WHP Cruise Summary Information
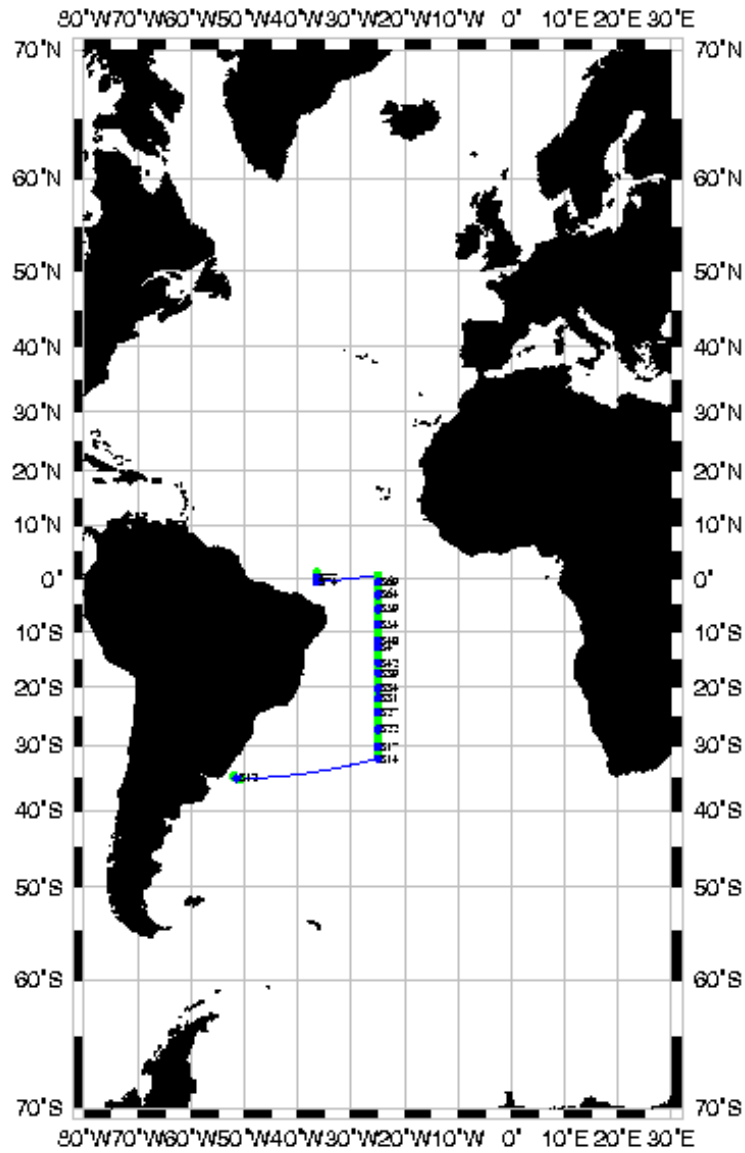
WOCE section designation	A16C
Expedition designation (EXPOCODE)	318HYDROS4
Chief Scientist(s) and their affiliation	Lynne Talley, SIO
Dates	1989.03.13 – 1989.04.19
Ship	MELVILLE
Ports of call	Montevideo, Uruguay to Bridgetown, Barbados
Number of stations	71

Geographic boundaries of the stations

$$0°00.10''N$$
$$52°00.90''W \qquad 24°57.20''W$$
$$35°13.30''S$$

Floats and drifters deployed	none
Moorings deployed or recovered	none
Contributing Authors	none listed

WHP Cruise and Data Information

Instructions: Click on items below to locate primary reference(s) or use navigation tools above.

Cruise Summary Information	Hydrographic Measurements
Description of scientific program	CTD - general
	CTD - pressure
Geographic boundaries of the survey	CTD - temperature
Cruise track (figure)	
Description of stations	
Description of parameters sampled	
	Salinity
	Oxygen
	Nutrients
	CFCs
Principal Investigators for all measurements	Helium
Cruise Participants	Tritium
Underway Data Information	**Acknowledgments**
	References
XBT and/or XCTD	
	Data Status Notes

Station locations for a16c

(Produced from .SUM files by WHPO)

WHP Ref. No.:   A16C
Last Updated: June 16, 1992

Cruise Dates: March 13 - April 19, 1989

Expedition: 318MHYDROS/4

Chief Scientist: Lynne Talley, SIO

Co-Chief Scientists: Mizuki Tsuchiya, SIO and James Orr, Princeton

Ship: R/V Melville

Ports of Call: Montevideo, Uruguay to Bridgetown, Barbados

1. SUMMARY OF WORK

On March 13, 1989 the R/V Melville, under the command of Captain Robert Haines, left Montevideo, Uruguay, to undertake hydrographic work first in the territorial waters of Uruguay and then along longitude 25°W from 32°S to 0°40'N, with a final short section across the equator at 36°30'W. The ship arrived in Bridgetown, Barbados on April 19, 1989, having completed the entire program with almost no difficulties. Seventy-one CTD/rosette stations were occupied; at 7 sites, large-volume Gerard samples were also collected. The first station number was 309, reflecting the integration of this cruise leg with the South Atlantic Ventilation Experiment (SAVE); Hydros 4 was the sixth and final leg of SAVE and was the fourth and final leg of the 25°W section of McCartney, Talley and Tsuchiya.

Rosette and Gerard station positions are listed in the .SUM file. For the most part, stations were spaced every 35 nautical miles (nm), with the exception of closer station spacing at the western boundary and 20nm spacing across the equator. Table 1 lists all properties which were determined from discrete samples collected at each station.

Table 1: Parameters measured on Hydros leg 4 (A16C)

Parameter	Principal Investigator	Institution
CTD/O_2 and Salinity Oxygen and Nutrients	J. Swift	SIO
CFCs	R. Weiss and W. Smethie	SIO and LDGO
Helium/tritium	W. Jenkins	WHOI
Kr-85 (LVS) or Ar-39 C-14 (LVS) Ra-228 (surface)	R. Key	Princeton
Ra-226 and Ra-228	J. Orr	Princeton
CO_2	T. Takahashi	LDGO
Air chemistry XBTs	R. Weiss	SIO

In addition to standard and large-volume hydrographic stations, T-7 XBT's were dropped at 20nm intervals along the cruise track between stations 313 and 314; surface samples were collected at most locations. Other than along this portion of the cruise track, 1 XBT was dropped each day for regular reporting, as described below. XBT and underway sampling stations are listed in Table 2.

The scientists in charge of CTD/rosette sampling were L. Talley and M. Tsuchiya; J. Orr was responsible for the large volume component.

A. CTD/Rosette Sampling

The CTD work and basic water sampling were carried out by Scripps Institution of Oceanography's Shipboard Technical Support/Oceanographic Data Facility (STS/ODF) with help from other members of the science party. D. Muus and J. Boaz were team leaders for the two twelve-hour watches. Rosette handling was optimal with four people on deck and one at the CTD console. Rosette water sampling team sizes varied depending on the number of properties being samples; the minimum size was 2 (oxygen, salinity and nutrients) and the maximum size was 6 (adding CFC's, helium, tritium, and CO_2).

Sampling at each station included a CTD/O_2 cast with a rosette carrying 36 ten- liter bottles. A single Neil Brown Mark-3 CTD was used throughout the cruise. Also mounted on the rosette frame and connected to the CTD were a transmissometer and a Benthos altimeter. A Benthos pinger with a self-contained battery pack was mounted separately on the rosette frame; its signal was displayed on the precision depth recorder (PDR) in the ship's laboratory. The rosette/CTD was suspended from a three- conductor wire which provided power to the CTD and relayed the CTD signal to the laboratory.

Each CTD cast extended to within 10m of the bottom unless the bottom returns from both the pinger and the altimeter were extremely poor. All 36 bottles were used on stations exceeding 3500m depth. Water samples were collected from the ten-liter bottles for salinity, oxygen, nutrients (silicate, phosphate, nitrate and nitrite), chlorofluorocarbons (CFC-11 and CFC-12), total and partial CO_2, helium-3, and tritium. All but the helium and tritium analyses were done at sea.

CTD data was relayed at 25 Hz, acquired with an ODF deck unit, and partially processed in real time on ODF's Integrated Solutions, Inc. (ISI) computers. Analog data was recorded simultaneously on VCR tapes as a backup. Real-time processing included 0.5 second block-averaging with a filter to remove bad samples; preliminary corrections were applied in real time to the data which were then continuously updated on up to 4 plots displayed on the computer monitor. Immediately after each station, the data were pressure-sequenced and desired plots were produced. During the course of the cruise, M. Johnson of ODF continued the calibration procedures using discrete salinity and oxygen samples collected from the rosette. The CTD

temperature calibration was monitored with one rack of reversing thermometers mounted on the second bottle from the bottom; at station 367 a second rack near the bottom was added in order to monitor a drift in temperature difference between the thermometers and the CTD.

Salinity samples were analyzed on two Guildline Autosals by F. Mansir and C. Hallman; oxygen samples were titrated by D. Muus, A. Hester, and M. Tsuchiya; nutrient analyses on a modified Technicon autoanalyzer were performed by D. Masten. L. Cartwright reread all of the nutrient charts as part of the usual ODF quality control. D. Muus processed the discrete salinity, oxygen, and nutrient measurements. During the cruise, summaries and plots of all data were available for quality control and interpretation within a day of collection. D. Muus and M. Tsuchiya carefully checked all of the data as it became available. Vertical sections of all parameters were available throughout the cruise. All ODF data were available on the ISI computers for further dynamic computations and mapping throughout the cruise.

The total station time (actual CTD time plus extra time when the Melville was stopped on station during which the CTD was not in the water) on each station was commonly 2 to 4 hours depending on the water depth. The extra time was generally 0.3 to 0.4 hours per station, even in excellent weather which we enjoyed throughout the cruise, because of the relative difficulty of handling the large double rosette package with an 800 lb. weight.

CFC samples were collected at a subset of the stations and were analyzed at sea on two separate systems, for Ray Weiss of SIO and Bill Smethie of Lamont-Doherty Geological Observatory (LDGO). P. Salameh and M. Trunnell operated the SIO system and J. Raznewski the LDGO system. After some initial cross-checking of methods on the two systems, results produced by the two systems on duplicate samples were in good agreement. Plots of all data were available at sea; vertical sections were produced at the conclusion of the cruise using an interface to the ODF system.

Throughout the cruise, air and surface water samples were analyzed every half hour for CH_4, N_2O, and CO_2 by P. Salameh for Ray Weiss.

Partial and total CO_2 measurements were made at a subset of the stations for Taro Takahashi (LDGO) by M. Noonan and K. Bosley. Station data plotting was available on the Melville's VAX 730; vertical sections were plotted on the ODF system. At approximately every fourth station, duplicate samples at a pair of surface bottles (4 m) were collected for comparison of the at-sea LDGO measurements with later analysis by C. Keeling at SIO. Four standards prepared in Keeling's laboratory were run during the cruise. At two stations, 15 samples were collected and analyzed for alkalinity. At three stations, air samples were collected for later pCO_2 analysis at LDGO.

Samples for later analysis of helium-3 and low-level tritium were collected at approximately every fourth station by S. Doney for the Jenkins group at Woods Hole Oceanography Institution (WHOI).

Surface samples for radium analysis were collected near the location of every CTD/rosette station and at approximately 2° longitude intervals along the steam from the last station to Barbados by J. Orr.

Vertical sections of all properties, gridded using Roemmich's (1983) method and contoured using NCAR graphics, are included in this report.

B. Gerard Sampling

As with SAVE Legs 1-5, large volume samples were collected by Gerard barrel (250-liter) hydrocasts. These samples were often processed sequentially for Krypton- 85 (or Argon-39), Carbon-14, and Radium-228. However, for many samples, this complete suite of analyses was not performed because of the different region of interest for each species within water column. Also, each species must be processed and the extract sent to its shore-based analytical facility; different samples quotas are mandated by the different facilities.

Ancillary measurements (on small volumes) for each Gerard cast included salinity (both on Gerards and their attached 5-liter Niskins), temperature (from the reversing thermometer on the 5-liter Niskin), total CO_2 (on each Gerard where C-14 was analyzed), and chlorofluorocarbons (from the five-liter Niskin only for all samples of Kr and from the top and bottom samples of the 6 Gerards tripped for one Ar sample). Unfortunately, no Barium samples were collected from the attached five-liter Niskins because analytical supplies were exhausted during the previous SAVE Leg 5.

Typically, two 9-barrel Gerard casts were taken per station and were separated by one rosette cast. Four people were required on deck for the Gerard barrel handling. Upon arrival on station, first in the water was the deep Gerard cast. For the deep cast, any depths specifically targeted for sampling were selected using the CTD/O_2 profile from the immediately preceding station (usually within 35nm). Subsequent to the deep Gerard cast, the rosette was deployed and results from its CTD/O_2 trace were used similarly to target depths for the subsequent shallow Gerard cast. Selection criteria included samples from the surface mixed layer, in and around the thermocline at predetermined sigma-theta surfaces (25.6, 26.2, 26.5, 26.8, 27.1, and 27.4), the salinity minimum associated with the Antarctic Intermediate Water (AAIW), the salinity maximum- oxygen maximum associated with the North Atlantic Deep Water (NADW) (1700-3000m), sigma-2 = 36.85, and sigma-4 = 46.85. Near bottom samples were collected at approximately 20, 150, and 500m above the bottom. Remaining Gerard barrels were used to "fill-in" gaps, leaving spaces no larger than 400m between samples; some stations required up to 500m spacing to adequately cover the water column.

In total, seven large volume stations were taken. The first two stations were taken while steaming off the Uruguayan slope en route to longitude 25°W. At the first, station 310 in 1091m of water, one cast of 9 Gerard barrels adequately covered the water column. The second station, station 313 (3066m), consisted of 3 casts because the more typical 9-barrel surface cast was split into 2 casts of 5 and 4 barrels. This split was initiated to facilitate more processing time for the new Kr-Ar analyst while simultaneously eliminating idle wire time while sitting on this station.

Subsequent large volume sampling occurred only after steaming to 25°W where the ship turned and headed due north. Station 316 (previously referred to as LV1) and station 332 (LV2) were sampled in typical fashion employing shallow and deep casts. Further north along 25°W, station 340 was sampled again with 2 Gerard casts; however, this special station was planned to augment the limited sampling (shallower) feasible during SAVE Leg 2 at the same position; on that leg, only two Gerards were available per cast. Thus station 340, previously referred to as SR1 (SAVE Repeat 1), was sampled with one deep Gerard cast and an additional cast collected near the bottom for Argon-39. Unlike all other stations, station 349 (LV3) necessitated 3 Gerard casts: (1) deep, (2) shallow, and (3) a cast specifically targeted at sampling Argon-39 within the NADW. Finally, station 376 (LV4) was also sampled with the usual 2-cast sampling strategy, however, its original position at the equator along 25°W was shifted to 36°30'W. This shift allowed for sampling of the Antarctic Bottom Water (AABW) by moving from relatively shallow waters overlying the Mid-Atlantic Ridge (between the Romanche and St. Paul Fracture Zones) to the deeper water column above the Ceara Abyssal Plain. The bottom water at 25°W lies at a depth of approximately 3200dbar and 2.5°C, while that at the altered position exhibits the presence of AABW with 0.5°C water at its 4500dbar bottom.

During Hydros 4, 3 samples were collected for Ar-39 (6 Gerards/sample), 32 samples for Kr-85, 108 for C-14, and 194 for Ra-228 (85 of these were taken from surface soaks, i.e., not via Gerard sampling).

C. XBT and Underway Sampling

Except during the initial Uruguayan section, at least one XBT was dropped every afternoon for reporting to the National Oceanic and Atmospheric Administration (NOAA). During the transit from station 313 to 314, an XBT was dropped every 2 hours, for a total of 78 stations at approximately 20nm spacing. In all cases, T-7 probes were used, extending to a nominal depth of 760m. Data were acquired by an MK-9 system on the Melville's VAX 730 computer. Plots, isotherm depths, and inflection points were available immediately after each drop. Inflection point data were relayed from the VAX 730 to NOAA each day. M. Moore of STS also produced a separate file of isotherm depths for the closely spaced section; these were transferred to ODF's system where vertical sections were produced by M. Johnson.

At XBT stations 33 to 74, surface samples were drawn and analyzed for salinity, total CO_2 and partial CO_2.

D. Bottom Depth

An Edo Western precision depth recorder (PDR) was operated continuously during the cruise, except in Brazilian territorial waters surrounding St. Peter and Paul Rocks. The PDR operation was overseen by J. Boaz. An underway watch was maintained to log data every 5 minutes; data were entered on the VAX 730 and merged with navigation for later transfer to the Geological Data Center at SIO. M. Moore also produced Carter-corrected depths for use in plotting the vertical sections. The PDR functioned well in shallow depths and regions of sedimentation. However, along 25°W, the bottom topography was highly irregular and probably rocky; the trace was generally very difficult to follow, despite repeated maintenance.

2. PRELIMINARY RESULTS

During the cruise, vertical sections, vertical profiles, printed output and all files on the ODF computers permitted a preliminary look at the data and its implications. In addition, dynamic heights and geostrophic velocities were computed; isopycnal maps of various properties were constructed using all of the SAVE data and several other cruises which had been included in the computer data files. Because it is impossible in this space to describe all of the data or to anticipate all of the uses to which it will be put, only a few selected items are discussed, highlighting what we think are some major new features exposed by the Hydro 4 transect of the Brazil Basin. Isopycnal maps of salinity (at 27.1 sigma-theta) and oxygen (at 37.02 sigma-theta) constructed from the SAVE, Hydros, AJAX, and 11°S stations illustrate some of these points.

A. Brazil Current (Hydros 4 stations 309-313 and Hydros 3 stations 305-308).

The surface expression of the Brazil Current (upper 1000dbar) is confined to stations 309 to 312, that is, within 60km of the 200m isobath. (The strong southward current in this region resulted in an arced station "line"). In the upper 1000m immediately offshore of the Brazil Current was a cold/fresh "eddy"; offshore of the cold feature is another warm/saline feature. Thus the circulation in the upper 1000m reflects the meandering and intermingling of the Brazil and Malvinas Currents.

The low salinity AAIW, at about 800dbar, is cleary split by the strong offshore northward flow: since the AAIW in both the Brazil Current and the offshore cold eddy is much saltier than the AAIW at station 305 and east, it appears that the AAIW in the cold eddy originated in the Brazil Current rather than farther to the south.

Between 1000 and 2000m lies the Upper Circumpolar Water, evidenced by a strong oxygen minimum and $NO_3/PO_4/SiO_3$ maxima. It is best "developed", with greatest extrema, offshore. It is separated vertically from the Lower Circumpolar Water (LCW) by the unmistakable NADW. The LCW, centered at 3520dbar, is also an oxygen minimum and is also best developed offshore.

The NADW, between 2000 and 3000dbar, is an obvious salinity and oxygen maximum. The extrema are highest right at the continental rise, indicating southward flow there.

Just above the bottom, where potential temperature is negative, is a slight but significant salinity minimum, which is also an oxygen maximum. Displaced slightly inshore (at stations 306-308) is a high silicate and nitrate feature, right at the bottom. Its source (direction of flow) is not clear at present, although it is of Antarctic origin.

Geostrophic velocities were computed for the section. An initial reference level at the bottom was used. The initial velocities were compared with the water mass features from which the direction of flow could be deducted. With a reference level at the bottom (deepest common level for a station pair), the velocity profiles matched the deduced water mass flow directions quite nicely. The only questionable flow feature is the direction of the bottom water: placement of a level of no motion at the 0˚C isotherm was also tried; this produced weak northward bottom flow with almost no change in velocities through the rest of the column and little change in transport.

Preliminary isopycnal maps, constructed from all SAVE data, at 27.1 sigma-theta (AAIW), 36.95 sigma-2 (Middle NADW), 37.02 sigma-2 (O2 minimum), 45.88 sigma-4 (Lower NADW), 46 0 sigma-4 (transition), 46.02 sigma-4 (AABW), and 46.08 sigma-4 (Argentine Basin bottom), confirm that the flow directions acquired from a bottom reference level of no motion are qualitatively correct. The map at 46.08 sigma-4 shows no convincing direction of flow; hence the statement in the previous paragraph that the flow direction in this layer is as yet unknown.

Transports were calculated across the short section. Maximum northward transport was 23Sverdrups between stations 313 and 308; maximum southward transport was 37Sverdrups between stations 307 and 306. Integrated from the coast to offshore, the maximum southward transport was 45Sverdrups. Since it is difficult to determine exactly what should constitute the Brazil Current, two definitions are used:

(1)   between stations 309 and 312, covering the most intense coastal southward flow, yielding a total of 11Sverdrups to the bottom, and

(2)   maximum southward transport integrated offshore, yielding 45Sverdrups relative to the bottom or 42Sverdrups relative to the 0˚C isotherm. The maximum southward-integrated transport occurs at station 306. This definition of the Brazil Current therefore includes the southward-flowing NADW and the strong southward surface flow east of the cold intrusion. The northward flow between stations 312 and 308 is included in this total since it is presumed that in this extremely variable region, a large portion of the northward flow is merely returned to the south.

B. Equatorial Region

Of primary consideration here is the section at 25˚W. Very obvious in the water mass structure in the equatorial region are: the thermostat of the 13˚C water, which extends to 5˚S, and 8.5˚C "water mass" centered at the equator, the AAIW, the Upper, Middle and Lower NADW, an oxygen minimum separating the MNADW and LNADW, and the AABW.

The 13˚ water is remarkably well defined on CTD casts, with very abrupt transitions above and below the nearly uniform layer. The "8.5˚ water" is also fairly well defined and centered at the equator. Both of these water masses may be more a consequence of the local dynamics rather than an indication of a particular formation process. On the other hand, double diffusion may be of some importance in this region in the thermocline, as evidenced by frequent observations of stair- steps at the tropical stations.

An obvious natural feature which affects the equatorial flow at 25˚W is the mid-Atlantic Ridge, which rises from the abyssal plain (about 4500m deep) to 3200m at the equator. The rise occurs at about 1˚30'S, well within the range of equatorial flow. Since the ridge continues irregularly to the north at this longitude, equatorial flow is forced around the ridge to the south. The most dramatic effect in the vertical sections is the displacement of the high-oxygen core of the Lower North Atlantic Deep Water (LNADW) to the south where it hugs the ridge. It is most strongly developed between 1.7˚S and 4˚S. The cores of low nutrients associated with the high-oxygen core also show southward displacements from the equator. The effect of the bottom topography also extends to AAIW at much shallower depths, well above the ridge depth. The oxygen and nutrient sections show weakly developed cores of high concentration slightly south of the equator. Oxygen and salinity maps at 27.1 sigma-theta show that AAIW flows up the western boundary and spreads eastward at the equator. At 25˚W, the core is displaced to the south by the topography.

The UNADW is marked by a salinity and CFC maximum. The most extreme values of each are clearly located south and north of the equator, as if the eastward equatorial flow splits around the topographic barrier. The August, 1988, section at 25˚W which extended across the equator to 3˚S also showed the cores displaced somewhat to the south, although at that time salinity higher than 34.98psu was found at the equator, with no separate core north of the equator.

The MNADW, marked by an oxygen maximum and nutrient minima at about 2000dbar (saturation maximum at 1800dbar), is clearly displaced south of the equator at 25˚W.

Another effect of the ridge is to produce a well-mixed layer at the bottom centered at the equator. The layer is about 300m thick and is composed of water from shallower depths, being therefore anomalously warm, saline, light, and oxygenated relative to waters to the north and south at the same depth. This mixed layer is most evident in the CTD oxygen profiles.

The oxygen minimum separating the MNADW and LNADW is well developed only south of the equator. Two factors may be relevant, based on isopycnal maps: (1) eastward flow at this level, carrying high O_2 is directly at the equator and continuous with a core farther west, and (2) the water column is well-mixed at the bottom at the equator, as remarked above, specifically in the part of the column usually occupied by the oxygen minimum.

Finally, an equatorial geostrophic calculation has not yet been made, but the vertical sections of potential density suggest that there might be at least five identifiable layers in the equatorial region (within 4° of the equator). Two additional layers are found south of the ridge, within the equatorial zone (the LNADW and the Antarctic Bottom Water, which have strong density signatures).

C. North Atlantic Deep Water (NADW)

The well known split of NADW into Upper (salinity maximum), Middle (upper oxygen maximum), and Lower (lower oxygen maximum) was recognized and named by Wust (1935). This split is well defined on the short 36°30'W-equatorial section and on the 25°W section from the mid-Atlantic ridge (1.7°S) to about 16°S. The oxygen minimum that separates the MNADW and the LNADW is associated with a slight minimum or weak vertical gradient of salinity and with clearly defined maxima of SiO_3, PO_4, and NO_3. Salinity and oxygen decrease nearly monotonically at all depths in the NADW from the equator southward to 16°S. In what is perhaps the most memorable feature of the new 25°W data, a strong NADW core reappears at about 18°S, with highest salinity, oxygen and chlorofluorocarbons in a plug between 18 and 25°S. Sections of nutrients also show a core of low concentration in the NADW in these latitudes. The NADW in this region is not clearly differentiated into its three "parts", although the highest salinity is located slightly above the oxygen maximum. It is hypothesized that this strong core is flowing eastward, with its source at the western boundary. This is totally supported by isopycnal maps at intersecting densities, which show a tongue of high oxygen extending southward, from the North Atlantic, along the western boundary to this latitude and then stretching eastward across the Brazil Basin.

Of the isopycnals considered (listed above), the strongest signature of this boundary current and eastward flow is at 37.02 sigma-2, which is actually the density of the oxygen minimum splitting the MNADW and LNADW. The isopycnal maps show that the low oxygen north of 16°S originates in the southeastern South Atlantic and is brought northward and westward in broad anticyclonic flow; the high oxygen tongue centered at 22°S is the eastward limb of that flow.

A final remarkable feature of the 25°W section is the extremely sharp transition between the LNADW and AABW in the equatorial region. This undoubtedly results from the proximity to the North Atlantic and the nearly unaltered character of the LNADW.

D. Dynamic Heights and Circulation

Dynamic heights were computed at sea from the CTD data; because the quality of the CTD data is extremely high and because the calibration of the particular CTD used was quite stable throughout the cruise, the final, calibrated results will be similar. Dynamic heights and geostrophic velocities were calculated for all stations along 25°W, including those from Hydros 3 (SAVE 5) between 32°S and 54°S.

Dynamic height at all levels in the upper 1000dbar relative to any deeper reference level is maximum at 28°S; this then is the center of the subtropical gyre. As is known and is the case in all other ocean basins, the most dramatic fronts, with largest changes in dynamic height, occurs pole-ward of the subtropical gyre center, and are in the eastward flow. The identifiable thermal fronts on this section Hydros 3 along 25°W are: the subtropical front at 28-30°S, the Brazil Current at 42°S, the Subantarctic Front at 45-47°S, and the Antarctic Polar Front at 49-51°S. Even though the strongest fronts occur in the eastward flow, a regular but gentler undulation surface dynamic heights also occurs north of 28°S. The dominant length scale of undulations/frontal spacing from 54°S to the equator is about 4°of latitude (400km) and appears to be independent of latitude. (A similar phenomenon has been observed on a well-resolved meridional section in the eastern North Pacific.)

Because of the undulation in dynamic topography, geostrophic velocities are noisy, reversing constantly along the section. However, the dynamic topography indicates that the predominant large-scale flow north of 28°S is westward, all the way to the equator.

Further work with the velocities has not yet been completed, as this report is being written at the conclusion of the cruise. Because of the noise in the station-to-station velocities, it has not yet been possible to match them with the large-scale intermediate and deep circulations as deduced from the isopycnal maps; in particular the apparent eastward flow of NADW between 19 and 25°S has not emerged. Further work will be forthcoming and results presented in published form.

3. BOTTLE DATA COLLECTION, ANALYSES, AND PROCESSING

ODF CTD/rosette casts were carried out with a 36-bottle rosette sampler of ODF manufacture using a General Oceanics pylon. An ODF-modified NBIS Mark 3 CTD, a Benthos altimeter and a SeaTech transmissometer provided by Texas A&M University (TAMU) were mounted on the rosette frame. Seawater samples were collected in 10-liter PVC Niskin bottles mounted on the rosette frame. A Benthds pinger with a self-contained battery pack was mounted separately on the rosette frame; its signal was displayed on the precision depth recorder (PDR) in the ship's laboratory. The rosette/CTD was suspended from a three-conductor wire which provided power to the CTD and relayed the CTD signal to the laboratory.

Each CTD cast extended to within 10 meters of the bottom unless the bottom returns from both the pinger and the altimeter were extremely poor. The bottles were numbered 1 through 36. If one of these 36 bottles needed servicing and repairs could not be accomplished by the next cast, the replacement bottle was numbered 71-78. Added CTD levels, no water samples, were assigned bottle numbers 95-99. Subsets of CTD data taken at the time of water sample collection (a 10 second average) were transmitted to the bottle data files immediately after each cast to provide pressure and temperature at the sampling depth, and to facilitate the examination and quality control of the bottle data as the laboratory analyses were completed.

After each rosette cast was brought on board, water samples were drawn the following order: Freon (CFC-11 and CFC-12), Helium-3, Oxygen, Oxygen-18, pCO_2, TCO_2, Tritium, Nutrients (silicate, phosphate, nitrate and nitrite), Salinity and Suspended Particulate Matter. Table 3 is a tabulation of samples collected during all six legs (SAVE Legs 1 through 5 (STS/ODF, 1992) and HYDROS Leg 4 (STS/ODF, 1992)] unless otherwise noted and includes the Principal Investigators and their institutions. Other ancillary program samples were drawn after the core samples. The samples and the Niskin sampler they were drawn from were recorded on the Sample Log sheet. Comments regarding validity of the water sample (valve open, lanyard caught in lid, etc.) were also noted on the Sample Log sheets.

Gerard casts were carried out with approx. 270 liter stainless steel Gerard barrels on which were mounted 2-liter Niskin bottles with reversing thermometers. Samples for Salinity, 14C, 228Ra, 39Ar, and 85K were obtained from the Gerard barrels. The Gerard barrels were numbered 81 through 91 and the piggy-back Niskin were numbered 41 through 70. Surface samples taken from the ship's underway pump line were assigned a bottle number of 98 through 99. Salinity check samples were always drawn from the Niskin bottles for comparison with the Gerard barrel salinities to verify the integrity of the Gerard sample. Occasionally, barium and some of the samples normally taken from the rosette were also drawn from the Gerard-mounted Niskin bottle. These were also recorded on a Sample Log sheet.

The discrete hydrographic data were entered into the shipboard data system and processed as the analyses were completed. The bottle data were brought to a useable, though perhaps not final, state at sea. ODF data checking procedures included verification that the sample was assigned to the correct level. This was accomplished by checking the raw data sheets, which included the raw data value and the water sample bottle, versus the sample log sheets. Any comments regarding the water samples were investigated. The raw data computer files were also checked for entry errors. Investigation of data included comparison of bottle salinity and oxygen with CTD data, and review of data plots of the station profile alone and compared to nearby stations.

If a data value did not either agree satisfactorily with the CTD or with other nearby data, then analyst and sampling notes, plots, and nearby data were reviewed. If any problem was indicated the data value was flagged or deleted. (However, ODF

preserves in its archives all bottle data values).   Appendix B, the Bottle Data Processing Notes, includes comments regarding deletion of samples.

If it was determined that an entire 10 liter water sample was contaminated by leakage or other bottle or rosette malfunction, the level was reported with just the CTD data (pressure, temperature and salinity). This has been done to preserve the profile and accommodate investigators who prefer using bottle data files exclusively.

A. Pressure and Temperatures

All pressures and temperatures for the Niskin bottle data tabulations on the rosette casts were extracted from the processed CTD data, usually those from the corrected 10-second average bottle trip files collected during the up cast (see CTD DATA COLLECTION, ANALYSES, AND PROCESSING).

Gerard pressures and temperatures were calculated from Deep-Sea Reversing Thermometer (DSRT) readings.   Each DSRT rack normally held 2 protected (temperature) thermometers and 1 unprotected (pressure) thermometer. Thermometers were read by two people, each attempting to read a precision equal to one tenth of the thermometer etching interval.   Thus, a thermometer etched at 0.05 degree intervals would be read to the nearest 0.005 degree.   Each temperature value is therefore calculated from the average of four readings.   IT SHOULD BE CLEARLY NOTED THAT THE TEMPERATURES PRODUCED AND PUBLISHED BY ODF IN THIS REPORT ARE BASED ON THE INTERNATIONAL PRACTICAL TEMPERATURE SCALE OF 1968, RATHER THAN THE CURRENTLY USED INTERNATIONAL TEMPERATURE SCALE OF 1990. (The expedition took place before 1 January 1990, the starting date for ITS-90).

B. Salinity

Salinity samples were drawn into ODF citrate salinity bottles which were rinsed three times before filling. Salinity was determined after sample equilibration to laboratory temperature, usually within about 8-36 hours of collection.   Salinity has been calculated according to the equations of the Practical Salinity Scale of 1978 (UNESCO, 1981) from the conductivity ratio determined from bottle samples analyzed (minimum of two recorded analyses per sample bottle after flushing) with a Guildline Autosal Model 8400A salinometer standardized against Wormley P-108 standard seawater, with at least one fresh vial opened per cast, or from the corrected CTD conductivity, temperature, and pressure.

Accuracy estimates of bottle salinities run at sea are usually better than 0.002 psu relative to the specified batch of standard. Although laboratory precision of the Autosal can be as small as 0.0002 psu when running replicate samples under ideal conditions, at sea the expected precision is about 0.001 psu under normal conditions, with a stable lab temperature. Still, because a small droplet of fresh water, or the residue from a small evaporated droplet of seawater, can affect a bottle salinity in the third decimal place, and because the Autosal salinometer is sensitive to

environmental fluctuations, salinities from bottle samples have a lower true precision under field conditions than in the laboratory. ODF typically deleted the Niskin bottle salinity from this report and substituted the corrected CTD salinity whenever there was any question regarding its validity (see BOTTLE DATA PROCESSING NOTES).

C. Oxygen

Samples were collected for dissolved oxygen analyses soon after the rosette sampler was brought on board and after CFC and Helium were drawn. Nominal 100 ml volume iodine flasks were rinsed carefully with minimal agitation, then filled via a drawing tube, and allowed to overflow for at least 2 flask volumes. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice; immediately, and after 20 minutes, to assure thorough dispersion of the $Mn(OH)_2$ precipitate. The samples were analyzed within 4-36 hours. Dissolved oxygen samples were titrated in the volume-calibrated iodine flasks with a 1 ml microburet using the whole-bottle Winkler titration following the technique of Carpenter (1965). Standardizations were performed with 0.01N potassium iodate solutions prepared from pre-weighed potassium iodate crystals. Standards were run at beginning of each session of analyses, which typically included from 1 to 3 stations. Several standards were made up and compared to assure that fine results were reproducible, and to preclude basing the entire cruise on one standard with the possibility of a weighing error. A correction (- 0.014 ml/l) was made for the amount of added with the reagents. Combined reagent/seawater blanks were determined to account for oxidizing, or reducing in the reagents and for a nominal level of natural iodate (Brewer and Wong, 1974) or other oxidizers/reducers in fine seawater.

The quality of the KIO_3 is the ultimate limitation on fine accuracy of this methodology. The assay of the finest quality KIO_3 available to ODF is 100%, $\pm$ 0.05%. The true limit in the quality of the bottle oxygen data probably lies in the practical limitations of the present sampling and analytical methodology, from the time the rosette bottle is closed through the calculation of oxygen concentration from titration data. Overall precision within a group of samples has been determined from replicates on numerous occasions, and for the system as employed on this expedition one may expect ±0.1 to 0.2%. The overall accuracy of the data is estimated to be ±0.5%.

D Nutrients

Nutrients (phosphate, silicate, nitrate and nitrite) analyses, reported in micromoles/liter, were performed on a Technicon AutoAnalyzer. The procedures used are described in Hager et al. (1972) and Atlas et al. (1971). Standardizations were performed with solutions prepared aboard ship from pre-weighed standards; these solutions were used as working standards before and after each cast (approximately 36 samples) to correct for instrumental drift during analyses. Sets of 4-6 different concentrations of shipboard standards were analyzed periodically to determine the linearity of colorimeter response and the resulting correction factors. Phosphate was analyzed using hydrazine reduction of phosphomolybdic acid as described by

Bernhardt & Wilhelms (1967). Silicate was analyzed using stannous chloride reduction of silicomolybdic acid. Nitrite was analyzed using diazotization and coupling to form dye; nitrate was reduced by copperized cadmium and then analyzed as nitrite. These three analyses use the methods of Armstrong et al. (1967).

Sampling for nutrients followed that for the tracer gases, CFC's, He, Tritium, and dissolved oxygen. Samples were drawn into approx. 45 cc high density polyethylene, narrow mouth, screw-capped bottles which were rinsed twice before filling. The samples may have been refrigerated at 2 to 6°C for a maximum of 15 hours.

4 CTD DATA COLLECTION, ANALYSES, AND PROCESSING

Hydros-4 was processed with Year-2 of SAVE (Legs 4 and 5), therefore there may be references made to the SAVE Expedition.

71 CTD casts were completed using a 36-bottle rosette sampling system and STS/ODF CTD #1, a modified NBIS Mark III-B instrument. The CTD data were initially processed into a filtered, half-second average time-series during the data acquisition. The pressure and PRT temperature channels were corrected using laboratory calibrations. The conductivity/salinity channels were calibrated to salinity check samples acquired on each cast. The CTD time-series data were then pressure-sequenced into 2-decibar pressure intervals, and the pressure-series oxygen channel was corrected to match oxygen check samples acquired on each upcast.

A CTD Laboratory Calibrations
A.1 Pressure Transducer Calibration

Each CTD pressure transducer was calibrated in a temperature-controlled bath by comparison with pressures generated by a Ruska Model 2400 piston gage. The mechanical hysteresis loading and unloading curves were measured both pre- and post-cruise at cold temperature (-1 to 0.5°C bath) to a maximum of 8830 psi, and at warm temperature (28-30°C bath) to a maximum of 2030 psi.

B PRT Temperature Calibration

The CTD-1 PRT temperature sensor was calibrated in a temperature-controlled bath by comparison with temperatures calculated from the resistance of a Rosemount Model 162CE standard platinum thermometer, measured by a NBIS model ATB 1250 resistance bridge. The Rosemount standard PRT was checked periodically in water and diphenyl ether triple-point cells. Seven or more calibration temperatures, spaced across the range of 0 to 30°C, were measured both pre- and post-cruise.

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Table 3: SCIENTIFIC PROGRAMS

Participating Institutions	Principal Investigators	Scientific Programs
STS/ODF	Mr. David Wirth	Salinity, Oxygen, Nutrients -Nitrate, Nitrite, Phosphate, Silicate CTD Profiles
LDGO	Dr. Wallace S. Broecker	Carbon-14
MIAMI	Dr. H. Gote Ostlund	
MIAMI	Dr. Zafer Top	
WHOI	Dr. William J. Jenkins	Helium-3, Tritium
PRINCE	Dr. Jorge L. Sarmiento	Radium-228
PRINCE	Dr. Robert M. Key	Radium-226
SIO	Dr. Ray F. Weiss	Freon-11
LDGO	Dr. William M. Smethie, Jr.	Freon-12
LDGO	Dr. William M. Smethie, Jr.	Krypton-85
BERN	Dr. Heinz Loosli	Argon-39
LDGO	Dr. William M. Smethie, Jr.	
BERN	Dr. J.H. Oeschger	
LDGO	Dr. Taro Takahashi	Total CO_2, pCO_2
LDGO	Dr. Arnold Gordon	XBT Profiles
LDGO	Mr. Stanley Jacobs	

ANCILLARY PROGRAMS

TAMU	Dr. Wilford Gardner	Suspended Particulate Matter Transmissometer
SIO	Dr. Charles D. Keeling	Total CO_2
SIO/GDC	Mr. Smart M. Smith	Bathymetry
LDGO	Dr. James K.B. Bishop	Barium
SIO	Dr. Ray E Weiss	Underway pN_2O, pCO_2, pCH_4
------	-------	Underway Surface Measurements

Institution Codes:

BERN: Physics Institute of Bern, Switzerland
LDGO: Lamont-Doherty Geological Observatory of Columbia University
MIAMI: University of Miami
PRINCETON: Princeton University
SIO: Scripps Institution of Oceanography
SIO/GDC: Scripps Institution of Oceanography/Geological Data Center
STS/ODF: Shipboard Technical Support/Oceanographic Data Facility
TAMU: Texas A & M
WHOI: Woods Hole Oceanographic Institution

List of Participants

Ship's Captain
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        Scripps Institution of Oceanography

Chief Scientist
        Lynne D. Talley
        Scripps Institution of Oceanography

Co-chief Scientists
        Mizuki Tsuchiya
        Scripps Institution of Oceanography

        James C. Orr
        Princeton University

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        Mary Carol Johnson
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Matthew T. Trunnell

Woods Hole Oceanographic Institution
Scott C. Doney

Naval Oceanographic and Hydrographic Service, Montevideo - Observer
Lieutenant Ignacio Barreira-Carrau

Volunteer
Larry Cartwright

318MHYDR4
A16c (HYDROS 4, pre-WOCE)
Talley/Tsuchiya

318MSAVE5
A16 (HYDROS3, SAVE5, pre-WOCE)
Smethie/McCartney

32OC202-1
A16 (MCTT - N. Atlantic, pre-WOCE)
McCartney/Talley/Tsuchiya

Data status: public. CTD data do not seem to be available in WHP
format except for 32OC202-1, although they are all available at NODC
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sum: no errors for all three
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hyd: no need to sort since Gerard casts are not included
        no CFC's, tritium or helium included