## Large Scale Data Products for Open Ocean Biogeochemistry

Models come and go. A good data set can last forever.

## **Existing Data Products**

- GLODAPv1.1 Global Ocean Data Analysis Project
- CARINA Carbon in the Atlantic
- Takahashi surface ocean pCO2 concentration and flux maps
- World Ocean Atlas

## Planned or in Progress

- PICES North Pacific equivalent of CARINA completion expected in 1.5yrs
- Codispotti Arctic Nutrients
- SOCAT Global collaboration to continue Takahashi effort
- GLODAPv2 merge of GLODAPv1.1 with CARINA and PICES with additions and corrections

## Current & Planned Projects

- Arctic Nutrients (L. Codispoti & M. Manizza; Univ. Maryland, Center for Environmental Science; mid-project)
- PICES (Japan, Korea, Russia, China, North America; data gathering stage) North Pacific
- SOCAT Global collaboration to expand Takahashi effort, near completion
- GLODAPv2 merge of GLODAPv1.1, CARINA, PICES with corrections, etc.

## Rationale

- Many scientific issues of the 21<sup>st</sup> century involve basin to global scale investigations.
- "Climate change" science requires more *accurate* data than previous problems; precision is not enough!
- Numerical model improvement is critical to modern science & this requires better data for initialization, comparison, assimilation, etc.

## Procedure

- Data identification, gathering & verification
- Attribution and reference to published work (metadata)
- Data format & primary QC (precision check, quality flag assignment)
- Secondary QC quantification of systematic measurement bias by cruise and parameter
- Public release of individual data files
- Data adjustment, approximation, concatenation
- Publication of data products

## Secondary QC

- *Initial* steady state assumption for abyssal waters
- Assume any data bias is additive or multiplicative
- Methods to objectively quantify bias
  - Crossover comparison (automated identification)
  - Data inversion
  - MLR residual analysis
  - Surface trend analysis
  - Internal consistency calculations for carbon
- *Subjective* verification then application





Once the linear regression had been calculated, it was possible to inves evidence of systematic differences between the various cruises. Details of found in Key (1999, 2000). For DIC, Eq. (4) gives the best functional for North Pacific data:

 $DIC = aNO_3 + bAOU + cSi + dS + eS^2 + f$ 

where a, b, c, d, e and f are the coefficients, and DIC, NO<sub>3</sub>, AOU, and Si



## Completed Projects: GLODAP GLobal Ocean Data Analysis Project

- Collaborative effort to estimate the global ocean anthropogenic CO<sub>2</sub> distribution and inventory.
- Data from WOCE, JGOFS, OACES, SAVE and smaller projects (122 cruises).

### **GLODAP** Stations



http://cdiac.ornl.gov/oceans/glodap/Glodap\_home.htm



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http://cdiac.ornl.gov/oceans/glodap/Glodap\_home.htm

## What is available in GLODAP

- Three calibrated data sets, one for each ocean (Pacific, Atlantic, Indian) offered in various formats
- 3-D objectively mapped distributions for carbon parameters and tracers
- Distribution maps of nutrients, oxygen, temperature, salinity *not* produced - other products better for these parameters (far more data).

## Major GLODAP Accomplishments

- Global inventory and distribution for DIC, alkalinity, CFC-11, CFC-12,  $\Delta^{14}$ C, bomb- $\Delta^{14}$ C.
- Discrete calibrated data and objective 3-D maps.
- First global ocean inventory of anthropogenic CO<sub>2</sub> based on high quality open ocean measurements.
- Quantified the impact of anthropogenic CO<sub>2</sub> on the global ocean carbon system.
- Revised global air-sea gas exchange rate based on GLODAP bomb-<sup>14</sup>C inventory
- OCMIP: Model initialization, comparison and calibration
- Modeling ocean acidification with GCM
- Objective evaluation of numerical ocean model performance and metric development
- Global pH distribution (calculated from DIC and Alk)
- >30 other reviewed publications, but many potential others

#### **Pacific Ocean Correction Factors**

Section	No	EXPOCODE	Station Range	Salinity <sup>a</sup>	Oxygen	NO <sub>3</sub>	PO <sub>4</sub>	SiO2	TCO2	TALK
WOCE <sup>b</sup>										
P17N	1	31DSCGC91_1	all	-0.72	1.0147	1.000	0.9870	1.000	-7.0	-12.0
P02	2	49K6KY9401_1	all	0	1.000 <sup>c</sup>	1.0200	0.9620	1.000	-4.0	14.0
P06	3	316N138/3,4,5	1-72 75-188 190-267	0.50 -0.59 -1.17	1.0003 1.0036 0.9999	1.000 1.000 1.000	0.9875 0.9914 1.000	1.000 1.000 1.000	-0.6 -0.6 -0.6	0 0 0
P08S	4	49XK9605	all	1.82	1.0059	1.0159	1.0335	1.0300	2.0	6.0
P09	5	49RY9407_1	1-53 54-105	-0.50 0.77	0.9923 0.9945	0.9900 0.9900	1.000 1.000	1.000 1.000	1.1 1.1	0





**Figure B1.** Estimated error field for the Pacific Ocean TA distribution at 1200 m (see Figure 2, left center, for the corresponding property map). Note that the size of the error is strongly correlated with distance from data. These mapping error estimates assume no measurement or other error types.

## GLODAPv1.1 Problems

- Additive nutrient adjustments resulted in some near-surface negative values
- Insufficient manpower to do uniform 2nd QC on all parameters
- No data from Arctic or marginal seas
- No specific attention given to shallow water regions

#### **The CARINA Data Project & Products**

Data rescue project for deep sea carbon dioxide and nutrients data

Data with an estimated value of ~ 50 million Euros (85 billion KRW) was rescued



### The CARINA Group

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## What is CARINA?

- An internally consistent data base available as three data products, one each for the Arctic Mediterranean Seas, the Atlantic and the Southern Oceans
- CARINA data synthesis project is an international collaborative effort of the EU IP CARBOOCEAN, and International partners.
- It has produced a merged internally consistent data set of open ocean subsurface measurements for biogeochemical investigations, in particular studies involving the carbon system
- The CARINA database includes data from **188 cruises**.
- The salinity, oxygen, nutrient, inorganic carbon system and CFC data have been subject to extensive quality control and adjustments have been applied when necessary.
- All of the individual cruise data files have been made available in WOCE exchange in a single location along with metadata and references

## **CARINA Arctic Stations**



Ocean Data View

### **CARINA** Atlantic Stations



### **CARINA Southern Ocean Stations**



## History

- 1999 Initiated at meeting in Delmenhorst
- By 2002, ~30 cruises (excluding GLODAP) had been collected
- 2004 data transferred to CIDAC and Princeton
- 2005 CARINA became a CARBOOCEAN activity
- June 2006 initial meeting in Iceland, at this time ~80 cruises collected, Region extended to include Arctic and Southern Oceans. Regional leaders assigned.
- 2007 2008 three workshops.
- Development of software and internet tools.
- 2009 188 individual CARINA cruise files and merged products made public via CDIAC.
- Project documention on CDIAC and articles in a special issue of ESSD (Earth System Science Data).

## **CARINA Data Synthesis and QC**

#### • Assembly and primary QC (precision)

- Common format, common units (pH scale, volumetric to gravimetric etc.)
- Data flags assigned, in cooperation with PI's, i.e. primary QC

#### • Secondary QC, (accuracy)

- Concentrations in deep water are compared to identify biases.
- Adjustments are applied to the data
- Interpolation of missing data, calculation of 3<sup>rd</sup> carbon parameter
- Three merged data files are produced.

#### The link:

#### http://cdiac.ornl.gov/oceans/CARINA/Carina\_inv. html

### Secondary QC Influence Deep Oxygen in the GIN Sea Before After



Cruise sorted by date

#### Trend and consistency of final Greenland Sea Oxygen data

Decreasing O<sub>2</sub>, a consequence of reduced deep convection in Greenland Sea giving way to increased advection of Arctic deep waters



# **Scientific Highlights**

- Agreement between recent methods found along the whole Atlantic, except for the  $\Delta C^*$  method which produce inventories five times lower in the Southern Ocean.
- $C_{ANT}$  inventory was 54 ±8 Pg C for the Atlantic Ocean for 1994 using 5 selected sections and a combination of the five methods.
- Using the whole CARINA data for the Atlantic south 65°N a total inventory of 55 PgC was obtained for 1994.
- The temporal increase of  $C_{ANT}$  inventory between 1997 and 2003 (12%) follows that given by the atmospheric.
- Strong reduction, of about three times, in the  $C_{ANT}$  inventory between high and low NAO scenarios in the Irminger Sea related with the water mass formation.
- Temporal variation in the water mass formation in the North Atlantic has a very strong impact in the  $C_{ANT}$  storage rates.

## **Lessons Learned**

- CARINA benefited from, and impoved upon the GLODAP project.
- Use of Certified Reference Materials *critical* to data qualtiy.
- Complete data records were not retained for many cruises. By the time the data were released many who had made the measurements were no longer working in the field.
- Timely reporting ensures metadata can be obtained if not originally provided.
- Timely reporting essential for the common effort of Global Synthesis, detecting decadal change, etc.
- Early data release benefits data generators!
- CRM usage desperately needed for nutrients.

## What is Available from CARINA

- Merged, calibrated data files in various formats covering the Arctic, Atlantic, and Southern Ocean
- Significant metadata including bibliography with papers that have used the included data
- 2nd QC software
- Full record of 2nd QC tests
- Special issue of ESSD with details



#### <u>CARINA: a consistent carbon-</u> relevant data base for the Arctic, Atlantic and Southern Oceans"

- 1. CARINA; an overview
- 2. CARINA Southern Ocean data; Atlantic Ocean sector
- 3. CARINA Southern Ocean data; Indian Ocean sector
- 4. CARINA Southern Ocean data; Pacific Ocean sector
- 5. Overview of the Nordic Seas CARINA data and salinity
- 6. CARINA CFC data in the Nordic Seas
- 7. CARINA DIC data in the Nordic Seas
- 8. CARINA Alkalinity data in the Nordic Seas
- 9. CARINA oxygen data in the Nordic Seas
- 10. CARINA nutrient data in the Nordic Seas
- 11. CARINA Arctic Ocean data.
- 12. CARINA nutrient data in the North Atlantic.
- 13. Overview of North Atlantic CARINA data and salinity.
- 14. CARINA CFC data in the North Atlantic
- 15. CARINA DIC data in the North Atlantic.
- 16. CARINA Alkalinity data in the North Atlantic.
- 17. CARINA Oxygen data in the North Atlantic.
- 18. Quality control procedures and methods used for the CARINA data set.
- 19. CARINA pH data.
- 20. Iceland and Irminger Sea Time Series





**Fig. 2.** Surface water pCO<sub>2</sub> and SST data obtained in the Vanuata area, 20–25°S and 165–175°E in the South Pacific in 1993–1996. The mean seasonal variability for the 4-year period is established assuming that the seasonal variations remained unchanged over this period. The open circles are monthly mean values and the error bars represent one standard deviation of observations. The values for months with no measurements are linearly interpolated using adjacent monthly mean values, and are shown with open squares. The heavy horizontal line indicates the annual mean. The differences between the monthly mean and the annual mean indicate the seasonal corrections used for deseasonalization.







Net Flux (grams C m<sup>-2</sup> year<sup>-1</sup>)

## Conclusions

- Large calibrated ocean data compilations are required for current scientific questions
- Primary and secondary QC can improve precision and accuracy of oceanographic cruise data
- These data products are of significant value to the producers and the oceanographic community