Intergovernmental Oceanographic Commission
Reports of Meetings of Experts and Equivalent Bodies

Joint IOC-JGOFS CO_2 Advisory Panel Meeting

Fifth Session

La Jolla, California, USA
13-17 June 1994

UNESCO

In this Series, entitled

Reports of Meetings of Experts and Equivalent Bodies, which was initiated in 1984 and which is published in English only, unless otherwise specified, the reports of the following meetings have already been issued:

1. Third Meeting of the Central Editorial Board for the Geological/Geophysical Atlases of the Atlantic and Pacific Oceans
2. Fourth Meeting of the Central Editorial Board for the Geological/Geophysical Atlases of the Atlantic and Pacific Oceans
3. Fourth Session of the Joint IOC-WMO-CPPS Working Group on the Investigations of 'El Niño' *(Also printed in Spanish)*
4. First Session of the IOC-FAO Guiding Group of Experts on the Programme of Ocean Science in Relation to Living Resources
5. First Session of the IOC-UN(OETB) Guiding Group of Experts on the Programme of Ocean Science in Relation to Non-Living Resources
6. First Session of the Editorial Board for the International Bathymetric Chart of the Mediterranean and Overlay Sheets
7. First Session of the Joint CCOP(SOPAC)-IOC Working Group on South Pacific Tectonics and Resources
8. First Session of the IODE Group of Experts on Marine Information Management
9. Tenth Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies in East Asian Tectonics and Resources
10. Sixth Session of the IOC-UNEP Group of Experts on Methods, Standards and Intercalibration
11. First Session of the IOC Consultative Group on Ocean Mapping *(Also printed in French and Spanish)*
12. Joint IOC-WMO Meeting for Implementation of IGOSS XBT Ships-of-Opportunity Programmes
13. Second Session of the Joint CCOP/SOPAC-IOC Working Group on South Pacific Tectonics and Resources
14. Third Session of the Group of Experts on Format Development
15. Eleventh Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies of South-East Asian Tectonics and Resources
16. Second Session of the IOC Editorial Board for the International Bathymetric Chart of the Mediterranean and Overlay Sheets
17. Seventh Session of the IOC-UNEP Group of Experts on Methods, Standards and Intercalibration
18. Second Session of the IOC Group of Experts on Effects of Pollutants
19. Primera Reunión del Comité Editorial de la COI para la Carta Batimétrica Internacional del Mar Caribe y Parte del Océano Pacífico frente a Centroamérica *(Spanish only)*
20. Third Session of the Joint CCOP/SOPAC-IOC Working Group on South Pacific Tectonics and Resources
21. Twelfth Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies of South-East Asian Tectonics and Resources
22. Second Session of the IODE Group of Experts on Marine Information Management
23. First Session of the IOC Group of Experts on Marine Geology and Geophysics in the Western Pacific
24. Second Session of the IOC-UN(OETB) Guiding Group of Experts on the Programme of Ocean Science in Relation to Non-Living Resources *(Also printed in French and Spanish)*
25. Third Session of the IOC Group of Experts on Effects of Pollutants
26. Eighth Session of the IOC-UNEP Group of Experts on Methods, Standards and Intercalibration
27. Eleventh Session of the Joint IOC-IHO Guiding Committee for the General Bathymetric Chart of the Oceans *(Also printed in French)*
28. Second Session of the IOC-FAO Guiding Group of Experts on the Programme of Ocean Science in Relation to Living Resources
29. First Session of the IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials
30. First Session of the IOCARIBE Group of Experts on Recruitment in Tropical Coastal Demersal Communities *(Also printed in Spanish)*
31. Second IOC-WMO Meeting for Implementation of IGOSS XBT Ship-of-Opportunity Programmes
32. Thirteenth Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies of East Asia Tectonics and Resources
33. Second Session of the IOC Task Team on the Global Sea-Level Observing System
34. Third Session of the IOC Editorial Board for the International Bathymetric Chart of the Mediterranean and Overlay Sheets
35. Fourth Session of the IOC-UNEP-IMO Group of Experts on Effects of Pollutants
36. First Consultative Meeting on RNODCs and Climate Data Services
37. Second Joint IOC-WMO Meeting of Experts on IGOSS-IODE Data Flow
38. Fourth Session of the Joint CCOP/SOPAC-IOC Working Group on South Pacific Tectonics and Resources
39. Fourth Session of the IODE Group of Experts on Technical Aspects of Data Exchange
40. Fourteenth Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies of East Asian Tectonics and Resources
41. Third Session of the IOC Consultative Group on Ocean Mapping
42. Sixth Session of the Joint IOC-WMO-CCPS Working Group on the Investigations of 'El Niño' *(Also printed in Spanish)*
43. First Session of the IOC Editorial Board for the International Bathymetric Chart of the Western Indian Ocean
44. Third Session of the IOC-UN(OALOS) Guiding Group of Experts on the Programme of Ocean Science in Relation to Non-Living Resources
45. Ninth Session of the IOC-UNEP Group of Experts on Methods, Standards and Intercalibration
46. Second Session of the IOC Editorial Board for the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico
47. First Session of the IOC Editorial Board for the International Bathymetric Chart of the Western Indian Ocean
48. Twelfth Session of the Joint IOC-IHO Guiding Committee for the General Bathymetric Chart of the Oceans
49. Fifteenth Session of the Joint CCOP-IOC Working Group on Post-IDOE Studies of East Asian Tectonics and Resources
50. Third Joint IOC-WMO Meeting for Implementation of IGOSS XBT Ship-of-Opportunity Programmes
51. First Session of the IOC Group of Experts on the Global Sea-Level Observing System
52. Fourth Session of the IOC Editorial Board for the International Bathymetric Chart of the Mediterranean
53. First Session of the IOC Editorial Board for the International Chart of the Central Eastern Atlantic *(Also printed in French)*
54. Third Session of the IOC Editorial Board for the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico *(Also printed in Spanish)*
55. Fifth Session of the IOC-UNEP-IMO Group of Experts on Effects of Pollutants
56. Second Session of the IOC Editorial Board for the International Bathymetric Chart of the Western Indian Ocean
57. First Meeting of the IOC *ad hoc* Group on Ocean Mapping in the WESTPAC Area
58. Fourth Session of the IOC Consultative Group on Ocean Mapping
59. Second Session of the IOC-WMO/IGOSS Group of Experts on Operations and Technical Applications
60. Second Session of the IOC Group of Experts on the Global Sea-Level Observing System
61. UNEP-IOC-WMO Meeting of Experts on Long-Term Global Monitoring System of Coastal and Near-Shore Phenomena Related to Climate Change
62. Third Session of the IOC-FAO Group of Experts on the Programme of Ocean Science in Relation to Living Resources
63. Second Session of the IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials
64. Joint Meeting of the Group of Experts on Pollutants and the Group of Experts on Methods, Standards and Intercalibration
65. First Meeting of the Working Group on Oceanographic Co-operation in the ROPME Sea Area
66. Fifth Session of the Editorial Board for the International Bathymetric and its Geological/Geophysical Series
67. Thirteenth Session of the IOC-IHO Joint Guiding Committee for the General Bathymetric Chart of the Oceans *(Also printed in French)*
68. International Meeting of Scientific and Technical Experts on Climate Change and Oceans
69. UNEP-IOC-WMO-IUCN Meeting of Experts on a Long-Term Global Monitoring System
70. Fourth Joint IOC-WMO Meeting for Implementation of IGOSS XBT Ship-of-Opportunity Programmes
71. ROPME-IOC Meeting of the Steering Committee on Oceanographic Co-operation in the ROPME Sea Area
72. Seventh Session of the Joint IOC-WMO-CPPS Working Group on the Investigations of 'El Niño' *(Spanish only)*
73. Fourth Session of the IOC Editorial Board for the International Bathymetric Chart of the Caribbean Sea and the Gulf of Mexico *(Also printed in Spanish)*
74. UNEP-IOC-ASPEI Global Task Team on the Implications of Climate Change on Coral Reefs
75. Third Session of the IODE Group of Experts on Marine Information Management
76. Fifth Session of the IODE Group of Experts on Technical Aspects of Data Exchange
77. ROPME-IOC Meeting of the Steering Committee for the Integrated Project Plan for the Coastal and Marine Environment of the ROPME Sea Area
78. Third Session of the IOC Group of Experts on the Global Sea-level Observing System
79. Third Session of the IOC-IAEA-UNEP Group of Experts on Standards and Reference Materials
80. Fourteenth Session of the Joint IOC-IHO Guiding Committee for the General Bathymetric Chart of the Oceans
81. Fifth Joint IOC-WMO Meeting for Implementation of IGOSS XBT Ship-of-Opportunity Programmes

CONTINUED ON INSIDE OF BACK COVER

Intergovernmental Oceanographic Commission
Reports of Meetings of Experts and Equivalent Bodies

Joint IOC-JGOFS CO_2 Advisory Panel Meeting

Fifth Session

La Jolla, California, USA
13-17 June 1994

UNESCO

IOC/JGOFS/CO_2-V/3
Paris, 2 December 1994
English only

This report is a continuation of the series of Carbon Dioxide Panel Meeting Reports I through IV previously printed under a cover reflecting the Panel's original joint sponsorship by the Joint Global Ocean Flux Study (JGOFS) and the Committee on Climatic Changes and the Ocean (CCCO). With the decision to phase out CCCO in December 1992, agreement was reached to continue this Panel under joint sponsorship of JGOFS and IOC.

TABLE OF CONTENTS

1. WELCOMING

1 The fifth session of the Joint IOC-JGOFS Advisory Panel on Ocean CO_2 was held 13-17 June in La Jolla, California. The meeting was hosted by the Scripps Institution of Oceanography at the new Interplanetary Physics and Geophysics Building. E. Frieman, the Director, welcomed the participants to Scripps and discussed some of the organizational changes affecting science policy at the highest levels of government in the U.S. He noted that the National Science and Technology Council has been elevated to a higher level and that it's subcommittee on Environment (where US JGOFS is overseen) is co-chaired by R. Watson and D.J. Baker.

2. ADOPTION OF THE AGENDA

2 Liliane Merlivat also welcomed the Panel and the invited guests and expressed appreciation to Andrew Dickson for handling the meeting arrangements. She then addressed the provisional agenda and invited discussion on proposed changes. After brief discussion the Panel adopted the agenda in Annex I. Merlivat then assigned rapporteurs for each item on the agenda. A complete list of meeting participants is provided in Annex II.

3. RECENT IOC EVENTS REGARDING GOOS

3 Alexiou reminded the Panel that GOOS had five modules: ocean climate, living marine resources, health of the ocean, the coastal zone, and a services module. The ocean climate module is to serve as the ocean component of the GCOS. An intergovernmental committee, I-GOOS, and a non-governmental scientific and technical committee, J-GOOS, have been established and are provided staff support by a GOOS Support Office in the IOC.

4 An I-GOOS planning session was held in Melbourne, Australia, 18-21 April 1994. The planning session gave particular consideration to designing an internal structure for GOOS. The conceptual structure adopted by the session is illustrated in Figure 3-1. It delineates the interactions between I-GOOS and J-GOOS, giving J-GOOS scientific design responsibility while I-GOOS is responsible for implementation.

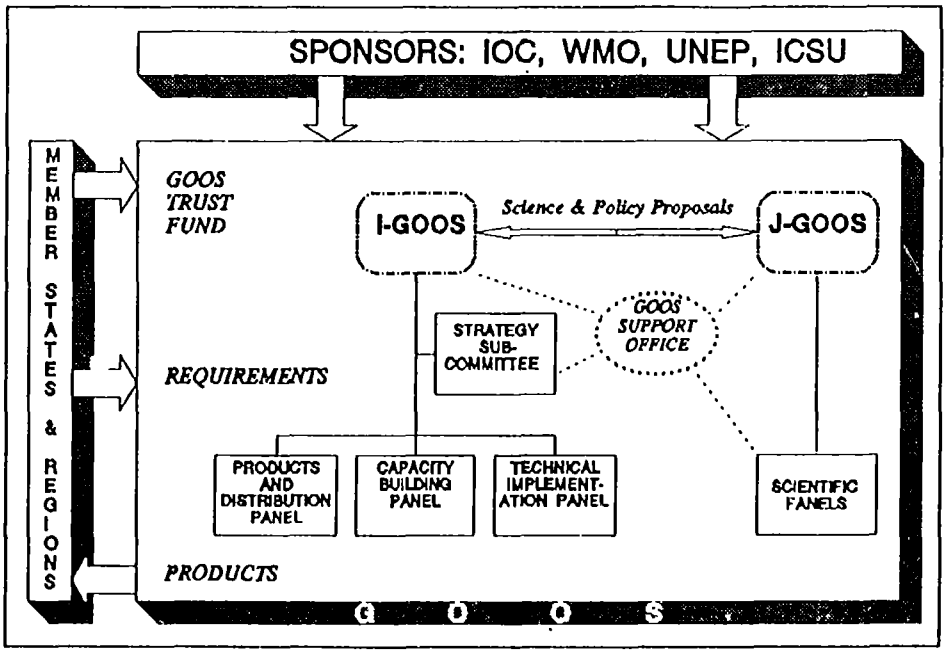


Figure 3-1. GOOS administrative structure

5 The planning session recommended establishing a Strategy Sub-Committee (to advise I-GOOS on requirements, policy, marketing and resources related issues), and two Panels to address Technical Implementation, and Products and Distribution. Support for these Panels and the Sub-Committee is to be provided by the GOOS Support Office. An intersessional *ad hoc* group was set up to revise and define more precisely the contents of the Coastal Module of GOOS and to prepare an outline of a strategic plan for the next session of I-GOOS. The development of a data management policy for GOOS was assigned to another working group to formulate the guiding principles for a GOOS data management policy.

6 The First Session of J-GOOS was held at IFREMER in Nantes, France, 25-27 May 1994. This session was largely devoted to organizational issues. GOOS needs were reviewed from the I-GOOS perspective by M. Glass, the chairman of I-GOOS, who stressed the need for providing output products to the users for immediate applications, especially in the coastal zone. An intersessional working group on the coastal zone was established to develop possible terms of reference for a J-GOOS Coastal Zone Panel. It was also noted that membership in J-GOOS needed to be enhanced for biology, biological processes, fisheries expertise, living marine resources and organic chemistry.

7 Subsequent discussion revealed concerns regarding how ocean chemistry would be handled in GOOS after WOCE, e.g., will sufficient parameters be monitored to fully interpret the carbon cycle, the thermodynamics, etc.; this includes more than just pCO_2 and C_T. Merlivat indicated this was the eventual goal but that GOOS is unlikely to achieve all its goals at once.

4. PROGRESS REPORTS

4.1 RESULTS OF pCO_2 EQUILIBRATOR CALIBRATION TESTS

8 The main aim of this exercise (held the week prior to this meeting) was to compare the various instruments in action so as to help the Panel assess the likely comparability of oceanic pCO_2 measurements made by different groups with different systems. Thirteen groups from eight different countries brought their pCO_2 sea-going systems together in La Jolla to participate in the laboratory intercomparison workshop. Participants were:

CNRS / ORSTOM, Paris, France (Yves Dandonneau)
CSIRO, Hobart, Australia (Bronte Tilbrook)
Institute of Ocean Sciences, Sidney, Canada (Glenn Smith)
Institute für Meereskunde, Kiel, Germany (Arne Kurtzinger)
Meteorological Research Institute, Tsukuba, Japan (H. Inoue, Masao Ishii)
Netherlands Institute for Sea Research, Texel, The Netherlands (Erica Koning, Bram Majoor)
NOAA: PMEL, Seattle & AOML Miami, USA (Cathy Cosca, David Ho)
Okayama University, Okayama, Japan (Eiji Ohtaki, E. Yamashita, T. Yasui, F. Fujiwara)
Plymouth Marine Laboratory, Plymouth, UK (J. Robertson, A. Watson)
Research Institute of OceanoChemistry, Osaka, Japan (T. Kimoto)
Scripps Institution of Oceanography, La Jolla, USA (R. Welss, R. Vanwoy)
Université Pierre et Marie Curie, Paris, France (C. Brunet, B. Schauer)
Woods Hole Oceanographic Institution, Woods Hole, USA (B. Adams, C. Goyet)

9 Each group checked their calibration using their own approach with the 6 gases provided by Dickson . Each group ran their equilibrator with their analytical system at least twice in a controlled experiment in which at least five other laboratories were using the same stable water source at the same time.

10 The results will be analyzed in the weeks to come following this Panel meeting and eventually published. Some points were already clear:

(i) It is important in intercomparisons like this to consider systems as a whole, not just as separate modules.

(ii) For several systems the intercomparability will be less than we would have liked to see.

(iii) The laboratory exercise will yield information leading to improved practices and more reliable operational measurements with smaller uncertainties.

(iv) Some equilibrators may require pressure corrections (or design changes).

11 The subject of units triggered an extended discussion on whether and how to standardize the way measurements are made, the units used for reporting data (in wet or dry gas), the ancillary data required, and the method for temperature corrections. Nearly all groups make their measurements as dry gas and convert them to wet pCO_2. Watson's group was the only one measuring wet pCO_2. Takahashi suggested the following should be reported: mole fraction, dry or wet, atmospheric pressure, salinity, equilibrator temperature, and equilibrator pressure if it differs from atmospheric. There was general agreement on this but the Panel was reluctant to establish standard practices at this point without further study. The key point on which there was unanimity, was that it is important to provide sufficient information to convert to any units no matter what was analyzed.

4.2 ANALYTICAL METHODS FOR THE CARBON SYSTEM (NEW REPORT)

12 The US Department of Energy CO_2 science team have been collaborating on a revised version of the "Handbook of Methods for the Analysis of the Various Parameters of the Carbon Dioxide System in Sea Water".

13 The new version (Version 2.0 - edited by A. G. Dickson & C. Goyet) comprises carefully written procedures for the measurement of each of the carbon dioxide parameters in sea water: total dissolved inorganic carbon, total alkalinity, $p(CO_2)$ (both on a continuous stream of sea water and on discrete samples), and pH (both electrometric and spectrophotometric procedures). It also includes a discussion of the quality control required to ensure valid measurements using these procedures, and incorporates an appendix of physical and thermodynamic data used in the various procedures and in related calculations.

14 This version is now complete, and is expected to be available for distribution at the end of August 1994. Those hundred or so scientists who requested copies of version 1 of this Handbook will automatically be sent copies of Version 2. A brief article describing the Handbook and how to obtain copies will be written for US JGOFS News, and the Handbook will be offered to the international JGOFS steering committee for possible adoption as official JGOFS protocols.

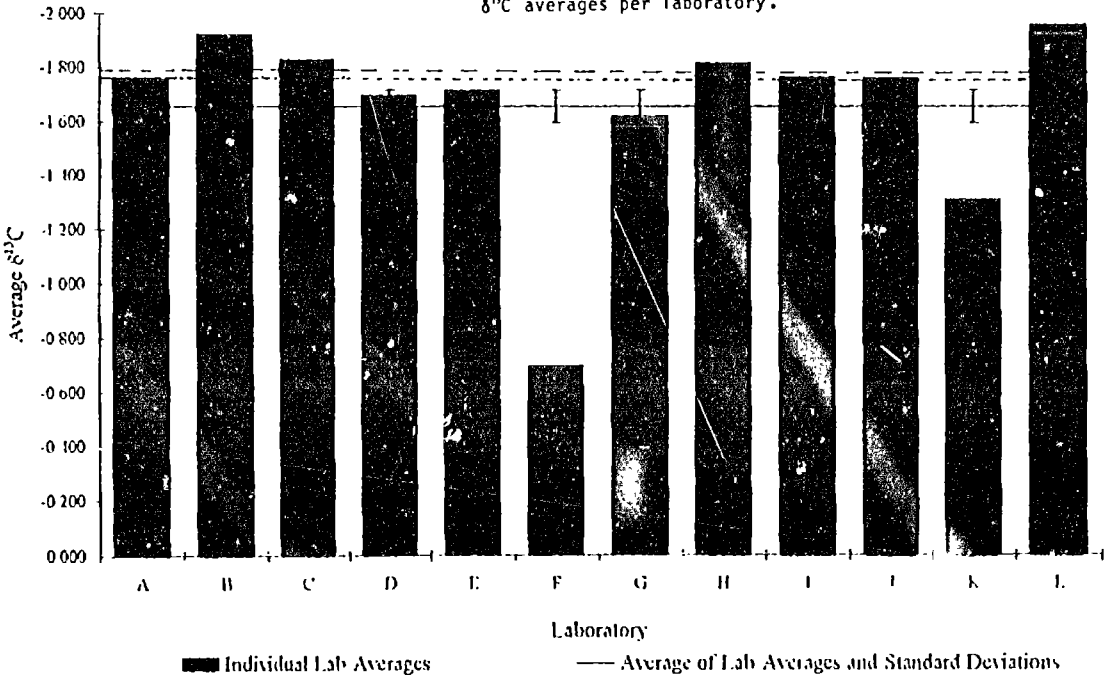
4.3 RESULTS OF $^{13}C/^{12}C$ INTERCALIBRATION AND PLANS

15 C.S. Wong presented the results of the recent $^{13}C/^{12}C$ inter-calibration exercise. Twelve laboratories, from seven nations participated (Australia, Canada, France, Germany, Japan, Norway, USA). Glass breakseals of aliquots of CO_2 gas with a $^{13}C/^{12}C$ ratio in the seawater range (+2 to -2 per mil) were drawn from an aluminum cylinder of CO_2 at 45 atm (below the liquefaction pressure of 57 atm at 20°C), prepared at IOS by mixing CO_2 enriched in ^{13}C (90%) with ^{13}C-depleted CO_2 at -40 per mil. The stability of the $^{13}C/^{12}C$ reference material was established at -1.79 per mil in May 1993 before the aliquots were drawn, and one year later at -1.75 per mil in May 1994.

16 The mass spectrometers of most participants were calibrated for $^{13}C/^{12}C$ using the isotopic ratio of CO_2 released by acidifying a limestone NBS- 19 (+1.95 per mil, PDB) and additional use of NBS-20 (-1.08 per mil, PDB) in some laboratories. Laboratories normally doing methane work used a graphite, NBS-15 (-41.59 per mil).

17 The mean $^{13}C/^{12}C$ value of all 12 laboratories was -1.65 ±0.34 per mil. The range was from -0.70 to -1.96 per mil with a standard deviation in the order of ±0.06 per mil for the results from individual laboratories shown in Figure 4-1. The data gave some hint of fractionation, perhaps caused by the aliquoting process.

Figure 4-1. Interlaboratory comparison; $\delta^{13}C$ averages per laboratory.



18 The results demonstrated the need for intercalibration, not only as a one-time approach, but as a continuing process to improve and maintain this isotopic analytical capability. It is critical to improve the compatibility of results from laboratories monitoring $^{13}C/^{12}C$ in the ocean and atmosphere. To distinguish exchange between the atmosphere and the terrestrial biosphere and oceanic uptake, Keeling stated that data sets with a precision of 0.02 per mil are needed. This requires an international calibrating system with isotopic standards of gaseous CO_2, seawater and solid limestone in order to maintain long term quality control of a global $^{13}C/^{12}C$ data set.

19 Keeling described the difficulties in maintaining good sets of standards for the oceanographic community. The NBS-19 standard has run out, underscoring a need to create our own standards both in gases and in water. The standards for $^{13}C/^{12}C$ in air have been drifting with time, up to 0.1 per mil per year. The problem of how to assure the long term existence and stability of seawater $^{13}C/^{12}C$ standards is becoming increasingly critical. In practice there is a need for a suite of standards at different levels around +2 to -8 per mil to cover the range in air and ocean, and a solid limestone standard as stable reference for checking gaseous and sea water reference materials.

20 Wong and Gunther informed the Panel they were conducting independent long-term tests on the stability of $^{13}C/^{12}C$ ratios in stored seawater. Early results indicated the seawater reference materials prepared by Dickson were well controlled for ^{13}C as well as C_T.

21 Wong outlined steps planned for continuing this work:

(1) Complete a report of the 1993 intercalibration exercise for distribution in December 1994.
(2) Improve methodology for preparing "breakseal" standards and introducing a "common" reference gas for the mass spectrometer.

(3) Distribute (both IOS and SIO) a seawater reference for $^{13}C/^{12}C$ intercalibration. The timetable calls for the distribution of improved breakseal standards and "common" reference CO_2 gas in December 1994 and seawater in early 1995 to test the extraction efficiency in laboratories.

(4) Obtain a large quantity of a good batch of limestone to be ground to the right size fraction and to be kept as a solid standard, sufficient in quantity for the oceanographic community for several decades.

22 Pearman noted that an intercomparison of $^{13}C/^{12}C$ is planned by the atmospheric community and suggested that the Panel co-ordinate with them. It was agreed that a letter be sent informing the appropriate atmospheric entity about the activities of this ocean CO_2 Panel and inviting a cooperative relationship in developing stable carbon isotope standards.

4.4 CO_2 DATA CO-ORDINATION

23 Merlivat indicated that Susan Kadar had begun to work on the inventory of the existing CO_2 data. She has not made much progress, however, because of conflicting priorities on her time. She hopes to have a clearer schedule this fall that will allow her to devote more time to the effort.

24 Merlivat stressed there is a need to accelerate the process of bringing together a uniform global data base. She expressed disappointment that advantage was not taken of the gathering of most of the right people at the Carqueiranne Conference to pull together the information for the inventory.

25 The Panel debated the possible approaches to move ahead. It was recognized that eventually some central agency would have to take over. Still, some motivated, CO_2-wise individuals would have to do the preparatory work and give some thought to what correlative information must be reported by those holding data, and to the needs of users of the data sets (e.g., modelers) to access and utilize the data most conveniently for their purposes. It was appreciated that the distributed data concept was gaining believers. The fast developing technology for accessing data sets wherever they are, through some central dial-up system, makes this approach an attractive option in the not too distant future. Large central data centers may become a thing of the past.

26 The discussion emphasized the following key points:

(i) A standard format should be established for reporting data.
(ii) The best quality data can be expected if it is prepared in the appropriate format by the investigator with his/her name appended.
(iii) A written report attached to the data is needed to describe how they were obtained.

27 G. Pearman pointed out that this issue has been discussed at length in the atmospheric community. They finally decided to support:

(i) a large database in which all the data would be presented in the same format; and
(ii) an inventory of people and available data sets.

Pearman emphasized that overseeing this work requires a senior scientist.

28 Recognizing that additional measures were necessary to move the pCO_2 inventory along, a subpanel of A. Polsson, A. Dickson and H. Inoue were appointed to work on this. They will meet for 3 days in the fall to consider the design of a standard format and an effort to assist Kadar by beginning to compile an inventory of pCO_2 data sets known to exist among the Panel members.

29 C.S. Wong noted that he is preparing a review paper including data sets from Japan, U.S. (PMEL and WHOI), Canada and Australia.

5. IRON ENRICHMENT INVESTIGATIONS

5.1 FERTILIZATION EXPERIMENT (IRONEX)

30 IRONEX was mounted in the equatorial Pacific in November 1993, to test the idea by the late John Martin, that large-scale dumping of iron in the ocean might be an effective way to combat the rise of anthropogenic carbon dioxide in the atmosphere. The equatorial Pacific is one of the "high nutrient, low chlorophyll" regions of the world's oceans where iron concentrations might be limiting phytoplankton productivity (others are the subarctic Pacific and the Southern Ocean). In these areas biological activity does not completely remove nitrate and phosphate from surface water. New production in these waters is therefore less, and the CO_2 content higher than it would be if all the nutrients were consumed. This leads to higher levels of CO_2 in the undisturbed atmosphere than would otherwise be the case. While Martin hypothesized that the root cause of this was limitation by iron, others have suggested that tight control of phytoplankton by grazing organisms, or, in subpolar regions, lack of light or deep mixing could be more important.

31 During the experiment, a small (8 km x 8 km) patch of ocean was enriched with iron. The mixed layer was enriched with 7600 moles over a period of 24 hours, sufficient to raise the concentrations in surface water by about 4 nM. Simultaneous with the iron, 0.35 moles of the inert tracer sulphur hexafluoride were released in order to track the patch and monitor the fate of the iron and its effect on the local ecosystem.

32 Within the patch, marked increases in primary production and chlorophyll standing stock were observed over the week following release. Significant depression of surface fugacities of CO_2, by 4-15 μatm, was also apparent within 48 hours of the iron release, and did not systematically change after that time. However, the effect was only a small fraction (~10%) of the CO_2 drawdown that would have occurred had the enrichment resulted in the complete utilization of all the available nitrate and phosphate. Thus artificial fertilization of this ocean region did not cause a very large change in the surface CO_2, in contrast to the effect observed in incubation experiments where addition of similar concentrations of iron usually results in complete depletion of nutrients. The preliminary conclusion is that there is currently little basis to believe that an increase in oceanic Fe supply, natural or man-made, would tend to lower atmospheric CO_2.

33 However, there are caveats: the iron was released in a single pulse, and it is possible that a larger effect would have been observed if it had been released in a more continuous fashion. Furthermore, the response would be expected to be ecosystem-dependent, and it may be that other regions (the Southern Ocean for instance) would show qualitatively different behaviour to that observed in the equatorial Pacific. These hypotheses could be tested by a modification of the procedures for this study.

34 Millero described the study of the Galapagos high productivity plume conducted during the same period. Stations were taken in and outside the plume; observations of pCO_2 and nitrates were made underway. A second leg examined the natural system around the Islands. Very high upwelling was observed off the western coast which is easily seen in the surface temperatures. He converted fugacity data to C_T and looked at C_T *vs* nitrate and found non-Redfield ratios. Millero suggested that iron in the runoff from the land could become complexed with organics or attached to colloids to produce particles that would settle and perhaps be recycled in some way to reuse the iron. He speculated that photochemical reactions might play a role as well, converting particulate iron to a soluble form.

35 The enrichment experiment was the first attempt to learn about the response of the ocean by direct manipulation of a small section of the un-enclosed marine ecosystem and was made possible by recent advances in tracer technology. Such experiments offer a potentially fruitful new approach in marine science. Another tropical experiment is being planned for 1995, and one in the Southern Ocean is under consideration in the longer term.

6. QUANTIFYING THE ANTHROPOGENIC CO_2 SIGNAL

6.1 CO_2 IN THE 1994 UPDATE OF THE IPCC REPORT

36 Graham Pearman reported on the second draft of the 1994 IPCC Report on "Radiative Forcing of Climate Change". The report includes the following topics which are related to the charges of this panel; 1.1 - Description of carbon cycle; 1.2 - Past record of atmospheric CO_2; 1.3 - Anthropogenic carbon sources; 1.4 - Climate feedbacks on CO_2 cycle; 1.5 - Modeling the future atmospheric CO_2.

37 On the basis of the results of 1-dimensional box-diffusion ocean models calibrated using the distribution of bomb ^{14}C, and those of three 3-dimensional GCM models, the report supports an estimate of 2.0 ± 0.8 GtC/yr for oceanic uptake of industrial CO_2. It states that marine biota play a small role in the oceanic uptake of industrial CO_2. Even if all available nutrients were used up, only 100 ppm change could be expected. However, species changes in marine biota may constitute a feedback in response to climate changes. Coastal ocean areas which occupy about 8% of the global ocean area do not contribute significantly to industrial CO_2 uptake. The oceanic carbon reservoir may respond to climatic changes in a variety of ways. An increase in ocean water temperature would give a positive feedback (a 1°C increase would result in a 10 ppm increase of pCO_2), whereas an increase in nutrient utilization over high latitude oceans would give a negative feedback. The remineralization rate of biogenic debris in water columns may also increase with increasing temperature, but its effect on CO_2 feedbacks is not clear. Oceanic circulation may be also changed. Preliminary model calculations indicate that the effect is small, of the order of 10s of micro-atmospheres.

38 The report concludes that useful estimates of fluxes have been obtained form pCO_2 data but that a direct measurement of industrial CO_2 taken up by the oceans is not feasible at present. Models have to be employed. To test the results of the model studies, the following observational studies are promising; a) measurements of temporal changes in ^{13}C in CO_2 dissolved in ocean water; and b) oxygen/nitrogen ratios in firn ice and glacial ice samples. In the atmosphere, the effects of industrial CO_2 sources overshadow the effects of all other sources and sinks. Strong sinks located in mid-latitudes are unexplainable, and southern high-latitude CO_2 sources postulated by Tans et al. (1990) remain unconfirmed.

39 The ensuing discussion was limited by the fact that few members of the Panel had had an opportunity to review the report. Nevertheless, a number of issues were raised. Tilbrook questioned the reliability of results from models calibrated using ^{14}C; there is crosstalk between calibration and validation and the models have difficulty getting the mixing right. Watson believed the Report focussed too much on very large changes, (e.g., of doubling and quadrupling CO_2), but in fact small changes due to feedbacks over a long period of time are important to climate as well. Takahashi pointed out that, in view of the large seasonal variability of carbon-13 (up to 2 o/oo) observed in high northern latitudes, seasonal variability in carbon-13 in oceans must be taken into consideration. Merlivat cited a manuscript "Partitioning of Ocean and Land Uptake of CO_2 as Inferred by carbon-13 from the NOAA/CMDL Global Air Sampling Net work" by P. Ciais, and pointed out that measurements of carbon-13 in atmospheric CO_2, especially with high temporal resolution, are important. However, large errors in measurements are a problem. Keeling also warned of large errors in carbon-13 measurements and cited that the carbon-13 values for the 1986 NBS standard are not consistent with the values recently determined by C. S. Wong. Keeling believed carbon isotope observations were key to partitioning terrestrial and ocean uptake but available resources were inadequate to the task. The case for reducing the uncertainties and providing calibration standards for these measurements has not been made strong enough. People outside the marine community need to be reminded that ocean observations remain a high priority need.

All in all, the Panel concluded it was difficult to disagree with the report as a whole, but there was some restiveness about the overall tone and the impression one may get from the emphasis on model results that the carbon cycle is better understood than it is. It was agreed that greater

consultation between the members of the Panel and the authors of the IPCC report would be beneficial and that this should be a matter for discussion at the Panel meeting.

6.2 SLOWING OF ATMOSPHERIC CO_2 INCREASE - RECENT DATA

40 C.D. Keeling presented the results of atmospheric CO_2 measurements and pointed out that 90% of the world's fossil fuel use is in the northern hemisphere and that a gradient is building between the northern and southern hemisphere. Less than half of the fossil fuel CO_2 that has been inserted in the atmosphere since the industrial age remains in the atmosphere. Since Keeling began his records in 1958, the record shows that the atmospheric CO_2 concentration growth rate was highest in recent years (> +2.5 ppm/yr). The rate began to decrease in 1991, at about the time of the Pinatubo eruption, to about +0.5 ppm/yr. It began increasing again in mid-1993. The record also shows other periods of changes in CO_2 emissions that correspond temporally with the oil crisis and the Iran-Iraq war. He also showed global annual air temperature records (which include marine observations), and demonstrated that temperature fluctuations correlated well with changes in the atmospheric CO_2 increase rate. Mean global temperatures were nearly constant between 1958 and 1976, increased from 1976 to 1990, and decreased since 1990.

41 Keeling's atmospheric ^{13}C data indicate that, before 1991, the variation of the oceanic uptake had been opposing that of the variation in the terrestrial biosphere uptake. The effect of the oceans on the atmospheric CO_2 concentration had thus been canceling the terrestrial effects. The annual variations in fossil fuel consumption are known to be too small to account for the magnitude of the variations in atmospheric CO_2, so the conclusion is that the biosphere has been responsible. Keeling postulated that, after 1992, these uptake effects were in phase, thus reinforcing each other to reduce the rate of increase in atmospheric CO_2. Why the ocean and terrestrial biosphere had opposing variations in uptake until 1991 and then switched to be reinforcing -- both acting as sinks, is unexplained. The ensemble of data indicate the big sink seems to be the terrestrial sink.

Keeling further noted that the Indian monsoons failed during every El Niño year before 1991, and then inexplicably broke that pattern with the 1991 El Niño event. This led him to propose that the recent period of unusually slow increase in atmospheric CO_2 might be attributed to changes in the global atmospheric circulation, which affected precipitation globally and hence the terrestrial ecosystem. He observed that the timing, at least, of the Pinatubo eruption suggests it is possible that such a specific event might act as a trigger for changes in global atmospheric circulation and thus precipitation.

6.3 EFFECTS OF VOLCANIC ERUPTIONS AND EL NIÑO

42 C.S. Wong reported the following observations related to volcanic eruptions and El Niño events on possible changes in the biological pump:

(i) There seem to be skin-effect differences between the N-S hemispheres and between the El Niño area and the North Pacific that would have effects on fluxes. Over the North Pacific, the ocean skin temperature has been estimated to be 0.26°C to 0.43°C lower than the bulk temperature. The relative shifts between adjusted and unadjusted fluxes due to skin effects on a seasonal basis vary from + 56% and -71%. Wong's group are currently developing estimates of flux changes during El Niño years.

(ii) In the Gulf of Alaska, the silicate concentration in surface waters was reduced to zero during the 1972, 1976 and 1979 El Niño events from the seasonal maximum value of about 30 µmol/liter. The zooplankton biomass increased from about 100 to 200 grams/liter in the 1956-59 period, to greater than 300 grams/liter during the 1980-89 period (Brodeur and Ware, 1992). This could be due to many reasons including an acceleration of the biological pump, changes in species composition resulting in more efficient grazing and therefore more zooplankton, or subarctic circulation changes related to stronger winds during ENSO years.

(iii) Volcanic events seem to cause an increase of ocean uptake of silicate. Off Kamchatka, he observed in 1992 a large silicate flux of 1200 mg/m^2/day using sediment traps. One possible cause may be related to the annual outbursts of dust storms from China in May/June. Another may be the effect of explosive eruptions of the Kliuchevskoi volcano on the Kamchatka Peninsula, ejecting ash clouds to 1000 m above the summit on May 13, 1992. Wong speculated that dust and volcanic fallout could be adding iron and thus stimulating productivity. At the HOT site, primary productivity doubled but accumulations in sediment traps decreased.

6.4 IMPORTANCE OF WINTER pCO_2 OBSERVATIONS FOR MODELS

44 Takahashi reported on his efforts to compare pCO_2 observations with model results. Winter observations are well correlated, but spring and summer are characteristically scattered; correlations with fall observations begin to tighten again. Ocean pCO_2 is dependent on temperature and biological effects. At Station P changes in these variables tend to cancel each other and raw pCO_2 data show no distinct seasonal cycle. However, pCO_2 normalized to 10°C reflects the total CO_2 change and shows the seasonal cycle. C_T variations are not canceled by temperature and biology in winter and more C_T is seen in winter than in summer. Takahashi has looked at nutrient data and found that phosphate data follow a similar trend. If seasonal data are not segregated, trends are not easily seen. He concludes therefore that winter data may be the best checks for testing the mixing parts of GCMs. Takahashi is examining C_T levels against variations in alkalinity, nutrients and temperature with the idea that evidence of uptake may be seen in changes in the ratios of these quantities. He concluded by encouraging the further development of pCO_2 underway systems to include measurements of nutrients, C_T and temperature.

7. JGOFS-WOCE UPDATE

45 C. Goyet reported on planned activities of the US-JGOFS in the Arabian Sea where five cruises will take place in 1995, and on the CO_2 survey in the Indian Ocean during 1994-1996. Information was also presented about a Dutch measurement programme (NIOZ, Hein de Baar) in the Atlantic Ocean during several legs of "Polar Stern" expedition ANTX in 1991/92.

7.1 DISCUSSION OF THERMODYNAMIC CONSTANTS

46 C. Goyet discussed differences of thermodynamical equilibration constants published by Goyet and Poisson (1989) and by Roy et al. (1993). In order to make the two sets of constants comparable, the data were converted to a uniform pH scale (sea water scale). The data were then independently fitted with a series of 481 polynomial and rational functions which were ranked by their fit standard error. The common function that best fits independently pK_1^* and pK_2^* for both studies is a rational function of the form:

$$pK^* = (a + bt + cS + dS^2 + eS^3) / (1 + ft + gt^2 + ht^3 + iS)$$

where pK^* represents either pK_1^* or pK_2^*
t represents the temperature in °C measured on the temperature scale ITS 90
S represents the salinity measured on the practical salinity scale
a, b, c, d, e, f, g, h and i are constants

47 The differences between the two sets of constants were calculated as a function of temperature and salinity. For both K_1 and K_2 the highest discrepancy was found at about 10°C. Then, the experimental data of Goyet and Poisson and Roy et al. were combined to generate one set of equilibration constants using the same empirical fit function as above. On the basis of these constants, pCO_2 changes with temperature over the range of 5 to 20°C were calculated and compared with computations where the Goyet/Poisson constants were used. Differences were largest (up to 10 μatm) at the high end of the temperature difference range (i.e., T > 20°C).

48 In the ensuing discussion, Dickson and Millero suggested that a fit function based on thermodynamical relationships be considered rather than one on statistics. They further raised the question of whether it was meaningful to combine two different data sets which are partly based on different experimental approaches. There may not be a need for a combination as both sets of equilibrium constants are consistent with the best laboratory measurements at the present level of uncertainty.

8. NEW TECHNOLOGIES

8.1 SHIP-OF-OPPORTUNITY pCO_2 SYSTEM

49 Watson reported on the Plymouth Marine Laboratory programme which was started to deploy instruments capable of collecting pCO_2 and temperature data in a completely automated fashion from merchant ships. Two ships are currently instrumented in this way: the ST HELENA (travelling from Cardiff to Tenerife and on to St Helena island in the Eastern South Atlantic, and the PRINCE OF SEAS which runs from Newport, UK to Jamaica and on to Costa Rica. Both ships have roughly six-week cruise schedules. The systems log pCO_2, (an IR system is employed), sea temperature and equilibration temperature, atmospheric CO_2, barometric pressure and position (obtained from a GPS). Calibration is done every two hours at two points: 250 and 400 μatm.

50 The systems are slowly being de-bugged -- slowly, because there is usually only a day or two to work on the system when the vessel reaches port in the UK. Problems have to be diagnosed and fixed within this time, and success cannot be gauged until the vessel returns six weeks later. Quality data are beginning to be regularly received after nearly a year of operations. Problems included software debugging, over-voltages in the ship's power, algal growth in the equilibrator and blockages in the seawater line.

51 The systems have been designed to cope with the harsh environment of a ship's engine room. They incorporate GPS and can therefore make intelligent decisions about when and where to sample. There seems no reason why they could not send and receive information on a daily basis via the ship's INMARSAT communications systems. The air-conditioned racks can be the basis for other automated measurements such as fluorescence, nutrients, etc. Though some development and reduction to practice is still required, a network of such systems worldwide clearly could be a useful contributor to GOOS.

8.2 BUOY pCO_2 SYSTEM

52 Merlivat updated the Panel on her lab's pCO_2 sensor development. The system, intended for use on a drifter, employs a thymol blue cell with a spectrophotometer that is linear in the 200-500 μatm range. The cell has known alkalinity and salinity and only the pCO_2 changes via a membrane. Thus only T is additionally required. It has been field-tested against the IR system measurements made by Dandonneau on the Panama to Noumea run. Plans are to install it on a drifter with a fluorimeter.

8.3 SHIPBOARD pH SYSTEM

53 Dickson described a sea-going system for pH measurements of surface water which provides precise pH values that are consistent with the best available equilibrium constants for acid-base processes in sea water (see Figure 8-1). It also uses thymol blue and spectroscopic techniques. This instrument can make an accurate measurement of pH approximately every two

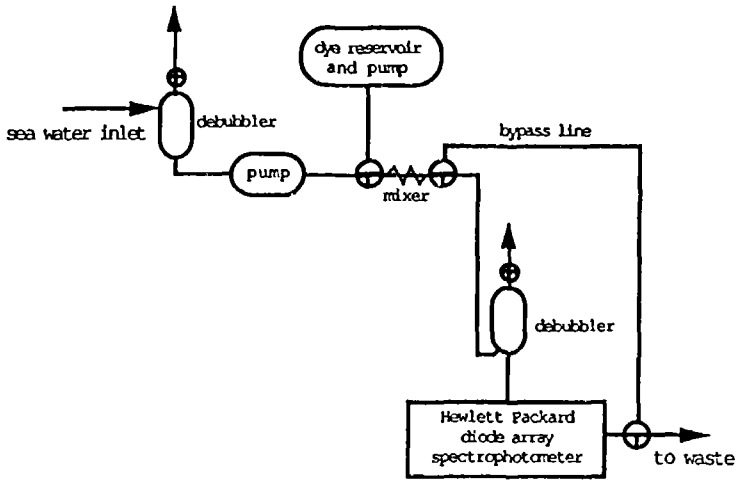


Figure 8-1. Schematic of SIO system for underway measurement of the pH of sea water.

minutes, and will provide an additional, useful, tool for the study of the dynamic biogeochemical processes which occur in the upper ocean. Figure 8-2 (from Fuhrmann & Zirino, 1988) shows clearly the correlation between pH and other ocean variables, and presents a tantalizing glimpse of the oceanographic information potentially available in high-quality pH measurements.

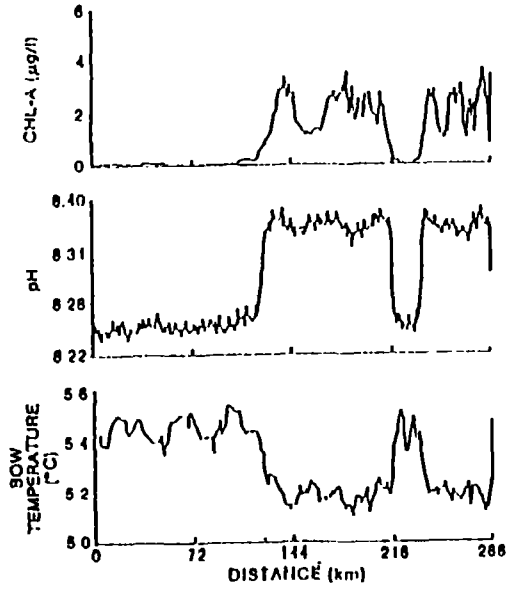


Figure 8-2. Horizontal profiles of sea surface temperature, pH, and chlorophyll-*a* obtained during the Varifront V expedition of 1983 (from Fuhrmann & Zirino, 1988).

54 While the degree of precision which can be sustained in potentiometric pH measurements at sea may be open to debate, it seems clear that the advent of spectrophotometric measurement of oceanic pH (Byrne & Breland, 1989) sets the precision of oceanic pH measurements in a new domain. Standard deviation obtainable using an automated Byrne system is ± 0.0008 pH; manually, ± 0.0004 has been achieved.

55 A prototype has been used on two cruises: one in the Atlantic in 1993 on the NOAA vessel Malcolm Baldrige and one in the Pacific on the NOAA vessel Discoverer (see Figure 8-3). The results are encouraging with an at-sea precision that is clearly better than 0.001 pH units and an estimated uncertainty of ± 0.004. Only a limited amount of operator intervention is required (about 1-2 hours / day). Principle sources of problems were temperature changes and mixing of dye at

constant rate. Bubble problems were manageable. The new system will adjust cell temperature to *in situ* temperature.

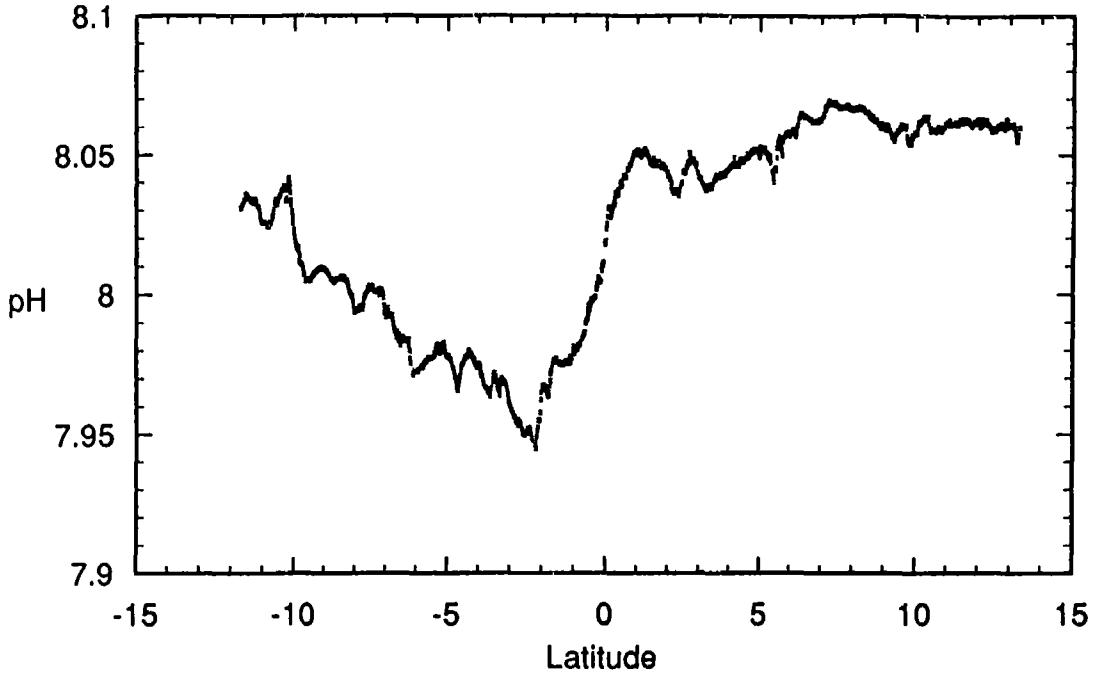


Figure 8-3. Underway pH data measured on NOAA R/V Discoverer (Feb 1994) on a transect across the equator at about 110°W. Negative latitudes are south; the data have been corrected to sea surface temperature.

56 Dickson is also working on a C_T system to go with pH system. Since pH is closely related to pCO_2, the pH data can be used for quality control of the pCO_2 system.

8.4 MULTI-PARAMETER SHIP-OF-OPPORTUNITY PACKAGE

57 C.S. Wong has been running a prototype system on ships of opportunity in the Pacific between the North American west coast and Australia. Additional routes are planned between Japan and Vancouver, and between Vladivostok and Vancouver, beginning later in 1994 to gather data on pCO_2, wind, SST, salinity, nutrients, and chlorophyll-a. He is developing a packaged shipboard system in co-operation with Nojiri, of Japan's National Institute of Environmental Studies (NIES), and Kimoto, of Kimoto Electric. Eventually, measurements will be made of pCO_2, CTD, C_T in air and water, chlorophyll-a, particles, NO_3, PO_4, SiO_2, A_T, DMS, $^{13}C/^{12}C$ in air and water, plus meteorological data with GPS for positioning. This final system will take three people to operate on a round-the-clock basis.

8.5 AUSTRALIAN ATMOSPHERIC CO_2 MONITORING

58 Pearman reported that efforts to measure the atmospheric CO_2 concentration profile have proven unsuccessful thus far. Emissions for all of Australia can only be verified to within a factor of two or three for all gases. Under these circumstances he held little hope, in the near future, of measuring mitigation effects to within 10% as required by international agreements. Pearman described a model grid developed for Australia with 60 km resolution. Over time, the three predominant circulation patterns bring air from all sections of the continent to Tasmania. This makes for the intriguing possibility of obtaining data, at a single location - Cape Grim, on air transported from all parts of Australia.

9. TIME SERIES OBSERVATIONS

9.1 JAPANESE WESTERN PACIFIC TIME SERIES DATA

59 Dr. Tsunogai informed the Panel of Japanese time-series sections in the western North Pacific Ocean since 1989. These sections, with water column chemistry and atmospheric green house gases, were occupied once or twice per year along 137°E (summer and winter) from the equator to 34°N, and along 155°E (summer) from 10°S to 30°N. Unfortunately, the important region north of 40°N is not included at present. The data are useful for detecting seasonal and interannual variability of air-sea exchange of CO_2 and change in the carbonate system of the ocean, as well as its spatial variability. They reveal large-scale features of CO_2 sources and sinks and a large difference between the two longitudes in the western Pacific. The surface pCO_2 data show winter undersaturation and summer supersaturation along 137°E, except near the equator where CO_2 was always supersaturated. Further to the east the summer values were not so supersaturated. Winter values are quite consistent while summer data show great variability. Data on atmospheric CO_2 and CH_4 were used to observe their secular increases. The data, available from the Japanese Meteorological Agency, will be incorporated into the report of the Greenhouse Gas Data Centre of WMO as part of the WMO WDCGG Data report series.

60 Other work in the East China Sea demonstrated the importance of the continental shelf zone as a CO_2 sink by observing the carbonate system four times along one fixed section. The same conclusion reached from the total carbonate at a section along 165°E was realized in the $\delta^{13}C$ data set. A comparison of Japanese data on $\delta^{13}C$ at stations along 165°E with data from GEOSECS stations indicates a more negative $\delta^{13}C$ in more recent times in the intermediate water down to at least 1200 m. The largest difference was about 0.4 per mil. The penetration depth and decrease in $\delta^{13}C$ was found to be much greater in the western North Pacific than that in the eastern North Pacific reported by Quay and his colleagues.

61 A plot of the $\delta^{13}C$ against AOU (the difference between saturated dissolved O_2 and the observed value), shows the gradient coinciding fairly well with the $\delta^{13}C$ of organic particles. The segment representing the $\delta^{13}C$ value of original non-altered water, however, is much larger than that in equilibrium with the air at the surface conditions of the North Atlantic or the Antarctic oceans. This means that the deep water is made from the warm water transported to the high latitudes before attaining the equilibrium for CO_2 at the air-sea interface.

9.2 AUSTRALIAN SOUTHERN OCEAN DATA

62 Bronte showed data which suggests that spatial changes in atmospheric pCO_2 often correspond to regional variations in surface ocean pCO_2 (up to 80 μatm) in the extreme southern hemisphere. The atmospheric data were obtained by the CSIRO Division of Atmospheric Research from air flask samples collected on Southern Ocean cruises. These data provide evidence that air-sea exchange is directly influencing atmospheric CO_2 distribution over the Southern Ocean. The work supports the view of many atmospheric chemists that pCO_2 data obtained from the present atmospheric monitoring sites are not necessarily zonally representative, and that increased sampling density for the atmosphere could lead to improved estimates of air-sea carbon fluxes derived by inversions of the atmospheric data.

10. NATIONAL REPORTS

10.1 AUSTRALIA

63 Bronte reported the following summary of Australian plans for field work in 1994-95. The Australian effort is focussed on the Southern Ocean sector between 60°E and 160°E.

(i) Measurements of carbon parameters (pCO_2, DIC, alkalinity, ^{13}C, ^{14}C, and nutrients) are scheduled along SR3 for WOCE cruises in January 1995, September 1995 and November 1996.

The section has already been completed in October 1991, May 1993, and January 1994.

(ii) Measurements of carbon parameters along the circum-Antarctic WOCE section S4, between 110°E and 160°E in January 1995.

(iii) Surface underway measurements of fCO_2 and discrete sampling for $^{13}C/DIC$ on numerous resupply voyages between Australia and Antarctica in the 1994-95 period.

(iv) Limited carbon analyses on *SOUTHERN SURVEYOR* cruises in the sub-Antarctic zone in January 1995 and November 1995. Additional work in the region is being considered for 1997 on the *AURORA AUSTRALIS*.

10.2 CANADA

64 C.S. Wong's report on Canada's current activities and plans in the Atlantic and Pacific is summarized below. An expanded report with illustrations is included as Annex III.

(i) Atlantic -- Marine Chemistry Division, Bedford Institute of Oceanography (E.P. Jones) Canadian CO_2 activities in the Atlantic Ocean (1993-1994) focus on JGOFS/WOCE expeditions in the Newfoundland Basin and the Labrador Sea. Work on a simple model of the CO_2 uptake and ventilation in the Labrador Sea was begun under a contract let to Memorial University in the summer of 1994. Plans for 1994-95 include two expeditions under JGOFS/WOCE objectives: the fourth repeat section (since 1991) in the Labrador Sea in May-June 1994, and a second control volume experiment in the Newfoundland Basin in November 1994.

65 Under the Arctic Programme, a 55-day expedition into the Canadian Basin of the Arctic Ocean will provide an opportunity for measurements of CO_2, freons and carbon tetrachloride, that are being done on the two other expeditions.

(ii) Pacific -- Centre for Ocean Climate Chemistry, Institute of Ocean Sciences (C.S. Wong) The Pacific CO_2 activities 1993-1994 focus on the WOCE line P1W section in Okhotsk Sea from the Siberian shore to Kurile Island using Russian research ship MV NESMEYANOV in September 1993. WOCE repeat section, line P between station P and west coast of B.C. was occupied 3 times during 1993/94 with T,S, nutrients, freons and CO_2 measurements.

66 An air-sea CO_2 monitoring programme has been initiated in 1994 as part of a bilateral agreement with the National Institute of Environmental Studies (NIES) of Japan, to monitor atmospheric CO_2, surface ocean pCO_2, $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios, nutrients and chlorophyll-a on the MV SKAUGRAN between Japan and Vancouver. A similar study will begin in late 1994 between Vladivostok and Vancouver, to obtain winter data in Okhotsk Sea, Bering Sea and N.E. Pacific waters. A programme to quantify biological removal of CO_2 as detritus carbon and $CaCO_3$ included moorings of sediment traps at Station P (50°N, 145°W) and a coastal station in productive waters off Vancouver Island.

67 Modelling work includes the development of an inverse model of the carbon cycle in the North Pacific Ocean, based on multiple-tracers of T, S, oxygen, alkalinity, dissolved inorganic carbon, nutrients, and a carbon dioxide cycle model, based on nitrogen.

68 Planned activities in 1994/95 focus on field programmes of JGOFS/WOCE section P 15N along 170°W from 57°N to 10°S in September-November, 1994, air-sea CO_2 study using ships of opportunity and time series of moored sediment traps in N.E. Pacific and coastal waters, and continuation of carbon-cycle modelling.

10.3 CHILE

69 G. Daneri described the Chilean JGOFS programme plans and activities for the next three years. These include an assessment of the air sea CO_2 exchange in the upwelling areas off the

coast of Chile. The field work is concentrated around two fixed stations, one coastal (850m depth) and one oceanic (4200m depth) near 30°S. Two cruises to these stations of 15 days duration, one in summer and one in winter will be carried out each year over the three-year period. Both stations have permanent moorings. The deep sea mooring has sequentially sampling sediment traps at 1000, 2000, and 3000 meter depths, and five recording current meters at these depths and at 200 and 500 meters. The coastal station mooring has current meters at 200, 500, and 750 meters. Parameters being measured are; particulate organic and inorganic carbon, dissolved organic carbon and nutrients (nitrite, nitrate, phosphate, silicate, and ammonia). Meteorological data are also observed.

70 Up till now, measurements of the carbonate system have been lacking but beginning with the August 1994 cruise, pH and A_T measurements will be implemented. With funds provided by Germany equipment will be purchased for measurements of pCO_2 beginning with the two 1995 cruises. More details and the participating institutions are included in Annex IV.

10.4 FRANCE

71 Merlivat reported that French plans outlined in last year's report for the period 1993-1999 continue unchanged. Scheduling is shown in Figure 10-1.

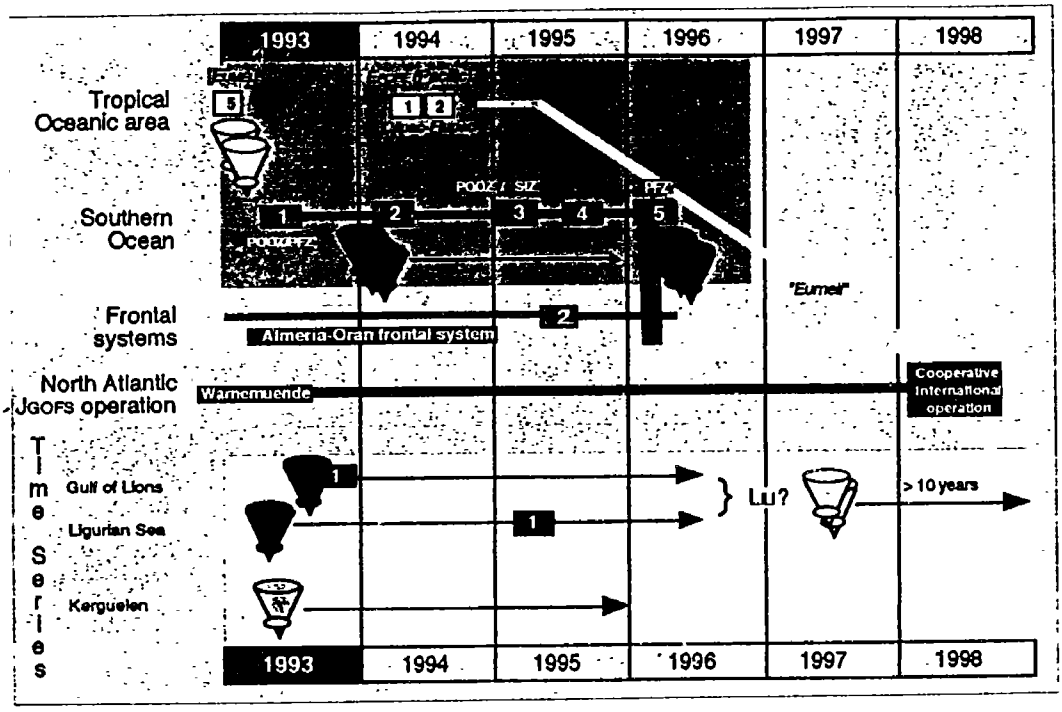


Figure 10-2. Schedule of JGOFS-France activities at sea (cruises, moorings deployment and retrieval) between 1993 and 1998.

10.5 GERMANY

72 B. Schneider reported plans for two WOCE *METEOR* cruises to make measurements of the carbonate system: one in the North Atlantic (to Ireland, Newfoundland, Greenland and back to Ireland) in 1994, and the second in the Indian Ocean in 1995. C_T, A_T, and pCO_2 will be measured.

10.6 JAPAN

73 Tsunogai reported that his group will join a cruise in the Southern Ocean (November 1994 - March 1995) to observe carbon system variables. He also informed the Panel that the JAPAN National Institute of Industrial Resources and MITI completed a cruise in June along 165°E across the equator and recovered sediment traps.

74 The following universities, research institutes and governmental agencies are independently carrying out ocean carbon observations:

75 Japan Meteorological Agency and Meteorological Research Institute. The operational time-series observation described in section 9.1 will be permanently continued. In this year, measurements of CFCs have been added. Besides the time-series sections along the two longitudes, the equatorial Pacific, especially in its central part will be studied intensively for the surface water $p(CO_2)$.

76 National Institute for Resources and Environment. Ocean chemistry plus sediment trap experiments along the section 175°E from 45°N to 15°S will be continued for once a year for 5 years. The carbonate system will be analyzed by using many observed components such as CFCs and biological species.

77 National Institute for Environmental Studies. Their observations have been concentrated in the coastal zone, however, they will extend to cover the oceanic zone used by regular lines of merchant vessels. The lines are Tokyo-Vancouver and Tokyo-Sydney.

78 Japan Marine Science and Technology Centre of Science and Technology Agency. The centre has 3 oceangoing vessels and will add one large vessel, *MUTSU*, which will serve the future GOOS. These vessels will be used to acquire oceanic carbon chemistry in various experiments, e.g., MASFLEX (Marginal Sea Flux Experiments).

79 Hokkaido University and other national universities. The staff and students of Hokkaido University are participating in many cruises on various national university ships such as HAHUKO MARU of Tokyo University and conducting observations of components of the ocean carbon system. The Ministry of Education, Science and Culture supports fundamental studies for GOOS from 1993 for 5 years. Chemical oceanographers are engaged in these studies.

80 Tokai University and other private universities: Tokai University has a research vessel, which can be used for the carbon studies. The scientists in private universities are also participating in the programmes planned by the governmental agencies.

10.7 NORWAY

81 T. Johannessen informed the Panel that the Norwegian Carbon Budget and Deep Convection Programme (CARDEEP) was proceeding according to plans outlined in Annex VIII of last year' Panel meeting report. Begun in 1993 and scheduled to continue through 1995, the objective is to better understand the role deep water forming regions in the Greenland, Iceland and Norwegian Seas play in the global oceanic CO_2 uptake.

10.8 UNITED KINGDOM

82 Watson presented the UK's plans for the 1994/95 period as follows:

Nov 1993: IRONEX Equatorial Pacific (see section 5). (Completed)

Mar 1994: ADOX II -- Capetown - Capetown covering the Southern Ocean from 0°E to 120°E, 50°S - 64°S. Underway pCO_2, nutrients, oxygen, chlorophyll. (Completed)

Sep 1994: ARABESQUE I; November 1994: ARABESQUE II. NW Indian Ocean and Arabian Sea: These two cruises are JGOFS-type investigations with measurements of fCO_2, TCO_2, nutrients, chlorophyll, productivity and speciation.

Mar/Apr 1995: WOCE WHP A-23 cruise, Weddell sea to Rio -- WOCE parameters, including fCO_2, C_T, will be measured.

Jun 1995: A possible second IRONEX cruise in the equatorial Pacific, plus, continued unattended merchant vessels lines from the UK to Tenerife and the UK to Jamaica (see section 8.1)

10.9 UNITED STATES OF AMERICA

83 Takahashi reported on the three ongoing major field programmes which comprise the US oceanic CO_2 measurement programme. The next planned phases of these programmes are briefly summarized below. Annex V contains details on these plans and on completed field activities.

(i) The DOE Ocean CO_2 Programme in association with the WOCE Programme. During 1995, the CO_2 measurement programme will be concentrated on the Indian Ocean. The completed and anticipated activities are summarized in Tables 1 and 2 of Annex V.

(ii) JGOFS Process Studies. The field phase of the US/JGOFS Arabian Sea Study, which is jointly funded by the National Science Foundation, Office of Naval Research and National Aeronautics and Space Administration, will be started in 1994 and will be continued through 1995. The schedules and objectives of the various cruises for the Arabian Sea Study are provided in Table 3 of Annex V.

(iii) NOAA Ocean CO_2 Programme. Underway measurement systems for surface ocean pCO_2 are installed on the NOAA Ships BALDRIDGE and DISCOVERER on a permanent basis yielding spring and fall coverage of Caribbean and equatorial Pacific areas. In addition, NOAA will continue long N-S section studies along 5 sections in the Pacific (50°N-60°S), one section in the Atlantic (65°N-65°S), and one section in the Indian Ocean. The recent and future activities are listed in Table 4 and Table 5 respectively, of Annex V.

11. FUTURE GOALS OF THE PANEL

84 A. Watson opened this discussion by expressing the view that one of the most important goals must continue to be the development of a global database for oceanic CO_2 parameters. During the past five years, the field has exploded in terms of the number of scientists involved and measurements being made. For much of this activity the scientific justification has been that of climate change and the importance of understanding the CO_2 cycle globally. However, the data remains fragmented and un-coordinated.

85 This situation has been recognized by the panel for some years, and at the 4th session (1993) it was hoped that the attempt by S. Kadar at the WOCE office in Woods Hole to co-ordinate CO_2 data would begin solving the problem. However, this effort appears to have stalled. Watson believed that an alternative has to be found as a matter of urgency, and suggested the Panel itself might consider taking on at least the first phase, i.e., of making an inventory of existing data. Such an inventory might contain the following information: who owns the data, in what area and at what date it was collected, if it is or will be available for release, what ancillary variables can be obtained with it, and some reference to the methods used.

12. RELATED MEETINGS

86 The Panel's attention was brought to the following scheduled meetings that will have sessions dealing with ocean CO_2.

87 Dickson, Poisson and D.E. Pollock (the latter from the South African Sea Fisheries Research Institute) are organizing a IAPSO symposium for the XXI General Assembly in Boulder, Colorado, USA, 2-15 July 1995. It will focus on processes that influence the distribution and flux of CO_2 in the oceans, including those phenomena that affect the extent of oceanic-atmospheric exchange.

88 Pearman mentioned the IUGG will be in Melbourne, Australia in 1997.

89 Millero informed the Panel that he is well along with organizing an Ocean CO_2 Conference in January 1996 in Puerto Rico. At present, he is trying to form an organizing committee and line up sponsors. The Panel encouraged Millero and decided to play a prominent role in assisting with the conference. Poisson, Wong, Tsunogai, Millero and Keeling agreed to form an organizing committee to put together the program for the conference. Keeling suggested that the CO_2 community should agree to hold ocean and atmospheric CO_2 conferences in alternate years. Millero thanked the members for their support and indicated he would be contacting the members for assistance in various ways later this year.

13. RESTRUCTURING THE PANEL

90 Merlivat announced that she was relinquishing her position as chair of the Panel after this meeting, believing she had served a full term and it was time for a change. She also took this opportunity to encourage the Panel to formalize some kind of rotation of membership. Alexiou suggested that the Panel consider assembling a slate of replacement candidates for one- third of the existing membership by the next meeting, and for a second third for the meeting thereafter. These candidates could be proposed to the cosponsors: SCOR/JGOFS and IOC who would ultimately make the selections.

91 The Panel then addressed the matter of selecting a new chairman. Andrew Watson was nominated and unanimously elected.

14. NEXT PANEL MEETING

92 The Panel decided to hold its next meeting in conjunction with the Ocean CO_2 Conference being planned by Millero in Puerto Rico in January 1996 (see section 12). Though this would mean that no meeting would be held next year, the Panel concluded that the 18-month interval was not overly long and there were travel and other advantages to having the meeting concurrent with Millero's conference.

15. REFERENCES

93 Brodeur, R.D. and D.M. Ware, 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. *Fish. Oceanogr.* 1, 32-38.

Byrne R. H. & J. A. Breland (1989) High precision multiwavelength pH determinations in seawater using cresol red. *Deep-Sea Research* 36, 803-810.

Fuhrmann R. & A. Zirino (1988) High resolution determination of the pH of seawater with a flow-through system. *Deep-Sea Research* 35, 197-208.

Goyet, C. and A. Poisson, 1989. New determination of carbonic acid dissociation constants in seawater as a function of temperature and salinity. *Deep-Sea Research*, 36, 1635-1654.

Roy, R.N., L.N. Roy, M. Lawson, K.M. Vogel, C. Porter-Moore, W. Davis and F.J. Millero, 1993. *Marine Chemistry*, 44, 2-4, 249-267.

Tans, P.P., Y. Fung and T. Takahashi, 1990. Observational Constraints on the global atmospheric CO_2 budget, *Science*, 247, 1431-1438.

ANNEX I

AGENDA

1. WELCOMING

2. ADOPTION OF THE AGENDA

3. RECENT IOC EVENTS REGARDING GOOS

4. PROGRESS REPORTS

4.1 RESULTS OF pCO_2 EQUILIBRATOR CALIBRATION TESTS

4.2 ANALYTICAL METHODS FOR THE CARBON SYSTEM (NEW REPORT)

4.3 RESULTS OF $^{13}C/^{12}C$ INTERCALIBRATION AND PLANS

4.4 CO_2 DATA CO-ORDINATION

5. IRON ENRICHMENT INVESTIGATIONS

5.1 FERTILIZATION EXPERIMENT (IRONEX)

6. QUANTIFYING THE ANTHROPOGENIC CO_2 SIGNAL

6.1 CO_2 IN THE 1994 UPDATE OF THE IPCC REPORT

6.2 SLOWING OF ATMOSPHERIC CO_2 INCREASE - RECENT DATA

6.3 EFFECTS OF VOLCANIC ERUPTIONS AND EL NIÑO

6.4 IMPORTANCE OF WINTER pCO_2 OBSERVATIONS FOR MODELS

7. JGOFS-WOCE UPDATE

7.1 DISCUSSION OF THERMODYNAMICAL CONSTANTS

8. NEW TECHNOLOGIES

8.1 SHIP-OF-OPPORTUNITY pCO_2 SYSTEM

8.2 BUOY pCO_2 SYSTEM

8.3 SHIPBOARD pH SYSTEM

8.4 MULTI-PARAMETER SHIP-OF-OPPORTUNITY PACKAGE

8.5 AUSTRALIAN ATMOSPHERIC CO_2 MONITORING

9. TIME SERIES OBSERVATIONS

9.1 JAPANESE WESTERN PACIFIC TIME SERIES DATA

9.2 AUSTRALIAN SOUTHERN OCEAN DATA

10. NATIONAL REPORTS

10.1 AUSTRALIA

10.2 CANADA

10.3 CHILE

10.4 FRANCE

10.5 GERMANY

10.6 JAPAN

10.7 NORWAY

10.8 UNITED KINGDOM

10.9 UNITED STATES OF AMERICA

11. FUTURE GOALS OF THE PANEL

12. RELATED MEETINGS

13. RESTRUCTURING THE PANEL

14. NEXT PANEL MEETING

ANNEX II

LIST OF PARTICIPANTS

Art ALEXIOU
UNESCO.IOC
1, rue Miollis
75015 Paris
Tel: (33 1) 45 68 40 40
Fax: (33 1) 40 56 93 16
Omnet: A.ALEXIOU

Chris ATWOOD
Marine Physical Laboratory - 0902
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0902
U.S.A.
Tel: (619) 534 25 82
Internet: catwood@mpl.ucsd.edu

Giovanni DANERI
Dept. of Oceanography and Fisheries
Universidad del Mar
Amunategui 1838
Vina del Mar
CHILE
Tel: (54 32) 62 55 44
Fax: (54 32) 62 55 44

Andrew DICKSON
Marine Physical Laboratory
University of California, San Diego
9500 Gilman Drive
La Jolla, CA 92093-0902
U.S.A.
Tel: (619) 534 25 82
Fax: (619) 456 90 79
Omnet: A.DICKSON

Peter GUENTHER
CO_2 Research Group
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0902
U.S.A.
Tel: (619) 534 47 30
Fax: (619) 534 07 88

Catherine GOYET
Woods Hole Oceanographic Institution
Clark 4
Woods Hole, MA 02543
U.S.A.
Tel: (508) 457 20 00/25 52
Fax: (508) 457 21 93
Internet: Cathy@C02.WHOI.EDU

Truls JOHANNESSEN
Centre for Studies of Environment
and Rescurces
University of Bergen
Hoyteknologisenteret
N-5020 Bergen
NORWAY
Tel: (55) 54 42 49
Fax: (55) 32 48 01
E-Mail: truls.johannessen@geol.vib.no

Charles D. KEELING
Scripps Institution of Oceanography
Mail Code 022D
La Jolla, CA 92013
U.S.A.
Tel: (619) 534 42 30
Fax: (619) 534 07 84
Internet: cdKeeling@ucsd.edu
Omnet: C.Keeling

Ralph KEELING
Scripps Institution of Oceanography
UCSD
La Jolla, CA 92093-0236
U.S.A.
Tel: (619) 534 75 82
Internet: rkeeling@ucsd.edu

Liliane MERLIVAT **(Chair)**
Université Pierre et Marie Curie
LODYC Tour 14, 2ème étage
4 place Jussieu
75252 Paris Cedex 05
FRANCE
Tel: (33 1) 44 27 70 72
Fax: (33 1) 44 27 38 05
Tlm: L.MERLIVAT

Frank J. MILLERO
Rosenstiel School of Marine & Atmospheric
Sciences (RSMAS)
4600 Rickenbacker Causeway
Miami, FL 33149-1098
U.S.A.
Tel: (305) 361 47 07 or 47 31
Fax: (305) 361 47 11 or 361 46 89
E-Mail: fmillero@RSMAS.Miami.edu
Omnet : F.MILLERO

Paulette P. MURPHY
PMEL/NOAA
7600 Sand Point Way NE
Seattle, WA 98115
U.S.A.
Internet: murphy@pmel.noaa.gov

Graeme PEARMAN
CSIRO Division of Atmospheric Research
PMB #1 Mordialloc
3195 AUSTRALIA
Tel: (3) 586 76 50
Fax: (3) 586 75 53
Internet: GIP@DAR.CSIRO.AU

Alain POISSON
Laboratoire de Physique et Chimie Marines
Case 134
Universite Pierre et Marie Curie
4, Place Jussieu
75252 Paris Cedex 05
FRANCE
Tel: (33 1) 44 27 48 69
Fax: (33 1) 44 27 49 93
Internet: apoisson@ccr.jussieu.Fr
Omnet: A.POISSON

J. RUSSELL
Scripps Institution of Oceanography
Marine Physical Labs
University of California, San Diego
La Jolla, CA 92093-0220
U.S.A.
Tel: (619) 534 25 82
E.mail: Jrussell@ucsd.edu

Bernd SCHNEIDER
Institute for Baltic Sea Research, Dept Marine Chemistry
Seestrasse 15, 18119 Rostock-Warnemunde
GERMANY
Tel: (381) 519 73 20
Fax: (381) 519 74 40
Internet: Bschneider@chemie.10.warnemuende.d400.de

Taro TAKAHASHI
Lamont-Doherty Earth Observatory
Palisades, NY. 10964
U.S.A.
Tel: (914) 365 85 37
Fax: (914) 365 20 12
Internet: taka@ldeo.columbia.edu

Bronte TILBROOK
CSIRO Marine Laboratories
P.O. Box 1538
Hobart, TAS 7001
AUSTRALIA
Internet: tilbrook@ml.csiro.au

Shizuo TSUNOGAI
Laboratory of Marine and Atmospheric Geochemistry
Division of Ocean & Atmospheric Sciences
Graduate School of Environmental Earth Science
Hokkaido University, Kita 10, Nishi 5, Sapporo 060 JAPAN
Tel: (11) 706 23 68
Fax: (11) 747 97 30

Andrew WATSON
Plymouth Marine Laboratory
Prospect Place
West Hoe, PL1
Plymouth 3DH
U.K.
Tel: (752) 22 27 72
Fax: (752) 67 06 37
Internet: ajwa@unixb.nerc-pml.ac.uk
Omnet: PML.UK

Ray WEISS
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0220
U.S.A.
Tel: (619) 534 25 98
Fax: (619) 455 83 06
Internet: rfweiss@ucsd.edu

C.S. WONG
Centre for Ocean Climate Chemistry
Institute of Ocean Sciences
9860 W.Saanich Road
P.O. Box 6000
Sidney, B.C. V8L 4B2
CANADA
Tel: (604) 363 64 07
Fax: (604) 363 64 76
Internet: cswong@IOS.BC.CA
Omnet: IOS.BC

ANNEX III

CANADIAN PLANS AND ACTIVITIES

Canada's current activities and plans in the Atlantic and Pacific are as follows:

(1) Atlantic -- Marine Chemistry Division, Bedford Institute of Oceanography (E.P. Jones)

Canadian CO_2 activities in the Atlantic Ocean (1993-1994) focus on JGOFS/WOCE expeditions in the Newfoundland Basin and the Labrador Sea (Figures 1 and 2). Observations in the Labrador Sea show considerable year-to-year variability in the ventilation of the intermediate depth waters (Fig. 3). This is an interesting, significant and somewhat unexpected finding that will complicate models required to describe the sequestering of anthropogenic CO_2. Preliminary reports linking CO_2, freons and carbon tetrachloride in the North Atlantic have been presented at scientific meetings, such as CMOS Congress, Federicton 1993 and Ocean Science Meeting, San Diego 1994. Work on a simple model of the CO_2 uptake and ventilation in the Labrador Sea was begun under a contract let to Memorial University in the summer of 1994.

Plans for 1994-95 include two expeditions under JGOFS/WOCE objectives: the fourth repeat section (since 1991) in the Labrador Sea in May-June 1994, and a second control volume experiment in the Newfoundland Basin in November 1994. Under the Arctic Programme, a 55-day expedition into the Canadian Basin of the Arctic Ocean will provide an opportunity for measurements of CO_2, freons and carbon tetrachloride, that are being done on the two other expeditions.

(2) Pacific -- Centre for Ocean Climate Chemistry, Institute of Ocean Sciences (C.S. Wong)

The Pacific CO_2 activities 1993-1994 (Fig. 4) focussed on the WOCE line P1W section in Okhotsk Sea from the Siberian shore to Kurile Island using Russian research ship *MV NESMEYANOV* in September 1993. The penetration of anthropogenic CO_2 and freons F-11, F-12 reached a depth of about 1,000-1,200 meters into the interior of Okhotsk Sea (Fig. 5). WOCE repeat section, line P between station P and west coast of B.C. was occupied 3 times during 1993/94 with T,S, nutrients, freons and CO_2 measurements.

An air-sea CO_2 monitoring programme has been initiated in 1994 as part of a bilateral agreement with the (NIES) of Japan, to monitor atmospheric CO_2, surface ocean pCO_2, $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios, nutrients and chlorophyll-a on the *MV SKAUGRAN* between Japan and Vancouver (Fig. 4). A similar study will begin in late 1994 between Vladivostok and Vancouver, to obtain winter data in Okhotsk Sea, Bering Sea and N.E. Pacific waters. The pCO_2 data for the MV LILLOOET between Vancouver and Australia 1984-88 were worked up to assess air-sea CO_2 flux for subtropical waters and evidence of significant oceanic uptake in 35°-45°N was revealed after removing climatic noise due to warming.

A programme to quantify biological removal of CO_2 as detritus carbon and $CaCO_3$ included moorings of sediment traps at Station P (50°N, 145°W) and a coastal station in productive waters off Vancouver Island. Data from one year of moorings in N.W. Pacific waters and off Kamchatka Peninsula showed very interesting results of an extraordinarily high diatom bloom off Kamchatka in May/June 1993 during the time of an outburst of winds with dust from China, leading to possible iron fertilization.

Modelling work includes the development of an inverse model of the carbon cycle in the North Pacific Ocean, based on multiple-tracers of T, S, oxygen, alkalinity, dissolved inorganic carbon, nutrients, and a carbon dioxide cycle model, based on nitrogen.

Planned activities in 1994/95 focus on field programmes of JGOFS/WOCE section P 15N along 170°W from 57°N to 10°S in September-November, 1994, air-sea CO_2 study using ships of opportunity and time series of moored sediment traps in N.E. Pacific and coastal waters, and continuation of carbon-cycle modelling.

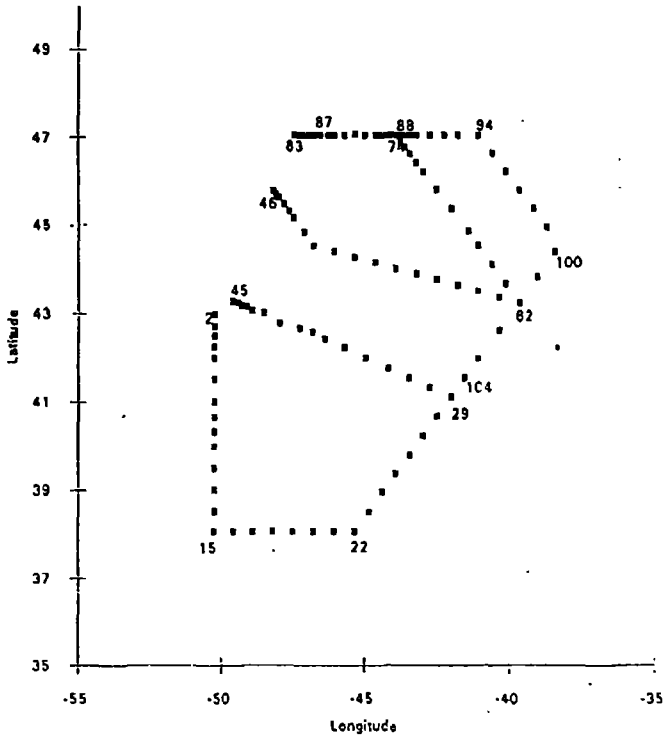


Figure 1. Canadian JGOFS/WOCE hydrographic stations in the Newfoundland Basin (1993-1994).

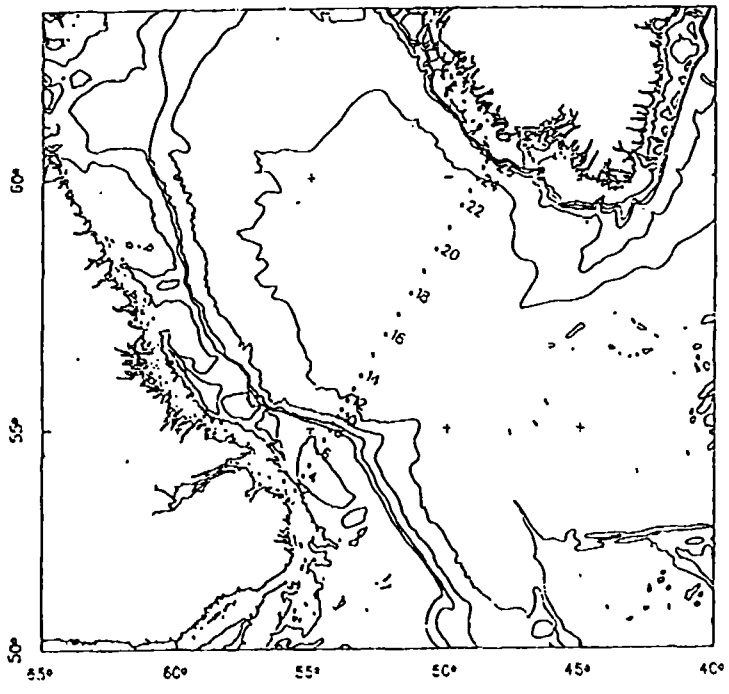


Figure 2. Canadian JGOFS/WOCE hydrographic stations in the Labrador Sea (1993-1994).

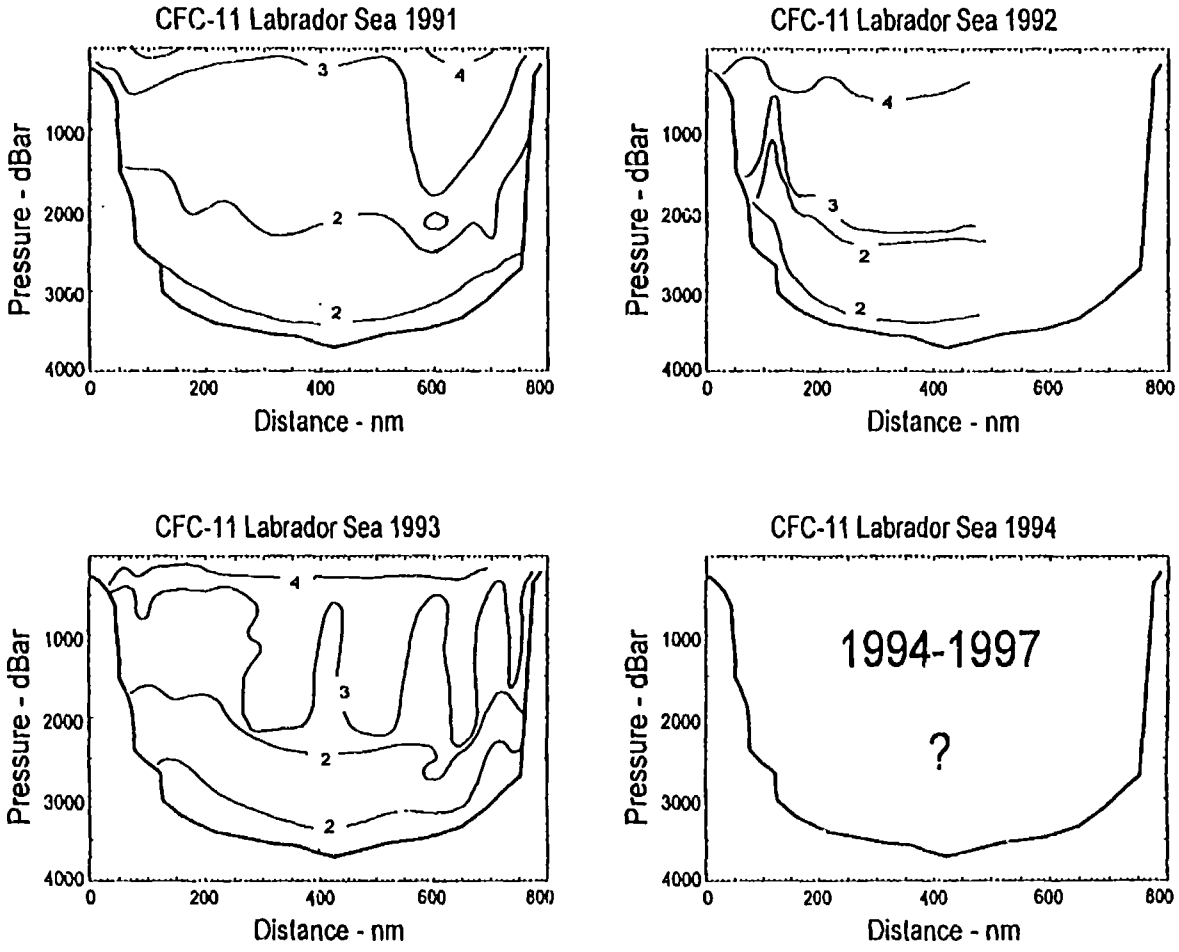


Figure 3. Variability of ventillation in intermediate depth waters of the Labrador Sea (1991-1993).

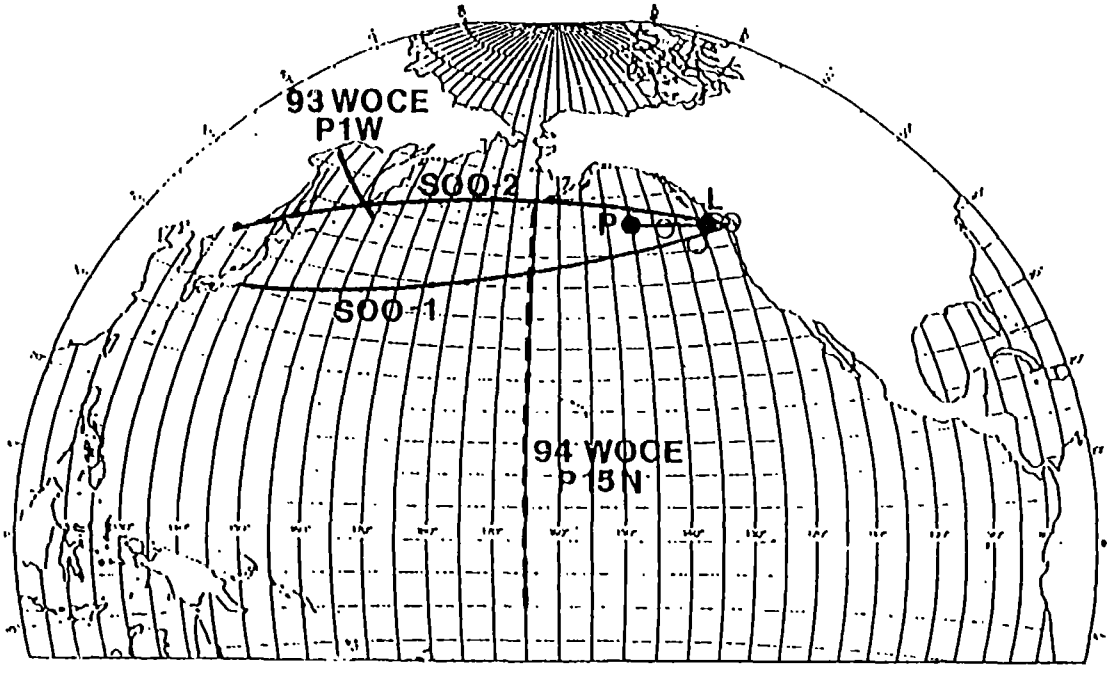


Figure 4. Canadian CO_2 activities in the Pacific Ocean (1993-1994).

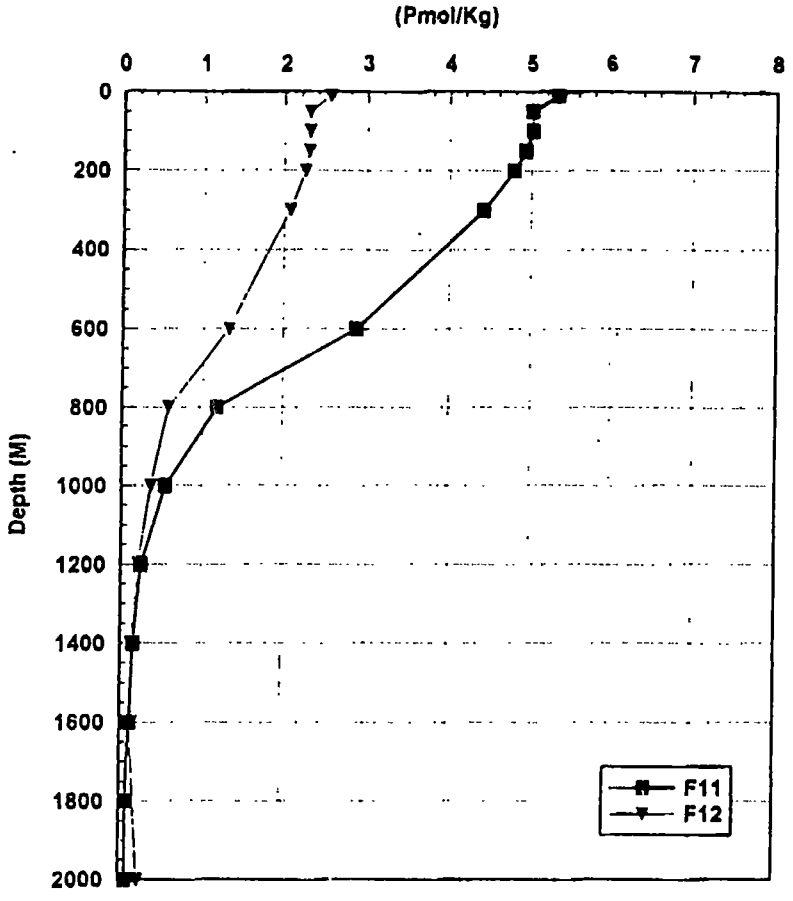


Figure 5. Pemetration of anthropogenic CO_2 and freons (F-11 and F-12) in Okhotsk Sea (1993).

ANNEX IV

CHILEAN NATIONAL STATEMENT

The Chilean JGOFS programme is part of the international Joint Global Ocean Flux Study (JGOFS) programme of the Scientific Committee for Ocean Research (SCOR) and the International Geosphere-Biosphere Project (IGBP). One of the primary aims of the JGOFS-International programmes is to address the role of the marine biota in climate change and the Chilean JGOFS programme has been designed to fulfill part of this global objective in the Eastern Boundary Current (EBC) region off Chile. The Chilean JGOFS programme is the only EBC study taken up in the JGOFS implementation plan (SCOR, IGBP 1992).

The eastern boundary currents, of which the Peru-Chile current system is an archetype are sites of intensive air-sea exchange of heat and CO_2 and other gases, upwelling of cold subsurface water, rich in nutrients and dissolved inorganic carbon, promotes strong initial outgassing of CO_2 to the atmosphere. The upwelling also sets the stage for subsequent high biological production and associated strong uptake of inorganic carbon, lowering surface layer partial pressure of CO_2 such as to promote uptake of CO_2 from the atmosphere.

One of the primary aims of the JGOFS-Chile programme is to assess the net exchange of CO_2 with the atmosphere in the upwelling area off Central and Northern Chile. In order to fulfill this aim the following two objectives have been set: a) to quantify and model the cycling of carbon within the EBC region off Chile, including exchange between the surface layer and the deep ocean, and exchange between the nearshore upwelling regions and the open ocean; and b) to quantify and model air-sea exchange of CO_2 in the EBC region off Chile. It is also expected that the results obtained will be used to access the role of the Eastern Boundary Currents in global carbon cycling.

The field work is concentrated off the chilean coast around two fixed stations, one coastal (water depth 850 m) and one oceanic (water depth 4200 m). Two cruises of 15 days duration, one in the summer and one in the winter, will be carried out each year over the three year period. In addition in both stations deep sea moorings have been permanently deployed. In the oceanic station the deep sea mooring, consists of 3 sequentially sampling sediment traps (Fa Hagenic Elektronic) at 1000, 2000 and 3500 meters depth and 5 recording current meters (Aanderaa RCM-7) at these depths and at 200 and 500 meters. The mooring in the coastal station features 3 current meters (Aanderaa RCM-7) at 200, 500 and 750 meters depths. The main parameters being measured include Particulate Organic Carbon (POC), Particulate Inorganic Carbon (PIC), Dissolved Organic Carbon (DOC), Nutrients (Nitrate, Nitrite, Phosphate, Silicate and Ammonia). A meteorological buoy provides data for the calculation of the air-sea exchange coefficient of CO_2 as well as ground truth for satellite derived surface wind needed for extending calculations of the air-sea exchange coefficients across the Peru-Chile EBC region.

The Chilean JGOFS programme has been running for nearly three years and during this time some important observations on current dynamics, sedimentation rates and basic biological processes have been made in the EBC region of Northern Chile. Despite this progress one of the most obvious shortcomings of the Chilean JGOFS programme has been a lack of measurements of any of the parameters that define the carbonate system. It is expected however to implement pH and alkalinity measurements during the next Chilean JGOFS cruise scheduled for August 1994 and measurements of pCO_2 during the cruises scheduled to take place in 1995.

The universities and research institutes taking part in the Chilean JGOFS programme include: Borno Institute for Ocean and Climate Studies, Sweden; Oceanographic Institute, University of Gothenburg, Sweden; Departamento de Geofisica, Universidad de Chile, Chile; Departamento de Oceanologia, Universidad de Concepcion, Chile; Instituto de Fomento Pesquero, Chile; Universidad Catolica de Valparaiso, Chile; Department of Geoscience, University of Bremen, Germany; Department of Geophysics, University of Copenhagen, Denmark; Centro de Cienclas y Ecologia Aplicada, Universidad del Mar, Chile; Department of Marine Chemistry, University of Hamburg, Germany.

ANNEX V

THE US OCEAN CO_2 MEASUREMENT PROGRAMME

1. DOE Ocean CO_2 Programme

The major aim of this programme is to measure the distribution of CO_2 in the entire global oceans in association with the WOCE Hydrographic Programme. The WOCE lines which have been investigated for CO_2 during the period between 1990 and 1994 are summarized in Table 1. During all of these expeditions, the total CO_2 concentration was measured using a coulometer (SOMMA and other types of sample injection methods) and the SIO Reference Solutions prepared by Andrew Dickson. For the second carbonate chemistry parameter, either the pCO_2 in seawater or the alkalinity (some cases both) were measured. The measurements were made by groups from the following institutions: Brookhaven National Laboratory, Lamont-Doherty Earth Observatory (Columbia University), Princeton University, Rosenstiel School of Marine and Atmospheric Sciences (University of Miami), Scripps Institution of Oceanography (University of California San Diego) and Woods Hole Oceanographic Institution.

Table 1 - The WOCE Hydrographic lines which have been investigated for CO_2 in 1990-1994

Line Nos.	Locations	Line Nos.	Locations
PACIFIC OCEAN		ATLANTIC OCEAN	
P-21(ext)	E-W along 18°S; 152°E-75°W	A-1	E-W along 58°N; 40°W-10°W
P-6(rev)	E-W along 35°S; 154°E-79°W	A-5	E-W along 23°N; 75°W-15°W
P-13	N-S along 165°E; 55°N-10°S	A-8	E-W along 12°S; 38°W-11°E
P-14	N-S along 175°E; 60°N-35°S	A-9	E-W along 20°S; 40°W-12°E
P-16	N-S along 150°E; 20°N-65°S	A-10	E-W along 32°S; 52°W-15°E
P-17	N-S along 130°W; 52°N-67°S	A-12/S2	E-W along 50°W; 30°W-15°E
P-19	N-S along 90°W; 10°N-67°S	A-14	N-S along 18°W; 5°N-32°S
S-4	E-W along 67°S; 70°W-170°E	A-21/S2	N-S along 70°W; 55°S-62°S
		A-24	N-S along 32°W; 5°N-60°S

Table 2 - The DOE CO_2 Programme in association with the WOCE Indian Ocean Hydrographic Programme, December 1994 through January 1996

Dates	WOCE Lines	Group	Dep Port	Arr Port	Days at sea
12/1/94-1/19/95	I-8S/I-9S	BNL	Fremantle	Fremantle	50
1/24/95-3/6/95	I-9N	Princeton	Fremantle	Colombo	42
3/10/95-4/16/95	I-8N/I-5E	U. Hawaii	Colombo	Fremantle	38
4/10/95-6/7/95	I-3	RSMAS	Fremantle	Port Louis	49
6/11/95-7/11/95	I-5W/I-4	BNL	Port Louis	Port Louis	31
7/15/95-8/24/95	I-7N	U. Hawaii	Port Louis	Matrah	41
8/29/95-10/18/95	I-1	WHOI	Matrah	Singapore	51
11/6/95-11/24/95	I-10	Princeton	Singapore	Singapore	19
11/28/95-1/19/96	I-2	BNL/Hawaii	Singapore	Mombasa	53
??/?/96-??/?/96	S-4I	LDEO	?	?	55(?)

2. US/JGOFS Programme

An extensive field study was conducted in the equatorial Pacific during 1992. During the February, 1992, expedition for the 140°W study line, an El Niño condition was encountered and investigated. The results are compared with those obtained during the August expedition representing a non-El Niño condition. The magnitude of the equatorial CO_2 source as expressed by the air-sea pCO_2 difference as well as the concentrations of nutrient salts were reduced to about 50% of the non-El Niño values.

The field phase of the US/JGOFS Arabian Sea Study, which is jointly funded by the National Science Foundation, Office of Naval Research and National Aeronautics and Space Administration, will be started in 1994 and will be continued through 1995. The expedition schedule, chief scientists and major objectives for each expedition are listed in Table 3. This programme will be conducted in close collaboration with the corresponding programmes of European countries. A Southern Ocean Programme is being planned for 1996-1998. The field area is likely to be south of New Zealand along 170°W.

Table 3 - Schedule for the US/JGOFS Arabian Sea Study

Date	Chief Scientist	Objective of Expedition
1994		
9/18-10/7	L. Codispoti	Intercalibration cruise; Singapore to Muscat
10/11-10/24	C. Eriksen	Bottom survey and mooring deployment
10/28-11/21	S. Honjo	Bottom survey, sediment trap deployment, coring
11/28-12/19	D. Young	NRL/Seasoar
1995		
1/8-2/5	M. Roman	Process study #1 (winter monsoon)
2/9-3/3	K. Brink	NRL/Seasoar
3/7-4/4	J. Marra	Process study #2 (inter-monsoon)
4/9-4/22	R. Weller	Service moorings
4/26-5/15	J. Dymond	Process study #3, coring, sediment traps
6/21-7/13	K. Brink	NRL/Seasoar (summer monsoon)
7/17-8/15	R. Barber	Process study #4 (summer monsoon)
8/18-9/15	S. Smith	Process study #5 (summer monsoon)
9/18-10/11	R. Arnone	NRL/Seasoar
10/14-10/25	R. Rudnick	Mooring recovery
10/29-11/26	W. Balch	Process study #6 (bio-optics)
11/30-12/29	W. Gardner	Process study #7 (bio-optics)
1996		
1/1-1/12	W. Prell	Recovery of Sediment traps

3. THE NOAA OCEAN CO_2 PROGRAMME

The NOAA CO_2 groups in the Pacific (PMEL) and Atlantic (AOML) laboratories investigated in 1992 the equatorial Pacific areas in close association with the US/JGOFS Equatorial Pacific Programme. In addition, they are continuing long N-S section studies along 5 sections in the Pacific (50°N-60°S), one section in the Atlantic (65°N-65°S), and one section in the Indian Ocean. Underway measurement systems for surface ocean pCO_2 are installed on the NOAA Ships BALDRIDGE and DISCOVERER on a permanent basis yielding spring and fall coverage of Caribbean and equatorial Pacific areas. The recent and future activities are listed in Table 4 and Table 5 respectively.

Table 4 - 1990-1994 Field activities by the US/NOAA CO_2 researchers

Dates	Expeditions	Locations
		ATLANTIC
7/1991	S. Atlantic-91 Leg 1	25/32°W from 5°N to 42°S along WOCE A-16
8/1991	S. Atlantic-91 Leg 2	Montevideo to 4°S, 2°W
7/1993	N. Atlantic-93 Leg 1	25/28°W from 5°S to 14°N along WOCE A-16
8/1993	N. Atlantic-93 Leg 2a	20/28°W from 14°N to 32°N along WOCE A-16
8/1993	N. Atlantic-93 Leg 2b	20°W from 32°N to 64°N along WOCE A-16
		EQUATORIAL PACIFIC
2/1992	Eq. Pac. Spring Leg 1	From 10°N to 10°S along 110°W and 125°W
3/1992	Eq. Pac. Spring Leg 2	From 10°N to 10°S along 170°W
4/1992	Eq. Pac. Spring Leg 3	From 10°N to 10°S along 140°W
9/1992	Eq. Pac. Fall Leg 1	From 10°N to 10°S along 140°W and 125°W
10/1992	Eq. Pac. Fall Leg 2	From 10°N to 10°S along 140°W
11/1992	Eq. Pac. Fall Leg 3	From 10°N to 10°S along 95°W and coastal sections at 5°S and 12°S
		PACIFIC
2/1990	CGC-90	15°S to 60°S along 170°W (WOCE P-16S)
2/1991	CGC-91	20°N to 58°N along 150°W (WOCE P-16N); and 20°N to 50°N along 135°W
2-3/1994	CGC-94	67°S to 22°N along 115/110°W (WOCE P-18)

Table 5 - Future expedition schedule for the NOAA Ocean-Atmosphere Carbon Exchange Study

Dates	Expeditions	Locations
4/1995	IO-95	50°E to 75°E along 10°N (WOCE I-1)
8/1995	IO-95	40°S to 7°N along 70°E (WOCE I-8)
2/1996	CGC-96	67°S to 20°S along 170°W (WOCE P-14S)

82. Second Meeting of the UNEP-IOC-ASPEI Global Task Team on the Implications of Climate Change on Coral Reefs
83. Seventh Session of the JSC Ocean Observing System Development Panel
84. Fourth Session of the IODE Group of Experts on Marine Information Management
85. Sixth Session of the IOC Editorial Board for the International Bathymetric Chart of the Mediterranean and its Geological/Geophysical Series
86. Fourth Session of the Joint IOC-JGOFS Panel on Carbon Dioxide
87. First Session of the IOC Editorial Board for the International Bathymetric Chart of the Western Pacific
88. Eighth Session of the JSC Ocean Observing System Development Panel
89. Ninth Session of the JSC Ocean Observing System Development Panel
90. Sixth Session of the IODE Group of Experts on Technical Aspects of Data Exchange
91. First Session of the IOC-FAO Group of Experts on OSLR for the IOCINCWIO Region
92. Fifth Session of the Joint IOC-JGOFS CO_2 Advisory Panel Meeting