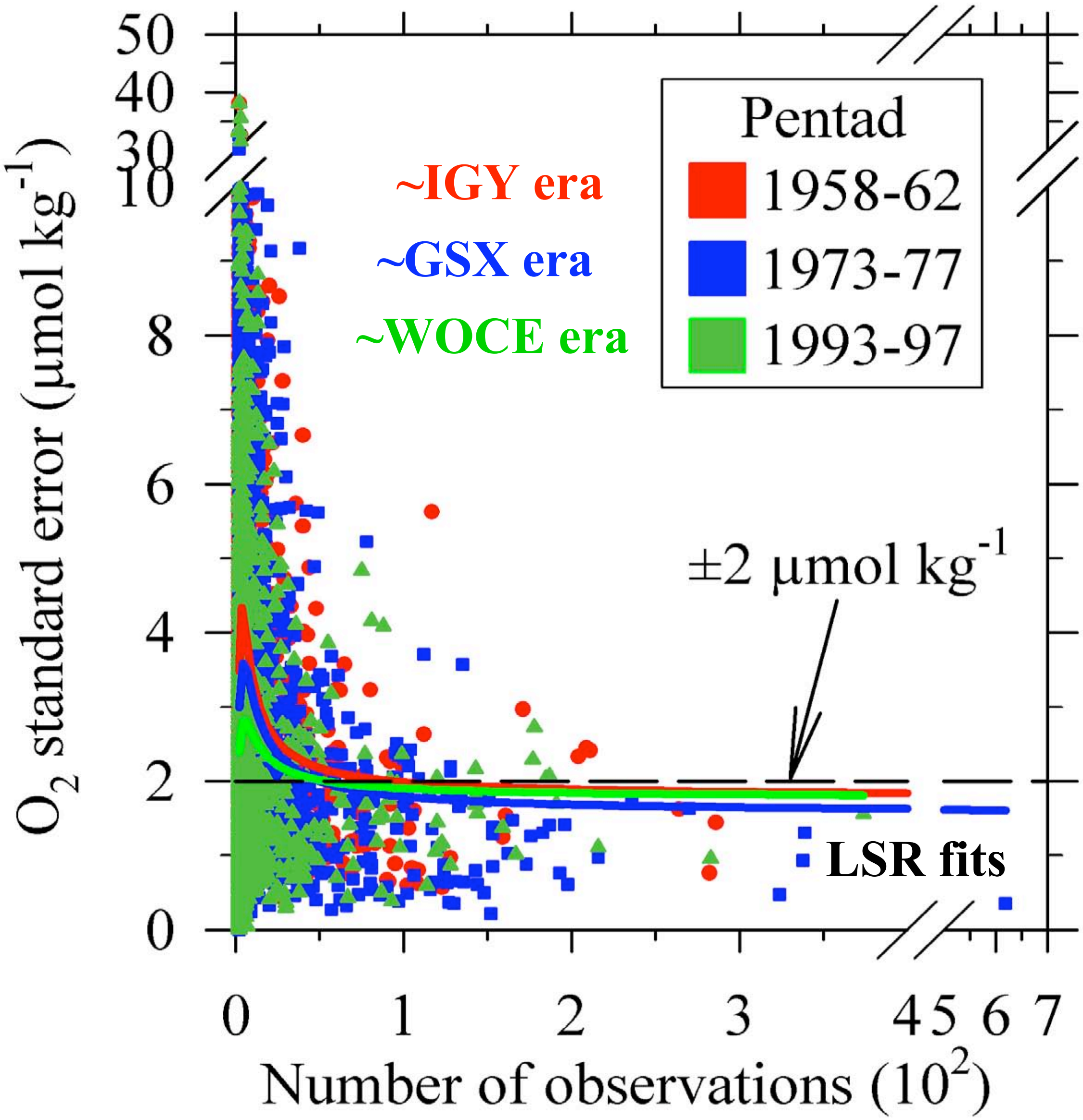
Classical winkler (1888-…)

Carpenter (1965) "whole-bottle method"

Automated methods (WOCE)

Culberson *et al.* (1991-present)

Comparison of standard error of the O_2 mean at each 1° grid box

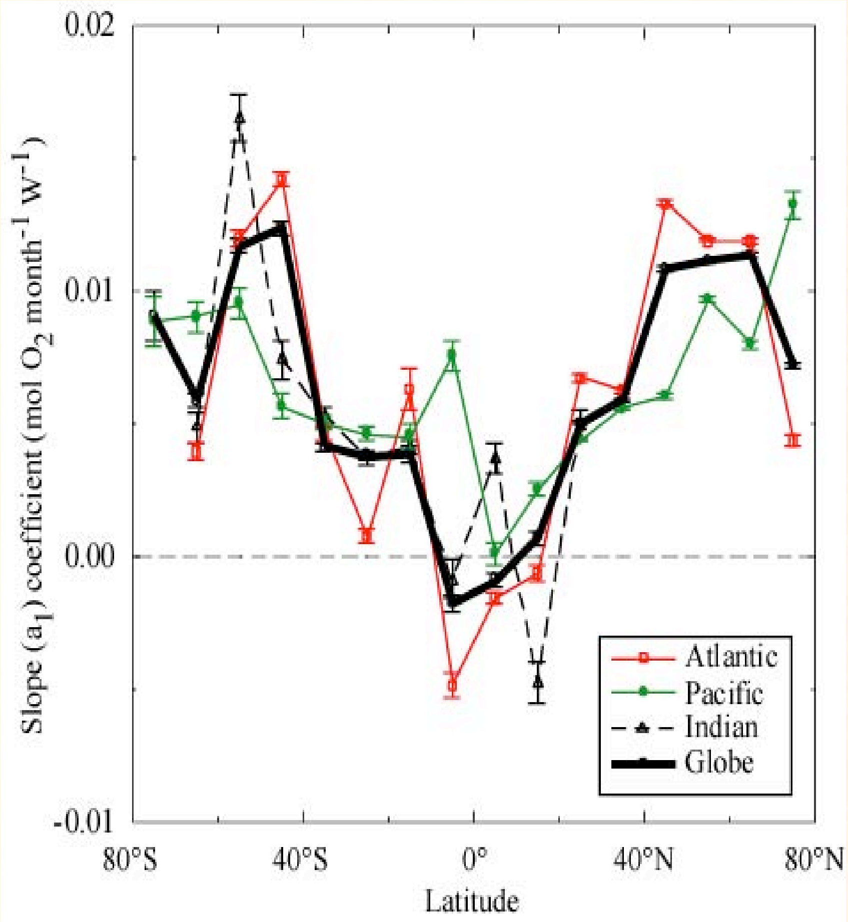


Comparison of the standard error (SE) of the mean of all *WOD01* data collected in each 1° grid box for the 1958-62, 1973-77, and 1993-97 periods between the surface and 100 m depth. The solid lines represent fits to the SE for each period.

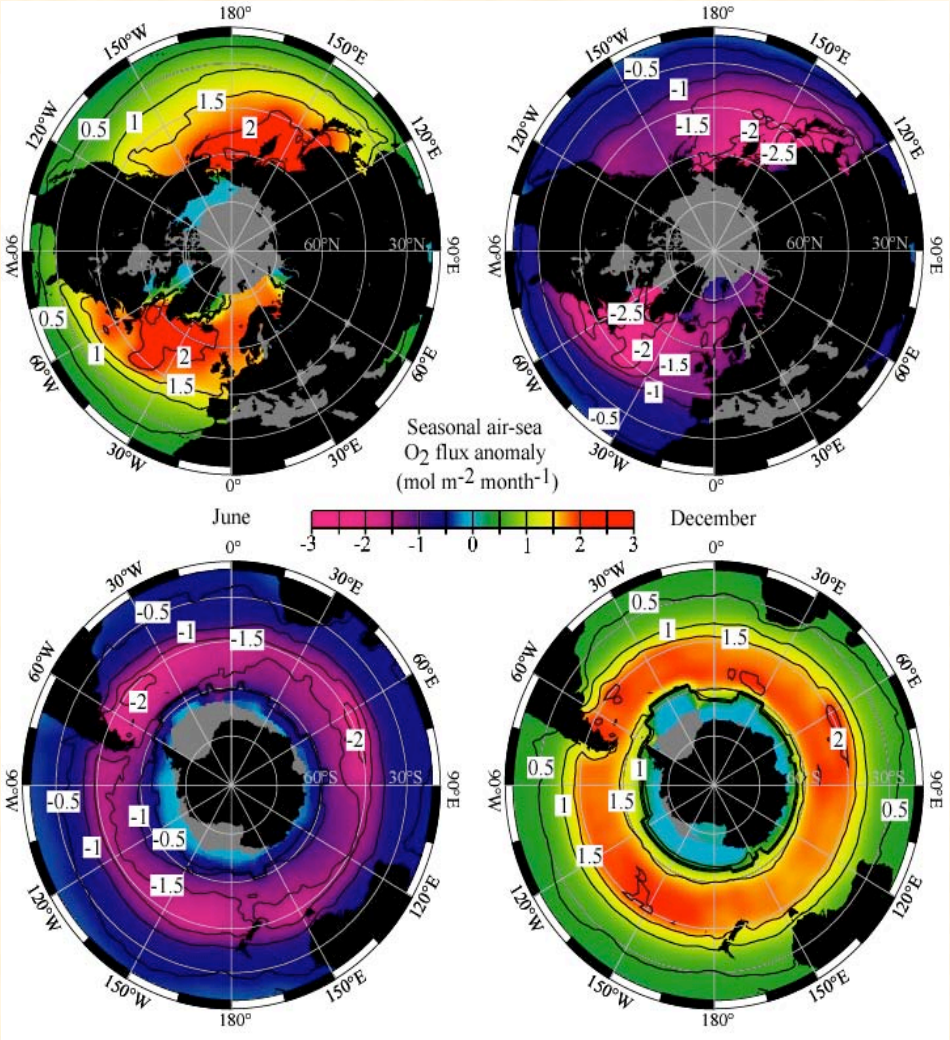
Garcia *et al.*, 2005

Surface air-sea fO_2/heat slope seasonal

about -5 nmol O_2 per J of heat



1 nmol = 10^{-9} mol



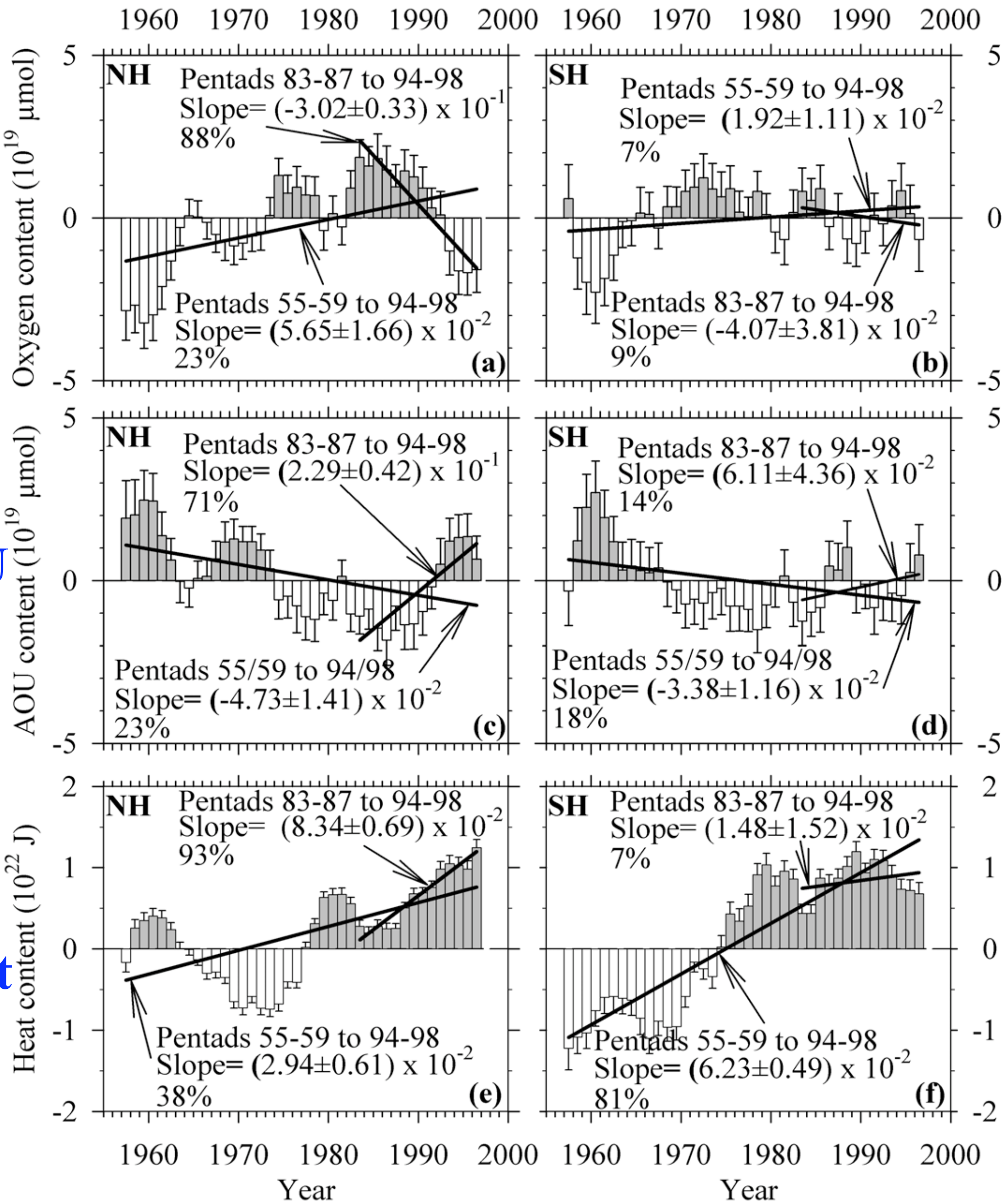
Garcia and Keeling [2001], *JGR*

Variability in O_2, AOU, and heat content (0-100 m)

O_2

AOU

Heat



83-98 NH: -30 Tmol O_2 /decade
~ -4 nmol O_2 per J of heat
~ -6 nmol O_2 per J of heat (model)

NH O_2 amplitude ~ _ of the seasonal O_2 amplitude

~ 4 μmol/kg [~ 0.1 ml/l]

Variability in oxygen (top panel), apparent oxygen utilization (middle panel), and heat (bottom panel) content of the 0-100 m layer in the Northern (NH) and Southern (SH) Hemispheres (1957-61 to 1994-98). The 1957-61 to 1986-90 grand mean content has been removed. The vertical lines about each pentad value represent ±1 standard errors. Shading denotes positive contents. The black lines are linear least-squares fits for the 1957-61 to 1994-98 and for the 1983-87 to 1994-98 periods.

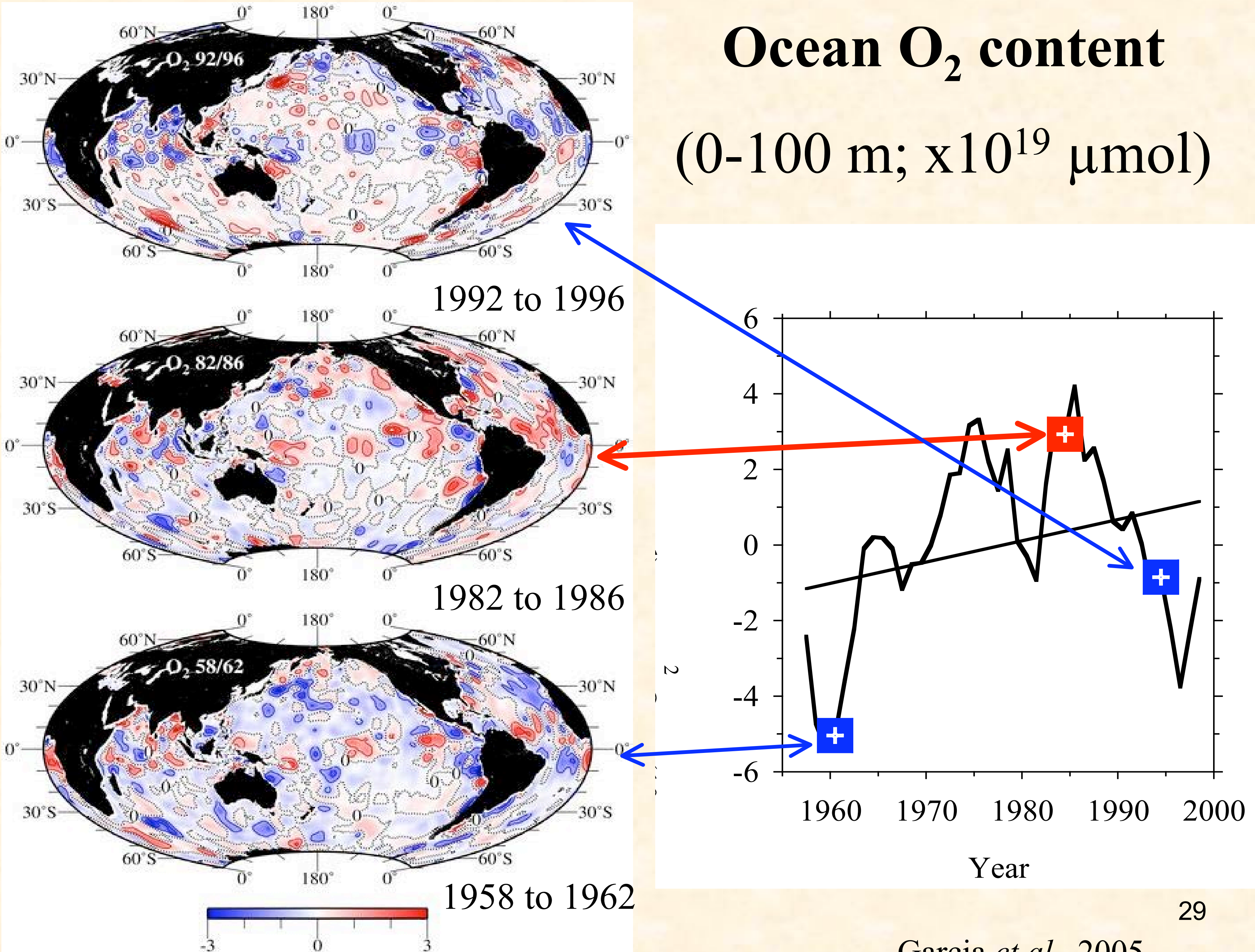
Garcia *et al.*, 2005

1 Tmol = 10^{12} mol ; 1 nmol = 10^{-9} mol

OS

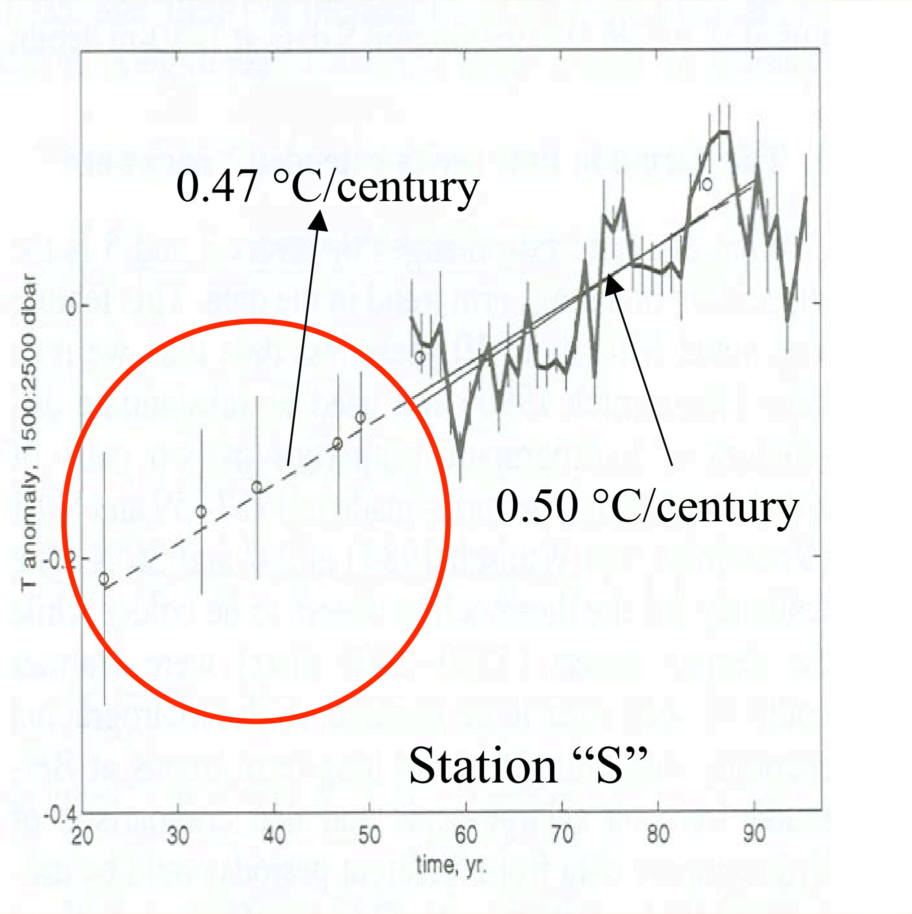
Ocean O_2 content

(0-100 m; x10^{19} µmol)



Garcia *et al.*, 2005

Attribution? Significance? bias?



Temperature time series (1-1.5 km) extended using NODC data near Station "S". After Joyce and Robbins (1996). *J. of Climate* **9**(12):3121-3131.

Observation-based estimates

Worthington (1956). The temperature increase in the Caribbean deep water since 1933. *DSR* **3**:234-235.

Roemmich and Wunsch (1984). Apparent changes in the climatic state of the deep North Atlantic. *Nature* **307**:447-450.

Levitus *et al*., (1989a,b,c,d, 1994,1995)

Ocean warming: Model and observations

Levitus *et al*., (2001)
Barnett *et al*. (2001)
Reichert *et al*.(2002)
Hansen *et al*. (2002)
Barnett *et al*., (2005)

Other papers…

Future work

1) Describe spatial and temporal variability of T and S anomalies, ocean heat content, steric sea level, chemical variability…

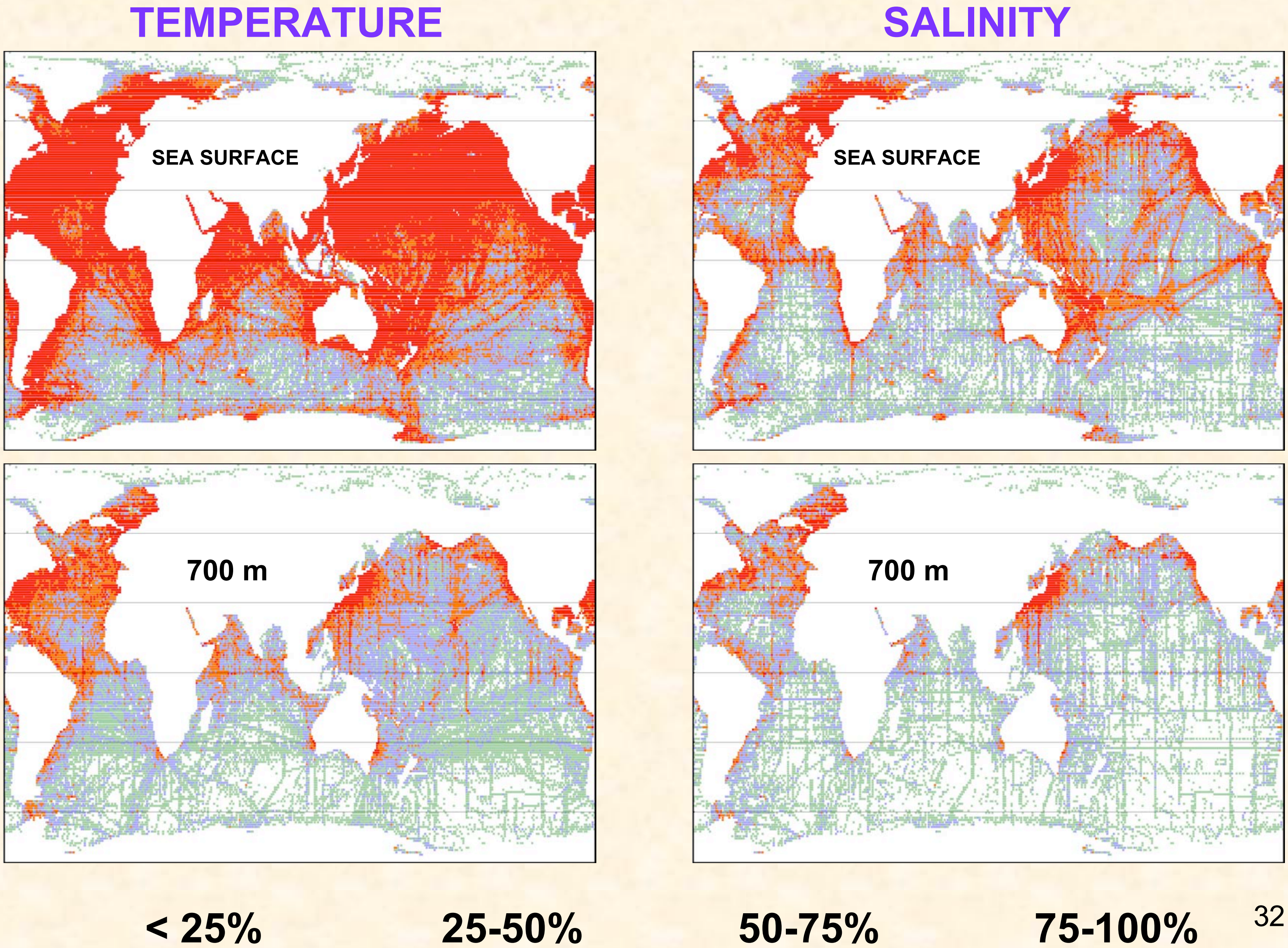
2) Add "new" historical and modern data;

3) Argo profiling float data will allow improved estimates of important quantities such as ocean heat content, thermosteric sea level, etc.

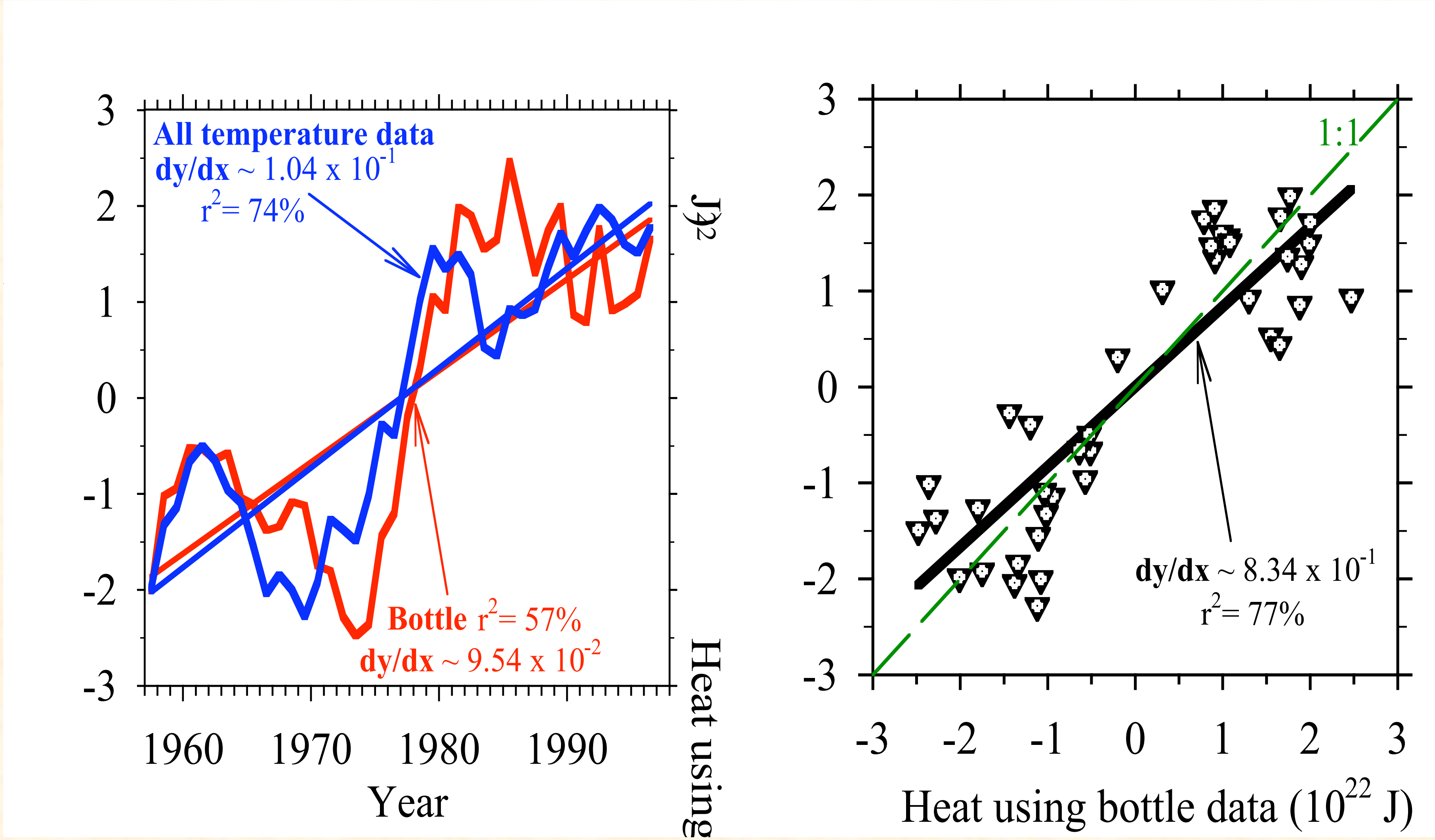
This will not be routine due to need for extensive quality control of the data stream because of problems with data and sampling of mesoscale phenomenon.

Thank you

Percentage of pentads with data for 1955/59 – 1994/98



Comparison of heat content computed using all temperature data and all temperature with concurrent O_2 data (70°S-70°N; 0-100 m)



Estimates of variability in O_2 or AOU concentration in the World Ocean

Location	Time span (years)	Depth range (m)	ΔO_2 (µmol/kg)	ΔAOU (µmol/kg)
N. Atlantic (24.5°N section)	1981-1992	800-2200	-7	
N. Pacific (basin mean)	1972-1990	1000-1750		-4
N. Pacific (22°-44°N)	1980-1997	100-600	-9 to -20	
N. Pacific (48°-60°N)	1950-2000	50-900		+5 to +25
S. Pacific (28°S section)	1967-1995	800-1200	-5 to -8	
S. Indian (32°S section)	1962-1997	300-800 2500-4000	-7 to -8 +3	
Southern Ocean (50°-60°S)	1965-1995	> 400	-5 to -15	

Updated from Keeling and Garcia (2002) . Other references: **1.** Garcia et al (1998); **2.** Keller et al (2002); 3. Emerson et al 2001; **4.** Andreev and Watanabe (2002) ; **5.** Shaffer et al. (2000); **6.** Bindoff and McDougal (2000); **7.** Matear et al. (2000)

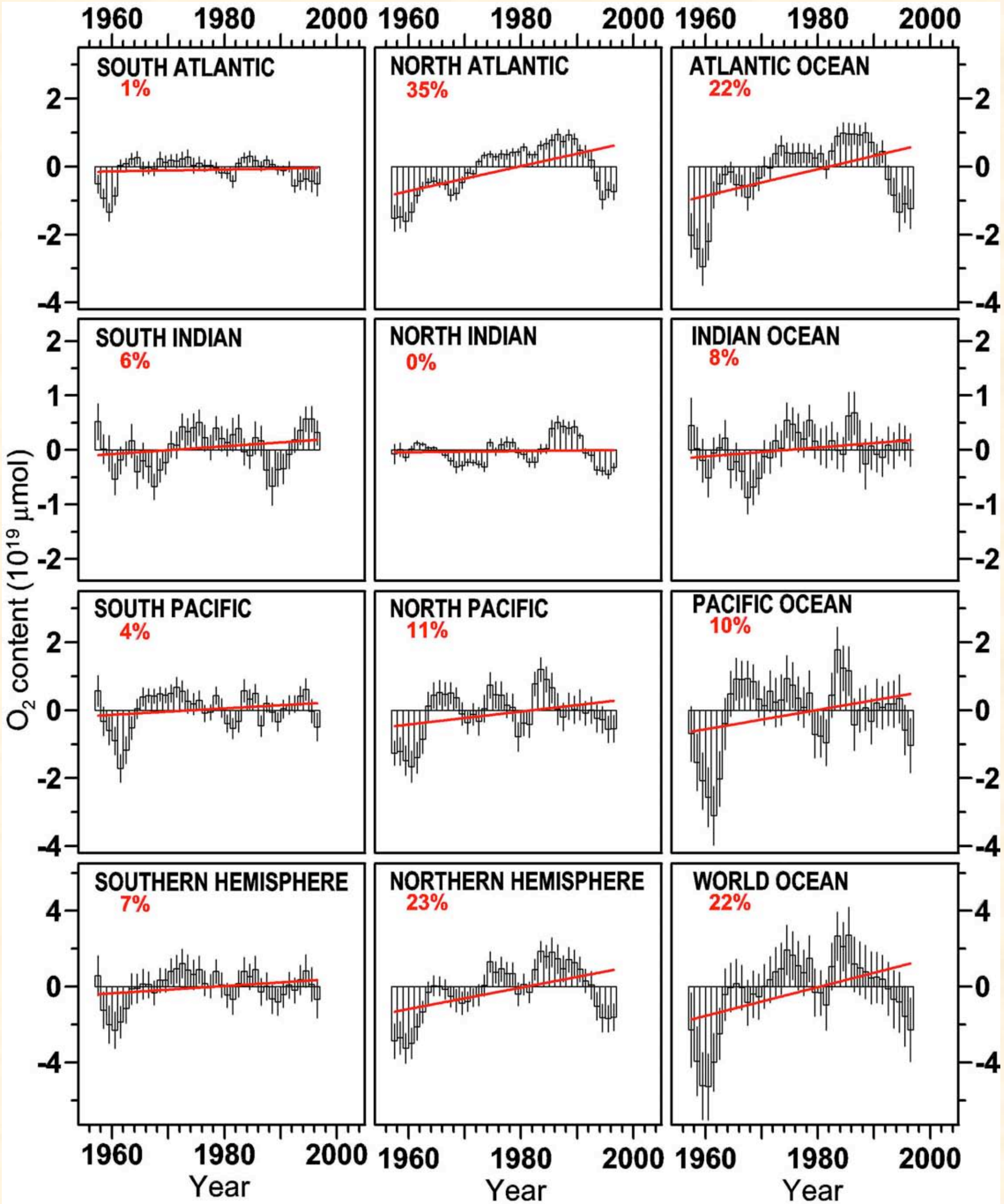


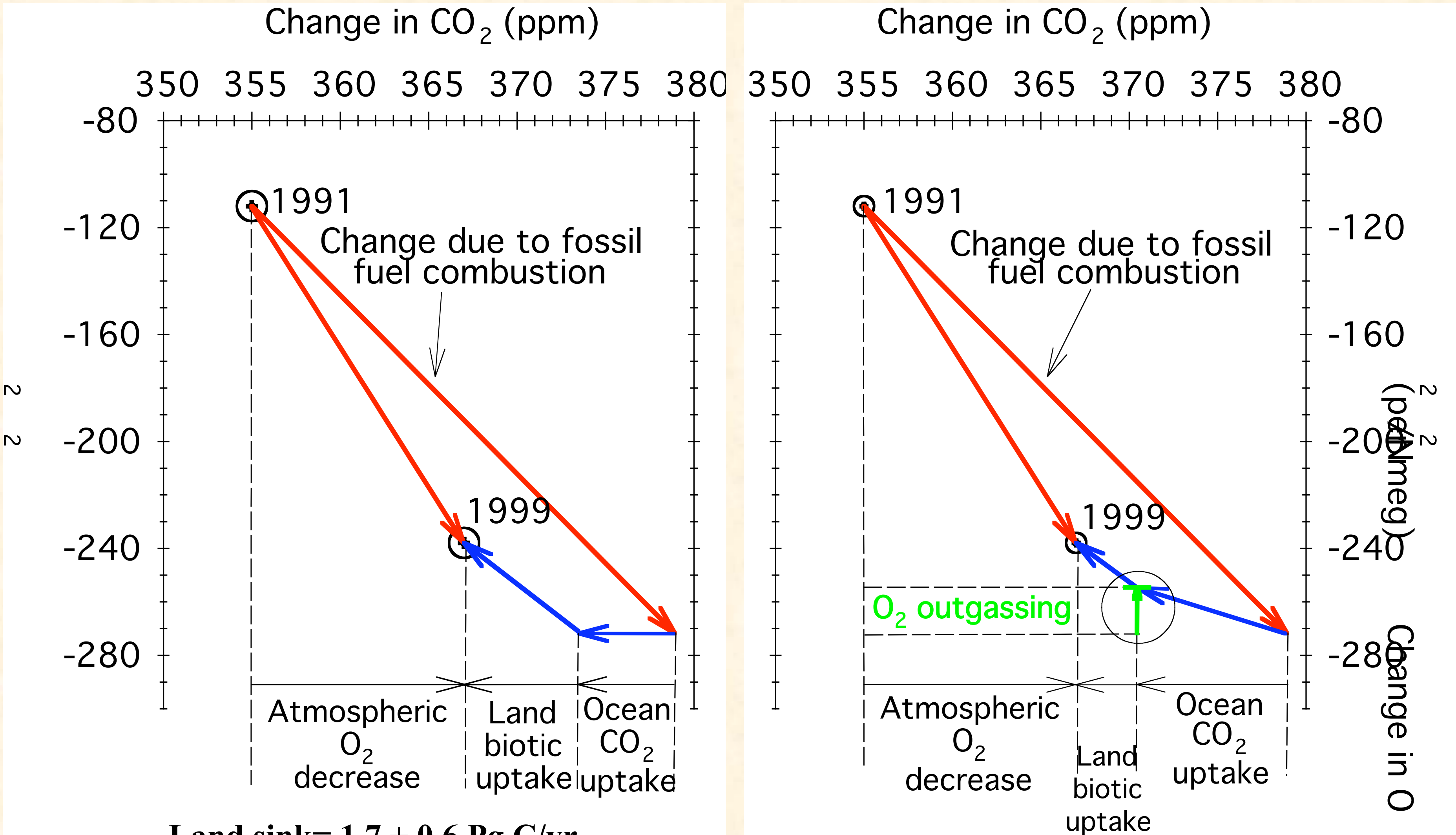
Figure S1. Variability in oxygen content of the 0-100 m depth layer for major ocean basins (1957-61 to 1994-98). The 1957-61 to 1986-90 grand mean content has been removed. The vertical lines about each pentad value represent ±1 standard errors. The red lines are linear least-squares fits for the 1957-61 to 1994-98 period.

After Garcia et al., 2005

$\Delta O_2 = \alpha_F F$ °@$\alpha_L L$; $\Delta CO_2 = F$ °@O °@L

NO OCEAN O_2 SINK/SOURCE

OCEAN O_2 SOURCE = 7 x 10^{13} mol/yr



Land sink= 1.7 ± 0.6 Pg C/yr

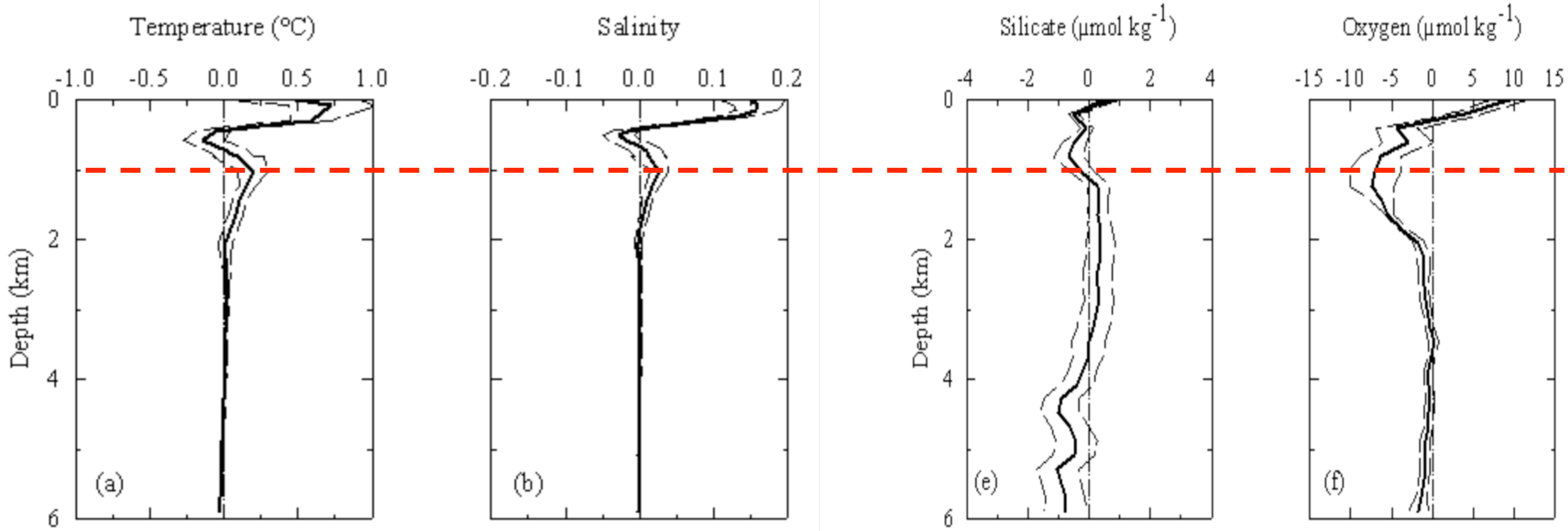
Oceanic sink= 1.5 ± 0.4 Pg C/yr

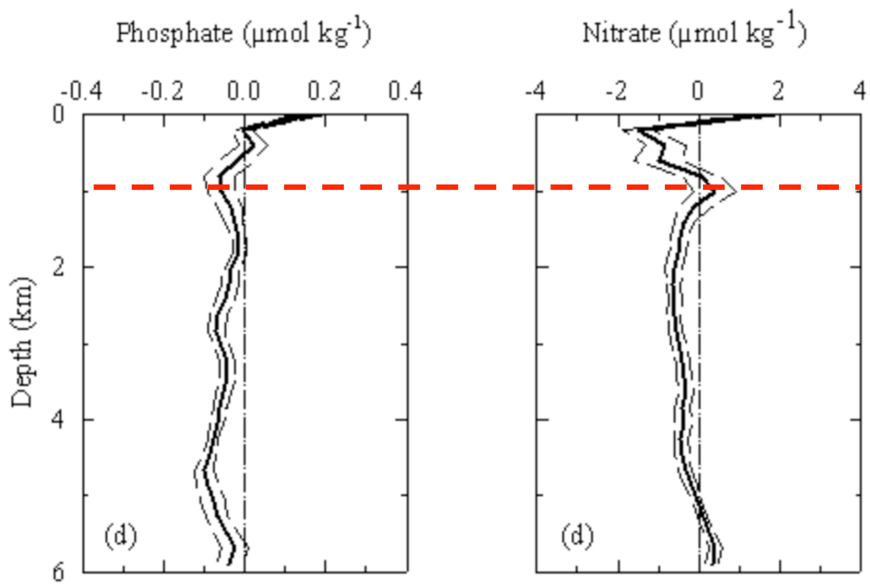
Keeling et al. [1996]

Land sink= 0.9 Pg C/yr

Oceanic sink= 2.3 Pg C/yr

After Manning [2000]



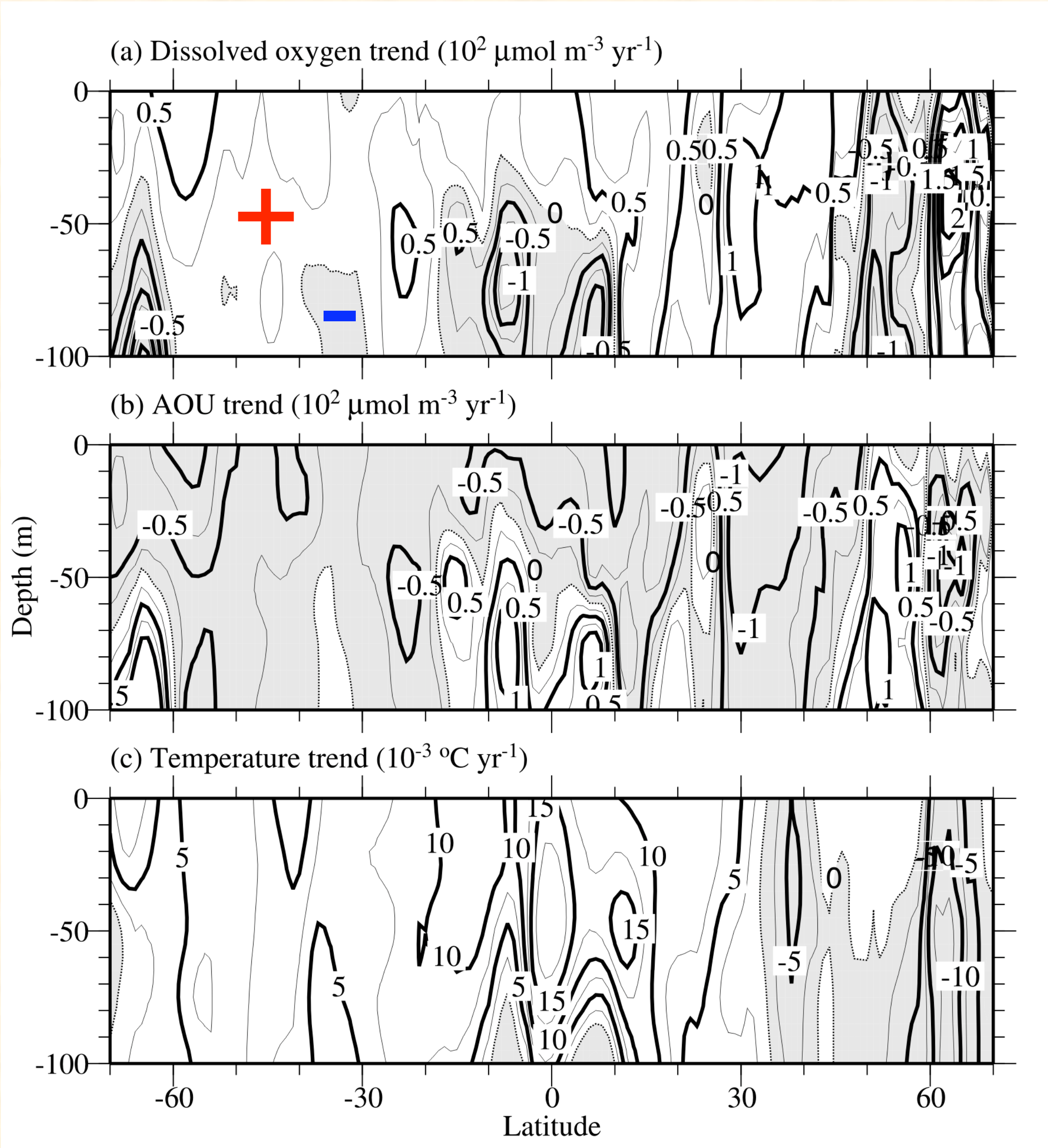


Comparison of two trans-Atlantic 24.5N sections:

1992 (A5) - 1981 (AT109-I)

Garcia *et al.* 1998. *JGR*

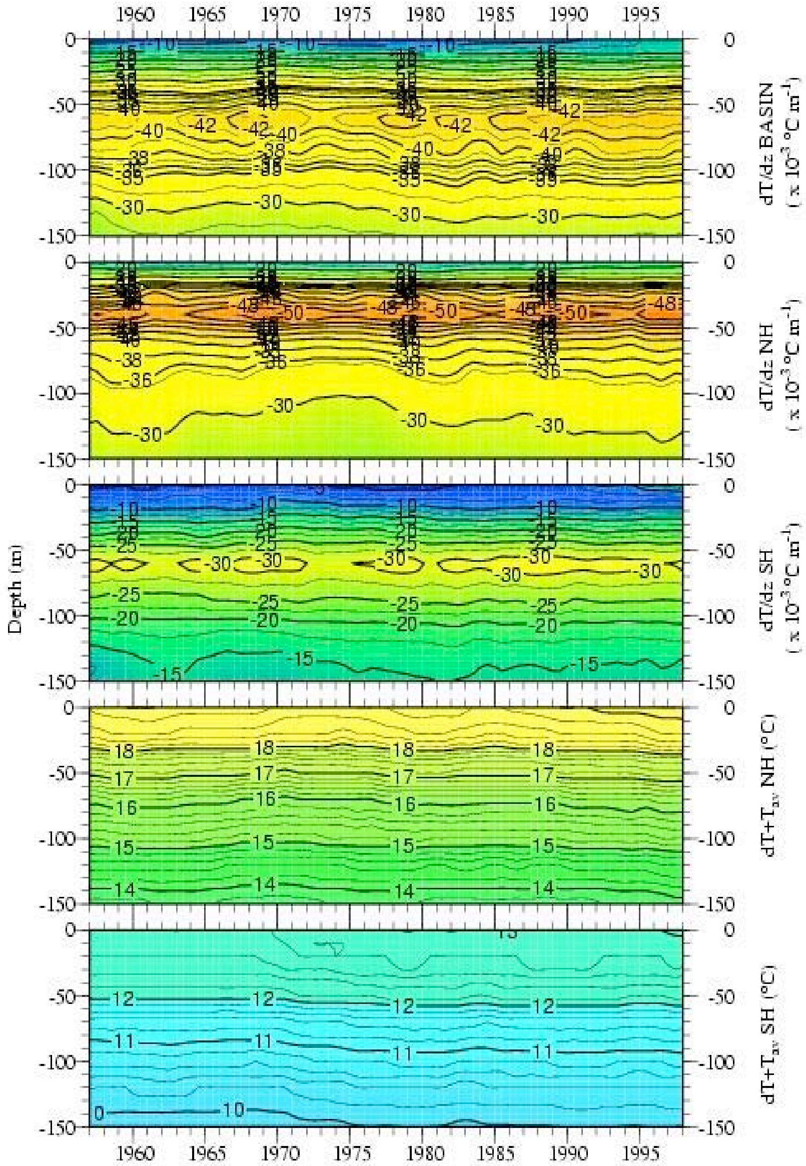
Linear Trends of the Zonal Means



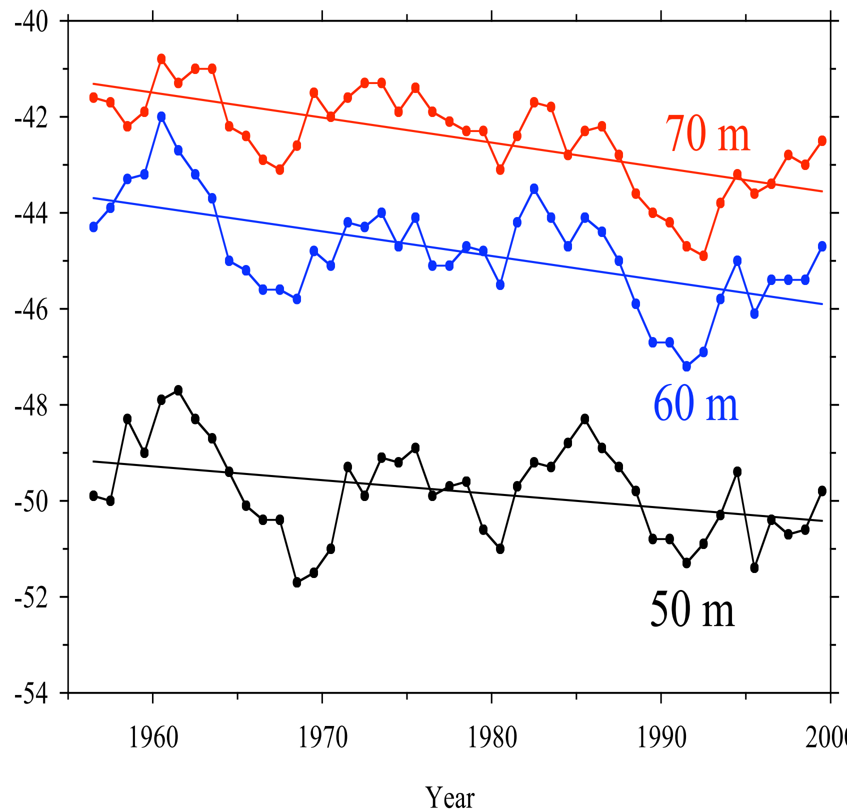
Linear trends (1955-59 through 1994-98) of the zonally averaged pentadal (a) Oxygen, (b) Apparent Oxygen Utilization (AOU), and (c) temperature anomalies. Shading denotes negative trends. The contour intervals are 0.25 x 10^2 µmol m^{-3} yr^{-1} for O_2 and AOU, and 0.2 x 10^{-3} °C yr^{-1} for temperature.

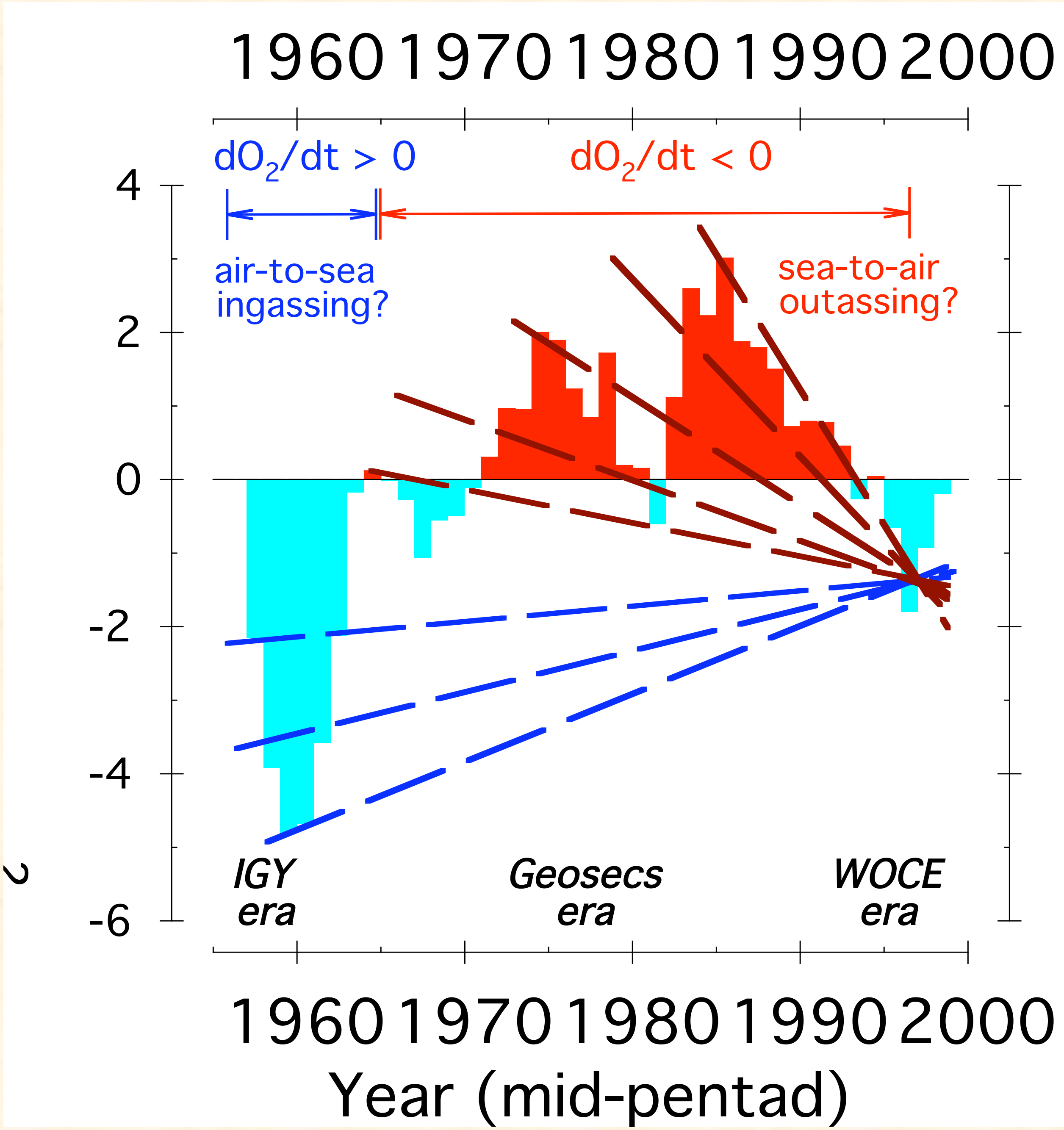
Garcia et al., 2005

Extra-tropical World Ocean



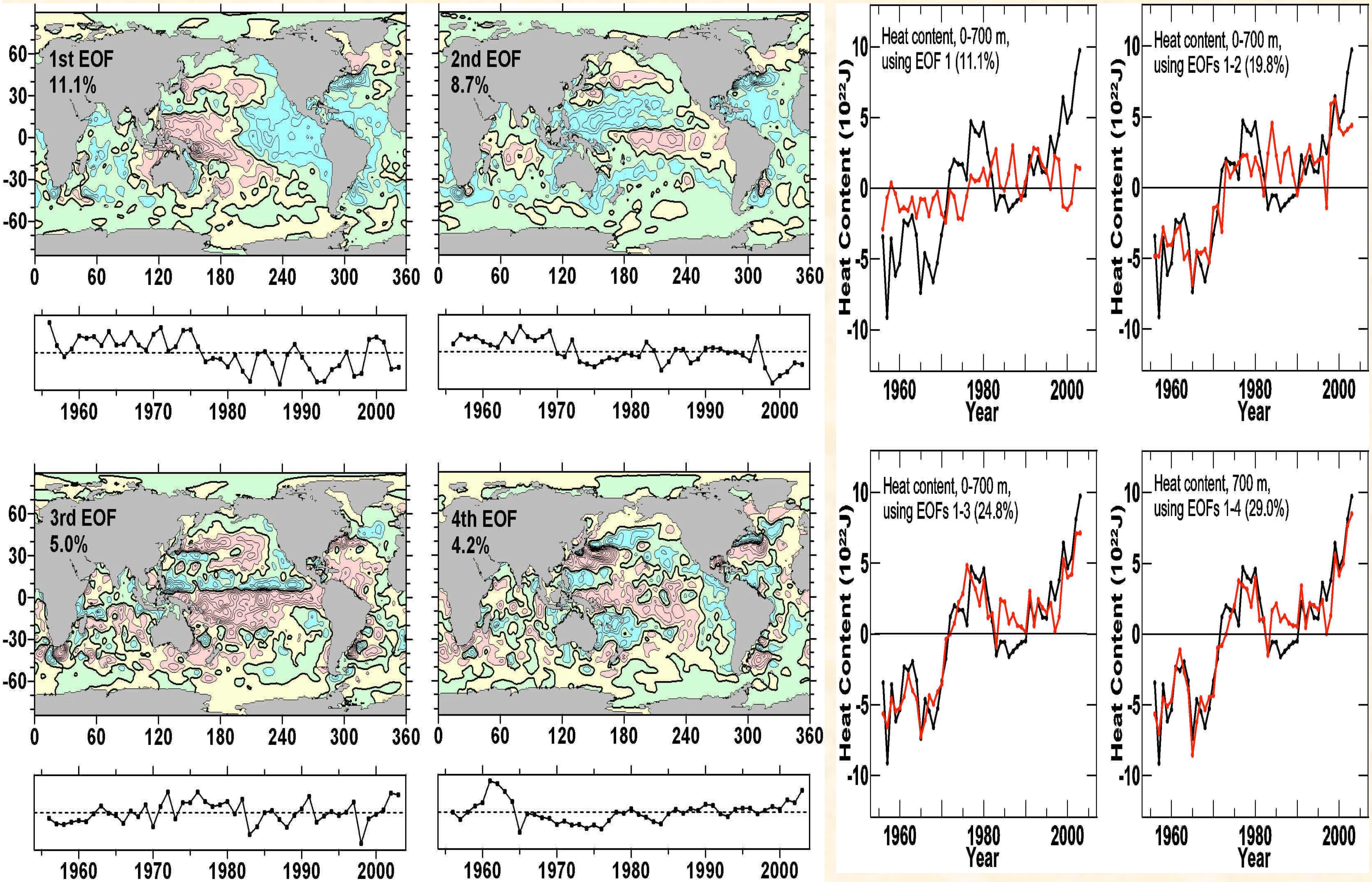
Variability in δt/δz (°C/m)



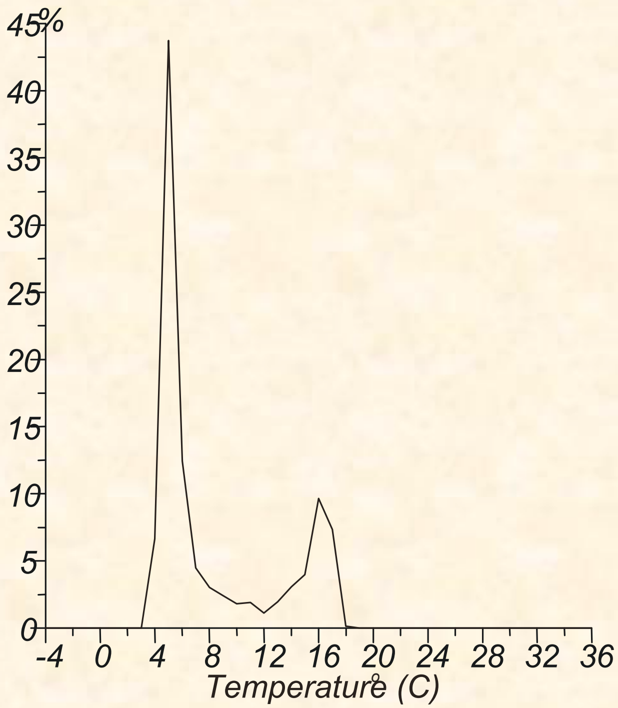


Garcia et al., 2005

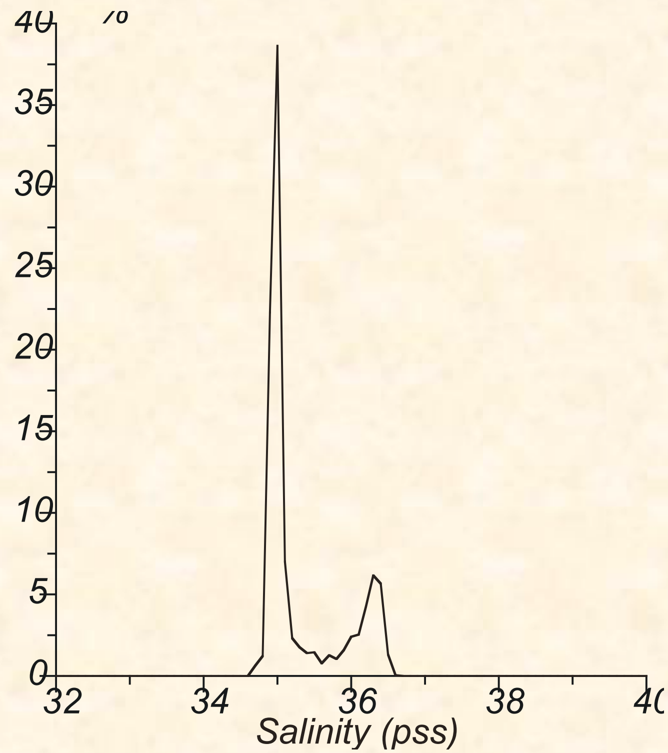
Yearly heat content based on EOF (Levitus *et al*., 2005 submitted)



Empirical temperature-salinity frequency distributions for the 5-degree square (70-75°W, 35-40°N) at 500 m depth. 2208 T-S pairs



Bin width: 1.0°C x 0.1 pss



Statistics

	m_x	s_x	μ_x	s_{MAD}	m_w	s_w	a3	$a3_q$
Temperature	8.85	4.61	6.07	1.41	8.85	4.59	0.90	0.84
Salinity	35.37	0.54	35.05	0.11	35.37	0.54	1.08	0.87

m_x = arithmetic mean;
s_x = standard deviation;
$:_x$ = sample median;
s_{MAD} = robust estimator for standard deviation based on MAD (median absolute deviation from median)
m_w = estimate of the mean based on the winsorized series of data
s_w = estimate of the standard deviation based on the winsorized series of data
$Q_{0.25}$ = lower quartile;
$Q_{0.5}$ = median
$Q_{0.75}$ = upper quartile;
a3 = direct estimation of the coefficient of skewness
a3q = quartile coefficient of skewness (a robust estimator)

Utility of NODC/WDC profile-plankton data as indicated by citations in the scientific literature
(Source: ISI *Scientific Citation Index* as February 2005)