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THE ACCLAIM PROGRAMME IN THE SOUTH ATLANTIC AND SOUTHERN OCEANS

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Abstract

The ACCLAIM sea level network consists of six coastal tide gauge sites and approximately a dozen bottom pressure stations in the South Atlantic and Southern Oceans. Since 1985, an extensive dataset of regional sea level and bottom pressure measurements has been acquired. This dataset is being employed at POL in a number of scientific analyses and is available to any interested research worker through the World Ocean Circulation Experiment. In this paper, a review is given of the development and status of the ACCLAIM network and the technology installed at each site. Plans are presented for developments over the next 1-2 years.

DESCRIPTION OF ACCLAIM

In April 1983, at the initiative of Dr. David CARTWRIGHT, the Proudman Oceanographic Laboratory (POL, then called the Institute of Oceanographic Sciences, Bidston), installed a bottom mounted pressure tide gauge in shallow water in Clarence Bay, Ascension Island as a contribution to FOCAL (Francais Ocean Climat Atlantique Equatorial) and SEQUAL (Seasonal Equatorial Atlantic Experiment - United States) studies of the tropical Atlantic (CARTWRIGHT et al., 1987). When the gauge was refurbished in 1985, it was to become the first of a network of sea level monitoring sites extending southwards through the South Atlantic and into the Southern Ocean. The three main intended purposes for the network were, and remain:

(1) To provide a set of sea level recorder pairs, spanning the Antarctic Circumpolar Current (ACC) wherever possible, which, together with data from sea level monitoring stations of other countries, will provide a dataset of ACC geostrophic current variability for comparison to results from

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numerical ocean models of the region, such as the Fine Resolution Antarctic Model (FRAM) developed by UK groups (WEBB et al., 1991). The several pairs of gauges will test the zonal coherence of the variability and its relationship to meteorological and oceanographic forcings. This activity is a key component of Core Project 2 of the World Ocean Circulation Experiment (WOCE, 1988a,b).

(2) To provide a dataset of sea level 'ground truth' in the region for comparison to data from the satellite radar altimeters carried on satellites such as ERS-1 (ESA, 1989), and its follow-on ERS-2, and TOPEX/Poseidon (FU and LEFEBVRE, 1991), again primarily for WOCE studies.

(3) To initiate a set of long term sea level measurements at as many sites as possible of the Global Sea Level Observing System (GLOSS) (IOC, 1990; WOODWORTH, 1991a) for application to inter-decadal global climate change studies.

This programme of work was complemented in (1) and (2) by the use of deep sea bottom pressure recorders (BPRs) together with inverted echo sounders (IESs) in order to provide proxy-sea level measurements in the deep ocean or at locations where the installation of conventional coastal gauges is impractical. It was further extended in (2) by the commencement of a programme of research by POL and other UK groups into the use of satellite radar altimetry for oceanographic studies, based initially on data from the US Navy Geosat satellite (DOUGLAS and CHENEY, 1990). The whole project became known as ACCLAIM ('ACC Levels by Altimetry and Island Measurements'), an acronym which omits the important contribution of the BPR/IESs.

Figure 1 provides an overview of sites which contribute, or have contributed, to the ACCLAIM sea level dataset as of January 1992 and illustrates schematically the role of sea level recorder pairs for purpose (1). Sub-surface pressure measurements at coastal sites are made by means of 'ACCLAIM coastal gauges' (see below) at Tristan da Cunha, St.Helena, Port Stanley (Falkland Islands), Signy (South Orkney) and Faraday (Antarctic Peninsula), while Ascension and Rothera (Antarctic Peninsula) will be added in the near future. Meanwhile, monitoring at Ascension has continued with a bottom mounted pressure gauge (see below). In addition, Faraday has a conventional stilling well float gauge maintained for over 30 years by the British Antarctic Survey (BAS) and recently upgraded by BAS and POL. Coastal tide gauges may eventually be installed at South Georgia and in the South Sandwich Islands, both of which are GLOSS sites, should access to those stations become more regular and should new base installations be established. However, at present there are no plans to do so.

Deep BPRs (SPENCER and VASSIE, 1985), similar to those employed for tidal studies at many locations in the Atlantic and elsewhere (CARTWRIGHT et al., 1988) and in the tropical Atlantic for the investigation of equatorial processes (CARTWRIGHT et al., 1987), have been deployed at a number of locations in the South Atlantic. The first set in 1985-86 consisted of three recorders positioned in a triangle around Tristan da Cunha, each approximately 100 nautical miles from the island, for the purpose of comparing 'sea levels' (in effect sea pressures) at the island to those obtained in the nearby deep ocean, as would be observed by a radar altimeter

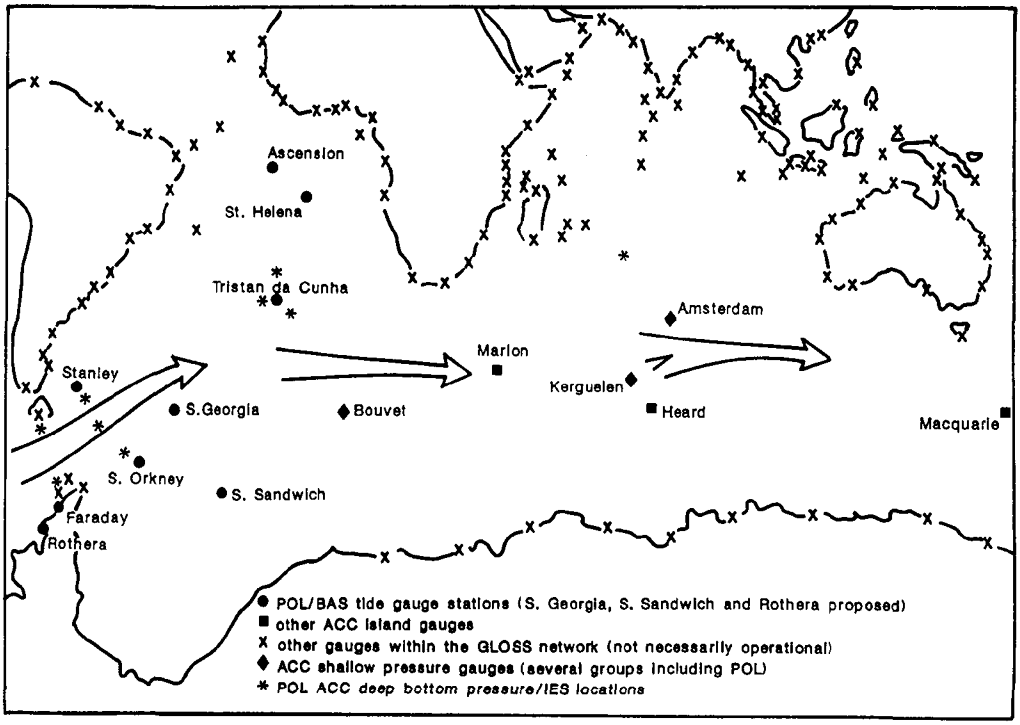

Fig. 1.- Map showing the locations of ACCLAIM sea level and bottom pressure stations and those of collaborating organisations. The use of recorders in pairs to monitor changes in ACC flow is shown schematically.

(Fig. 2). The recorder at station 'B' was not recovered. In the subsequent year 1986-87, the pressure variations at each of the deep sites were found to be highly coherent over daily timescales or longer (Fig. 3), demonstrating the high quality of the pressure data and the large spatial scale of the pressure fluctuations. Consequently, later deep deployments at Tristan were made just at the northerly site of the three (site 'A'). The 1986-87 deployment at 'A' included the first experimental use by POL of an IES system. This was obtained from the Sea Data company and was developed from an earlier University of Rhode Island design (BITTERMAN, 1976). IESs, when used in combination with BPRs, have been found to provide high quality proxy-sea level data (WIMBUSH, 1990). Preliminary results from the Tristan dataset, and comparisons to Geosat information, can be found in WOODWORTH (1991b) and WOODWORTH et al. (1991) and a detailed report is in preparation.

A coarse 'picket fence' of a line of deep BPRs was first attempted between Port Stanley and Signy during 1988-89 (Fig. 1), again with the objective of comparing on and off-shore pressures, but also with the intention of providing information on the variability of the subdivision of the flow between different parts of the ACC in similar fashion to work with BPRs at the Drake Passage a decade ago by WHITWORTH and PETERSON (1985). The 'fence' consisted of three bottom stations in

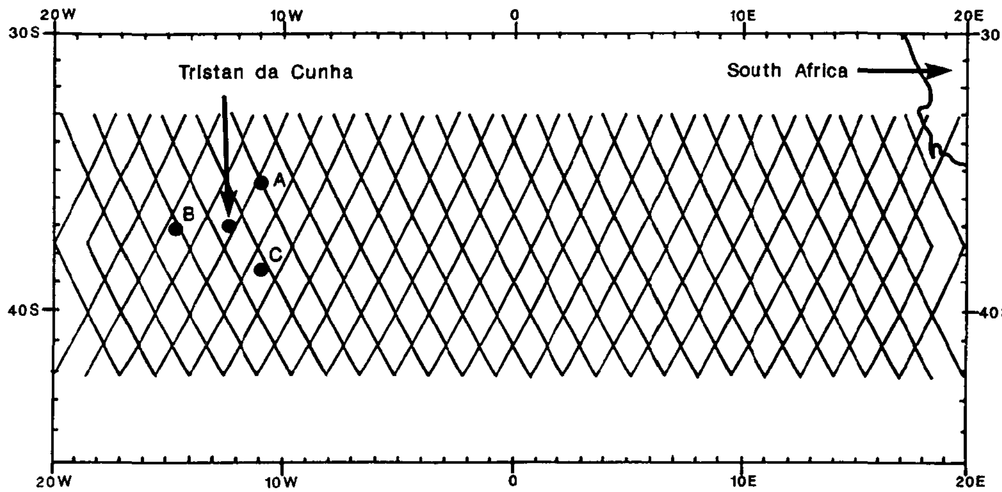

FIG. 2.- Map showing the location of three bottom pressure stations (A, B and C) each approximately 100 nautical miles from the island of Tristan da Cunha and in 4000 m of water, and the ground track of the Exact Repeat Mission of the US Navy Geosat altimeter satellite.

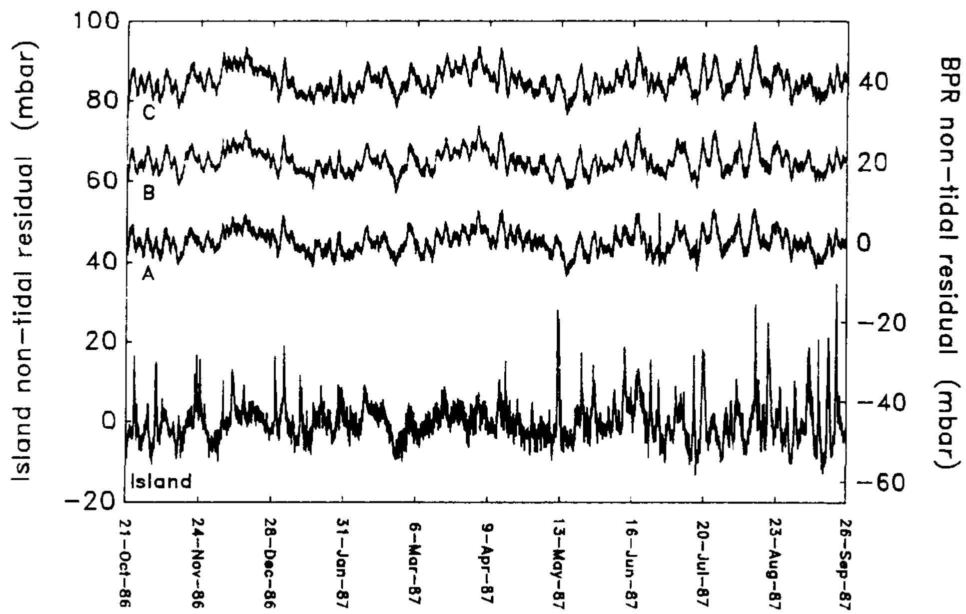

FIG. 3.- BPR records from stations A, B and C around Tristan da Cunha from 1986/87 giving an indication of the spatial coherence of bottom pressure changes in the area. Records have been offset vertically for presentation purposes. The lower graph shows corresponding data from the 'ACCLAIM coastal gauge' on the island, and the sea level spikes which occur from wave set-up during periods when atmospheric frontal systems move through the area. (N.B. One mbar of pressure change is equivalent to one centimetre of water to within approximately hald a percent).

its first year, with one at either end and one in the middle (stations 'FS1', 'FS2' and 'FS3'), and with an IES at 'FS2'. The southern-most BPR near Signy ('FS3') was not recovered. Five were deployed in the second year (1989-90) of which only three at the original three positions were eventually recovered. In the third and fourth years, the 'fence' was reduced to two BPRs, one at each end, with no further losses, in preparation for moving most of the equipment westward to the Drake Passage, as required for WOCE Core Project 2 studies. The first such Drake Passage deployments, consisting of a BPR/IES at 4000m depth at each side of the Passage, were made in December 1991. These IESs are of a different design to that used at Tristan da Cunha (Sea Data units being no longer available) and were acquired through collaboration with Lamont-Doherty Geological Observatory (MACCIO, 1991). The Sea Data IESs contained an automatic processing of the two-way travel time which generated a large number of early returns. Although the seasonal variations in the surface layer could clearly be detected in their data, the Lamont versions, which record the analogue return signal, are considered to be a significant improvement.

Early BPR deployments by POL in the Southern Indian Ocean took place near Amsterdam Island and at point 'ID2' during 1984-85, primarily with the aim of obtaining improved tidal constants. Subsequently, in collaboration with the Physical Oceanography Department of the National Natural History Museum of France, POL operated BPRs near to Amsterdam and Kerguelen Islands for three years from 1986-88 for the study of variations in flow of the ACC between the islands (VASSIE et al., 1992). From the time series of pressure difference, it is possible to determine changes in the mean geostrophic current between the islands at the level of the recorders (Fig. 4). The responsibility for monitoring at these sites has now been taken over by French groups and permanent coastal tide gauges will be installed at the islands during 1992.

Table 1(a) provides a compilation of all ACCLAIM time series from coastal tide gauges from 1985 to the end of 1991, while Table 1(b) lists deployments of bottom pressure instruments during the same period. For information on earlier deployments, see CARTWRIGHT (1987,1988) and references therein. Six additional BPRs deployed near Tristan and near Signy were not recovered and are not included in Table 1(b). Faulty release mechanisms, the difficulties of working in ice-infested areas and bad weather conditions were the causes. Two of the six, both at Tristan, are at known positions on the sea bed and may eventually be recovered. All operational stations as of January 1992 are listed in Table 1(c). All ACCLAIM data may be obtained freely for research purposes from the British Oceanographic Data Centre (BODC) at POL which, as one of the WOCE Sea Level Centres (WSLCs), will compile the global dataset of all required WOCE sea levels (WOCE, 1988a,b).

THE ACCLAIM COASTAL GAUGE

The ACCLAIM coastal gauge is a completely self-contained measurement system which measures the water pressure at a known level on a harbour side (Fig. 5). The pressure sensor is mounted in a Nylon block with a small bore oil filled copper pipe open to the ocean providing the effective pressure point. Barometric

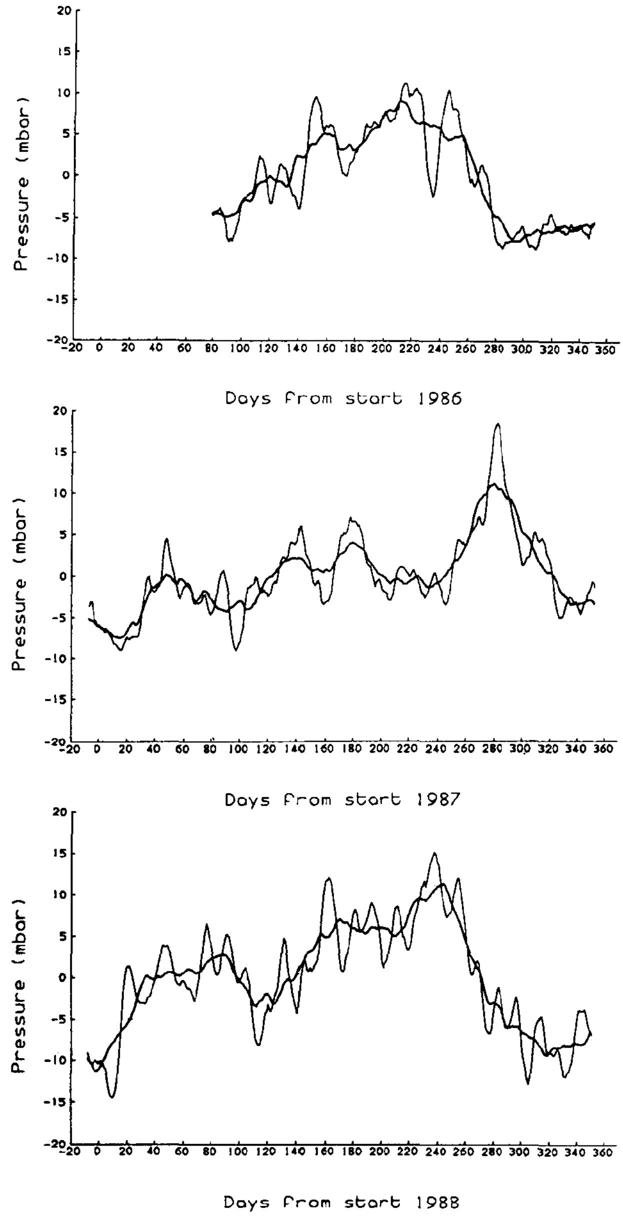

FIG. 4.- Time series of bottom pressure difference between Amsterdam and Kerguelen (mbar) at average depths of 175 and 106 m respectively for three consecutive deployments of one year each in 1986-88. The thin (thick) line is the result of the application of a simple running 9 day (31 day) filter. As the datums of the measurements will be different, the three time series cannot be connected together. At these latitudes, a 5 mbar variability in pressure difference corresponds to a 0.36 cm/sec variability in geostrophic current averaged between the islands.

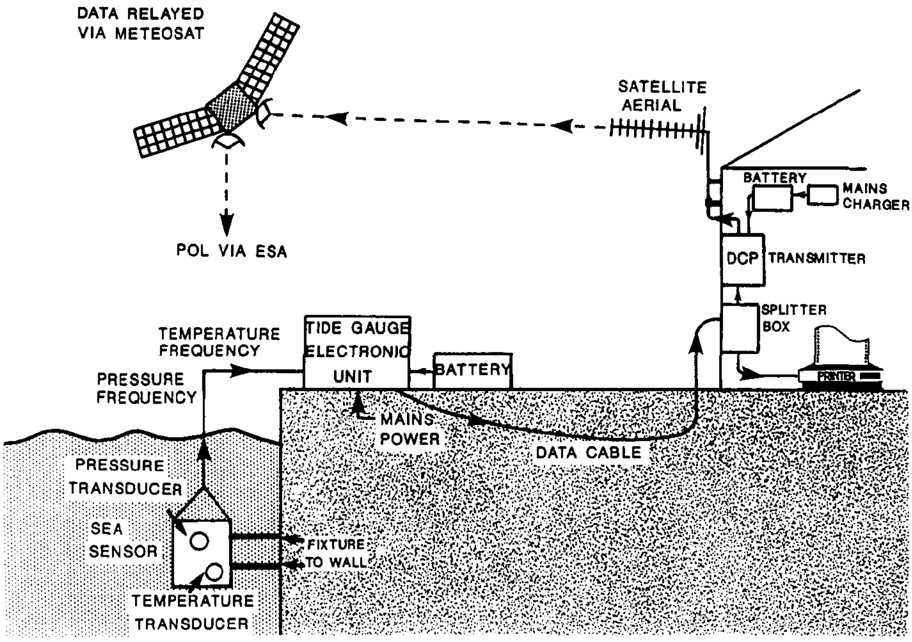

FIG. 5.- Schematic of the ACCLAIM coastal gauge showing the pressure and temperature sensors and tide gauge electronics, including the Data Collection Platform (DCP) which communicates with the Meteosat satellite. Data from the European Space Agency (ESA) are sent to POL via telex.

pressure is also recorded so that it can be subtracted from the sea pressure to yield real sea level, after correction for water density and acceleration due to gravity. Water pressure and temperature are measured in terms of the frequencies of Paroscientific digiquartz and Yellowstone thermistor sensors respectively. These are capable of operating side by side without cross talk. The frequencies are sent by cable to a CMOS 8085 processor in which, together with the signals from the barometer, they are combined with a real time flag and converted into hourly heights by means of previously determined calibrations. The computer passes its information to a Data Collection Platform (DCP) which transmits to the UK twice a day via the Meteosat satellite telemetry system (PALIN and RAE, 1987). The frequencies are also logged onto a backup cassette tape system and, at some sites, the data can also be output onto a local printer as a further backup. The system runs from rechargeable batteries and is capable of operating for several days in the event of a mains power failure. Maintenance is required only once a year, when the backup cassette tapes are changed.

Experience has shown that the use of an absolute pressure sensor for sea pressure, in combination with a separate barometer, is preferable to a differential system in hostile environments (IOC, 1991). In addition, atmosphere pressure is anyway required in most subsequent oceanographic analyses. The sea sensors are securely bolted to the harbour walls and are attached to heavy steel armoured signal cables further protected by galvanised steel pipes. Such arrangements are necessary in the hostile environmental conditions experienced at many sites. This careful design has ensured long life in the sea and some units have been operating continuously for over five years.

THE ASCENSION BOTTOM MOUNTED GAUGE

An offshore tide gauge has been operating in Clarence Bay, Ascension Island since April 1983 (CARTWRIGHT et al., 1987). The first installations were not completely satisfactory as the gauge occasionally moved position during storms. In May 1985, a more permanent setup was constructed which has survived to the present day. In this installation, the gauge instrument is placed inside a vertical plastic tube cast into a large concrete block on the sea bed. The block is located in a sheltered position, surrounded by rocks, at a depth of 14 metres. The tube has a lid to exclude light and so prevent build up of marine growth. Once a year the instrument is recovered and redeployed, usually with a one day gap, with the help of local divers.

The tide gauge itself is an Aanderra water level recorder type WLR5, an ideal high precision recording instrument for determining sub-surface water pressure at shallow depths. The basis of the WLR5 is a Paroscientific digiquartz sensor, as used for the ACCLAIM coastal gauge described above, with a thermistor for temperature measurement also included in the pressure sensor housing. The WLR5 contains quartz clock circuitry which triggers the measuring cycle every hour. Several channels, containing the pressure, temperature and internal checks, are written in sequence onto magnetic tape.

Although the sub-surface record obtained from this gauge has been of great interest, and is one of the longest in the tropical Atlantic, it is impossible to accurately relate its data to a datum on land, as required for the GLOSS programme. Consequently, it is intended to replace the bottom mounted gauge with a shore based instrument during 1992, with the two instruments run in parallel for a period.

FUTURE TECHNICAL DEVELOPMENTS

The ACCLAIM network can be seen to be already well on its way to meeting the objectives of the first two of its three main intended purposes as described above. However, considerable effort is being made, and will be required in future, towards having the coastal tide gauge components of the programme fulfil the third purpose of providing gauges for strategic long term global sea level monitoring. The coastal gauge network is at present principally one of sub-surface pressure measurements, although at most stations barometers have been operated for the subtraction of air pressures to yield sea level (after correction for water density and acceleration due to gravity) with regular tide pole or stilling tube measurements made in order to relate the gauge data to a land datum.

The developments proposed for the near future (next 1-2 years) at most coastal tide gauge sites have three main features:

(1) The use of new equipment alongside the existing digiquartz sub-surface pressure transducers in order to provide a near-automatic conversion of the tide gauge pressure data into sea levels referred to a land datum (i.e. the tide gauge benchmark). A method of performing this task has been described by SMITH et al. (1991).

(2) The consolidation of local benchmark networks at each site to conform to the recommendations of CARTER et al. (1989). This includes the installation of at least six benchmarks in the area of each tide gauge and the regular (at least annual) monitoring of short distance level changes between them.

(3) Precise geodetic connections between the gauges, the 'fundamental reference points' of the International Earth Rotation Service (IERS) global geodetic network (BOUCHER et al., 1988), and geodetic devices nearby the gauges (CARTER et al., 1989). The latter may include absolute gravity meters and DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite), GPS (Global Positioning System) and PRARE (Precise Range and Range Rate Equipment) ground stations. In most cases, the precise connections will be made using the differential GPS technique. POL has collaborated closely with French groups in the formation of the global DORIS doppler tracking network (VALETTE et al., 1992) to be used for the tracking of TOPEX/Poseidon, and has installed DORIS beacons at St.Helena, Tristan da Cunha, Signy and Rothera. It has also been associated with the development of the PRARE system (WILMES and REIGBER, 1987) which will be used to track the ERS-2 satellite.

Upgrades to the BPR equipment will centre on the development of the prototype POL 'Mark 5' recorder, which will be deployed on the sea bed for approximately five years with data sent to the surface periodically via small capsules (Fig. 6). In the first Mark 5, the capsules will be designed to be recovered by a ship after being released by the BPR on reception of an acoustic signal. In later versions, the capsules will release themselves by a timer switch, with data subsequently relayed to a satellite. The Mark 5 recorders will complement the use of the existing Mark 4 BPRs (SPENCER and VASSIE, 1985), which are normally deployed on the sea bed for approximately one year with the whole rig recovered at the end of that period. BPRs, accompanied by IESs whenever possible, will be used primarily in the Scotia Sea, at the 'choke points' of the ACC such as the Drake Passage, and in other areas relevant to the WOCE programme.

SCIENTIFIC APPLICATIONS

A large dataset, such as that of ACCLAIM, can be employed within a wide range of scientific analyses. As stated above, our main intentions have been to use gauges in pairs to learn more about the temporal variability of sea surface gradients across the ACC, and to lay the foundations for long term sea level monitoring for GLOSS. In addition, we hope to learn more about South Atlantic circulation, and to use the gauge data in joint large scale analyses with satellite altimetry (e.g. WUNSCH, 1991). However, many other processes, often specific to each site, can already be

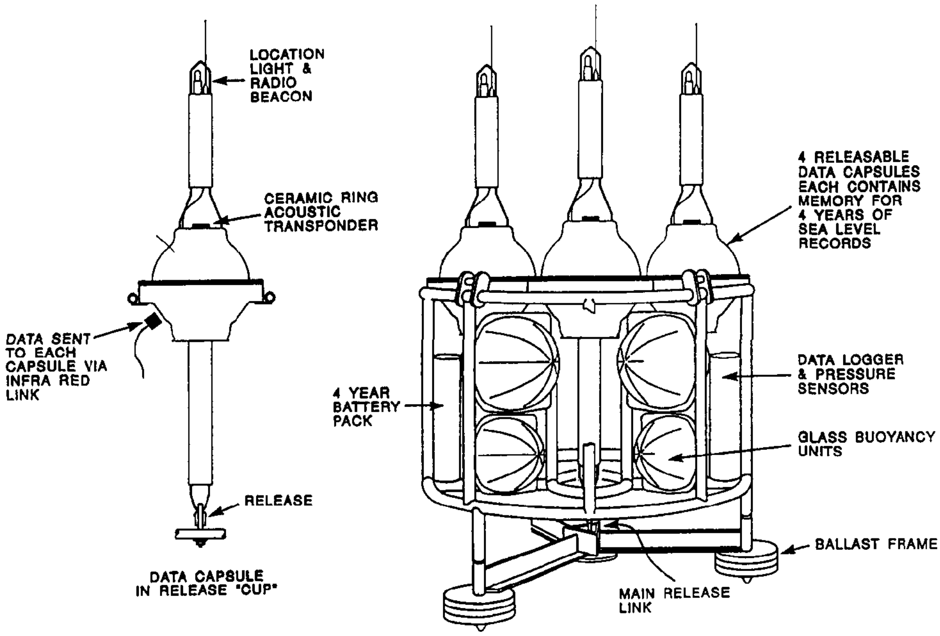

FIG. 6.- Schematic diagram of the Mark 5 long term deep sea pressure recording system with four recoverable data capsules. This initial system will be capable of recording data for five years in the deep ocean with data capsule recovery each year.

observed in the dataset. For example, Kerguelen possesses shelf waves of several centimetres magnitude (SAINT-GUILY and LAMY, 1988), while the gauge in the harbour at Tristan da Cunha often delivers a signal due to wave setup stemming from the frequent occurrence of swell in the area (Fig. 3). It is clear that the extraction of full information from the dataset will occupy researchers for some time.

Acknowledgements

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Table 1(a)

ACCLAIM Coastal Tide Gauge Datasets

Station	Recorder Type	Period of Data	Ancillary Data
Ascension	ABG	APR/83 - MAY/85	T
		MAY/85 - OCT/85	T
		OCT/85 - JUL/86	T
		JUL/86 - MAY/87	T
		MAY/87 - MAY/88	T
		MAY/88 - JAN/89	T
		JAN/89 - JAN/90	T
		JAN/90 - SEP/91	T
	Separate records for each year.		
St. Helena	A	AUG/86 - FEB/88	B
	Gap between Feb/88 and May/88.		
		MAY/88 - DEC/91	B
Tristan da Cunha	B	NOV/84 - OCT/86	
	Bubbler data 1984-86 is of poor quality.		
	A	OCT/86 - NOV/86	BT
	Gap between NOV/88 and FEB/89. No barometric pressure OCT/86 to OCT/87. No barometric pressure APR/88 to FEB/89. No temperature data NOV/88 to FEB/89		
		FEB/89 - DEC/91	BT
Port Stanley	A	NOV/88 - DEC/91	BT
	No barometric pressure MAR/90 to DEC/90.		
Signy	A	NOV/88 - SEP/89	BT
	Gap between OCT/89 and NOV/89.		
		NOV/89 - DEC/91	BT
Faraday	F	JAN/58 - DEC/91	various met. data

Compilation of available ACCLAIM coastal tide gauge data. Recorder type 'A' indicates an 'ACCLAIM coastal tide gauge'; type 'ABG' an 'Ascension bottom gauge'; type 'B' a bubbler gauge; and type 'F' a float gauge. Most records are reduced to integrations of pressure over one hour, centred on the hour. At some sites, several sensors were operated in parallel. Ancillary data type 'T' indicates sea temperature measurements; type 'B' indicates barometric pressure measurements.

Table 1(b)

ACCLAIM BPR/IES Datasets

Name	Lat	Lon	Depth	Period of Data	Ancillary Data
SOUTHERN INDIAN OCEAN					
ID2	28 19 S	66 50 E	3650	AUG/84 - FEB/85	T
Amsterdam	37 54 S	77 35 E	310	JUL/84 - FEB/85	T
	..	..	175	MAR/86 - DEC/86	
	..	..	..	DEC/86 - DEC/87	
	..	..	..	DEC/87 - DEC/88	
	..	..	465	MAR/86 - DEC/87	T
	..	..	..	DEC/87 - DEC/88	T
Kerguelen	48 52 S	70 10 E	106	FEB/86 - DEC/86	T to JUN/86
	..	..	..	DEC/86 - DEC/87	T
	..	..	..	DEC/87 - DEC/88	T
AROUND TRISTAN DA CUNHA					
Tristan A	35 31 S	11 02 W	4100	NOV/85 - SEP/86	T
	..	..	..	OCT/86 - SEP/87	T; IES
	..	..	..	OCT/87 - OCT/88	T
Tristan B	37 00 S	14 29 W	3500	SEP/86 - SEP/87	T
Tristan C	38 31 S	11 09 W	3400	NOV/85 - SEP/86	T
	..	..	3100	OCT/86 - SEP/87	T
FALKLAND-SIGNY DEPLOYMENTS					
FS1	53 33 S	57 01 W	2800	NOV/88 - NOV/89	T
	..	..	..	NOV/89 - NOV/90	T
	..	..	..	NOV/90 - JAN/92	T
FS2	56 42 S	52 32 W	3150	NOV/88 - NOV/89	T, IES
	..	..	2860	NOV/89 - NOV/90	T, IES
FS3	60 03 S	47 05 W	2180	NOV/89 - NOV/90	T
			2000	NOV/90 - JAN/92	T

Compilation of available ACCLAIM BPR records. Locations and depths (metres) are approximate and vary slightly each deployment. Records are based on integrations of pressure over one hour or one quarter-hour. At most locations several pressure sensors were operated in parallel. Ancillary data type 'T' indicates sea temperature measurements; type 'IES' indicates inverted echo sounder measurements. For deployments prior to 1985, see CARTWRIGHT et al. (1987,1988). For deployments since 1991, see text and Table 1(c).

Table 1(c)

Operational ACCLAIM Stations (January 1992)

Station	Gauge Type	Real Time
Ascension	ABG	N
St. Helena	A	Y
Tristan da Cunha	A	Y
Port Stanley	A	Y
Signy	A	Y
Faraday	F,A	Y
N. Drake Passage (56 29 S, 62 59 W, 3900m)	BPR/IES	N
S. Drake Passage (61 28 S, 61 17 W, 4000m)	BPR/IES	N
FS1 (53 31 S, 56 59 W, 2800m)	BPR	N
FS3 (60 03 S, 47 10 W, 2250m)	BPR	N

Operational ACCLAIM stations, either coastal sites or pelagic recorders, as of January 1992 together with gauge types. 'Real time' data transmission capability implies data available within 12 hours.