**Intergovernmental Oceanographic Commission**

Workshop Report No. 69 - Supplement

# IOC-SCAR Workshop on Sea-Level Measurements in Antarctica

Leningrad, USSR, 28-31 May 1990

**Submitted Papers**

**UNESCO**

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| 44 Suppl. | IOC-FAO Workshop on Recruitment in Tropical Coastal Demersal Communities *Submitted Papers*, Ciudad del Carmen, Campeche, Mexico, 21-25 April 1986 | E |
| 45 | IOCARIBE Workshop on Physical Oceanography and Climate Cartagena, Colombia, 19-22 August 1986 | E |
| 46 | Reunión de Trabajo para Desarrollo del Programa «Ciencia Oceanica en Relación a los Recursos No vivos en la Región del Atlantico Sudoccidental, Porto Alegre, Brazil, 7-11 de Abril de 1986 | S |
| 47 | IOC Symposium on Marine Science in the Western Pacific: The Indo-Pacific Convergence Townsville, 1-6 December 1986 | E |
| 48 | IOCARIBE Mini-Symposium for the Regional Development of the IOC-UN (OETB) Programme on "Ocean Science in Relation to Non-Living Resources (OSNLR)" Havana, Cuba, 4-7 December 1986 | E, S |
| 49 | AGU-IOC-WMO-CPPS Chapman Conference: An International Symposium on "El Niño" Guyaquil, Ecuador, 27-31 October 1986 | E |
| 50 | CCAMLR-IOC Scientific Seminar on Antarctic Ocean Variability and its Influence on Marine Living Resources, particularly Krill (organized in collaboration with SCAR and SCOR) Paris, France, 2-6 June 1987 | E |
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| 58 | International Workshop on the Technical Aspects of the Tsunami Warning System. Novosibirsk, USSR, 4-5 August 1989 | E |
| 58 Suppl. | Second International Workshop on the Technical Aspects of Tsunami Warning Systems, Tsunami Analysis, Preparedness, Observation and Instrumentation. *Submitted Papers* Novosibirsk, USSR, 4-5 August 1989 | E |
| 59 | IOC-UNEP Regional Workshop to Review Priorities for Marine Pollution Monitoring Research, Control and Abatement in the Wider Caribbean. San José, Costa Rica, 24-30 August 1989 | E, F, S |
| 60 | IOC Workshop to Define IOCARIBE-TRODERP Proposals. Caracas, Venezuela, 12-16 September 1989 | E |
| 61 | Second IOC Workshop on the Biological Effects of Pollutants, Bermuda, 10 September - 2 October 1988 | E |
| 62 | Second Workshop of Participants in the Joint FAO-IOC-WHO-IAEA-UNEP Project on Monitoring of Pollution in the Marine Environment of the West and Central African Region, Accra, Ghana, 13-17 June 1988 | E |
| 63 | IOC/WESTPAC Workshop on Co-operative Study of the Continental Shelf Circulation in the Western Pacific, Bangkok, Thailand, 31 October - 3 November 1989 | E |

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**Intergovernmental Oceanographic Commission**

Workshop Report No. 69 - Supplement

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## Submitted Papers

SC-92/WS-23

**UNESCO**

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# INTRODUCTION

Sea level measurements are required for a diverse range of scientific and practical applications. In Antarctica measurements present severe technical problems, but there is also a problem of coordination among the wide range of national and international organizations involved.

In order to improve the exchange of information among those interested in sea level measurements in Antarctica, the Global Sea-Level Observing System (GLOSS) of the Intergovernmental Oceanographic Commission, held a Workshop on Sea-Level Measurements in Hostile Conditions at the Proudman Oceanographic Laboratory (UK) in March 1988 (IOC Workshop Report No. 54). A further IOC Workshop on Sea-Level Measurements in Antarctica was held in Leningrad (USSR) in May 1990 (IOC Workshop Report No. 69). This second Workshop was held in collaboration with the IOC Southern Ocean Committee (IOCSOC) whose Chairman, Dr. V. Ivchenko, attended the meeting. The Scientific Committee on Antarctic Research (SCAR) of ICSU was a co-sponsor of the Leningrad Workshop.

In addition, SCAR undertook a survey, amongst its members, of present and past sea-level measurements in Antarctica. A tabulated summary of the survey is included in this volume, together with the other papers which were presented at the Workshop.

In total the papers presented here report on a wide range of on-going national activities. In addition to the formal presentations, the Leningrad meeting stimulated a range of valuable informal discussions and planning among the participants. Some of these plans are already being developed into actions.

Antarctic sea-levels are particularly valuable for studies of the secular trends in global sea-level. They can also contribute to an understanding of the history of glacial loading of Antarctica, which in turn relates to the sensitivity of marginal ice to climate change. Continuing concern about "green house" climate warming and possible future sea-level rises further enhances the importance of these studies.

As the activity and interest in Antarctic sea-level variations increases, the need for good communication and planning within an international context is evident. GLOSS will encourage co-operation as part of its on-going activities.

D.T. Pugh
Chairman, GLOSS Group of Experts

# THE AUSTRALIAN PROGRAMME FOR SEA LEVEL AND ITS LINKS WITH THE SOUTHERN OCEAN

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## Preamble

The strategic location of Australia and the unique marine signals which it experiences has fostered an expanding programme which focuses on regional low frequency sea level. The southern coast presents the greatest east west extent of ice-free coastline world-wide, and the fact that it is adjacent to the circumpolar ocean on a rotating earth is especially relevant.

In 1989, the Flinders Group was formally designated "The National Tidal Facility" (NTF) and also as the operational centre for new initiatives in sea level with clear climate links and with a particular focus upon the enigma of greenhouse rising sea level trends:-

- A Federal program plans to provide a baseline array of some seven or eight stations equipped with high resolution sea level monitors to be deployed around the Australian mainland for the purposes of greenhouse. The NOAA/NOS Global Programme for sea level has contributed two additional stations to this array and it is anticipated that other local and State programmes will add compatible systems. In recognition of the well-known inadequacies of performance of the traditional stilling-well tide gauges and the need to take urgent action within the programme, the decision has been made to take advantage of the NOAA/NOS development of the NGWLMS and, with NOS approval and assistance, to adopt the New Generation equipment for the Australian Program.

- The greenhouse implications are more serious for some countries than for Australia, and at particular risk are the island nations, especially those which comprise low-lying coral atolls. A second Australian initiative then is to establish an array of some eleven stations on behalf of the Forum Island Countries of the South Pacific.

- In a somewhat different category is a Development Aid Programme funded by the Australian Government in which training courses have been run in matters of tides and tidal phenomena for personnel from the ASEAN Countries of S.E. Asia and some 23 tide gauge installations have been deployed through the ASEAN Region. These systems are of somewhat lower resolution than those associated with greenhouse programs.

For this large region, the NTF is charged with collating and maintaining a data bank for sea level and tides together with associated phenomena. Interpretive and research aspects have identified many advantages of the strategic geographical location whereby sea level is seen to be an indicator of inter-ocean mass transport and the consequent links with climate through ocean-atmosphere interactive processes. In this context, as is to be expected, the Southern Ocean is seen to play a major role.

## Research Opportunities

Although the Australian initiatives for the monitoring of sea level arise primarily from a need to address greenhouse sea level trends, the proposed array has a far wider potential.

- Firstly it is the intention that these stations will be arranged to telemeter their observations by satellite or land line direct to the Flinders Tidal Laboratory. The original justification for this was in the interests of quality control and maintenance of continuous quality records. However the same provision presents the facility for the first time to monitor the topography of the ocean, and in particular the coastal ocean, in near real time. The change from a basis of noise-riddled data eighteen months or more old to the prospect now presented, offers an entirely new range of research opportunities.

- Secondly the hope that the simple installation of sea level recorders will identify sea level trend is greatly misplaced. As for most natural parameters the measurement of short period change presents little problem, but as one proceeds towards the measurement of absolute values, the complexities and uncertainties grow rapidly. In order to understand greenhouse trends it is necessary to explore the traditional energy cusp associated with the low frequency end of the spectrum of sea level energy as shown in Figure 1. Proceeding from right to left into this cusp requires the examination of the response of sea level in successive steps into the low frequency band, seeking assurance from physical meaning and/or spatial and temporal coherency. This technique has been a feature pioneered by the Flinders Group and it assumes an intensive program of research into a range of sea level signals so that they may be identified against a background of noise from random radiational sources but also from instrumental imperfections and human interference in the guise of maintenance. If this work is performed with care, not only does one take an excursion through a stimulating range of research prospects, but one ensures, in the only way possible, that greenhouse trends are estimated with certainty.

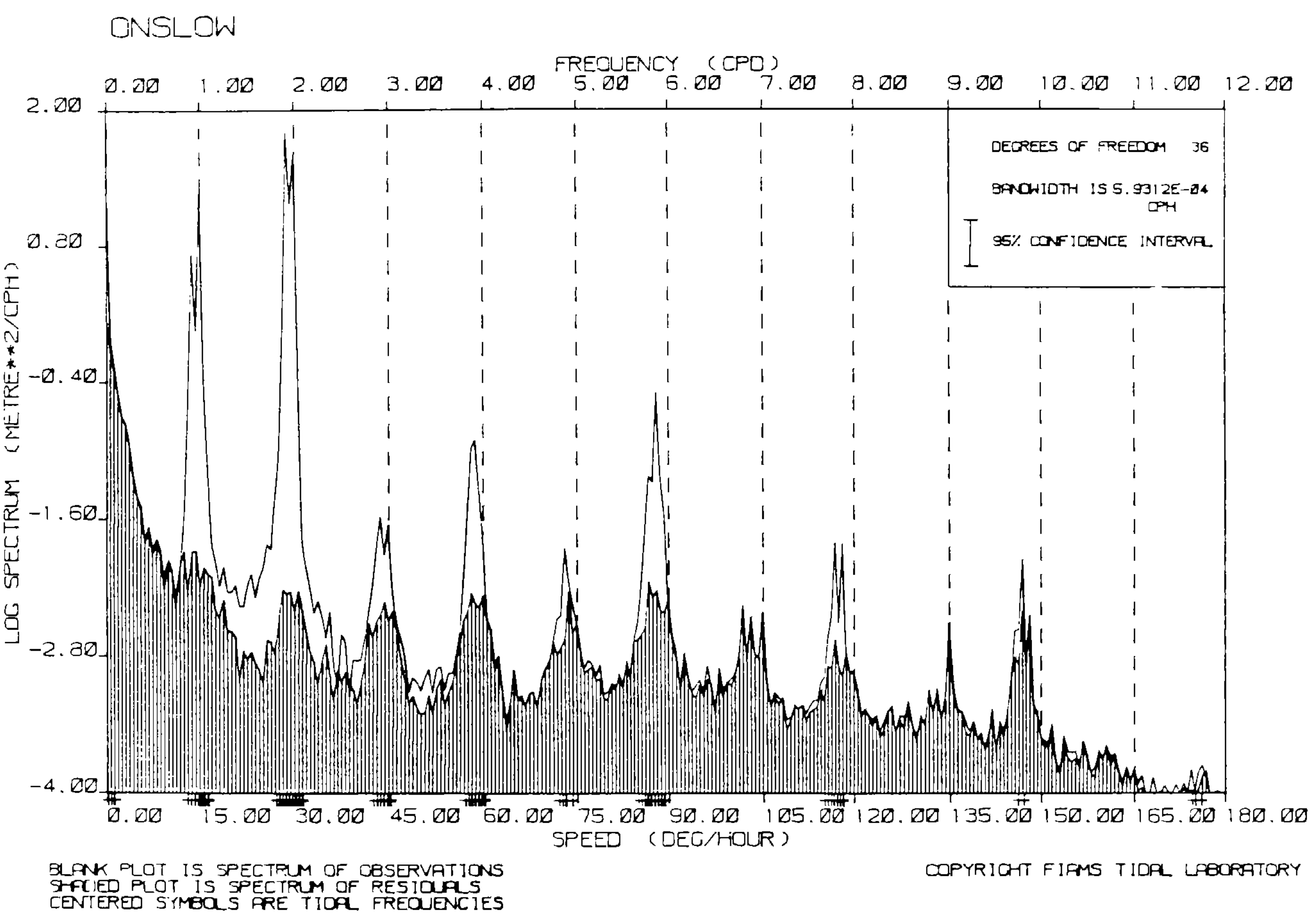


*Figure 1: Taking an annual record of sea level at Onslow a power spectrum analysis is provided before and after the removal of tidal oscillations by high resolution tidal analysis. The diagram is provided so as to show the significant cusp of apparent energy in the record at the low frequency end of the spectrum (to the left of the line which represents one cycle per day).*

By working systematically into the low frequency energy cusp, one progressively acquires an understanding of real signals against a background of noise. In this sense the Seasonal Variations of level have been carefully studied and have been seen to have regional and temporal coherence so that they may be accepted as real. From this source it is possible to examine large scale regional coastal gradients in relation to coastal currents and circulation and already strong links have been established with, for example, the onset of the Leeuwin Current from north to south down the west coast. There is much scope for research into such relationships and their inter-annual variability.

More exciting prospects arise in the treatment of longer period phenomena, say, monthly and annual mean sea levels. The FIAMS Group has seen the potential of sea level signals, in these temporal scales, to monitor large scale inter-ocean water transport with quite obvious links with climate. Figure 2 provides the evidence of such a claim in drawing attention to the clear negative correlation between residual (non-tidal) sea levels obtained for South Australia on the one hand and California on the other. If one links this feature with the FIAMS research philosophy, then quite exciting opportunities arise. Here one has in mind the following:-

* the adjacent circumpolar canal of the Southern Ocean,

* the eastwards circumpolar current driven by a strong westerly wind field,

* the "choke" of the southern tip of South America in a similar longitude to the Antarctic Peninsular which produces slightly higher ocean levels in the Pacific by comparison with the Atlantic,

* a return current through the Indonesian Straits, uniquely crossing the equator, with its ability to transport heat,

* an associated ocean/atmosphere coupling mechanism providing ENSO-type phenomena at intervals of 5 to 8 years.

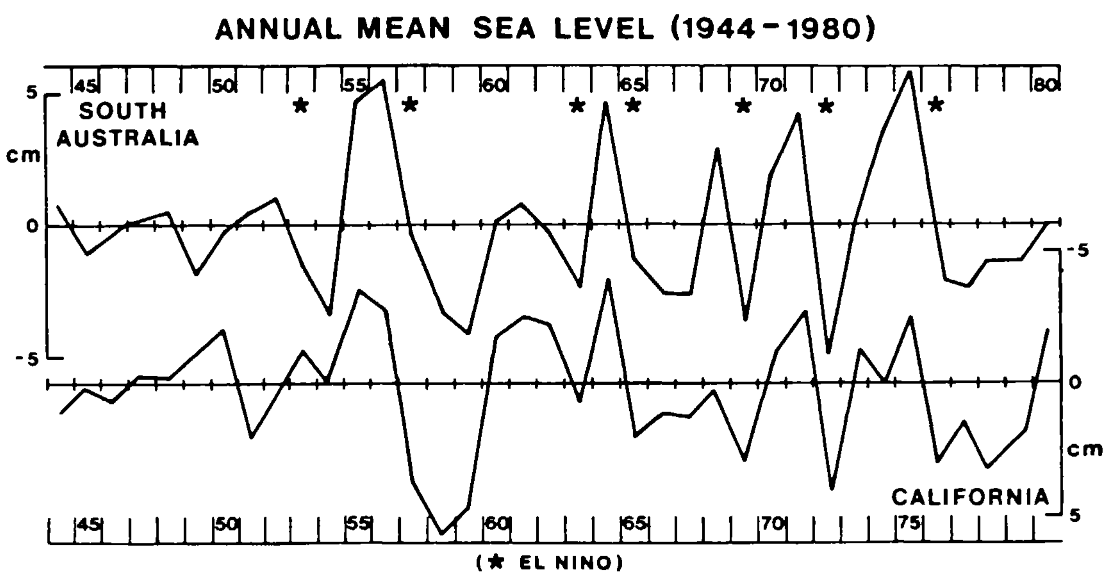


*Figure 2: Comparative interannual anomalies of sea-level over a 37 year period, having removed tidal oscillations. Tide Gauges on the South coast of Australia show annual mean sea-level randomly fluctuating through vertical excursions of ± five centimetres. Simultaneous equivalent data for California has obvious visual negative correlations (see inverted height scale). The evidence is that monitoring sea-level in SA has the potential to estimate mass transport of water on an inter-ocean scale.*

By carefuliy identifying the sea level anomalies associated with ENSO events, Figure 3 clearly demonstrates that the famed El Niño phenomenon in fact represents the <u>recovery</u> year of a two year event which can be identified in its initial stages in the Southern Ocean. The synonimity of the El Niño and Australian drought cycles places further emphasis on the importance of research into such climate links. The sea level signal is a strong indicator of inter-ocean transport. Real time data present the opportunity for a switch to forecasting mode. Preliminary existing work has clearly defined the potential and the new monitoring facilities provide the means to make significant research progress. In view of the potential economic value of such work considerable emphasis is due to analytical modelling of ocean/atmosphere coupling processes in this context and to recognise that this should be seen as a major area of expansion.

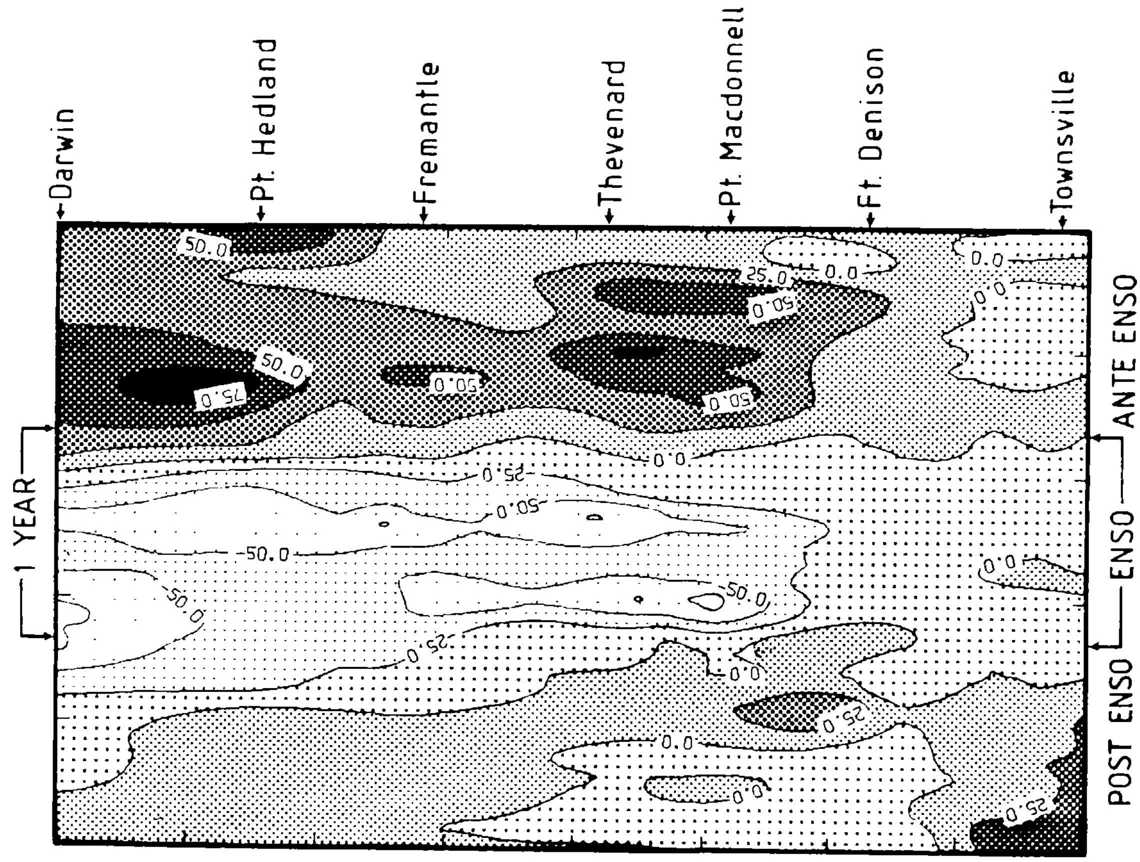


*Figure 3: Contours of sea-level perturbations from the long-term mean using a composite data set having removed tidal oscillations, comprising four ENSO events. From left to right the coverage is anticlockwise around the Australian coast line commencing at Darwin and using material for 24 individual ports extending to Cairns in the right margin. From top to bottom anomalies are shown for Ante-ENSO, ENSO and Post-ENSO years in millimetres. Note that in the Ante-ENSO year sea-level rises especially in SA, while in the ENSO year, sea-level falls. The Post-ENSO year has no significant anomalies.*

## <u>The Greenhouse Signal In Sea Level</u>

Greenhouse trends of course are a high priority target and the potential contribution for Australia is strategic for two reasons:-

i) The Continent represents a relatively stable platform from a tectonic point of view so that there exists a realistic chance to measure a signal which is close to the threshold of what is physically possible.

ii) Since most observing stations of suitable quality are in the Northern Hemisphere, and noting that the signal is regionally variable due to steric effects in the water column and to the isostatic adjustment due to greenhouse variation of ocean load on the earth's crust.

The signal itself is a composite of a wide spectrum of events of varying periods e.g. the incidence of storm surge phenomena, zonal winds, water properties together with the features observed earlier in El Niño/Southern Oscillation (ENSO) scales and in addition the coastally-trapped long waves. An important point to make is that it is necessary to conduct research into this total range and only if this task is conducted efficiently will accurate greenhouse estimates be made.

In the Appendix a brief survey is given of the statistical analysis of trend from selected Australian tide gauges. Relevant comments are:-

* One places little weight on the indication of a single station.

* Rather more weight may be accorded to the mean indication of the Australian array.

* But confidence in estimates of greenhouse trends from the historical record emerges only by accessing a global figure now recognised to be 1.5 ± 0.5 mm per year over the last century.

* Whereas the Global Climate Models suggest that the trend, even in historic times, has been markedly non-linear, the record indicates a contrary linear condition.

* Global Climate Models do not give confidence in their forecasts due to the large range of estimates.

The only responsible course of action is to monitor and interpret sea level behaviour over the next twenty years or so with high resolution and penetrating research into the many elements which contribute to the signal. The resulting estimates will have value as ground truth information, so as to assist the development of the Climate Models, and also in their own right so as to determine the characteristics of the trend for the purposes of extrapolation.

However the task implies a major research program in an attempt to identify the component signals and to assign some physical meaning to the respective mechanisms.

A major excursion into geodetic survey of necessity accompanies this approach to absolute sea level involving VLBI, SLR, & GPS proposals together with a study of the particular problems of datum stability in the coastal zone.

**Operational Support**

Further significance accrues from the proposal to monitor a regional instrumental array in near real time. In this context one should note that Australia has a unique opportunity to take advantage of a quirk of nature whereby non-tidal energy, in the form of coastally-trapped long waves, passes around the continent in an anti-clockwise fashion. Figure 4 provides an illustration of these features, over more than 3000kms of coastline, displaying typical periods of a few days and an amplitude sometimes equal to the tide itself. Given real-time access, the baseline array will have the capability to monitor the progress of these waves several times each day. The opportunity then arises to offer to Australian ports a facility whereby the conventional tidal predictions produced two or more years in advance, will be supplemented by sea level forecasts 12 or 24 hours ahead, with the latter providing estimates of meteorological perturbations of level in addition to the astronomical tide. The advantages which accrue are very significant for the efficiency of port operation. Such a service will optimise the control of draught in strategic and dredged channels and render the costly decisions concerning vessel demurrage much more realistic. Elsewhere such calculations would depend upon hydrodynamic modelling from questionable meteorological forecasts. In Australia a large fraction of the signal can be monitored and tracked, with modelling restricted to a residual correction. To be successful however there is a need for an initial research and development program of major scale, so that a facility which ultimately should be based upon a "user pays" basis is dependent upon an investment in research.

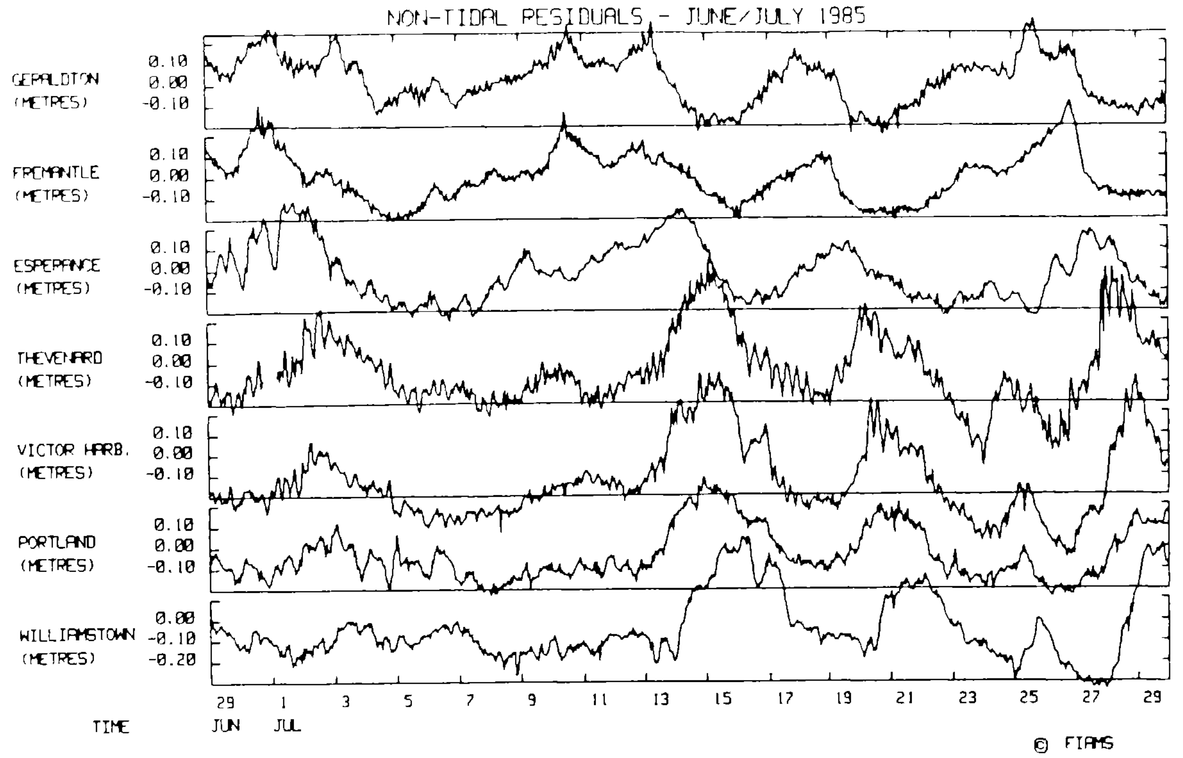


*Figure 4: For 7 ports moving anticlockwise around the Continent from Geraldton in WA to Williamstown in Victoria, the simultaneous non-tidal signal is plotted clearly showing the progression of coastal trapped long waves which are remarkably coherent in time and space.*

## The Southern Ocean

Whereas much international research effort into ENSO phenomena concentrates upon the tropical Pacific, the Flinders Group sees a larger scale mechanism in the form of a major gyre responding to events which began in the Southern Ocean so that variance in the Indonesian Throughflow might occur perhaps in the subsequent year. In this sense this protracted temporal scale is compatible with its major spatial dimensions so contributing a predictive capability.

In this connection it is appropriate to stress the significance of the suggestion that the NTF should conduct a feasibility study for a Sea Level Pilot Project for Southern Ocean Sea Levels under the sponsorship of UNESCO/IOC/IGOSS/GLOSS. In this context the Australian Antarctic Science Advisory Committee (ASAC) gave its strong support to the proposal and believes that "such a Centre would fill an important role in furthering Antarctic research, in Australia, in physical oceanography and allied disciplines". Submissions to access financial support for such a venture are in train.

Meanwhile NTF has attempted, with only moderate success, to maintain bottom-mounted pressure tide gauges on Macquarie and Heard Islands in an attempt to monitor variations of the Coriolis gradient representing acceleration of the circumpolar current on a rotating earth. Currently plans are afoot to upgrade these stations and to add the Antarctic base stations of Mawson, Davies and Casey to the programme. The plan is to use the Aanderaa vented differential pressure transducer system communicating daily via the Argos satellite.

## Associated Theoretical Studies

Although it is generally accepted that the Antarctic Circumpolar Current is primarily driven by the strong westerly wind field responding to the pressure gradients between the subtropical highs and the Antarctic Lows, the mechanism whereby energy is dissipated remains unclear. Recent work at Flinders by Jim Gunson (1988) has examined the atmospheric pressure field initially apparently constrained to a basic zonal wave number 3 by the disposition of continents & oceans and their seasonal temperature differentials. However instabilities in the flow of the geostrophic winds are seen to result in centres of low pressure being driven eastwards, perturbing their speeds and zonal wave numbers, with a predominant zonal wave number of 5 resulting. Using both analytical and numerical models and also recent sea level data from Macquarie Island, Gunson has studied the spatial distribution of sea surface amplitude response and has determined that the sea surface closely follows the variations in atmospheric pressure as an inverse barometer, even suggesting that from satellite altimetry one might proceed to calculate the atmospheric pressure field in a hazardous zone where normal meteorological data is extremely rare. Perhaps an important contribution to WOCE!

In a current follow-up exercise H. Phillips (1990) is attempting to explain the dissipation of wind-induced zonal momentum which might show why observations are an order of magnitude less than computed volume transport. Whereas Gunson has found evidence of topographic influence in the current, which in fact extends throughout the total depth, Phillips is examining the bottom drag with particular reference to the role played by the mid-ocean ridges. Again the intention is to compare the mechanism with the effect of continental land masses, thermodynamic effects, and Antarctic water discharge. Johnson & Bryden, 1989, examined the downward transmission of eatward momentum through interfacial Form Drag and found comfort from comparisons with observations for Drake Passage. Phillips is examining the mechanism in greater detail in an attempt to determine whether the agreement holds elsewhere.

In this and associated contexts a comprehensive series of studies is establishing a range of competence to address the very strategic issues associated with the Southern Ocean.

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**THE NATIONAL TIDAL FACILITY**
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## SECULAR VARIATIONS STUDY

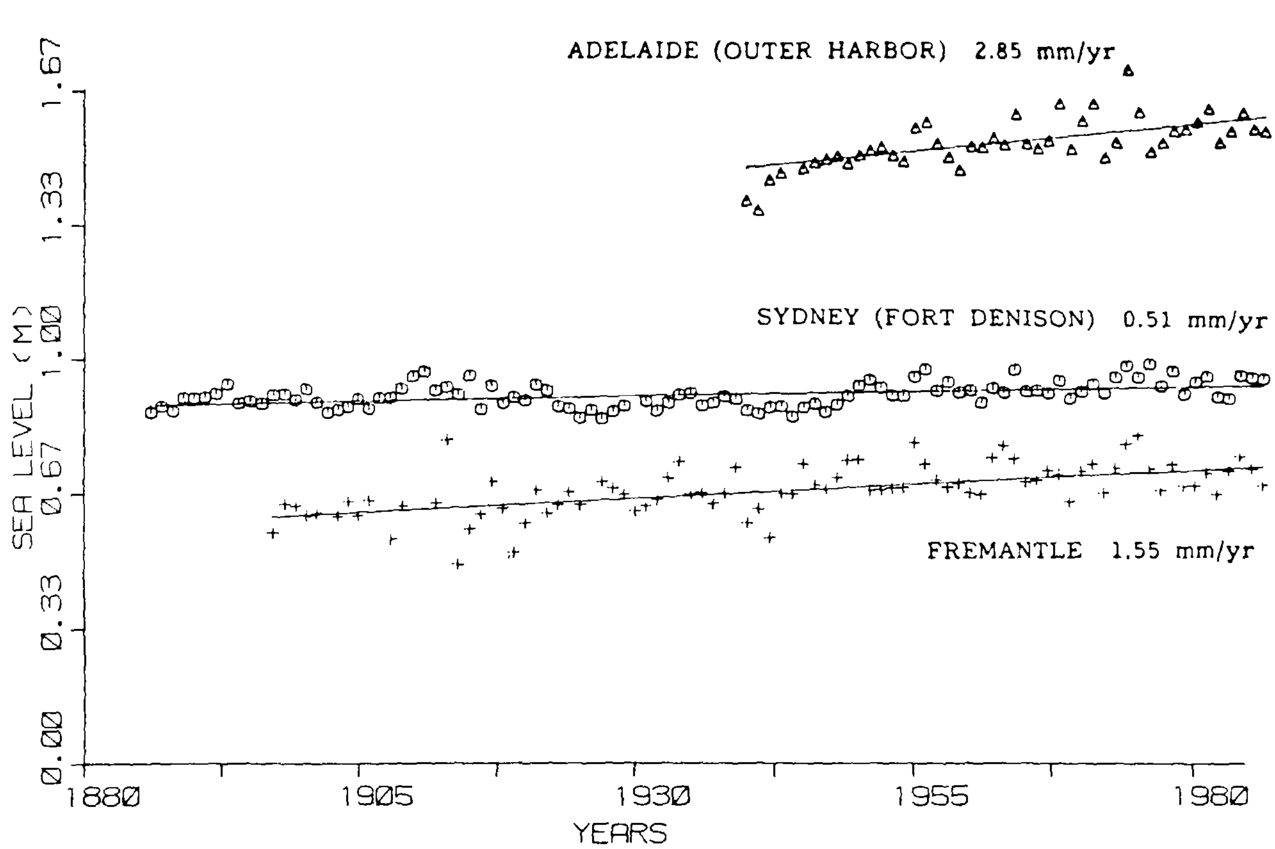
| LOCATION | A0 | Sa | | Ssa | | trend | % | res | | | no |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | H | g | H | g | | varn | s.d. | F | records | of |
| | m | mm | deg | mm | deg | mm/yr | expl | cm | value | start | months |
| CAIRNS | 1.425 | 92.46 | 3.2 | 16.82 | 4.9 | **4.04** | 71.6 | 4.5 | 69.7 | 1966 | 143 |
| TOWNSVILLE | 1.626 | 98.78 | 352.9 | 20.43 | 350.7 | **0.35** | 70.6 | 4.7 | 119.8 | 1960 | 254 |
| MACKAY | 2.973 | 107.85 | 350.8 | 14.39 | 8.4 | **0.97** | 63.9 | 5.9 | 57.3 | 1966 | 167 |
| BUNDABERG | 1.358 | 72.84 | 346.8 | 5.51 | 117.0 | **-0.43** | 53.6 | 4.9 | 45.8 | 1966 | 203 |
| BRISBANE | 1.181 | 56.03 | 13.8 | 13.89 | 127.4 | **3.24** | 41.8 | 5.7 | 22.2 | 1966 | 160 |
| NEWCASTLE | 0.979 | 40.05 | 32.5 | 23.01 | 125.2 | **0.31** | 26.0 | 5.7 | 16.6 | 1957 | 241 |
| CAMP COVE | 0.920 | 35.20 | 45.2 | 24.48 | 139.3 | **1.73** | 33.4 | 4.7 | 14.2 | 1966 | 147 |
| FORT DENISON | 0.936 | 40.20 | 48.6 | 24.62 | 135.1 | **0.77** | 33.8 | 4.8 | 24.6 | 1886 | 246 |
| POINT LONSDALE | 0.867 | 48.75 | 94.3 | 28.68 | 141.3 | **1.24** | 30.2 | 6.3 | 20.6 | 1962 | 243 |
| GEELONG | 0.460 | 55.51 | 86.3 | 25.0 | 143.0 | **0.65** | 39.5 | 5.3 | 16.8 | 1965 | 134 |
| WILLIAMSTOWN | 0.529 | 34.79 | 83.0 | 24.65 | 141.2 | **0.73** | 22.4 | 5.7 | 14.7 | 1966 | 259 |
| GEORGETOWN | 1.979 | 39.95 | 99.5 | 15.91 | 173.5 | **1.78** | 22.9 | 6.1 | 10.0 | 1965 | 174 |
| HOBART | 1.193 | 35.33 | 143.1 | 9.75 | 193.3 | **1.77** | 8.8 | 9.6 | 2.9 | 1966 | 156 |
| PORT MACDONNELL | 0.610 | 66.46 | 95.1 | 33.78 | 128.9 | **1.26** | 45.2 | 6.0 | 28.5 | 1962 | 178 |
| VICTOR HARBOR | 0.616 | 80.57 | 92.2 | 32.88 | 141.2 | **-0.25** | 40.4 | 7.7 | 26.8 | 1964 | 203 |
| OUTER HARBOR | 1.565 | 67.95 | 93.2 | 28.33 | 144.7 | **0.96** | 33.6 | 7.4 | 26.2 | 1940 | 264 |
| PORT ADELAIDE | 1.532 | 77.09 | 95.5 | 27.87 | 146.1 | **2.80** | 41.4 | 7.5 | 33.3 | 1933 | 241 |
| PORT LINCOLN | 1.030 | 82.83 | 87.4 | 32.76 | 154.1 | **1.50** | 53.0 | 6.0 | 53.5 | 1964 | 242 |
| THEVENARD | 0.998 | 84.71 | 85.5 | 22.22 | 148.2 | **0.66** | 47.2 | 6.7 | 36.2 | 1964 | 207 |
| ESPERANCE | 0.721 | 80.51 | 76.3 | 26.41 | 146.9 | **1.82** | 54.8 | 5.6 | 50.6 | 1965 | 214 |
| ALBANY | 0.778 | 92.84 | 76.0 | 27.99 | 145.0 | **-0.81** | 62.5 | 5.3 | 73.7 | 1960 | 226 |
| BUNBURY | 0.644 | 111.98 | 70.9 | 29.83 | 163.4 | **0.42** | 65.0 | 6.0 | 77.7 | 1963 | 214 |
| FREMANTLE | 0.718 | 101.37 | 71.2 | 28.66 | 146.0 | **0.30** | 59.5 | 6.3 | 74.9 | 1897 | 260 |
| GERALDTON | 0.871 | 110.58 | 55.2 | 33.37 | 152.0 | **-0.37** | 67.1 | 5.7 | 84.7 | 1963 | 213 |
| CARNARVON | 0.831 | 94.83 | 19.2 | 24.53 | 141.0 | **3.39** | 63.1 | 5.8 | 47.8 | 1965 | 145 |
| PORT HEDLAND | 4.167 | 101.79 | 345.6 | 12.73 | 124.9 | **-1.36** | 58.2 | 6.4 | 39.5 | 1960 | 147 |
| WYNDHAM | 4.236 | 144.15 | 322.8 | 55.63 | 10.8 | **1.30** | 66.6 | 7.7 | 58.0 | 1966 | 150 |
| DARWIN | 3.992 | 108.16 | 316.7 | 18.23 | 55.7 | **0.28** | 56.9 | 6.9 | 60.9 | 1966 | 236 |
| WEIPA | 1.651 | 303.27 | 309.1 | 56.85 | 296.4 | **1.68** | 85.0 | 9.6 | 142.1 | 1966 | 130 |

**The average trend is 1.1 $\pm$ 0.5 mm/year at the 95% significance level.**

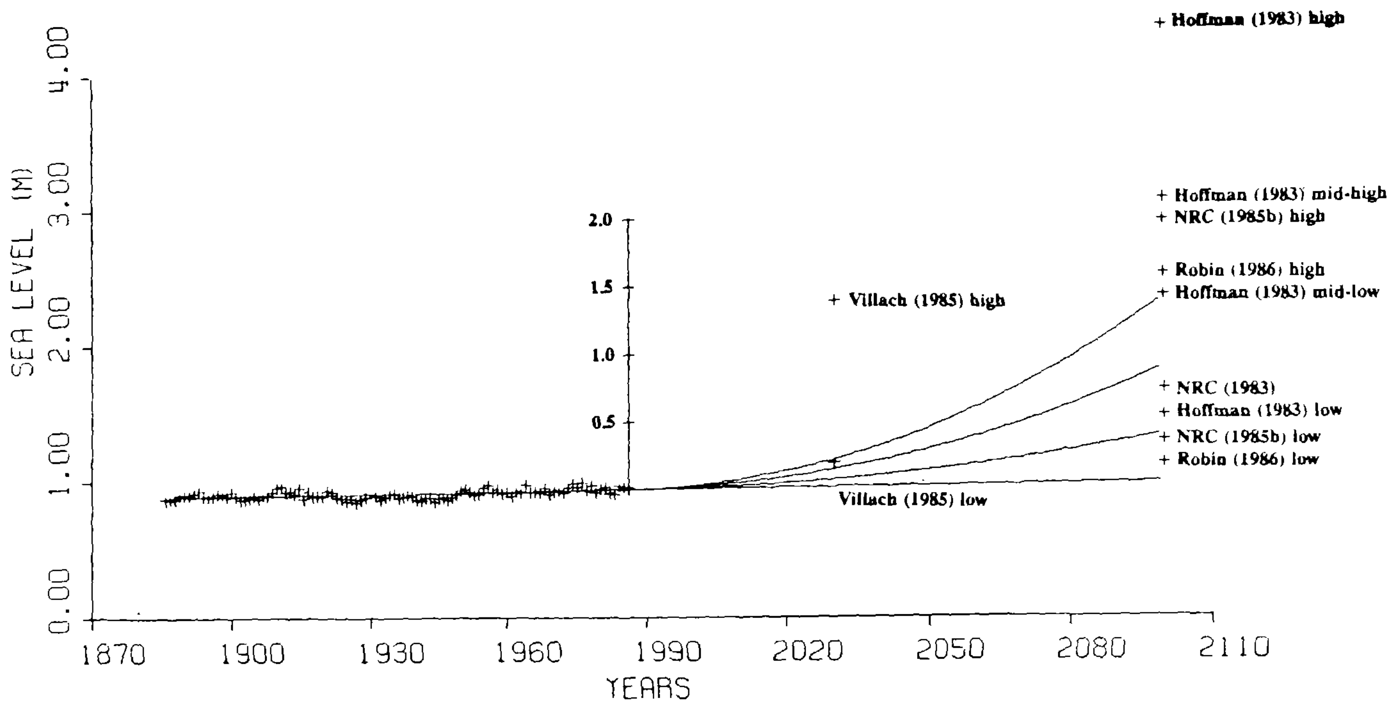
The data set consists of all those locations on the databank as at October 1989 that have a span of 10 years or greater, without regard to the amount of data in the span. The final column is the number of complete monthly means used in the regression. The beginning of the epoch is taken to be January 1966, so generally there is about a 23 year span for the more complete data sets.

The independent variables chosen to represent the monthly means are the terms corresponding to sines and cosines of period one year (Sa) and 6 months (Ssa), a term representing the time corresponding to the middle hour of the corresponding month (trend) and the regression constant (A0).

The table also contains columns for the percentage of the variation explained by the regression, the standard deviation of the residuals, the F value for the F-test and the year that the records on the databank for each location start.




The monthly means for the complete records for the three longest data sets on the databank were analysed in the same way and the regressed linear trends are presented on the figure above. The Figure also shows the annual means at each location regardless of the gaps in the data. The datum for each record is the local tide gauge zero.




The trend determined by the least squares regression outlined above is plotted for Fort Denison with the annual mean data. The projected changes to mean sea level at Fort Denison are then plotted to the year 2100. The lower line is a simple extrapolation of the linear trend, the other three curves are the lower, middle and upper scenarios adopted by the US National Research Council and published in a report entitled *Responding to Changes in Sea Level:Engineering Implications* published by the National Academy Press, Washington, DC 1987. The Figure also compares these with other estimates by various authors.

# Sea level French programme in the Southern Ocean

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Within the WOCE international programme, France already operates sea level measurements in the Indian sector of the Southern Ocean on the two Islands of Kerguelen (48° 52' S ; 70° 10' E) and Amsterdam (37° 53' S ; 77° 35' E). The scientific interest of these measurements is linked to the location of these islands, on the two sides of a major branch of the Antarctic Circumpolar current deflected to the north by the Kerguelen plateau, and squeezed between these two islands, cf figure 1. The major objective is thus to get continuous records of the sea level at these two points in order to monitor the CCA transport variability at the seasonnal and interannual time scales.

The programme started in 1986, through a cooperation between LOP (Physical Oceanography Laboratory of the Museum d'Histoire Naturelle, Paris) and POL (Proudman Oceanographic Laboratory, Bidston). Continental shelf absolute pressure tide gauges are maintained on site : one at Kerguelen by 100 m depth, and another at Amsterdam at 200 m depth. The instruments used were initially provided by POL : Anderaa continental shelf tide gauges with quartz pressure sensor, and a POL modified internal clock. They have been replaced by French manufactured tide gauges (by SUBER Company) with paroscientific quartz and c.mos. memory recorder. The gauges are moored and recovered on an annual basis, thanks the regular service of the "Marion-Dufresne" chartered by TAAF (French Southern and Antarctic Territories), over this South Indian Ocean Sector.

Three years of continuous records have already been obtained and analysed, leading to significant scientific results :

**a.** Harmonic tidal constituents are extremely well defined and stable from year to year. The results of these analysis for the years 1986, 1987 and 1988 are given on table 1. It can be noticed that:

1. The semi-diurnal constituents have very similar amplitudes and phases,

2. The diurnal constituents, on the contrary, are very different: $K_1$ is bigger in Amsterdam compared to Kerguelen, with a phase lag of 72°, and, by contrast, $0_1$ is bigger in Kerguelen (and bigger than $K_1$), with a similar phase shift of 75°,

3. When checking the solutions of Schwiderski (1983) at these two locations, it can be pointed out that, at Kerguelen, they are quite good, except for the amplitude of $M_2$ (36.1 cm instead of 40.7, i.e. 4.6 cm difference) and for the phase of $N_2$ (8° phase lag).

**b.** Very different energy density spectra hold over these two sited : by contrast to Amsterdam, which is a very small island surrounded by deep waters, Kerguelen Island is on top of a large plateau, and the intercomparison of the spectra of sea level variations (figure 2) clearly reveals besides the peak corresponding to diurnal and semi diurnal tides, energy density :

1. in the band of periods below 12 hr, with peaks about 8, 6 and 4 hrs which correspond to higher harmonic of tides,
2. in the band of periods between the local inertial period (15 hr 53') and 100 hr,
3. in a band of long periods, above 100 hrs.

SAINT-GUILY and LAMY (1988) have interpreted the contribution in the second band in term of second class waves trapped by the submarine shelf, rotating counter clockwise around the Island (topographic Rossby waves).

**c.** On the basis of the first 9 month's bottom pressure measurements (march to november, 1986), PARK and al. (1989) have estimated that the barotropic transport variability of the flow between these two islands has been of the order of 10 to 15 x $10^6$ $m^3$ $s^{-1}$ over a range of periods from 8 days to 3 months, and that the seasonal variability can be of the order of 30 x $10^6$ $m^3$ $s^{-1}$, which seems to be consistent with the ACC variability observed at the Drake Passage (WITHWORTH and PETERSON, 1985).

These preliminary results demonstrate the interest of this site for contributing to the future monitoring of the CCA variability through sea level measurements.

However these continental shelf gauges are not fulfilling the GLOSS requirements. This is why a complementary programme is ongoing to install coastal tide gauges on the Southern Indian Ocean Islands of Amsterdam, Kerguelen and Crozet, cf figure 1. The equipment of the Antarctic Dumont d'Urville base with a pressure sea level gauge is also considered. At present, two of these stations are under study, on the basis of the experience recently acquired in the Equatorial Atlantic where two sea level gauge stations with satellite data collection are operating. The tide gauge is a digiquartz pressure recorder moored nearshore, linked by an underwater cabled to an automatic station collecting the data and sending them to ARGOS system (see figure 3). Water pressure, salinity and temperature of the sea water, and atmospheric pressure are acquired by the station which encodes the data, and generates an Argos-compatible message. The station is programmable : measurement times, transmission period (time during which the message is transmitted). In the nominal operating mode adopted for the Equatorial Atlantic, the station triggers measurements at intervals pre-set by the user, and stores them for 24 hours in memory. The messages are received, decoded and processed at the ARGOS Global Processing Centers in Toulouse and Washington. After quality control, the data are available in three forms :

- online, by interrogating the Argos centers, via packet-swetching networks (Transpac, Tymnet, etc ...),
- possibly transmitted to regional or world data banks,

- offline, on listings, tapes or floppy disks.

Amsterdam and Kerguelen Island will thus be equipped in 1991. The exact sites of installation are not yet decided, the choices are depending on the natural conditions imposed by each of these islands (see LAMY, 1988 ; VASSIE, 1988). And support is expected to equip Crozet in a near future. The last priority will be on the Antarctic Dumont d'Urville Station, in the Geology Point Archipelago (140°01 E ; 66°40' S). This station is built on a rocky island, free of ice during two months, between december and february. The idea is to adapt the automatic station precedently designed to the special environment of Antarctica.

One important requirement for the GLOSS stations is the reference to benchmarks and their geodetic control. It must be noticed that three of the four sites cited herebefore (Kerguelen, Amsterdam and Dumont d'Urville) are already linked within a unique geodetic network through the radiopositionning satellite DORIS system now on board the SPOT 2 satellite, and planned to fly on TOPEX/POSEIDON, which is of major interest for a fully consistent relation of these sea level measurements with satellite altimetry.

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Kerguelen

| onde | 1986 amplitude | 1986 phase | 1987 amplitude | 1987 phase | 1988 amplitude | 1988 phase |
|---|---|---|---|---|---|---|
| M2 | 40.9 | 230.5 | 40.8 | 230.6 | 40.6 | 230.4 |
| S2 | 21.8 | 273.2 | 21.6 | 273.7 | 21.6 | 273.3 |
| N2 | 8.3 | 213.7 | 8.1 | 213.6 | 8.0 | 213.7 |
| K2 | 6.0 | 272.1 | 6.1 | 271.9 | 6.1 | 271.5 |
| O1 | 5.7 | 239.9 | 5.9 | 238.3 | 5.7 | 238.7 |
| K1 | 5.0 | 216.4 | 5.2 | 217.4 | 5.0 | 217.0 |
| Q1 | 1.8 | 234.9 | 1.5 | 230.8 | 1.7 | 232.5 |
| P1 | 1.6 | 217.6 | 1.6 | 215.4 | 1.6 | 210.0 |
| NU2 | 1.4 | 216.6 | 1.5 | 216.0 | 1.5 | 215.1 |
| T2 | 1.3 | 270.5 | 1.3 | 271.0 | 1.4 | 275.5 |
| MU2 | 1.3 | 209.7 | 1.2 | 205.8 | 1.2 | 204.6 |
| L2 | 1.3 | 236.0 | 1.3 | 240.2 | 1.3 | 243.9 |
| 2N2 | 1.1 | 177.1 | 1.1 | 182.3 | 1.1 | 187.9 |
| M4 | 0.4 | 326.4 | 0.4 | 324.7 | 0.5 | 327.5 |
| M6 | 0.4 | 189.4 | 0.5 | 185.1 | 0.6 | 190.4 |
| 2MN6 | 0.4 | 138.1 | 0.3 | 126.8 | 0.3 | 135.5 |
| LA2 | 0.3 | 236.6 | 0.4 | 243.7 | 0.4 | 243.4 |
| MS4 | 0.3 | 30.4 | 0.3 | 28.0 | 0.3 | 19.5 |
| J1 | 0.3 | 183.9 | 0.5 | 213.8 | 0.5 | 194.5 |
| S1 | 0.3 | 330.1 | 0.3 | 327.9 | 0.2 | 330.7 |
| MSN2 | 0.2 | 171.4 | 0.2 | 91.2 | 0.1 | 60.7 |
| MSN6 | 0.2 | 202.4 | 0.1 | 219.8 | 0.2 | 236.6 |
| 2SM2 | 0.1 | 245.9 | 0.1 | 236.4 | 0.1 | 230.0 |
| MN4 | 0.1 | 281.4 | 0.2 | 298.0 | 0.1 | 287.9 |
| OO1 | 0.1 | 219.4 | 0.2 | 209.8 | 0.2 | 229.7 |
| MK4 | 0.1 | 30.0 | 0.1 | 30.8 | 0.1 | 42.4 |

Amsterdam

| onde | 1986 amplitude | 1986 phase | 1987 amplitude | 1987 phase | 1988 amplitude | 1988 phase |
|---|---|---|---|---|---|---|
| M2 | 40.7 | 229.6 | 40.8 | 230.1 | 40.5 | 229.6 |
| S2 | 21.9 | 271.4 | 21.3 | 272.2 | 21.8 | 271.3 |
| K1 | 7.3 | 144.6 | 7.1 | 145.4 | 7.4 | 144.4 |
| N2 | 7.4 | 213.5 | 7.7 | 211.8 | 7.3 | 214.2 |
| K2 | 6.2 | 269.3 | 6.3 | 272.3 | 6.3 | 269.7 |
| O1 | 3.3 | 164.7 | 3.2 | 161.8 | 3.3 | 163.1 |
| P1 | 2.2 | 147.6 | 2.4 | 151.4 | 2.2 | 142.8 |
| NU2 | 1.4 | 216.0 | 1.8 | 216.9 | 1.4 | 216.2 |
| L2 | 1.2 | 241.1 | 1.5 | 238.0 | 1.3 | 253.4 |
| T2 | 1.1 | 288.3 | 1.0 | 289.1 | 1.3 | 272.7 |
| MU2 | 0.9 | 205.0 | 0.9 | 189.5 | 0.9 | 204.0 |
| 2N2 | 0.9 | 188.6 | 0.7 | 184.9 | 0.9 | 196.2 |
| Q1 | 0.8 | 179.6 | 0.9 | 184.4 | 0.8 | 184.2 |
| J1 | 0.5 | 161.5 | 0.5 | 131.8 | 0.5 | 152.6 |
| LA2 | 0.4 | 241.1 | 0.6 | 189.4 | 0.5 | 240.6 |
| S1 | 0.2 | 354.3 | 0.2 | 358.1 | 0.4 | 273.6 |
| OO1 | 0.3 | 182.5 | 0.3 | 162.3 | 0.3 | 170.8 |
| M3 | | | 0.2 | 135.7 | 0.2 | 137.9 |
| E2 | | | 0.2 | 197.2 | 0.2 | 188.1 |
| M4 | 0.2 | 315.7 | 0.2 | 317.9 | 0.2 | 320.1 |
| 2SM2 | 0.2 | 210.2 | 0.4 | 218.8 | 0.2 | 217.5 |
| MSK2 | | | 0.3 | 15.4 | 0.1 | 82.5 |
| MKS2 | | | 0.4 | 185.3 | 0.1 | 247.6 |
| MS4 | 0.1 | 51.7 | 0.1 | 56.6 | 0.1 | 55.4 |
| MN4 | 0.1 | 276.9 | 0.1 | 274.4 | 0.1 | 266.3 |
| M6 | 0.1 | 34.4 | 0.1 | 28.1 | 0.1 | 20.5 |
| 2MK3 | | | 0.1 | 214.1 | 0.1 | 177.6 |

**Table 1 :** Main tidal harmonic constituents at Kerguelen and Amsterdam, amplitudes in cm, phases g in d°.

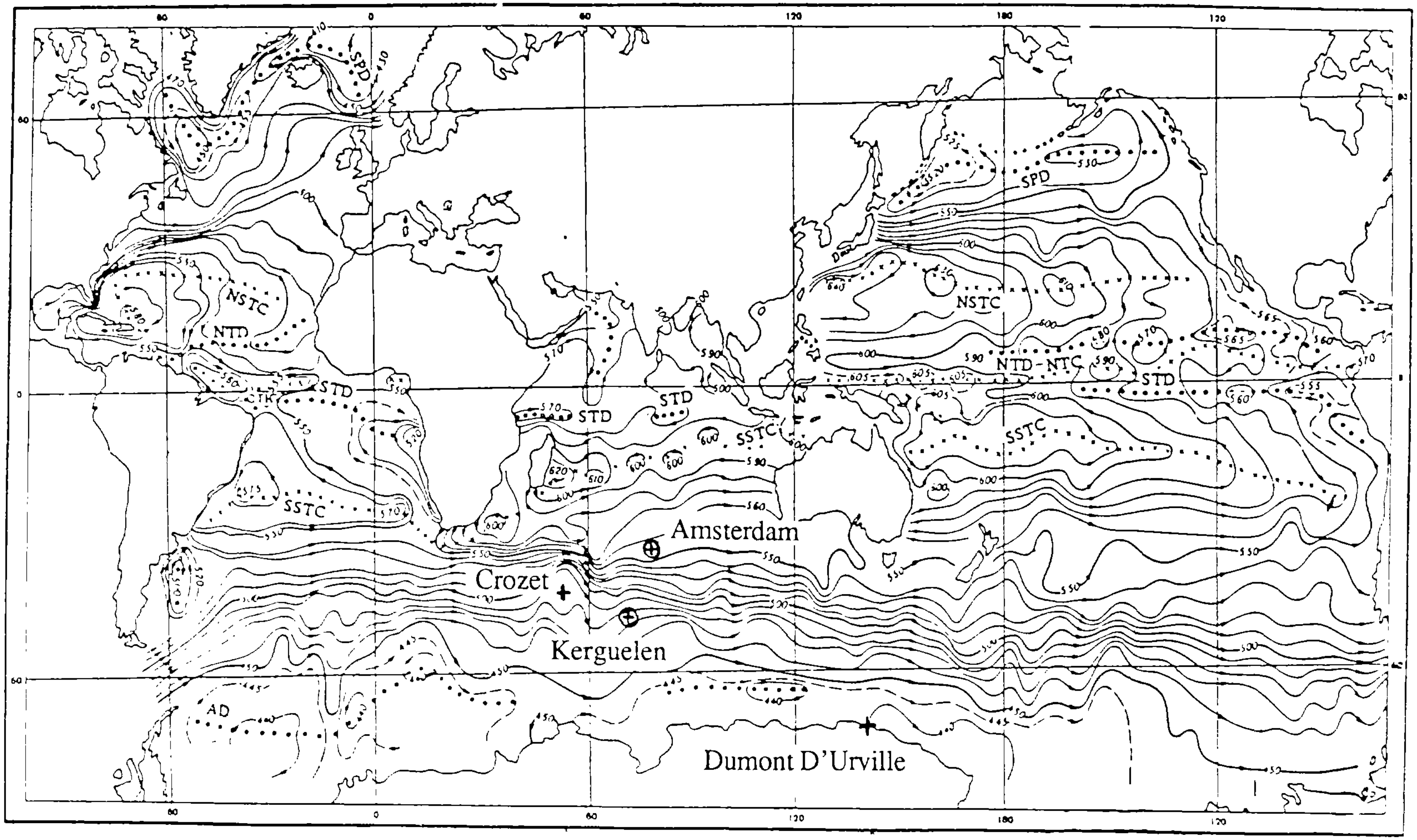


**Figure 1** : Location of the French South Indian Ocean Stations under implementation, within the Antarctic Circumpolar Current, as shown by the steric height (dynamic cm) at the sea surface relative to 1500 db, from BURKOW et al., 1973.

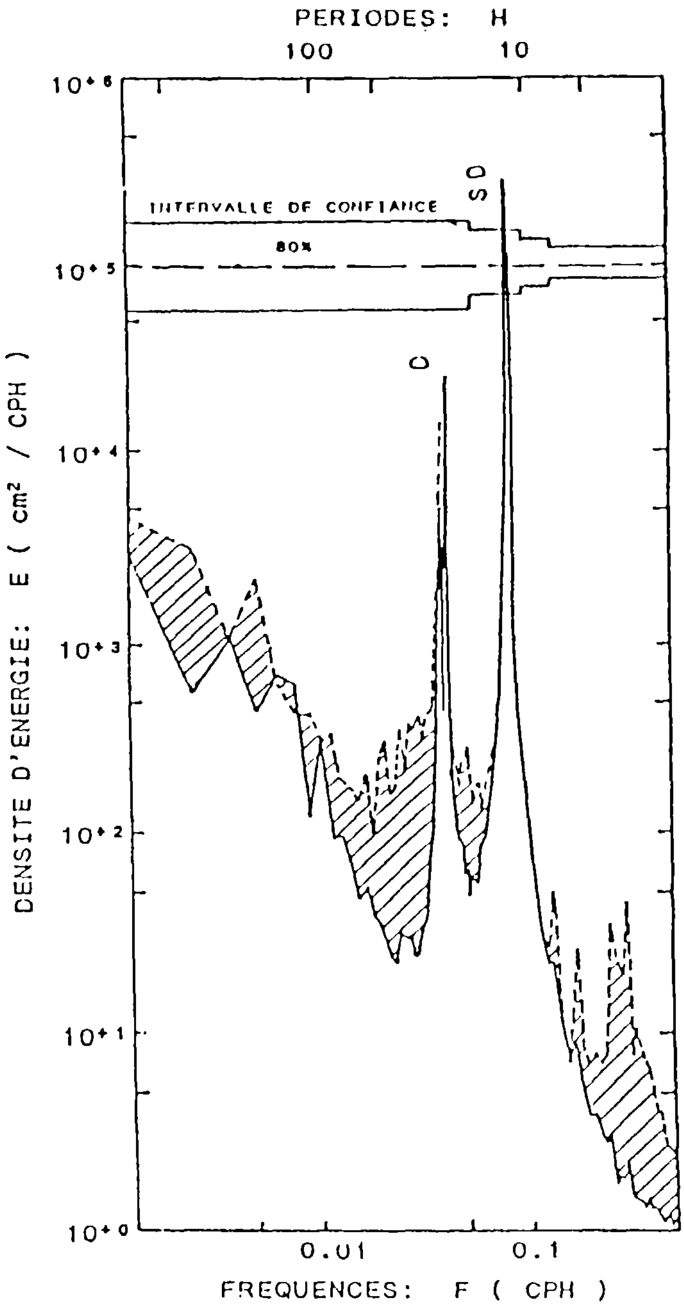


**Figure 2 :** Energy density spectra with respect to frequency obtained from the first year (1986) of bottom pressure records on Kerguelen Island (broken line) and Amsterdam Island (full line). The semi diurnal and diurnal components are clearly visible, but the more significant novelty of this analysis from SAINT-GUILY and LAMY (1988) is the existence over the Kerguelen plateau of a much larger level of energy, due to non linear tidal contributions, but also, and mainly, to topographic Rossby waves.

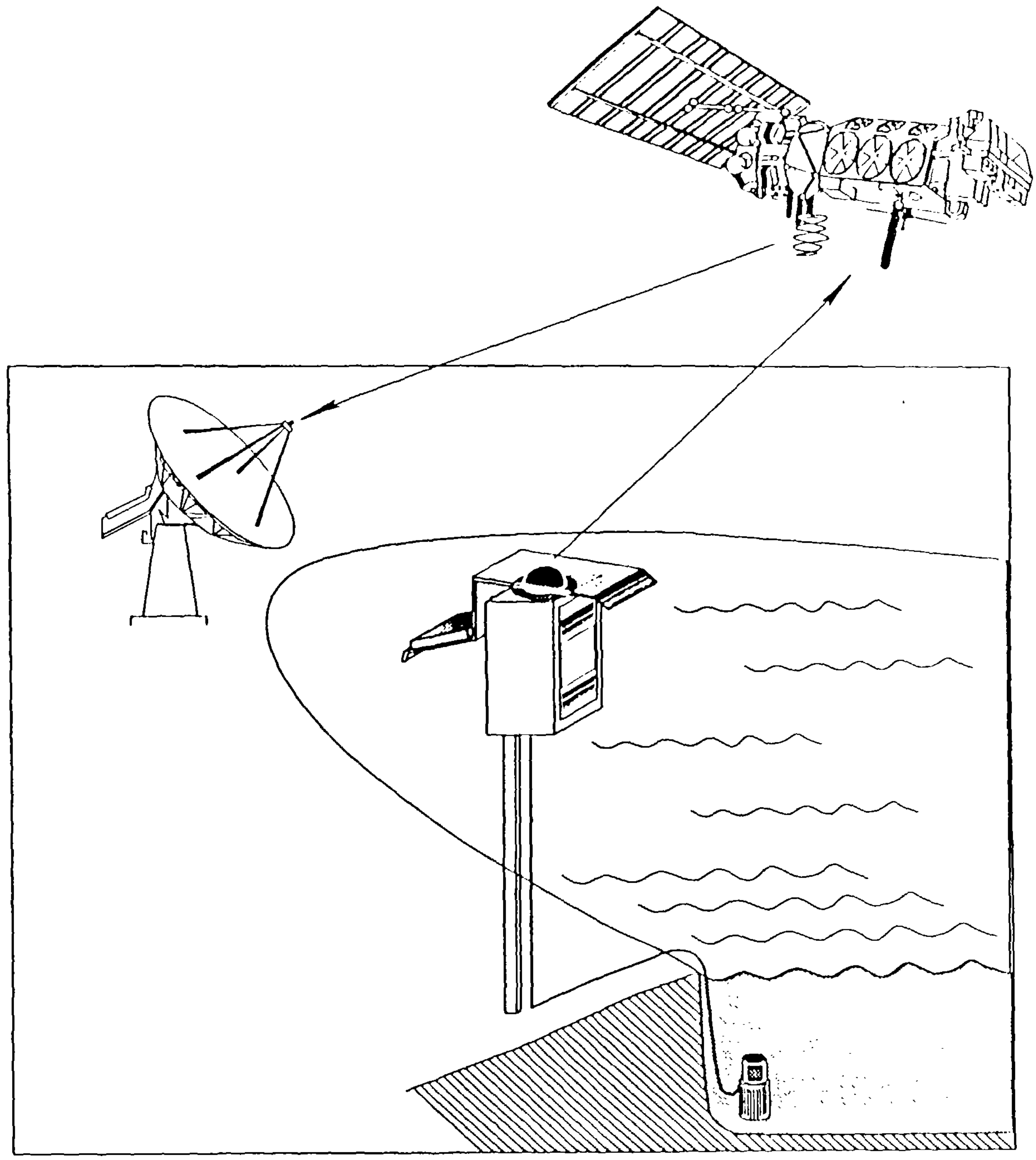

**Figure 3** : The ARGOS Tide Station implemented by ORSTOM in the Equatorial Atlantic, as one of the French contributions to TOGA. The station is under redesign and adaptation for the South Indian Ocean Islands.

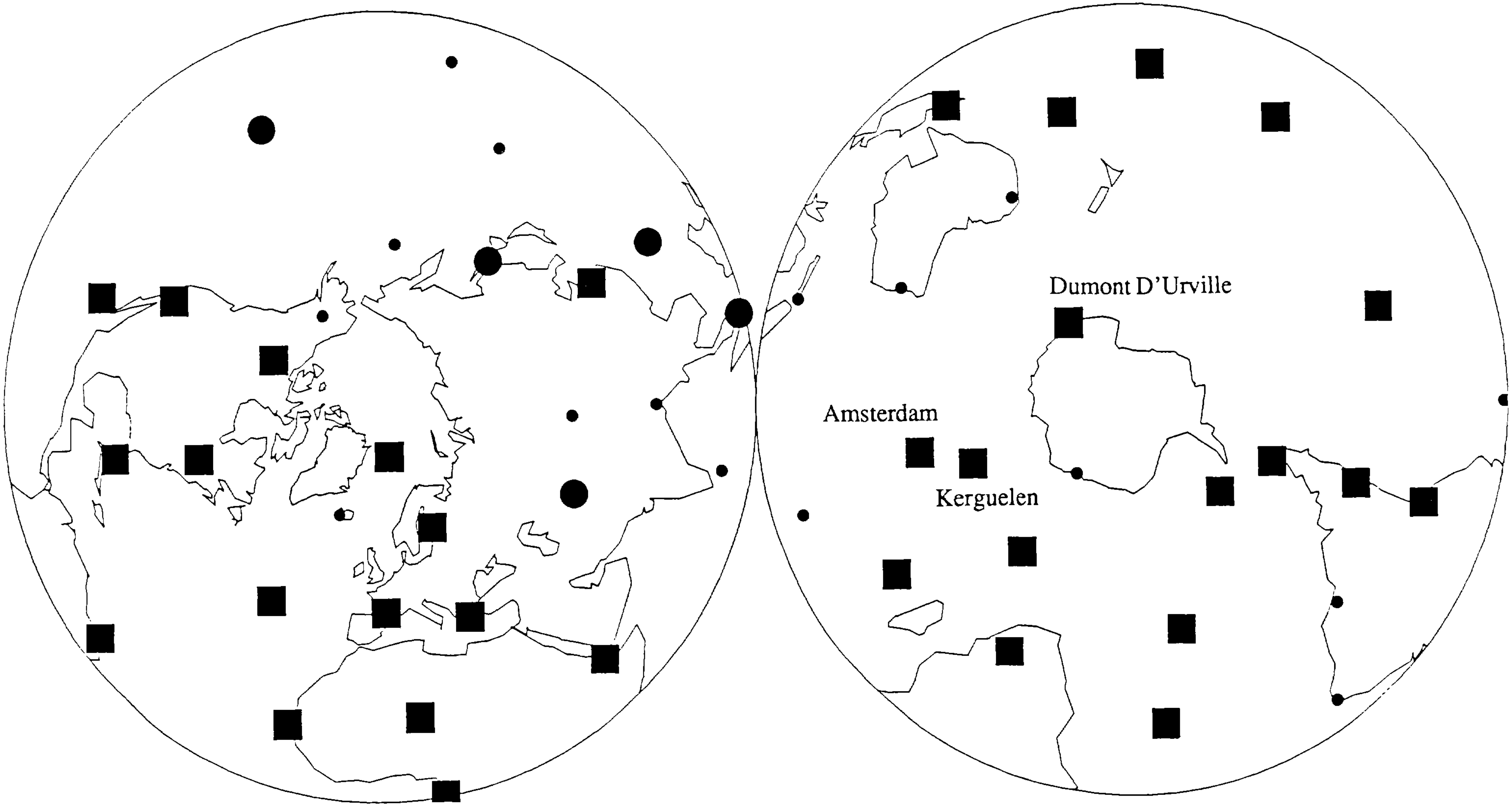


**Figure 4** : Network of the radiopositionning beacons of the DORIS system, updated 14/02/1990. Squarred : installed - large circles : accepted - small circles : negociation. Note the presence of beacons in Kerguelen, Amsterdam and Dumont D'Urville, already in site, and the one in negociation at the Syowa Antarctic Japonese Station.

# SEA LEVEL MEASUREMENTS
# IN McMURDO SOUND ANTARCTICA

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## 1. INTRODUCTION

Sea level measurements have been made in McMurdo Sound, Antarctica, for a variety of purposes and over wide ranging time scales since 1957.

Many of the observations have been made manually at hourly intervals over periods of, typically, 24 hours. These have been used to determine a mean sea level reference height for photo-control surveys or bench mark traverses. These results are not considered to be particularly accurate and may be in error by as much as 0.5 metres.

Longer term recordings over periods of one month or more have been used for sea current studies, mean sea level determinations and tide predictions.

The Antarctic environment is a difficult one in which to establish permanent tide gauges. Self contained power supplies which will perform throughout the long cold winter are usually necessary and there are the problems associated with the presence of seasonal sea ice to overcome.

Despite the fact that they are not currently operational, the tide gauges which were established in 1988 at Scott Base and Cape Roberts have shown that it is possible to establish such instrumentation. With some additional careful site preparation there appears to be little reason why these installations can not be successfully maintained on a permanent basis.

The importance of making tidal readings with respect to properly fixed and referenced bench marks should not be under-estimated. Tide gauges need to be checked regularly to ensure that reliability, accuracy and stability are maintained, particularly if long term changes in sea level are being investigated. If a gauge is shifted or replaced in a different vertical location, a continuous record can be assured if the relationship of the two positions is determined through a levelled connection to common bench marks.

## 2. SUMMARY OF TIDE OBSERVATIONS

The following notes give brief descriptions of the known tidal observations which have been made in McMurdo Sound over the last 30 years.

Figure 1 on page 3 shows the locations of all the sites described below.

Field book references are given for those tide observations made by surveyors participating in the New Zealand Antarctic Research Programme. References to reports summarising the surveyors' work are also noted. Bench mark connections have been made for all observations described below.

### 2.1 1957 - 1959: Scott Base

The first attempt to install a long term sea level recorder in McMurdo Sound occurred as part of the New Zealand International Geophysical Year programme.

A Foxboro liquid level recorder operated intermittently from March to July 1957 then continuously from December 1957 to January 1959. Methods of installation, descriptions of the sites and some brief results are given by MacDonald and Burrows (1959).

A total of 3 sites were occupied on the sea ice some 50 - 60 metres off Pram Point in the vicinity of Scott Base. The difficulties encountered (fire, hole freezing over, equipment failure) at the first two sites were overcome and resulted in a successful operation at the third site for over a year.

Each site was levelled with respect to a stainless steel bench mark onshore, thus establishing a sea level datum reference point.

Gilmour *et al.* (1962) calculated the tidal constituents for four periods, each of 29 days duration, from the records collected by MacDonald and Burrows (1959).

### 2.2 1970 - 1971: McMurdo Station

Between late December 1970 and early February 1971, a Foxboro tide gauge was operated from the rock pier housing the intake and outlet to the nuclear power plant at McMurdo Station.

The data was collected to study the correlation between tides and sea currents in southern McMurdo Sound. A comparison between the tidal constituents from a 30 day tidal record at McMurdo Station and the means of the constituents derived by Gilmore *et al.* (1962) for Scott Base is presented by Heath (1971a). These records provided a basis for the correlation of tides and sea currents in McMurdo Sound by Heath (1971b).

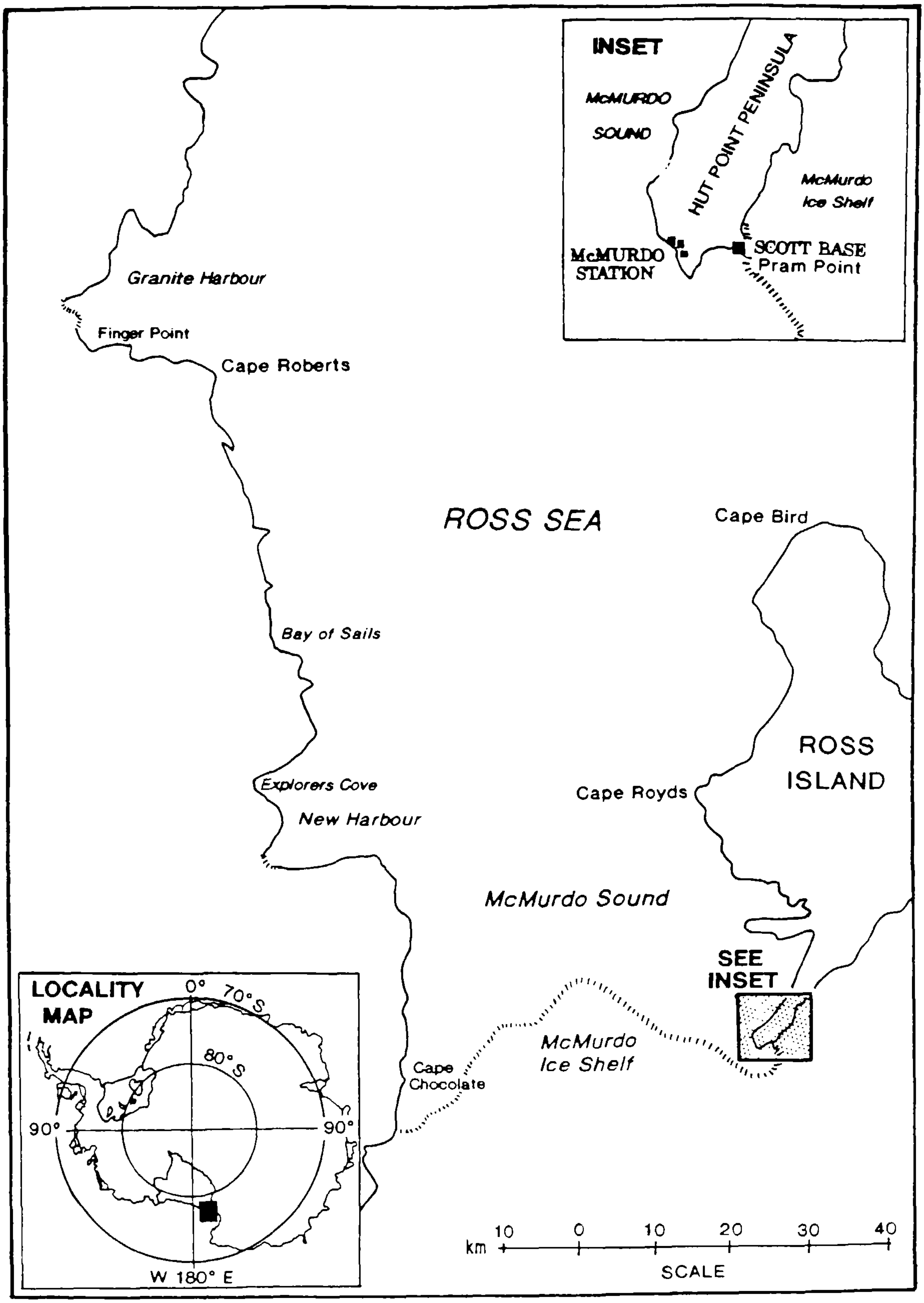


Figure 1
Locations of tidal observations made in McMurdo Sound

## 2.3 1971: Bay of Sails

Several levels were taken on the sea surface at the Bay of Sails over a period of 4 - 5 hours in January 1971 and are recorded in Ant. F.B. 97, p. 93[1].

These were used to derive a height origin for levelling into the Wright Valley and Lake Vanda.

## 2.4 1978: New Harbour

Hourly tide readings were taken over a period of 27 hours in November 1978 at Explorers Cove in New Harbour.

This data was used for a height origin for a bench mark traverse through the Taylor Valley and is recorded in Ant. F.B. 118, p. 1. Further details are reported by Fink (1979).

## 2.5 1979: Cape Royds

Hourly tide readings were taken over a period of 26 hours in December 1979 at Cape Royds.

These were used for a height origin for a photo-control survey and are recorded in Ant. F.B. 121, pp. 46 and 48. Further details are reported by Hall (1980).

## 2.6 1980: Cape Chocolate

Hourly tide readings were taken at Cape Chocolate over a period of 25 hours in November 1980.

These were used for a height origin for levelling in the Garwood and Marshall/Miers Valleys and are recorded in Ant. F.B. 122, p. 18. Further details are reported by Neale (1981).

## 2.7 1983: Cape Bird

Hourly tide readings were taken at Cape Bird over a 12 hour period in December 1983.

These were used for a height origin for a photo-control survey and are recorded in Ant. F.B. 144, p. 5.

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1 Surveyor's tidal observations are contained in the numbered series of Antarctic field books (Ant. F.B.) which are held by Head Office, Department of Survey and Land Information, Wellington, New Zealand.

## 2.8 1986: McMurdo Station

At the end of 1986 a portable ultrasonic tide gauge was installed by staff from the Department of Surveying, Otago University, Dunedin, New Zealand and the Department of Lands and Survey[1], in a heated hut which housed the water intake well for the aquarium at McMurdo Station.

This gauge, developed and manufactured by Ellwood Electronics, Dunedin, New Zealand, measures the height of the sea surface above a submerged transducer by timing the return period for a sound pulse reflected back from the water/air interface. The sampling interval can be set to meet user requirements and the data is stored on an EPROM device.

This gauge was not fully tested prior to installation in Antarctica and never produced any data. In addition, the water intake well was considerably modified to the extent that it was no longer suitable for the operation of the tide gauge. Belgrave and Rowe (1990) provide further details on the attempt to establish this gauge.

When installed, it was planned that this gauge would operate long term to provide a reliable determination of mean sea level and the harmonic constituents required for the preparation of tide predictions.

## 2.9 1988 - 1989: Cape Roberts

In November 1988 a gauge was established at Cape Roberts by the Antarctic Research Centre, Victoria University of Wellington, New Zealand, to study tidal driven currents in Granite Harbour.

The system used was a 25 psi (170 kPa) *Geokon 4500SLV* pressure transducer which measures the change in frequency of the vibration of a wire caused by pressure changes.

A hole was dug into the sea ice adjacent to the shore and a 9.9 metre long galvanised pipe was pushed through the ice-foot at the base of this hole and fixed to the rock so that the lower end of the pipe protruded into the sea water beneath the ice foot. The pressure transducer was passed down the pipe to the water and the data logging equipment positioned on surrounding high ground.

Unfortunately, when the breakout of the ice-foot occurred early in February 1989 the pipe was dislodged and the transducer lost. A total of 64 days' data was obtained from this gauge.

Details of this installation are contained in two immediate science reports by Pyne (1989 and 1990). Survey work associated with this gauge is recorded in Ant. F.B.s 167, pp. 29 - 32 and F.B. 182, pp. 39 - 41 and further information is recorded in Sole (1989).

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1 The Technical Division of the Department of Lands and Survey became known as the Department of Survey and Land Information on 1 April 1987.

## 2.10 1988: Granite Harbour

Following the establishment of the gauge at Cape Roberts (refer 2.9 above) the study of tidal driven currents required a measure of the tidal lag between Cape Roberts and the inner reaches of Granite Harbour.

For this reason the tide was monitored over a period of 28 hours at Finger Point (Granite Harbour) in November 1988. Tide levels were taken every 15 minutes and referenced to a bench mark. These observations were recorded in Ant. F.B. 182 pp. 42 - 44. Further details are given in Sole (1989).

## 2.11 1988 - 1990: Scott Base

Despite the lack of success with the *Ellwood* gauge in 1986 (refer 2.8 above) a further attempt to establish a permanent gauge was mounted.

Two major factors which influenced the selection of an alternative type of gauge and the installation method were the presence of sea-ice and a desire to avoid the construction of a special support structure for the gauge.

The gauge system identical to that installed at Cape Roberts (refer 2.9 above) was chosen. In order to provide a back-up unit in case of failure a second gauge was installed, this transducer producing a variable voltage output as pressure changes. The second gauge is a *Scottech Model WSISC*. The data logger equipment is housed in a laboratory nearby.

A concrete block was constructed with a recess in the top to house the two transducers and with steel rods protruding from the lower sides to assist in anchoring the block to the sea floor. Several bolted down bars hold the transducers in the recess.

A site was selected adjacent to the reverse osmosis water intake for Scott Base where the warm waste water returning to the sea keeps the build up of sea ice to a minimum.

A level connection was made from the transducers to nearby bench marks for height transfer and calibration purposes.

The data logger software makes readings once every 10 seconds from both transducers and averages these over a 10 minute period and records this mean value. Other data being recorded at the 10 minute interval is Julian Day and time (New Zealand Standard Time). At 2400hrs the maximum and minimum battery voltages and logger module temperatures are recorded. The data is transferred from the logger to 5.25 inch disks by Scott Base personnel once every 4 days. A sample printout of the recorded data is shown in Figure 2 and a graphical presentation of 30 days' data is shown in Figure 3.

A more detailed description of the establishment and operation of this gauge is given by Belgrave and Rowe (1990). The survey work associated with the establishment and monitoring of this gauge is recorded in Ant. F.B.s 167, p. 26, F.B. 168, p. 19, F.B. 169, pp. 3, 25, 29 - 30, F.B. 170, pp. 27, 31 and F.B. 182, pp. 19 - 20, 22. Reports by Sole (1989 and 1990) contain further information.

This tide gauge was operational for the period 8 November 1988 to 21 February 1990 when broken sea-ice cut the transducer cables during a storm. A replacement gauge was despatched and at the time of writing it is hoped that the technicians at Scott Base can effect repairs to enable the gauge to become operational once again.

```
112,50,2230,-9.21,2.125
112,50,2240,-9.17,2.137
112,50,2250,-9.13,2.138
112,50,2300,-9.09,2.121
112,50,2310,-9.07,2.124
112,50,2320,-9.01,2.103
112,50,2330,-8.91,2.112
112,50,2340,-8.87,2.131
112,50,2350,-8.8,2.154
112,50,2400,-8.75,2.15
115,1990,50,2400,12.54,-8.85,12.51,-13.22
112,51,10,-8.68,2.129
112,51,20,-8.64,2.116
112,51,30,-8.64,2.12
112,51,40,-8.52,2.116
112,51,50,-8.43.2.097
112,51,100,-8.36,2.05
112,51,110,-8.28,2.015
```

Figure 2
Sample of the recorded data

Interpretation:

| | | |
|---|---|---|
| 10 minute data: | 1st number: | Data type code (112) |
| | 2nd number: | Julian Day Number |
| | 3rd number: | Time (NZST = UT + 12 hr) |
| | 4th number: | Transducer 1 reading (feet)[1] |
| | 5th number: | Transducer 2 reading (metres)[2] |
| 2400 hr data: | 1st number: | Data type code (115) |
| | 2nd number: | Year |
| | 3rd number: | Julian Day Number |
| | 4th number: | Time (always 2400) |
| | 5th number: | Maximum battery voltage during previous 24 hours |
| | 6th number: | Maximum logger temperature during previous 24 hours (°C) |
| | 7th number: | Minimum battery voltage during previous 24 hours |
| | 8th number: | Minimum logger temperature during previous 24 hours (°C) |

1 The *Geokon* transducer records in imperial units.
2 The *Scottech* transducer records in metric units.

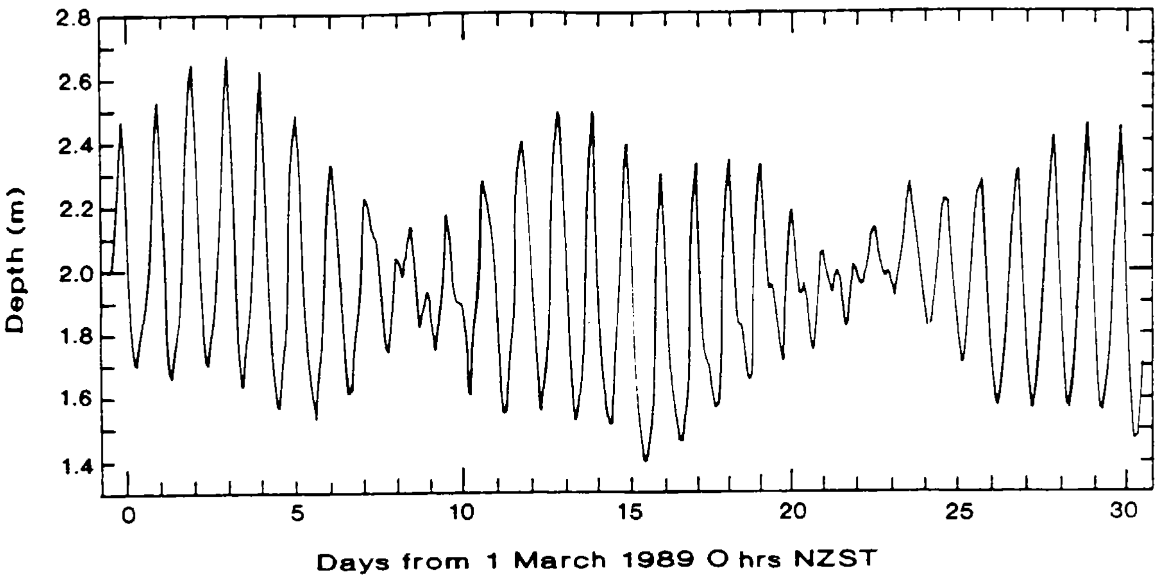


Figure 3
Plot of tidal data from Scott Base for March 1989

# 3. ANALYSIS OF TIDAL RECORDS

## 3.1 Scott Base Tide Gauges: 1957 - 1959 and 1988 - 1990

Until recently, the only analysis carried out on the 1957 - 1959 Scott Base tidal data appears to be that contained in Gilmour *et al.* (1962) where the tidal constituents derived from four 29 day periods centred on 17 December 1957, 16 January 1958, 16 June 1958 and 16 July 1958 are tabulated.

The microfilm record of all the charts from the 1957 - 1959 period was obtained and hourly tide heights extracted to the nearest 0.1 foot. Inspection of these records showed that the gauge was operating most reliably between 1 January 1958 and 21 January 1959. The data for this period was analysed and produced the results shown in Table 1.

| Constituent | 1958 Amplitude (m) | 1958 Phase ° | 1989 Amplitude (m) | 1989 Phase ° |
|---|---|---|---|---|
| O1 | 0.246 | 359 | 0.224 | 3 |
| P1 | 0.078 | 23 | 0.088 | 26 |
| K1 | 0.268 | 25 | 0.241 | 29 |
| N2 | 0.026 | 223 | 0.032 | 230 |
| M2 | 0.045 | 4 | 0.037 | 353 |
| S2 | 0.032 | 281 | 0.035 | 294 |
| K2 | 0.012 | 278 | 0.014 | 303 |
| M4 | 0.004 | 154 | 0.003 | 170 |
| MS4 | 0.003 | 225 | 0.003 | 232 |

Table 1
Comparison of constituents for Scott Base derived from 1958 and 1989 data

MacDonald and Burrows (1959) give details of the height relationship between the tide gauge and a reference bench mark. From this data and the tidal analysis, the height of the bench mark was determined to be 4.00 ± 0.08 metres. This compares with the previously published value of 3.97 metres (U.S. Navy Hydrographic Chart H.O. 6712), derived, presumably, from the limited analysis previously undertaken on the 1957 - 1958 records by Gilmour *et al.* (1962).

All available data from the transducer tide gauge for the period November 1988 to February 1990 has been analysed, the major constituents from this most recent data set are also shown in Table 1 above. The consistency between the two sets of results is readily apparent.

This tide gauge was also connected to a bench mark by levelling, in this case Scott Base Astro. From this data (Ant. F.B. 182, pp. 19 and 22) and the analysis, the height derived for Scott Base Astro is 15.70 ± 0.02 metres.

A comparison of the mean sea level determinations from 1958 and 1989 can be made because the relationship between the bench marks to which the tide gauges were referenced can be established through the survey system which exists in the Scott Base - McMurdo Station area. Table 2 gives the height for Scott Base Astro in terms of mean sea level derived from the two dates.

| | |
|---|---|
| 1958: | 15.81 ± 0.08 metres |
| 1989: | 15.70 ± 0.02 metres |

Table 2
Mean sea level heights for Scott Base Astro for 1958 and 1989

### 3.2 Cape Roberts Tide Gauge: 1988 - 1989

Analysis has been carried out on the 64 days of tidal records available from Cape Roberts, the results are shown below in Table 3. Because there are insufficient observations for a full determination of all constituents, the values for P1 and M2 have been inferred from K2 and S2 respectively.

| Constituent | Amplitude (m) | Phase ° |
|---|---|---|
| O1 | 0.219 | 11 |
| P1 | 0.071 | 40 |
| K1 | 0.216 | 33 |
| N2 | 0.041 | 242 |
| M2 | 0.054 | 3 |
| S2 | 0.046 | 306 |
| K2 | 0.012 | 329 |
| M4 | 0.007 | 143 |
| MS4 | 0.003 | 190 |

Table 3
Constituents for Cape Roberts

Despite the short sample period, the similarity betwen these results and those for Scott Base (Table 1) can be seen clearly.

An interim height of 14.65 ± 0.05 metres for Cape Roberts trig station is adopted, based the height connection to the tide gauge bench mark (Ant. F.B. 182, p. 39) and analysis of mean sea level.

### 3.3 Phase Lag Scott Base - McMurdo Station

Heath (1971a) compared a 30 day record taken at McMurdo Station and centred on 19 January 1971 with the mean of the constituents derived by Gilmour *et al.* (1962) for Scott Base and found, for the dominant constituent

(K1) a phase lag of 16° at McMurdo Station relative to Scott Base, making the tide at McMurdo Station approximately one hour later than at Scott Base. It must be recalled that this is based on only a single month's data at McMurdo Station and the analysis of 4 months of data at Scott Base from 1957 - 1958.

Taking the phases from the analyses now available for the entire 1958 - 1959 record, the time difference between Scott Base and McMurdo Station is reduced to approximately half an hour. Comparing the phases from the 1988 - 1990 Scott Base data with the 1971 McMurdo Station record the lag of McMurdo Station behind Scott Base decreases to only 12 minutes.

Because there is only one month of data available for McMurdo Station there is a limitation on the accuracy which can reasonably be expected from this comparison. Furthermore, there are no simultaneous observations at both sites to verify the results.

## 3.4 Phase Lag Scott Base - Cape Roberts

Simultaneous observations have been made at Scott Base and Cape Roberts throughout the duration of available tidal records at the latter site.

A comparison of the 3 major constituents for each site can be seen in Table 4 below. Note that the values shown for Scott Base are derived from the tidal record for the same period as those observations made at Cape Roberts and are, therefore, slightly different from the 1989 values shown in Table 1.

| Constituent | Scott Base Amplitude (m) | Scott Base Phase ° | Cape Roberts Amplitude (m) | Cape Roberts Phase ° |
|---|---|---|---|---|
| O1 | 0.237 | 3 | 0.219 | 11 |
| P1 | 0.082 | 34 | 0.071 | 40 |
| K1 | 0.248 | 27 | 0.216 | 33 |

Table 4
Comparison of constituents for Scott Base and Cape Roberts

Comparing the phases for K1 at these locations shows a lag for K1 of 6° (or 24 minutes) and 8° (32 minutes) for O1 which could produce a resultant tidal lag of close to half an hour for Cape Roberts behind Scott Base.

Extracting the observed times for 28 high tides and 26 low tides at both locations throughout December 1988 produced average time differences of 21 ± 4 minutes for low tides and 38 ± 9 minutes for high tides. The average of all 54 samples is 31 ± 5 minutes.

It is interesting to note that Scott Base is ahead of both McMurdo Station and Cape Roberts, yet is situated deeper into McMurdo Sound. This suggests that part of the tidal 'bulge' might propogate into McMurdo Sound from under the Ross Ice Shelf, having passed to the south of Ross Island. Further tide gauge installations will be required in the Ross Dependency to better determine the nature of the tidal motion.

# 4. FUTURE PROPOSALS

## 4.1 Scott Base

As mentioned at the conclusion of section 2.11 the gauge at Scott Base suffered damage in February 1990. The cables, not being fixed to a solid structure at the point where they enter the water, are prone to disturbance. Clearly, this event shows that the cables will require a greater degree of protection before the gauge can be considered to be truly permanent.

It appears that burying the cables in a shallow trench so that they are no longer exposed will be sufficient to ensure the continued operation of the gauge without interruption.

At present it is not known if the Scott Base personnel have been able to satisfactorily install the transducer which was despatched to replace the damaged system. It will be most unfortunate if this attempt is not successful as the next opportunity to try again will not occur until November 1990, resulting in the loss of some nine month's of records.

It has been suggested (V. Squire pers. comm.) that an increase in the averaging rate from 10 minutes to 1 minute would enable the seiches in McMurdo Sound to be detected. If implemented, this suggestion would result in a ten-fold increase in the quantity of data collected. This possibility has yet to be fully investigated.

## 4.2 Cape Roberts

The presence of fast ice at Cape Roberts and the break-out of the associated ice foot during the late austral summer appear to be the major obstacles to establishing a gauge at this site.

Experience to date has shown that the method of securing the gauge to the face of the rock outcrop is unsatisfactory. It is, therefore, proposed to drill a hole at an angle to emerge from the rock into the sea below the ice foot. Into this hole would be inserted a pipe through which the transducer could be lowered into the sea. Plans are being made in anticipation of carrying out this work in November 1990.

Power for the data logger is provided by a 12 volt battery connected to a solar panel for recharging during periods of daylight. Power and storage limitations will not permit the rapid sampling rate contemplated for Scott Base, at least during the first 2 - 3 years of operation.

## 4.3 Other Locations

A detailed study of the tidal circulation in McMurdo Sound would require more than the two gauges installed at Scott Base and Cape Roberts.

The tidal lag findings discussed in sections 3.3 and 3.4 indicate the possiblity of a south to north movement pattern through McMurdo Sound. Within the immediate vicinity of the Sound a suggested distribution of additional tide gauges could involve installations at Cape Chocolate, the northern end of Ross Island (or on Beaufort Island) and Cape Crozier at the eastern extremity of Ross Island. It must be noted that these are only initial suggestions and that some are designated as Specially Protected Areas or Sites of Special Scientific Interest. Furthermore, detailed site reconnaissance will be required before any selections can be finalised.

Any proposal to extend the McMurdo Sound tide gauge network is unlikely to be made until the Scott Base and Cape Roberts installations have been functioning reliably for 2 - 3 years.

## 5. ACKNOWLEDGEMENTS

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Special thanks go to the Victoria University of Wellington Antarctic Research Centre, in particular Mr A. R. Pyne, for establishing the Cape Roberts tide gauge in 1988, making equipment and the data available and assisting with the proposal to reinstate the gauge on a permanent basis.

Special mention is also due to the following D.O.S.L.I. personnel: Mr D. V. Belgrave for his practical advice and 'local' knowledge of conditions in Antarctica and Messrs J. W. Ritchie and M. D. Schumacher for organising the computer data files and providing the various analysis outputs.

Dr Hannah and Messrs Belgrave and Pyne are thanked for their helpful comments on earlier drafts of this paper.

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GEODETIC CONTROL FOR TIDE GAUGES IN ANTARCTICA

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## INTRODUCTION

Monitoring global sea level variation is much more complex than tracking the height of the sea surface relative to the local terrain at a set of globally distributed tide gauge stations. The Earth is a dynamic object, continuously changing shape in response to a variety of natural processes such as volcanism, tectonic plate motion, faulting, glacial rebound, and to human activities such as the extraction of oil and subsurface water deposits. As a result, the relative sea level at any given station can increase or decrease significantly, irrespective of any change in the total volume of the global oceans. And, because there are large areas where there are no land masses on which to mount tide gauges, the sea level determined by even hundreds of poorly distributed tide gauge stations may not provide a good estimate of the change in global absolute sea level. The tide gauge records must be cleansed of the effects of vertical crustal motions using geodetic measurements. In concept this is a simple process: the position and variations with time of each tide gauge must be determined relative to a global geodetic reference system, i.e., a well defined terrestrial reference frame. The difficulty is in achieving the requisite accuracy (rates to a fraction of a millimeter per year) over the full globe [Carter et al. 1989]. Only now are geodetic techniques, specifically Very Long Baseline Interferometry (VLBI) and absolute gravity, approaching the required accuracy. The Global Positioning System (GPS), and perhaps the Global Navigation Satellite System (GLONASS), are also expected to achieve the required accuracies (over regional spatial scales) within the next few years.

## VERY LONG BASELINE INTERFEROMETRY

Figure 1 shows the locations of operating and planned fixed geodetic VLBI observatories. The coverage in the northern hemisphere is reasonable already, and will continue to improve as planned new observatories are built. The "Quasar" network currently being built by the USSR will fill the largest remaining gap [Finkelstein and Yatskiv, 1989]. To achieve the greatest scientific return from the USSR system it is critical that the instrumentation be compatible with that at the stations already operating, i.e. the Mark III, K-3, and VLBA type of data acquisition terminals. This is widely recognized and appropriate arrangements are being made.

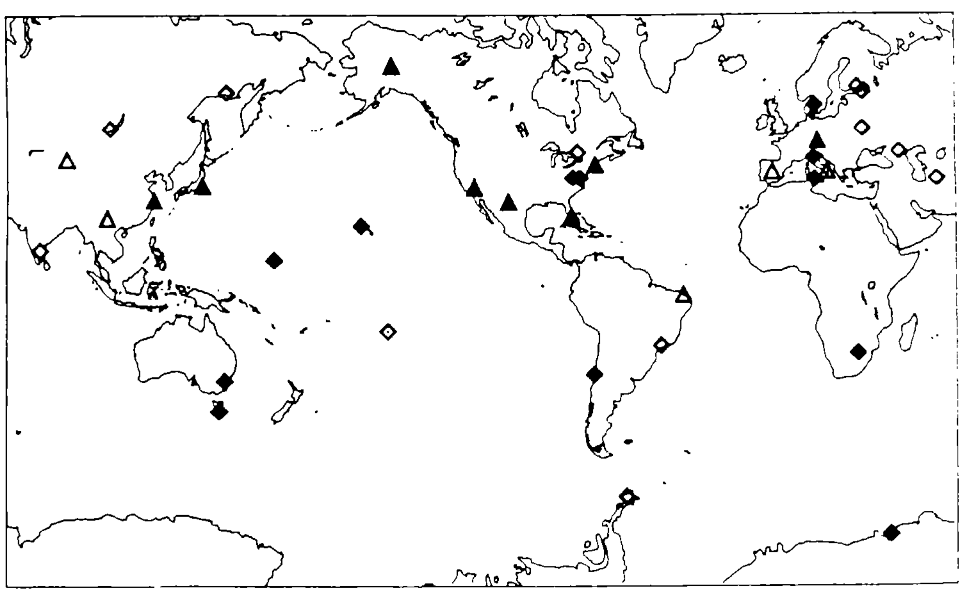

Figure 1. Map showing operating (solid) and planned (open) dedicated (triangles) and shared (diamonds) VLBI observatories.

During 1989 cooperative efforts between the National Geodetic Survey (NGS) and organizations in Australia (University of Tasmania) and South Africa (Hartebeesthoek Observatory) resulted in the first two regularly operating southern hemisphere geodetic VLBI stations. Work also began on the development of a new observatory near Fortaleza, Brazil, which will be operational in 1991. The Onsala Observatory, Sweden, the National Aeronautics and Space Administration, and NGS cooperated in test observations at the SEST Observatory, Chile, in April, 1990. Other nations are also developing observatories in the southern hemisphere. Japan has built an observatory at Syowa, and the Federal Republic of Germany and Chile have begun the construction of an observatory at O'Higgins station, on the Antarctic Peninsula. France has announced plans to develop a station in Tahiti, in the 1992-93 time frame.

Figure 2 shows the southern hemisphere VLBI network now expected to be operational by the mid 1990's. The network would be significantly improved by the addition of a third station in Antarctica, and the NGS and the Institute for Applied Astronomy, USSR, have begun exploring the possibilities of jointly developing such a station. Figure 3 shows the improved geometry that a station located in the vicinity of McMurdo would provide. In addition to improving the geometry of the southern hemisphere VLBI network the additional station would serve as a fiducial site for GPS operations in Antarctica, which would contribute to positioning tide gauges, mapping the ice caps using airborne laser altimeters on aircraft navigated by GPS, and to many other Antarctic scientific programs.

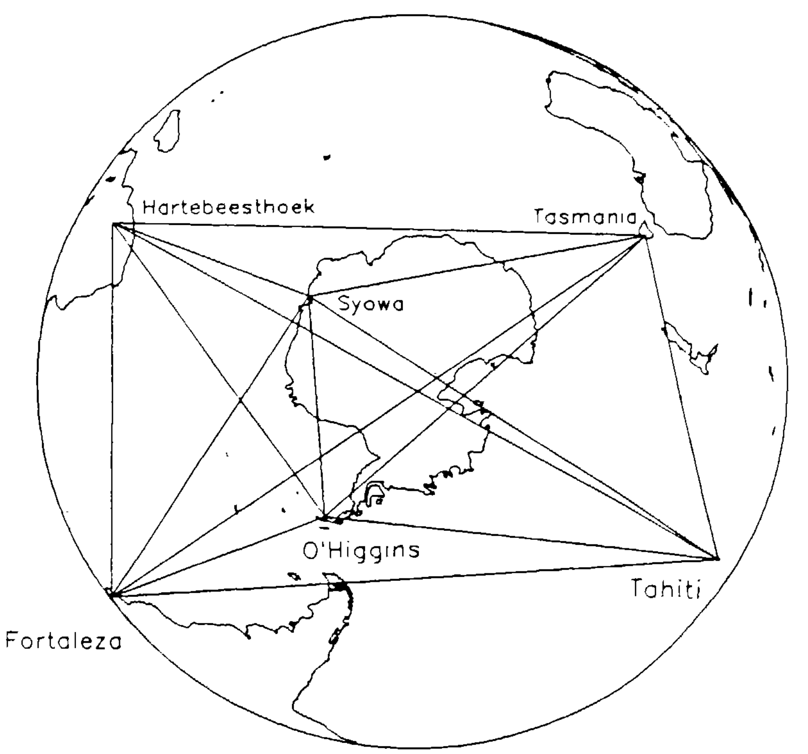


Figure 2. Map showing southern hemisphere VLBI network currently planned.

The VLBI instrumentation and procedures currently used yield interstation vectors accurate to the few centimeters level over spatial scales of thousands of kilometers in a 24-hour observing period. At that accuracy even 100 observing sessions per year will not yield rates of vertical crustal motion accurate enough for monitoring absolute global sea level. However, improvements which will be implemented within the next year promise to improve the accuracy by as much as an order of magnitude. Tests conducted by NASA during October 1989, achieved a repeatability of 1 mm in the horizontal components and

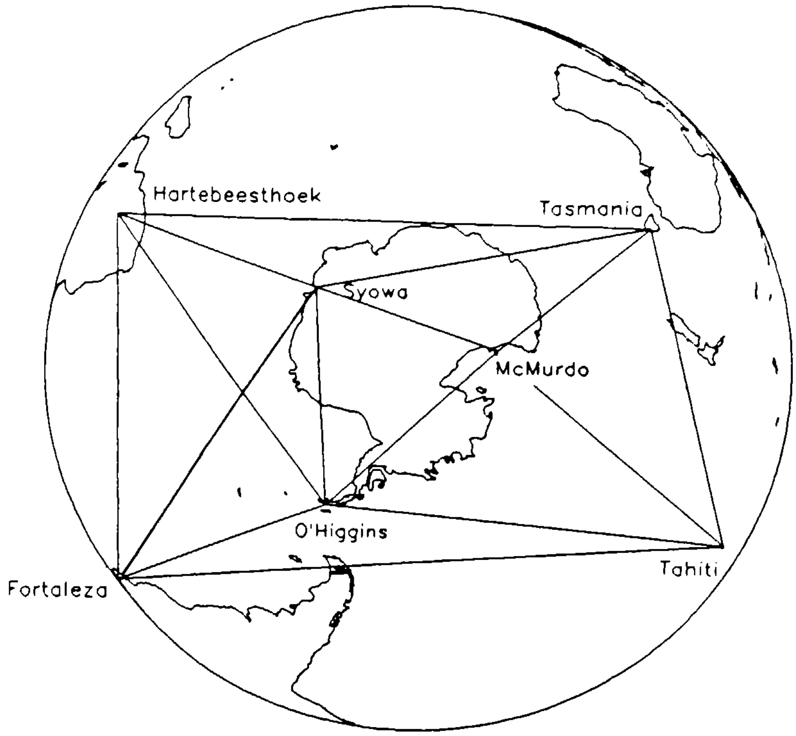


Figure 3. Map showing improved southern hemisphere VLBI network with station at McMurdo, Antarctica.

3 mm in the vertical component of a baseline approximately 800 kilometers in length. [T. Herring, private communication]. Figure 4 shows the scatter in the vertical coordinate of the Pie Town observatory which T. Herring obtained using his state-of-the-art data processing. The scatter does not appear random and may display systematic errors from atmospheric refraction. It would not be surprising to find that the scatter would increase somewhat over a longer time span, e.g. there may be seasonal atmospheric refractions effects that would contaminate the results. As a matter of fact there are known deformations of the Earth that are not yet included in the data reduction, such as the deformations caused by atmospheric loading of the crust. The NASA test results are very promising, but even when these improvements have been implemented operationally the limits of VLBI will still certainly not been reached. Haystack observatory has proposed an improved system that would increase the data recording rate to 896 megabits per second, improving the signal to noise ratio on existing telescopes or allowing the use of smaller aperture telescopes.

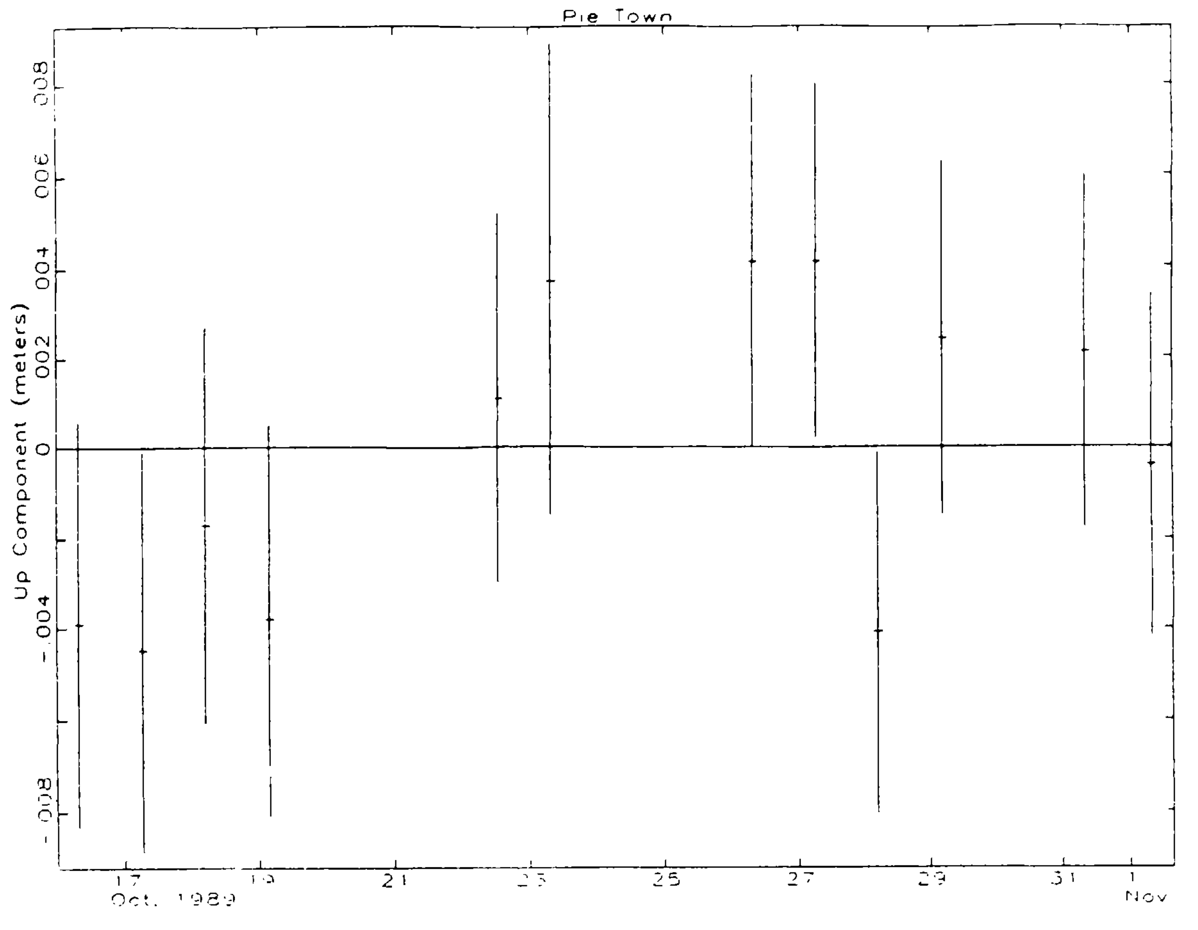


Figure 4. Plot of residuals from mean vertical coordinate for VLBI station Pie Town, from T. Herring.

## GLOBAL POSITIONING SYSTEM

GPS offers a less expensive and more portable method of positioning that can be used in conjunction with VLBI to survey tide gauge stations. Figure 5 is a sketch showing the combined use of fixed and mobile VLBI and GPS for tide gauge positioning. Essential to obtaining the required positioning accuracy is the establishment of a global tracking network to collect the observational data for computing accurate satellite ephemerides in the same coordinate system as VLBI. This task is being organized by the GPS Subcommission of the International Association of Geodesy. The network is known as the Cooperative International GPS Network (CIGNET). Figure 6 is a map showing the locations of operating and planned CIGNET stations. By comparing figure 6 with figure 1 it can be seen that several of the CIGNET stations are in fact collocated with VLBI observatories, which will ensure that the two reference frames will be compatible.

GPS can be used in dynamic or kinematic modes to accurately determine the path of moving objects, including remote sensing systems such as a laser profiling ice mapping system [Mader and Lucas, 1989].

The USSR is developing a satellite navigation system similar to GPS

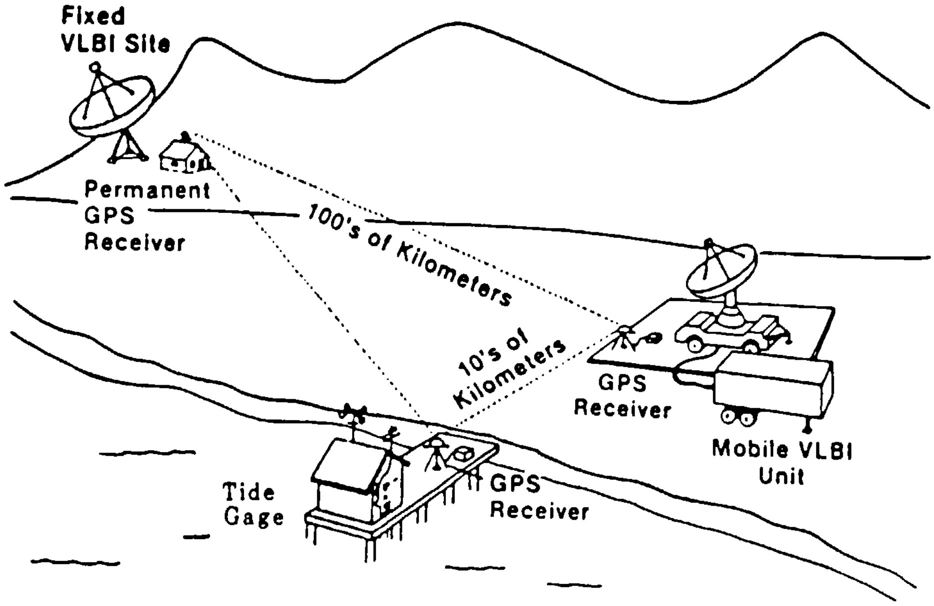


Figure 5. Sketch showing use of fixed and mobile VLBI and GPS for positioning tide gauges.

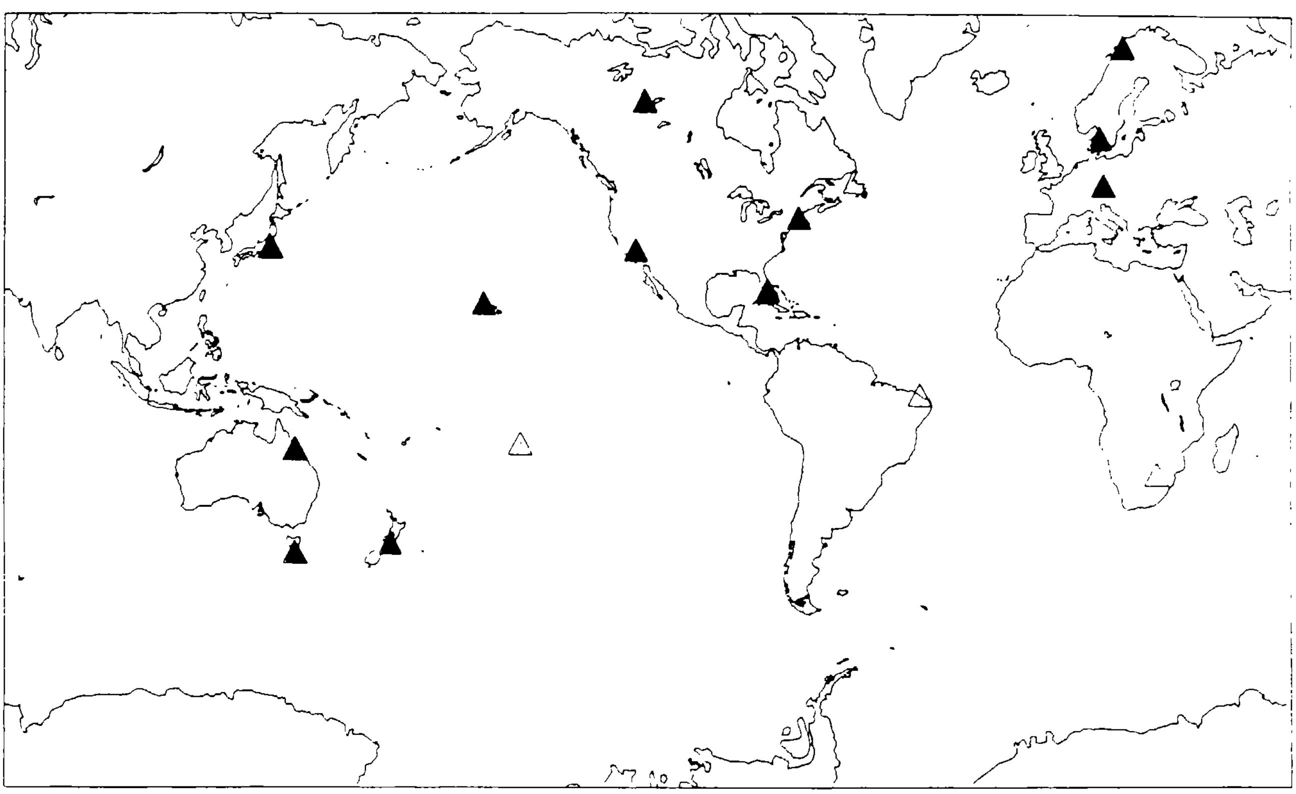

Figure 6. Map showing operational and planned CIGNET stations.

called the Global Navigation Satellite System (GLONASS). Combining the GPS and GLONASS systems would improve the number of satellites available at any time. Studies are underway to determine the feasibility of building receivers that would work with both systems.

## ABSOLUTE GRAVITY

The free-air gravity gradient near the surface of the Earth is approximately 3 microgals/cm. Uplift or subsidence that does not include the addition or removal of mass near the observation point, such as that associated with glacial rebound, must be accompanied by a change in gravity of 3 microgals per centimeter of vertical crustal motion. There are some difficulties in using gravity to sense vertical crustal motions, because the observed gravity changes with time for a number of reasons: changes atmospheric pressure patterns, ground water variations, polar motion, ocean tides, ocean loading. However, these phenomena can be observed or modeled and their effects taken into account, generally to the sub-microgal level.

Absolute gravity meters have been developed by researchers in several nations, including Japan, Italy, PRC, USSR, and USA. The NGS operates an absolute gravity meter built by the Joint Institute for Astrophysics (JILA), University of Colorado [Niebauer et al., 1986]. Figure 7 is a schematic showing how the meter operates. A mass is dropped in vacuum and its position is tracked with a laser interferometer. Use of atomic length and time standards allow the falling object's acceleration to be determined with part-per-billion accuracy. In it's original configuration the accuracy of the JILA instrument, based

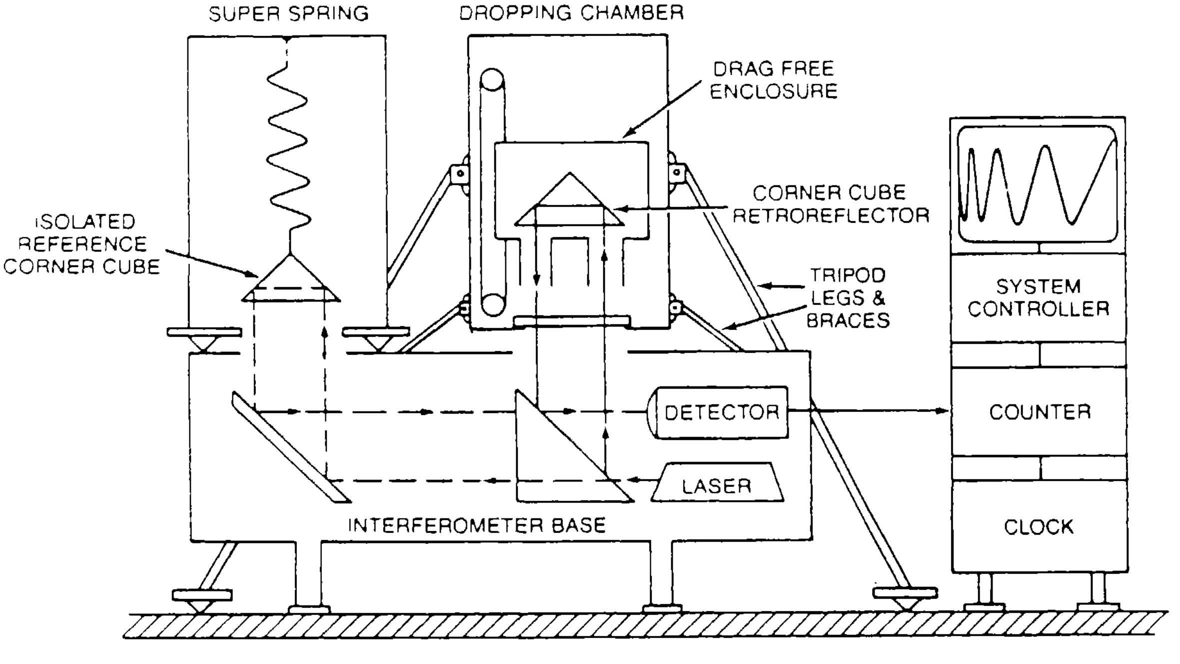


Figure 7. Sketch showing working principles of JILA absolute gravity meter.

on repeat visits to sites, was estimated to be 3 to 5 microgals [Peter et al. 1989]. Within the past few months NGS has implemented a number of improvements to the meter and the data processing procedures, and the scatter of repeat observations has been reduced to the 1 to 2 microgal level [Klopping et al., 1990]. At a recent international intercomparison test in Paris, 3 JILA and one Japanese meters agreed on the absolute gravity of a station to better than 1 microgal [F. Klopping, personal communication].

The NGS has already begun observing absolute gravity at tens of sites distributed across North America in an attempt to better map the vertical crustal motion associated with glacial rebound. This work is being done jointly with the Geological Survey of Canada, which also has a JILA meter [Lambert et al., 1989]. Cooperative observing projects are also in various stages of planning with organizations in Brazil, Taiwan, Norway, USSR, and Japan. NGS and the Institute for Applied Geodesy, FRG, are jointly funding the development of a new generation JILA absolute gravity meter. It is anticipated that absolute gravity will be measured in Antarctica at the Syowa and O'Higgins VLBI stations, and perhaps near other tide gauge stations.

## CONCLUDING REMARKS

One must only look at a map of the southern hemisphere, such as that shown in figure 2, to realize the central role that Antarctica must play in developing a global absolute sea level monitoring system. It is extremely fortunate that Japan and the FRG have committed the resources to develop Antarctic VLBI stations, which will also serve as GPS orbit tracking and fiducial stations. Recent results of sea level variation obtained by W.R. Peltier (private communications) suggest that the Antarctic ice cap may have melted several thousand years later than those in the northern hemisphere. If this turns out to be true, the contemporary vertical crustal motions in Antarctica, including particularly on the Antarctic peninsula, my be as large as 3 to 5 centimeters per year. The O'Higgins and Syowa VLBI stations should put useful bounds on such a model within a few years. Absolute gravity measurements should clearly be made on a regular basis at both stations beginning as soon as possible.

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# TIDE OBSERVATIONS IN THE ANTARCTIC
# THE CHILEAN EXPERIENCE

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**INSTITUTO HIDROGRAFICO DE LA ARMADA DE CHILE**

## BRIEF HISTORICAL REVIEW

From 1947 on, Chile began to carry out tidal observations in the Antarctic , together with the first permanent Antarctic base installation at Greenwich Island, South Shetland Islands. (Fig. 1).

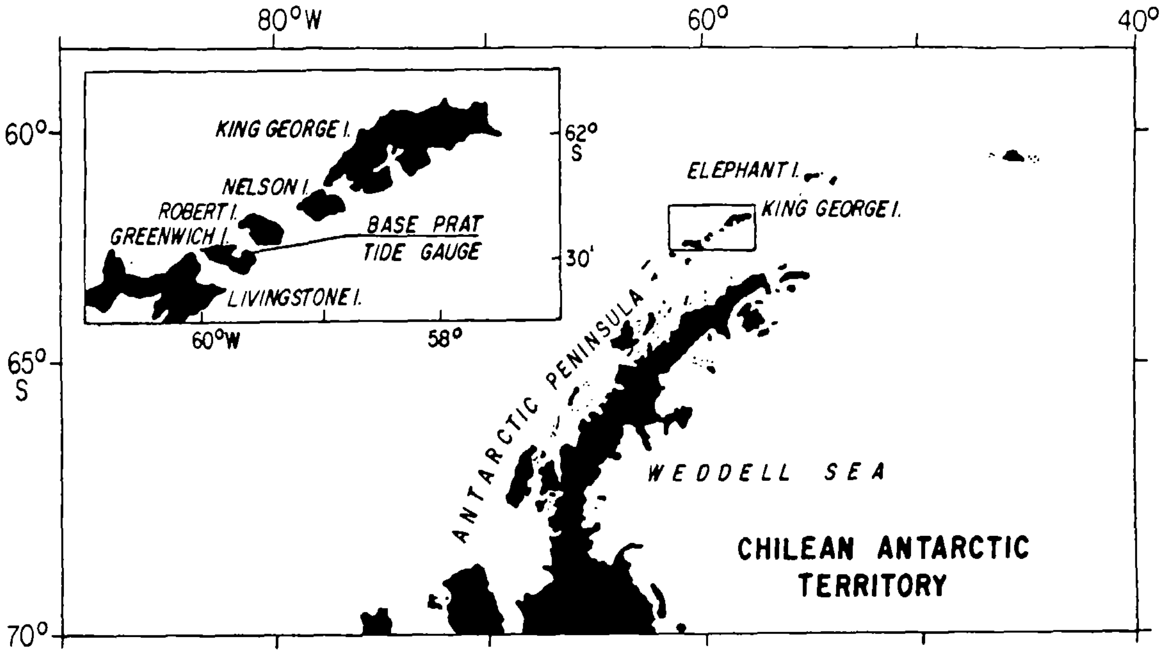


Figure 1.- Position of the first tide measurements carried out by the Chilean Navy in the Antarctica

Such observations carried out by assigned personnnel at the base consisted on readings taken at regular intervals, having a Tide Staff as reference. Those readings were taken continuously for a two weeks period during Southern hemisphere summer. The main objective was to get the data concerned so as to make the harmonic analysis and to characterize tide regime in the region.

Subsequent observations followed almost the same former pattern; this is to say, observations that are carried out for short periods of time using a tide staff, during summer season, both by permanent crew at the Chilean Antarctic Bases and by groups of hydrographers working in the area.

Early in the sixthies, instrumental observations were carried out, making use of portable stilling-well tide gauges, getting continuous records of sea level for periods up to three months.

In all cases, there was a fundamental factor that prevented observations from being carried out all year long. Such factor was the sea surface freezing, the whole year, excepting summer time. The later made almost impossible to use common tide observation method. This limited sea level measurements works to only Southern hemisphere summer time.

Due to the above mentioned, at the begining of the seventhieths, it was decided to iniciate permanent observations at Chilean antarctic bases in an experimental way. Bubbler Tide Gauges, which had proven to have several advantages over stilling well gauges (Pugh, 1972), were used in order to get continuous records, of several years length, for scientific and hydrographic purposes.

This was possible due to the experience gained by the Hydrographic Institute of the Chilean Navy in the operation of this kind of gauges along continental Chile in previous years which had given excellent results, notwithstanding the limitation of these instruments since they demand for attention at least twice a week. In the Appendix A, a list of short term sea level measurements, carried out from 1947, is shown, including information related to name, geographical position, dates of begining and end, duration and type of available data.

## RECENT EXPERIENCE

In 1971, the Hydrographic Institute of the Chilean Navy and the Chilean Antarctic Institute, depending on the Chilean Foreign Affairs Ministry, set up a joint program of mutual cooperation in relation to sea-level observations at the Antarctica, in order to achieve a knowledge of tide regimes in the Antarctic region under which Chile claims possesion of, for scientific and technological activities to be fulfilled by our country.

Such program considered the establishment of long-term tide stations, of five years period of operation, and short-term tide stations to be working for at least one month during summer time, using bubbler tide gauges. (Fig. 2).

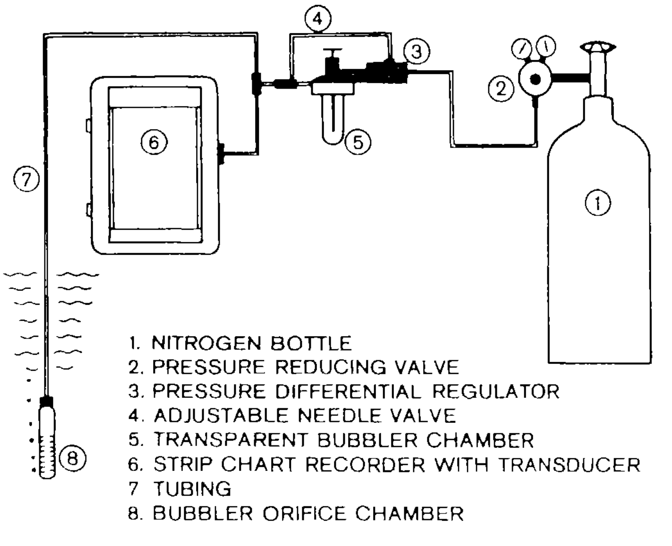


Figure 2.- Bubbler tide gauge sketch

Short-period stations would be installed and operated by trained personnel of the Hidrographic Institute of the Chilean Navy, supported by Chilean Antarctic Institute's resources. This was accomplished following a detailed program designed jointly between both Institutes.

Then, every year the necessary staff was instructed on bubbler tide gauge maintenance and operation. Afterwards, such people was assigned to the Antarctic Bases where long-term stations were installed.

In virtue of such plan, during 1972 a bubbler gas pressure tide gauge worked experimentally at the Antarctic Base "Libertador Bernardo O'Higgins" located at Puerto Covadonga, Antarctic Peninsula (lat. 63° 19' S, long. 57° 55' W), with the aim to gain experience under severe environmental Antarctic conditions, so as to subsequently install a tide station to be working permanently for five years in such area. The station began working continuously late in 1974.

However, there were several breakdowns along the year due to the rupture of the gas transmission system which runs between the sensor to the recording outfit, caused by ice movements as shown in Fig. 3. Records concerning observations carried out that year, show anomalies ascribable to sensor shiftings and displacements, reason by which this information was completely discarded after inspection and analysis.

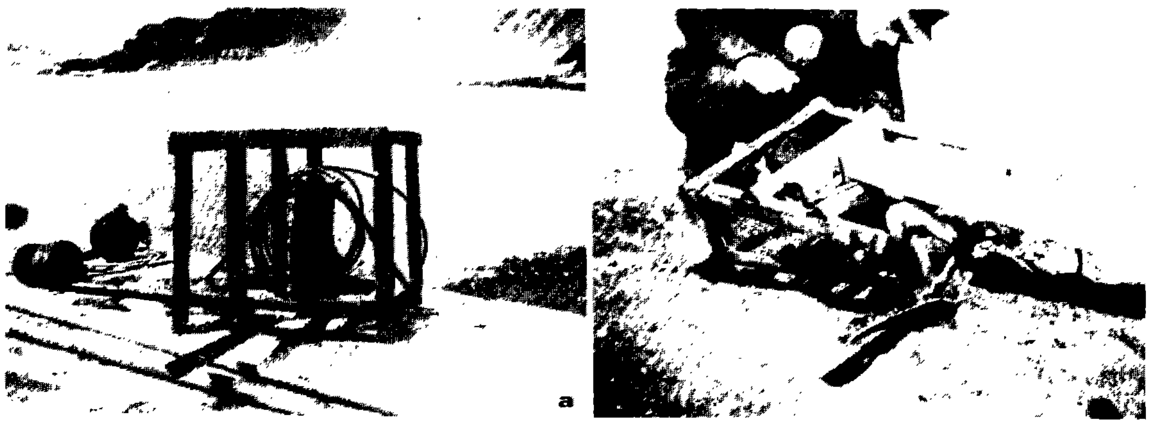


Figure 3.- Photographs showing basket were the sensor was located a) before deployment and b) Totally destroyed by ice movements, after one years operation

It was necessary then to reinstall the station with a new lay out of the gas tubing making an underground lay from the recorder to the orifice, protected inside a thick galvanized steel pipe. Equally, after a research of the maximum ice thickness the orifice was relocated in such a way that it would remain under the surface ice layer in any ice condition. After solving all those problems the station started working properly. Results of these measurements show a mixed semidiurnal regime, with important $M_2$ and $O_1$ components (I.H.A., 1981).

Following the experience gained at O'Higgins Base's Tide Station, continuously recording tides for five years, the station was moved to Fildes Bay, King George Island, where the Chilean Air Force base is located. The tide station was installed in the summer of 1979 and it worked for another continuous 5 years. At this site again, there were damages again on the gas tubing after the first year of operation, but this and another minor problems were already present at Puerto Covadonga site, so the solutions found in every case were adopted to improve all the installation operation.

The former is clear at the permanent tide station in Greenwich Island, operated by the Navy personnel of Arturo Prat base where there have been no problems since it started working in February 1983.

Figures 4, 5 and 6 show a graph of hourly heights recorded during one year operation in the above mentioned stations, and in appendix B, harmonic constants, corresponding to a one-year series in Base Prat, Base O'Higgins and Base Marsh respectively, are given.

# HOURLY HEIGHTS BASE O'HIGGINS 1975

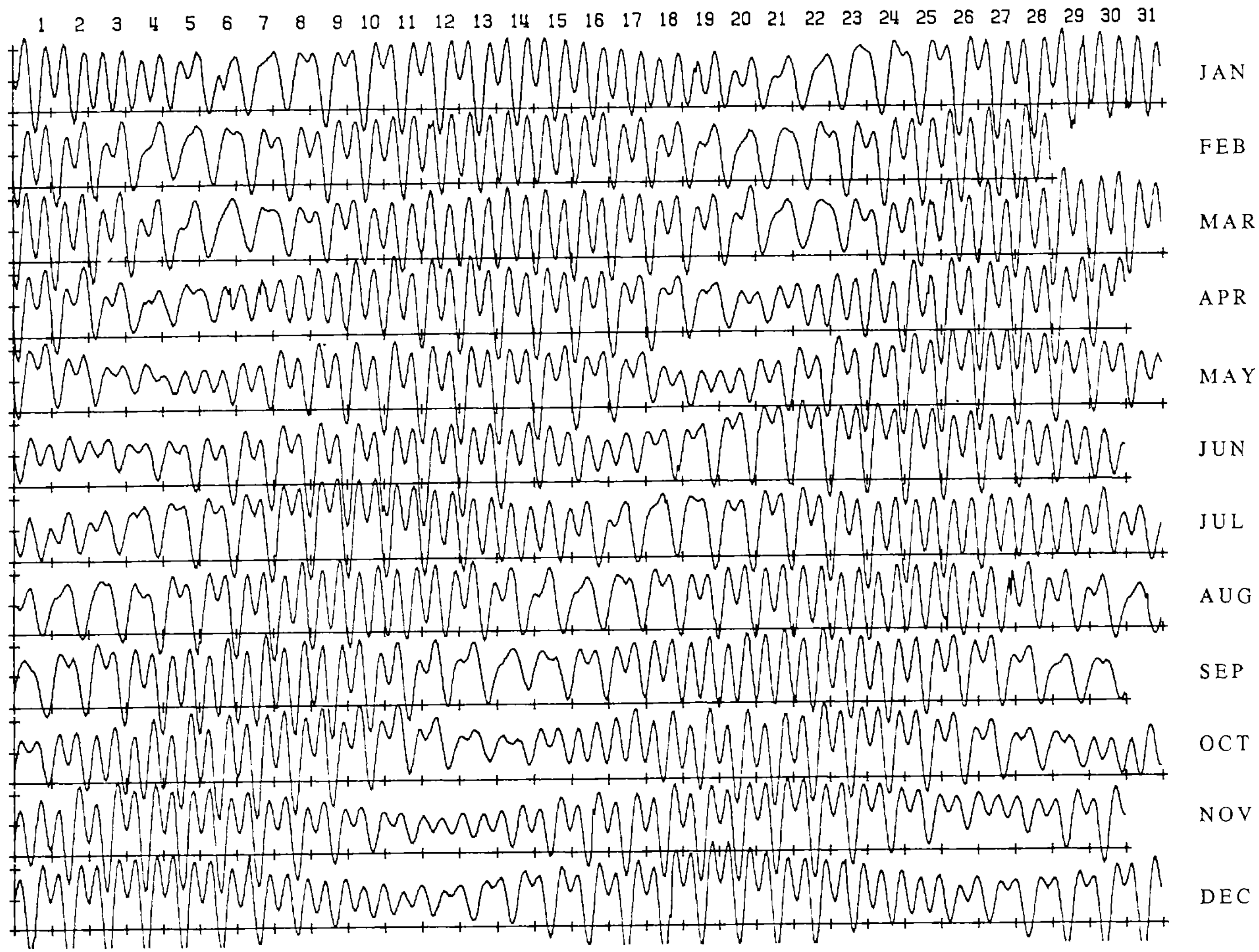


Figure 4.- Example of tide curve for Base O'Higgins station

# HOURLY HEIGHTS BASE MARSH 1983


Figure 5.- Example of tide curve for Base Marsh station

# HOURLY HEIGHTS BASE PRAT 1989

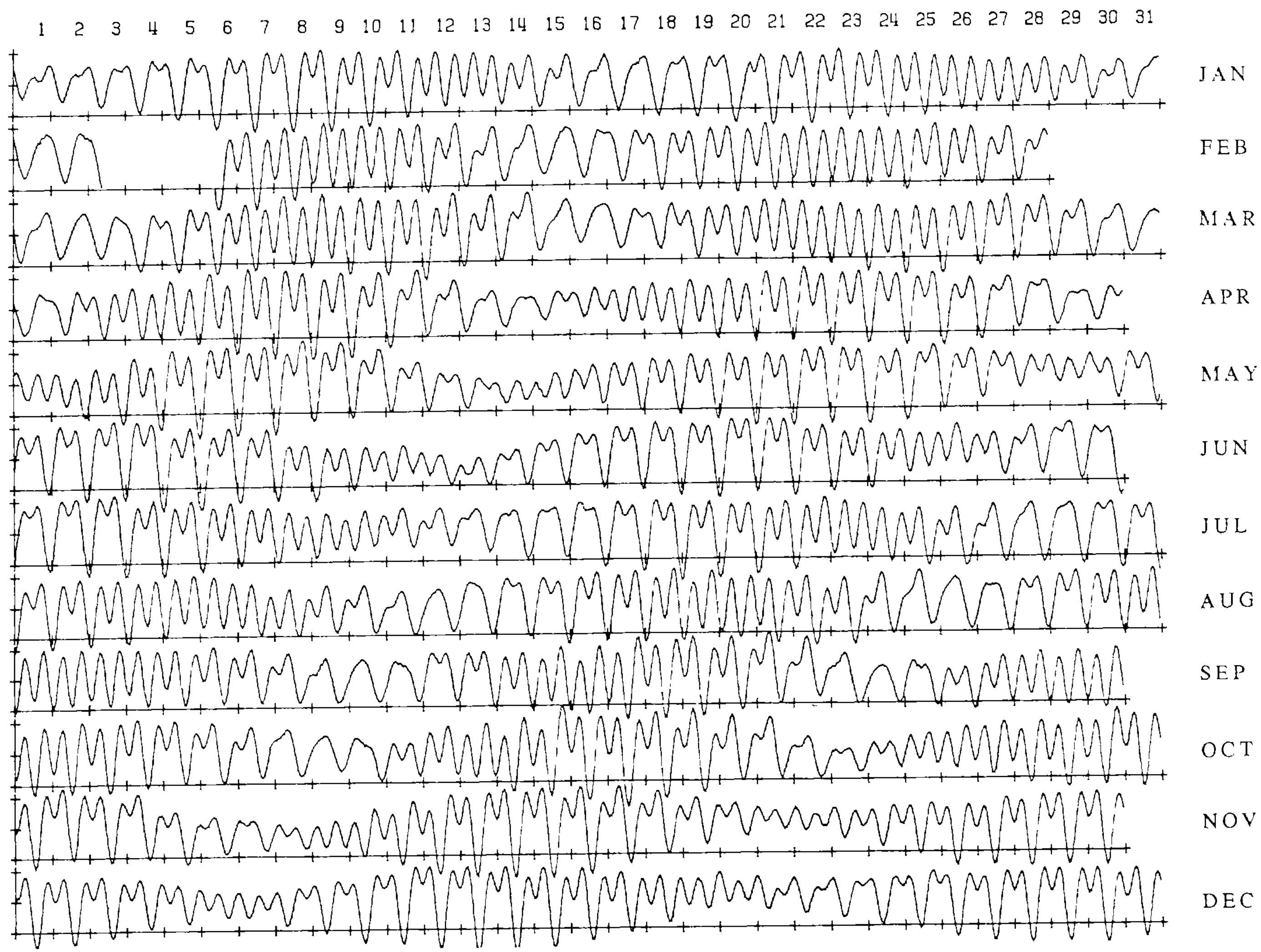


Figure 6.- Example of tide curve for Base Prat station

## OFTEN OCURRENCE PROBLEMS

During the first observations carried out in the Antarctica, most of problems experienced were due to the sea surface freezing, which made impossible readings over the Tide Staff and also impeded installing permanent structures, like tubes for floater tide gauges. (Fig. 7).

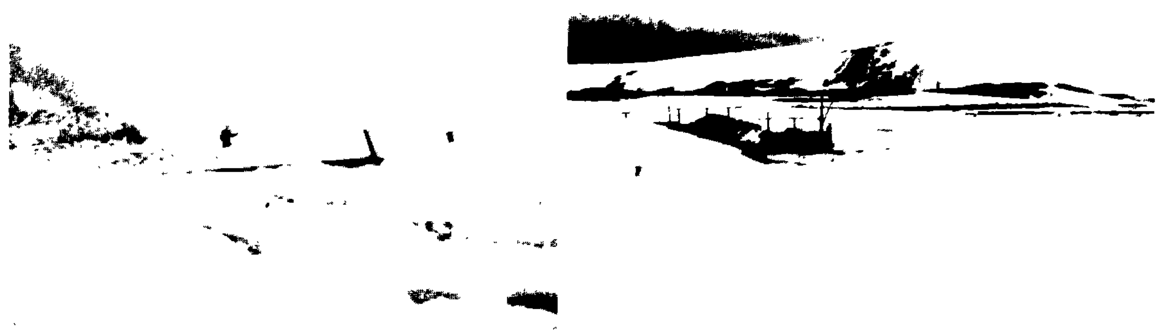

Figure 7.- Photographs showing freezing of the sea surface, taken at Base Prat and Base Marsh stations

This problem, inavoidable, oftenly caused displacement of the control scale and of every structure trapped within it, including small piers as is shown in photograph in Fig. 8. Fortunalety, this does not cause an unsolvable problem because the benchmark network, installed in the neighborhood of the station allows quantifying scale displacement, recovering original levels after a proper correction over the observed data. For most of scientific and hydrographic purposes this correcting procedure is adequate.

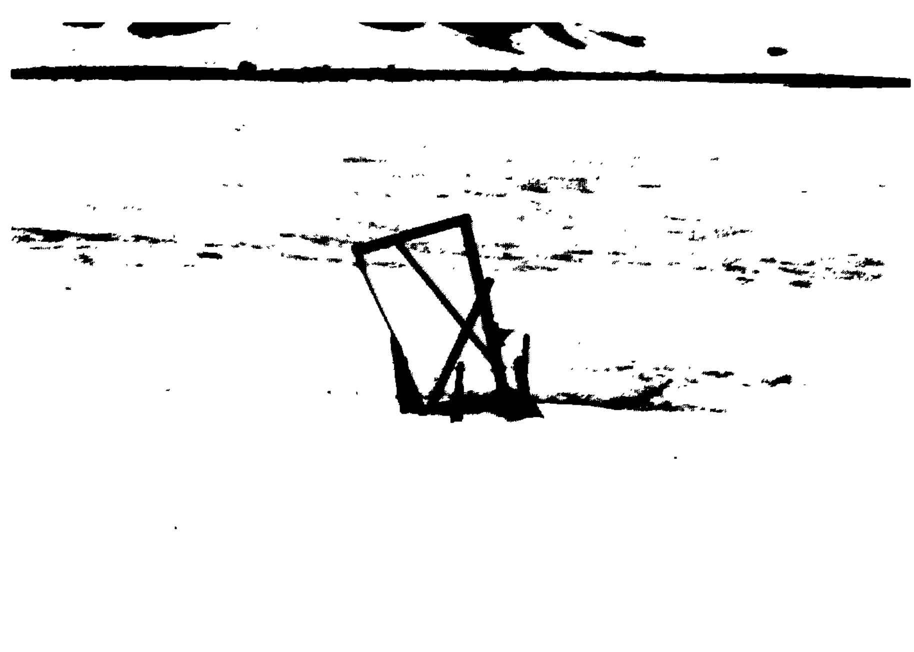

Figure 8.- Small pier trapped whitin the ice at Base Prat station. The ice movement caused the control tide staff shifting

During short-term tide observations, carried out every year along with Antarctic Campaigns, in general, unsolvable problems have not been experienced. In few occasions, when measurements are carried out near of a glaciar, great icebergs slip, specially during summer time, cause abnormal waves that may be dangerous to people in charge of measurements and, moreover, may destroy sensor and scale instalations if they are not properly secured, as shown in Fig. 9.

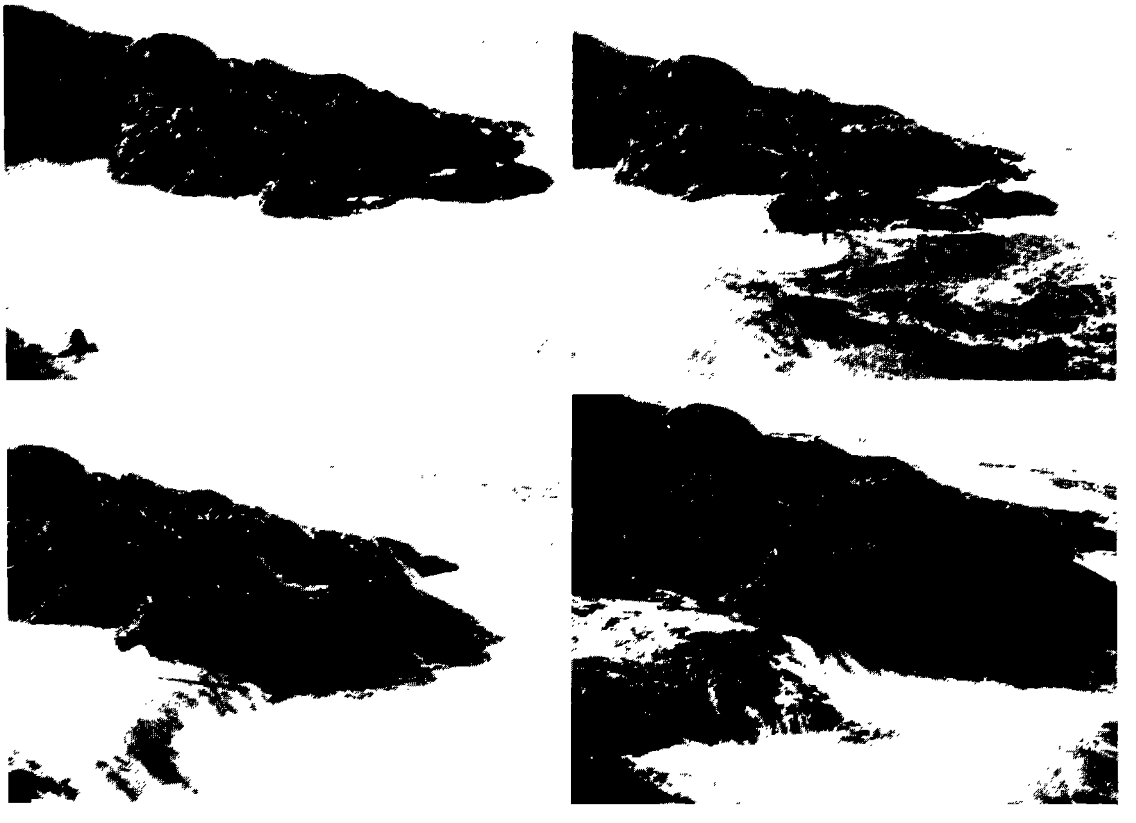

Figure 9.- Sequence of wave caused for iceberg slip which destroyed totally installation for short-term sea level observation

## THE FUTURE WORK

In the near future, plans to establish new permanent stations in the Antarctic Continent will be developed.

These plans will intend to replace bubbler gauges with new instruments, with few requirements for human supervision and with digital recording systems which will abbreviate processing time.

Requirements for real-time data transmission, using satellite or telemetry systems, are not going to be considered because the high costs involved and because there is not special requirements to do it at this moment.

When operational, the new system will allow us to establish additional Permanent Tide Stations and also more short-term measurements will be carried out, overcoming our present restrictions in the field work that refers mainly to personnel requirements

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# APPENDIX A

## SHORT-TERM SEA LEVEL MEASUREMENTS IN THE ANTARCTICA BY THE CHILEAN NAVY

| STATION NAME | POSITION | FROM/TO | RECORD LENGTH | DATA FORMAT |
|---|---|---|---|---|
| BASE PRAT (GREENWICH I.) | 62° 29' S 059° 38' W | 04. 3.1947/19. 3.1947 | 15 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 05. 1.1948/08. 2.1948 | 24 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 18.12.1955/21. 1.1956 | 33 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 17. 2.1957/01. 3.1957 | 10 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 08. 2.1965/27. 2.1965 | 19 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| CALETA GLORIA | 64° 49' S 062° 52' W | 05. 3.1951/10. 3.1951 | 6 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 6.1952/30. 6.1952 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 9.1952/30. 9.1952 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 6.1954/30. 6.1954 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 9.1954/30. 9.1954 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 6.1955/30. 6.1955 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 9.1955/30. 9.1955 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 6.1959/30. 6.1959 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 01. 9.1959/30. 9.1959 | 30 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| CALETA PENDULO (DECEPTION I.) | 62° 56' S 060° 35' W | 06. 2.1956/12. 2.1956 | 6 DAYS | HOURLY HEIGHTS |
| BAHIA SOUTH | 64° 52' S 063° 36' W | 08. 1.1963/ 4. 2.1963 | 28 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 15. 1.1985/17. 2.1985 | 33 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| CALETA ARMONIA | 62° 19' S 059° 10' W | 28. 1.1963/12. 2.1963 | 16 DAYS | HOURLY HEIGHTS, HIGH AND LOW TIDES |
| BASE O'HIGGINS (P. COVADONGA) | 63° 19' S 057° 55' W | 29. 1.1963/21. 2.1963 | 24 DAYS | HIGH AND LOW TIDES |
| | | 01. 2.1966/31. 3.1966 | 2 MONTHS | HIGH AND LOW TIDES |
| | | 27.12.1966/28. 2.1967 | 2 MONTHS | HOURLY HEIGHTS |
| | | 01. 1.1967/31. 1.1967 | 31 DAYS | HIGH AND LOW TIDES |
| | | 01. 1.1970/31. 3.1970 | 3 MONTHS | MARIGRAMS HOURLY HEIGHTS, HIGH AND LOW TIDES |
| | | 26.12.1971/ DEC. 1972 | 1 YEAR | MARIGRAMS, HOURLY HEIGHTS |
| | | 31.12.1974/ DEC. 1978 | 5 YEARS | MARIGRAMS, HOURLY HEIGHTS |
| BASE MARSH (FILDES BAY) | 62° 12' S 058° 56' W | 01.12.1972/31.12.1972 | 30 DAYS | HIGH AND LOW TIDES |
| | | FEB. 1979/FEB. 1983 | 5 YEARS | MARIGRAMS, HOURLY HEIGHTS |
| PUNTA SPRING | 64° 18' S 061° 05' W | 13. 1.1982/11. 2.1982 | 30 DAYS | MARIGRAMS, HOURLY HEIGHTS |
| CALETA BALLENEROS (DECEPTION I.) | 62° 59' S 060° 33' W | 16. 1.1984/14. 2.1984 | 30 DAYS | MARIGRAMS, HOURLY HEIGHTS |
| COOPER MINE (ROBERTS I.) | 62° 20' S 059° 30' W | 12. 1.1986/11. 2.1986 | 30 DAYS | MARIGRAMS, HOURLY HEIGHTS |

CHILEAN NAVY
HYDROGRAPHIC INSTITUTE

# HARMONIC CONSTANTS

## GENERAL INFORMATION

| | | | | |
|---|---|---|---|---|
| STATION NAME | : | **BASE MARSH** | | |
| LATITUDE | : | **62° 12' S** | LONGITUDE : | **058° 52' W** |
| COUNTRY | : | **CHILE** | | |

| | | | |
|---|---|---|---|
| TIME ZONE | : | **60° W (+4)** | |
| PERIOD COVERED | : | **FROM 01.NOV.1982** | **TO 04.NOV.1983** |
| $Z_o$ | : | **415.01 CMS. OVER ZERO STAFF** | |

| NAME | FREC. | AMPL. (cms) | PHASE (g) | NAME | FREC. | AMPL. (cms) | PHASE (g) |
|---|---|---|---|---|---|---|---|
| Sa | 0.0001140741 | 9.21 | 205.13 | | | | |
| Ssa | 0.0002281591 | 2.54 | 280.60 | $M_2$ | 0.0805114007 | 42.46 | 184.75 |
| MSm | 0.0013097808 | 1.86 | 66.60 | $H_2$ | 0.0806254748 | 0.91 | 299.15 |
| Mm | 0.0015121518 | 0.54 | 124.57 | $LDA_2$ | 0.0818211815 | 0.25 | 193.43 |
| MSf | 0.0028219327 | 1.45 | 216.98 | $L_2$ | 0.0820235525 | 1.85 | 206.95 |
| Mf | 0.0030500918 | 0.99 | 311.62 | $T_2$ | 0.0832192592 | 1.05 | 275.39 |
| $ALP_1$ | 0.0343965699 | 0.31 | 27.52 | $S_2$ | 0.0833333333 | 23.26 | 233.30 |
| $2Q_1$ | 0.0357063507 | 0.85 | 347.43 | $R_2$ | 0.0834474074 | 0.45 | 202.89 |
| $SIG_1$ | 0.0359087218 | 0.98 | 341.23 | $K_2$ | 0.0835614924 | 7.68 | 229.89 |
| $Q_1$ | 0.0372185026 | 6.13 | 351.10 | $ETA_2$ | 0.0850736443 | 0.47 | 266.97 |
| $RHO_1$ | 0.0374208736 | 1.06 | 3.79 | $MKS_2$ | 0.0807395598 | 0.95 | 186.98 |
| $O_1$ | 0.0387306544 | 29.19 | 0.95 | $MSN_2$ | 0.0848454852 | 0.34 | 358.77 |
| $TAU_1$ | 0.0389588136 | 0.64 | 193.40 | $M_3$ | 0.1207671010 | 0.12 | 156.58 |
| $BET_1$ | 0.0400404353 | 0.14 | 303.44 | $2MK_3$ | 0.1192420531 | 0.25 | 97.67 |
| $NO_1$ | 0.0402685944 | 2.73 | 25.34 | $SO_3$ | 0.1220639878 | 0.22 | 112.10 |
| $CHI_1$ | 0.0404709654 | 0.29 | 15.41 | $MK_3$ | 0.1222921469 | 0.09 | 130.81 |
| $PI_1$ | 0.0414385130 | 1.11 | 30.16 | $SK_3$ | 0.1251140794 | 0.21 | 217.34 |
| $P_1$ | 0.0415525871 | 9.29 | 14.22 | $MN_4$ | 0.1595106495 | 0.10 | 120.22 |
| $S_1$ | 0.0416666721 | 1.66 | 200.72 | $M_4$ | 0.1610228013 | 0.45 | 219.66 |
| $K_1$ | 0.0417807462 | 26.75 | 13.40 | $SN_4$ | 0.1623325821 | 0.02 | 46.35 |
| $PSI_1$ | 0.0418948203 | 0.70 | 164.69 | $MS_4$ | 0.1638447340 | 0.28 | 270.42 |
| $PHI_1$ | 0.0420089053 | 0.64 | 45.77 | $MK_4$ | 0.1640728931 | 0.13 | 228.45 |
| $THE_1$ | 0.0430905270 | 0.37 | 42.92 | $S_4$ | 0.1666666667 | 0.17 | 338.61 |
| $J_1$ | 0.0432928981 | 0.76 | 18.58 | $SK_4$ | 0.1668948258 | 0.04 | 281.86 |
| $OO_1$ | 0.0448308380 | 0.55 | 349.00 | $2MK_5$ | 0.2028035475 | 0.09 | 183.45 |
| $UPS_1$ | 0.0463429898 | 0.19 | 15.18 | $2SK_5$ | 0.2084474129 | 0.06 | 250.97 |
| $H_1$ | 0.0803973266 | 1.48 | 130.30 | $2MN_6$ | 0.2400220501 | 0.07 | 114.97 |
| $SO_1$ | 0.0446026789 | 0.33 | 21.84 | $M_6$ | 0.2415342020 | 0.02 | 179.95 |
| $OQ_2$ | 0.0759749451 | 0.39 | 227.07 | $2MS_6$ | 0.2443561347 | 0.13 | 20.54 |
| $EPS_2$ | 0.0761773161 | 0.45 | 330.82 | $2MK_6$ | 0.2445842938 | 0.04 | 311.71 |
| $2N_2$ | 0.0774870970 | 0.30 | 241.76 | $2SM_6$ | 0.2471780673 | 0.02 | 67.66 |
| $MU_2$ | 0.0776895680 | 0.53 | 56.54 | $MSK_6$ | 0.2474062264 | 0.05 | 141.97 |
| $N_2$ | 0.0789992488 | 5.50 | 154.59 | $3MK_7$ | 0.2833149482 | 0.03 | 256.80 |
| $NU_2$ | 0.0792016198 | 1.00 | 138.45 | $M_8$ | 0.3220456027 | 0.03 | 359.78 |

CHILEAN NAVY
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# HARMONIC CONSTANTS

## GENERAL INFORMATION

STATION NAME : **BASE PRAT**
LATITUDE : **62° 29' S** LONGITUDE : **059° 38' W**
COUNTRY : **CHILE**

TIME ZONE : **60° W (+4)**
PERIOD COVERED : **FROM 03.MAR.1984** **TO 12.MAR.1985**
$Z_o$ : **164.66 CMS. OVER ZERO STAFF**

| NAME | FREC. | AMPL. (cms) | PHASE (g) | NAME | FREC. | AMPL. (cms) | PHASE (g) |
|---|---|---|---|---|---|---|---|
| Sa | 0.0001140741 | 8.56 | 80.52 | | | | |
| Ssa | 0.0002281591 | 2.96 | 32.40 | M2 | 0.0805114007 | 41.52 | 167.13 |
| MSm | 0.0013097808 | 3.59 | 122.92 | H2 | 0.0806254748 | 0.90 | 126.63 |
| Mm | 0.0015121518 | 1.24 | 344.09 | LDA2 | 0.0818211815 | 0.33 | 273.51 |
| MSf | 0.0028219327 | 0.67 | 42.52 | L2 | 0.0820235525 | 2.55 | 192.75 |
| Mf | 0.0030500918 | 3.09 | 208.18 | T2 | 0.0832192592 | 1.68 | 219.56 |
| ALP1 | 0.0343965699 | 0.14 | 354.07 | S2 | 0.0833333333 | 23.02 | 213.96 |
| 2Q1 | 0.0357063507 | 0.92 | 317.69 | R2 | 0.0834474074 | 0.54 | 143.79 |
| SIG1 | 0.0359087218 | 0.84 | 343.43 | K2 | 0.0835614924 | 7.00 | 213.96 |
| Q1 | 0.0372185026 | 5.88 | 337.73 | ETA2 | 0.0850736443 | 0.26 | 251.10 |
| RHO1 | 0.0374208736 | 1.52 | 336.72 | MKS2 | 0.0807395598 | 1.05 | 131.65 |
| O1 | 0.0387306544 | 27.17 | 354.52 | MSN2 | 0.0848454852 | 0.31 | 101.26 |
| TAU1 | 0.0389588136 | 1.21 | 136.67 | M3 | 0.1207671010 | 0.16 | 113.19 |
| BET1 | 0.0400404353 | 0.14 | 165.10 | 2MK3 | 0.1192420531 | 0.41 | 59.12 |
| NO1 | 0.0402685944 | 1.81 | 12.25 | SO3 | 0.1220639878 | 0.23 | 90.45 |
| CHI1 | 0.0404709654 | 0.32 | 46.02 | MK3 | 0.1222921469 | 0.06 | 42.38 |
| PI1 | 0.0414385130 | 0.61 | 31.79 | SK3 | 0.1251140794 | 0.33 | 178.39 |
| P1 | 0.0415525871 | 8.22 | 3.17 | MN4 | 0.1595106495 | 0.16 | 124.28 |
| S1 | 0.0416666721 | 0.28 | 338.95 | M4 | 0.1610228013 | 0.63 | 200.64 |
| K1 | 0.0417807462 | 26.09 | 4.30 | SN4 | 0.1623325821 | 0.03 | 319.69 |
| PSI1 | 0.0418948203 | 0.39 | 89.26 | MS4 | 0.1638447340 | 0.35 | 268.30 |
| PHI1 | 0.0420089053 | 0.30 | 61.43 | MK4 | 0.1640728931 | 0.17 | 216.27 |
| THE1 | 0.0430905270 | 0.38 | 0.77 | S4 | 0.1666666667 | 0.16 | 325.93 |
| J1 | 0.0432928981 | 1.15 | 3.26 | SK4 | 0.1668948258 | 0.07 | 260.42 |
| OO1 | 0.0448308380 | 0.48 | 343.16 | 2MK5 | 0.2028035475 | 0.09 | 161.91 |
| UPS1 | 0.0463429898 | 0.14 | 44.12 | 2SK5 | 0.2084474129 | 0.01 | 168.47 |
| H1 | 0.0803973266 | 1.58 | 280.79 | 2MN6 | 0.2400220501 | 0.11 | 67.54 |
| SO1 | 0.0446026789 | 0.50 | 23.50 | M6 | 0.2415342020 | 0.11 | 205.14 |
| OQ2 | 0.0759749451 | 0.20 | 301.41 | 2MS6 | 0.2443561347 | 0.11 | 333.53 |
| EPS2 | 0.0761773161 | 0.24 | 278.47 | 2MK6 | 0.2445842938 | 0.10 | 341.62 |
| 2N2 | 0.0774870970 | 0.39 | 103.39 | 2SM6 | 0.2471780673 | 0.04 | 53.69 |
| MU2 | 0.0776895680 | 0.39 | 62.23 | MSK6 | 0.2474062264 | 0.05 | 162.60 |
| N2 | 0.0789992488 | 5.55 | 135.11 | 3MK7 | 0.2833149482 | 0.05 | 336.16 |
| NU2 | 0.0792016198 | 1.06 | 133.22 | M8 | 0.3220456027 | 0.02 | 245.85 |

CHILEAN NAVY
HYDROGRAPHIC INSTITUTE

# HARMONIC CONSTANTS

## GENERAL INFORMATION

STATION NAME : **BASE O'HIGGINS**
LATITUDE : **63° 19' S** LONGITUDE : **057° 55' W**
COUNTRY : **CHILE**

TIME ZONE : **60° W (+4)**
PERIOD COVERED : **FROM 30.DIC.1974** **TO 31.DIC.1975**
$Z_o$ : **188.18 CMS. OVER ZERO STAFF**

| NAME | FREC. | AMPL. (cms) | PHASE (g) | NAME | FREC. | AMPL. (cms) | PHASE (g) |
|---|---|---|---|---|---|---|---|
| Sa | 0.0001140741 | 3.31 | 119.66 | | | | |
| Ssa | 0.0002281591 | 3.24 | 78.79 | M2 | 0.0805114007 | 54.77 | 171.79 |
| MSm | 0.0013097808 | 4.27 | 159.59 | H2 | 0.0806254748 | 0.43 | 167.89 |
| Mm | 0.0015121518 | 4.59 | 133.47 | LDA2 | 0.0818211815 | 0.57 | 180.96 |
| MSf | 0.0028219327 | 1.74 | 220.79 | L2 | 0.0820235525 | 2.58 | 177.18 |
| Mf | 0.0030500918 | 4.64 | 205.03 | T2 | 0.0832192592 | 2.19 | 202.72 |
| ALP1 | 0.0343965699 | 0.50 | 286.30 | S2 | 0.0833333333 | 34.07 | 216.80 |
| 2Q1 | 0.0357063507 | 1.67 | 311.51 | R2 | 0.0834474074 | 0.24 | 155.21 |
| SIG1 | 0.0359087218 | 1.31 | 332.44 | K2 | 0.0835614924 | 9.46 | 217.27 |
| Q1 | 0.0372185026 | 9.43 | 340.14 | ETA2 | 0.0850736443 | 0.60 | 250.57 |
| RHO1 | 0.0374208736 | 1.96 | 343.85 | MKS2 | 0.0807395598 | 0.31 | 344.06 |
| O1 | 0.0387306544 | 41.43 | 351.17 | MSN2 | 0.0848454852 | 0.21 | 37.51 |
| TAU1 | 0.0389588136 | 0.57 | 49.40 | M3 | 0.1207671010 | 0.20 | 206.99 |
| BET1 | 0.0400404353 | 0.62 | 337.51 | 2MK3 | 0.1192420531 | 0.56 | 76.76 |
| NO1 | 0.0402685944 | 2.73 | 22.37 | SO3 | 0.1220639878 | 0.37 | 91.88 |
| CHI1 | 0.0404709654 | 0.27 | 328.48 | MK3 | 0.1222921469 | 0.09 | 138.15 |
| PI1 | 0.0414385130 | 0.73 | 359.80 | SK3 | 0.1251140794 | 0.60 | 187.62 |
| P1 | 0.0415525871 | 11.70 | 356.98 | MN4 | 0.1595106495 | 0.15 | 103.02 |
| S1 | 0.0416666721 | 0.84 | 7.98 | M4 | 0.1610228013 | 0.42 | 200.53 |
| K1 | 0.0417807462 | 36.54 | 1.24 | SN4 | 0.1623325821 | 0.10 | 358.31 |
| PSI1 | 0.0418948203 | 0.50 | 51.25 | MS4 | 0.1638447340 | 0.29 | 275.52 |
| PHI1 | 0.0420089053 | 0.46 | 285.35 | MK4 | 0.1640728931 | 0.16 | 206.06 |
| THE1 | 0.0430905270 | 0.36 | 356.17 | S4 | 0.1666666667 | 0.16 | 77.43 |
| J1 | 0.0432928981 | 1.43 | 11.27 | SK4 | 0.1668948258 | 0.10 | 271.59 |
| OO1 | 0.0448308380 | 0.90 | 359.32 | 2MK5 | 0.2028035475 | 0.12 | 168.76 |
| UPS1 | 0.0463429898 | 0.10 | 339.78 | 2SK5 | 0.2084474129 | 0.04 | 220.77 |
| H1 | 0.0803973266 | 0.49 | 295.98 | 2MN6 | 0.2400220501 | 0.08 | 44.67 |
| SO1 | 0.0446026789 | 0.38 | 335.93 | M6 | 0.2415342020 | 0.14 | 189.97 |
| OQ2 | 0.0759749451 | 0.14 | 245.40 | 2MS6 | 0.2443561347 | 0.27 | 341.68 |
| EPS2 | 0.0761773161 | 0.08 | 24.76 | 2MK6 | 0.2445842938 | 0.08 | 266.92 |
| 2N2 | 0.0774870970 | 0.29 | 139.38 | 2SM6 | 0.2471780673 | 0.05 | 164.99 |
| MU2 | 0.0776895680 | 0.60 | 103.95 | MSK6 | 0.2474062264 | 0.04 | 32.58 |
| N2 | 0.0789992488 | 7.30 | 148.10 | 3MK7 | 0.2833149482 | 0.08 | 240.18 |
| NU2 | 0.0792016198 | 1.11 | 149.79 | M8 | 0.3220456027 | 0.10 | 278.28 |

# Review of Soviet Antarctic sea-level activities

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May 1990

On the Antarctic map you can find 5 Soviet coastal stations where sea-level measurements were carried out during the period since 1956 (the first Soviet Antarctic Expedition - SAE)(Tab.1).

Table. 1

| Station | 1957 | 1958 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | 1972 | 1985 | 1989 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Molodezhnaya | | | | | X | X | X | X | X | X | X | X | | | |
| Mirny | X | X | X | | | X | X | X | | X | X | | | | |
| Novolazarevskaya | | | | | X | | X | X | | X | | | X | | |
| Bellinsghausen | | | | | | | | | X | X | | | | | X |
| Russkaya | | | | | | | | | | | | | | X | |

Tab.1 shows the years when sea-level measurements have been obtained. The main activities were during the period 1964-72. The longest period of observations was at the station Molodezhnaya, but it must be pointed out that this sea-level measurements can be qualified as of reduced quality. A certain progress has been made in the understanding of tides nature in the Southern ocean, different tidal characteristics have been calculated, but we consider this results as preliminary.

To collect some rough information about sea level different types of instruments were used. For example in 1960 at the Lazarev station (now closed the vertical movements of fast ice were concidered as tidal one. Most of the tide gauge observations were obtained on the fast ice. The general scheme of this type of measurements is shown. Here we have the sum of ice and water occilations. Another point is that position of tide gauges had been changed according to ice conditions.

As a result tidal constituents calculated for a certain month were different from year to year(Tabl. 2). May be it also depends on general ice distribution, but mainly it is due to rough data.

Table. 2

Harmonic constituents calculated from data available

| YEAR | M 2 |  | S 2 |  | N 2 |  | K 2 |  | K 1 |  | O 1 |  | P 1 |  | Q 1 |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | g | H | g | H | g | H | g | H | g | H | g | H | g | H | g | H |
| M o l o d e z h n a y a |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1962 | 159 | 19,0 | 177 | 18,5 | 160 | 3,8 | 177 | 5,0 | 35 | 21,8 | 350 | 21,8 | 35 | 7,3 | 350 | 4,4 |
| 1976 | 161 | 19,4 | 172 | 17,6 | 147 | 4,1 | 172 | 4,8 | 354 | 23,7 | 346 | 25,3 | 354 | 7,9 | 346 | 5,0 |
| 1968 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| July | 162 | 20,4 | 175 | 16,6 | 145 | 3,5 | 175 | 4,5 | 1 | 21,8 | 35 | 25,9 | 1 | 7,2 | 345 | 5,1 |
| August | 160 | 21,6 | 175 | 18,1 | 202 | 1,9 | 175 | 4,9 | 357 | 25,5 | 346 | 25,0 | 357 | 8,5 | 346 | 5,0 |
| Septem. | 162 | 20,3 | 174 | 17,7 | 169 | 4,1 | 174 | 4,8 | 3 | 21,4 | 349 | 24,2 | 3 | 7,1 | 349 | 4,8 |
| Octob. | 164 | 20,8 | 172 | 17,7 | 168 | 4,3 | 172 | 4,8 | 354 | 21,7 | 347 | 21,6 | 354 | 7,2 | 347 | 4,9 |
| Nøvem. | 161 | 20,3 | 172 | 17,6 | 147 | 4,1 | 172 | 4,8 | 354 | 23,7 | 346 | 25,3 | 354 | 7,6 | 346 | 5,0 |
| M i r n y |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1956 | 355 | 24,2 | 94 | 14,7 | 317 | 5,4 | 94 | 4,0 | 352 | 27,2 | 334 | 29,3 | 352 | 9,1 | 334 | 5,9 |
| 1957 | 28 | 28,0 | 107 | 17,0 | 354 | 6,0 | 107 | 4,6 | 2 | 29,8 | 355 | 30,0 | 2 | 10,0 | 355 | 6,0 |
| 1968 B e l l i n s g h a u s e n |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| Febr. | 164 | 44.4 | 211 | 27,9 | – | – | – | – | 2 | 23,7 | 344 | 25,6 | 2 | 7,9 | – | – |
| April | 159 | 47,3 | 214 | 26,3 | – | – | – | – | 2 | 27,4 | 350 | 29,3 | 2 | 9,1 | – | – |
| July | 160 | 47,3 | 214 | 26,3 | – | – | – | – | 359 | 27,9 | 10 | 29,6 | 359 | 9,3 | – | – |
| Octob. | 162 | 43,3 | 204 | 26,0 | – | – | – | – | 4 | 23,4 | 350 | 26,9 | 357 | 7,0 | – | – |
| May 1989 – February 1990 |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| May | 281 | 47,1 | 334 | 23,3 | 247 | 6,8 | 334 | 6,4 | 62 | 29,0 | 45 | 30,5 | 62 | 9,7 | 43 | 6,1 |
| June | 283 | 47,7 | 342 | 21,7 | 250 | 4,8 | 342 | 5,9 | 61 | 28,4 | 46 | 30,3 | 60 | 9,5 | 44 | 6,1 |
| July | 281 | 45,4 | 337 | 23,8 | 267 | 3,8 | 337 | 6,5 | 66 | 27,7 | 44 | 28,8 | 66 | 9,2 | 41 | 5,8 |
| August | 281 | 44,3 | 340 | 25,5 | 251 | 3,0 | 340 | 6,9 | 60 | 26,6 | 49 | 29,5 | 60 | 8,9 | 47 | 5,9 |
| Septem. | 281 | 43,4 | 332 | 24,9 | 274 | 5,9 | 333 | 6,8 | 62 | 29,7 | 43 | 27,6 | 61 | 9,9 | 41 | 5,5 |
| Octob. | 282 | 44,7 | 333 | 25,6 | 286 | 8,2 | 333 | 7,0 | 65 | 27,2 | 47 | 27,2 | 65 | 9,1 | 45 | 5,4 |
| Novem. | 282 | 48,9 | 321 | 27,1 | 248 | 6,9 | 321 | 7,4 | 57 | 30,0 | 51 | 31,1 | 57 | 10,0 | 49 | 6,2 |
| Febr. | 281 | 46,1 | 337 | 26,5 | 298 | 1,2 | 337 | 7,2 | 68 | 26,8 | 46 | 28,6 | 68 | 8,9 | 44 | 5,7 |

During Antarctic winter with a maximum amount of ice the diminishing of tidal amplitude and phase delay is not approved enough by the results obtained.

As a result of unsufficient coverage of the region by observations, imperfectly understood variability of tidal phenomena, do not yet allow us to predict tides in the given region with sufficient accuracy. The RMS error of tide prediction in one of the seasons was 10-14 cm and included errors caused by nonperiodic components wich were not excluded. The relationship was found between the seasonal variability of mean sea level(msl) and wind regime.

The seasonal variability of tide elements, their relationship with ice conditions gives reason to recommend for tide prediction the use of constituents determined from monthly series.

The results obtained were actively used in the practice of scientific and operative support of navigation in the Southern ocean.

Now we see that a lot of work must be done to improve sea level studies in Antarctica. Today none of the Soviet stations carries out permanent measurements. Now we revise long-term programm for developing coastal oceanographic observations in connection with GLOSS, WOCE etc.

In this connection several problems must be solved:

1. Coordination of the question of required and sufficient number of tide gauges, practicable location of this network covering main important points, based on information available and calculation results.
2. Coordination of joint activities in installing bottom tide gauges that can be done by Soviet research vessels in addition to the coastal network.
3. Drawing conclusions on the compatibility of observations carried out with different instruments and working out common conseption on instrument support of this type of observations in Antarctica.
4. Solving the problem of data bank, exchange of data with dew regards for common interests.

Along with arrangement of network modelling and forecast techniques for tides, surges, seasonal sea level ghanges should presumably be improved.

It is quite evident that most of this problems can be solved with international cooperation and joint efforts.

# RECENT WORKS OF TIDAL OBSERVATIONS AT SYOWA STATION

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## 1. Introduction

Tidal Observation at Syowa Station ( Figure 1 ) has been carried out as a part of JARE ( Japanese Antarctic Research Expedition ) by Hydrographic Department since 1965. Its history was divided to the followng 3 stages with the using systems, which was reported at the former meeting records by Y. Michida (1988).

I. Mechanical pressure gauge : 1965 - 1974
II. Strain gauge : 1975 - 1986
1) 1975-1985,
2) 1980- working.
III. Quartz oscillator : 1987 -
1) 1987(Jan.)-1989(Nov.),
2) 1988(Jan.)-1988(Nov.),
3) 1990(Jan.)- working.

In the first stage, the mechanical pressure gauge was unable to continue over 1 year so the sensor unit had to be recovered every year. In the second stage, the strain gauge was used for measuring the absolute pressure and its signals were transmitted through the electric cable to the recorder. The strain gauge installed in 1980 is working until now, but the drifts of reference point and the hysterisis of the sensor have become large. In the third stage, the quartz oscillator is used for the pressure sensor. The former two systems equipped with quartz oscillator were stopped in November 1989 and November 1988, respectively, by the troubles of the communicating cables. Therefore the new one was installed on January 25th, 1990 at the same place as the former systems, and is operated now.

## 2. Tide Observation System

Figure 2 shows the tidal observation system at Syowa Station. Tide gauge is fixed at the sea bottom 15 m below the sea surface with the anchor and sand bags. For the tidal signal, the water pressure compensated with the atmospheric pressure is measured with the quartz oscillator. The data sampled 5 times per second are averaged over one minute and recorded on a solid memory every 10 minutes. The sub-surface water proof cables are protected with plastic and wire tube and grounded by the sand bags. In order to keep this system, the protection of cables at the shoal zone is very important because the rushing sea ice attacks the cable at the beginning of warm season. Actually, the former systems, which were unable to be grounded tightly owing to the fast ice laid at the shoal zone, were both broken down in November. New system installed was grounded more tightly than the former systems because sea ice was fully open in January 1990.

## 3. Data transmitting

The hourly values of tidal observation are tabled at the beginning of the next month and the table are transmitted to the National Polar Research Institute (NPRI) at Tokyo with facsimile through a communication satellite. This transmitting system are tested since April 1990 and will be available soon.

Additionally, non-real time data of the hourly tide value are published in the series of " JARE Data Report " from NPRI every year.

4. Calibration

Tide gauge of the pressure type is easy to change the sensitivity and to drift the datum so that the calibration is essential to get reliable record for long period. At Syowa Station, sea ice opens during only some weeks in January. At that time, the calibration is carried out. Practically the actual sea level values are checked for one tidal cycle using the tide pole which is connected to the network of the bench marks by the leveling. However, sometimes the calibration was failed because sea ice did not open during the expedition. Figure 3 shows the resulted relative height of zero point of the tidal record ( 0 of g ) to the Bench Mark (No.1040) which was established on the base rock and levelled to the other Bench Marks. The zero points of the recent records since 1981 become more stable than those of the former records.

5. Mean Sea Level variation at Syowa Station

Using the data from January 1981 to December 1988 which datum level are nearly stable, monthly mean sea levels are calculated and shown in Figure 4. The values are referred to the level 4.191 m below the B.M.(1040) which is the calibration results for the first strain gauge in January 1975. For the seasonal change, the mean sea level is lowest in January and highest in May.

It is remarkable that annual mean sea level ( small white circle and dashed line ) tends to fall from 1982 to 1987 in the speed of about 4.5 cm/year. As the movement of sea level is relative to the ground, this tendency would be understood as the uplift of land around Syowa Station. This explanation is agreed with the results of Clark's model (1980) and the uplift would be caused by the rebound of ground due to the removal of land ice which occurred according to the glacial melting at the 5,000 years ago. However, the speed is too fast compared with the speed of model, and the other backup data are desirable to confirm the fact. Particularly the other tidal stations are desirable around the Antarctica in order to compare mean sea level movement.

6. Future

Another sensor will be installed at the same place as the present sensor in 1991 January by the next JARE party and the reliability and accuracy of tide observing system will be improved. Furthermore, deployment of other tide stations and network system are desired in order to study spatial change of mean sea level movement. As it is difficult for a country to make and to keep tide gauge network, international co-operation such as GLOSS will be more important in future.

Acknowledgement

The author wishes to thank Mr. Iwao Noguchi, who is director of ocean survey division and a contact person of Japan in GLOSS, for his kind encouragement.

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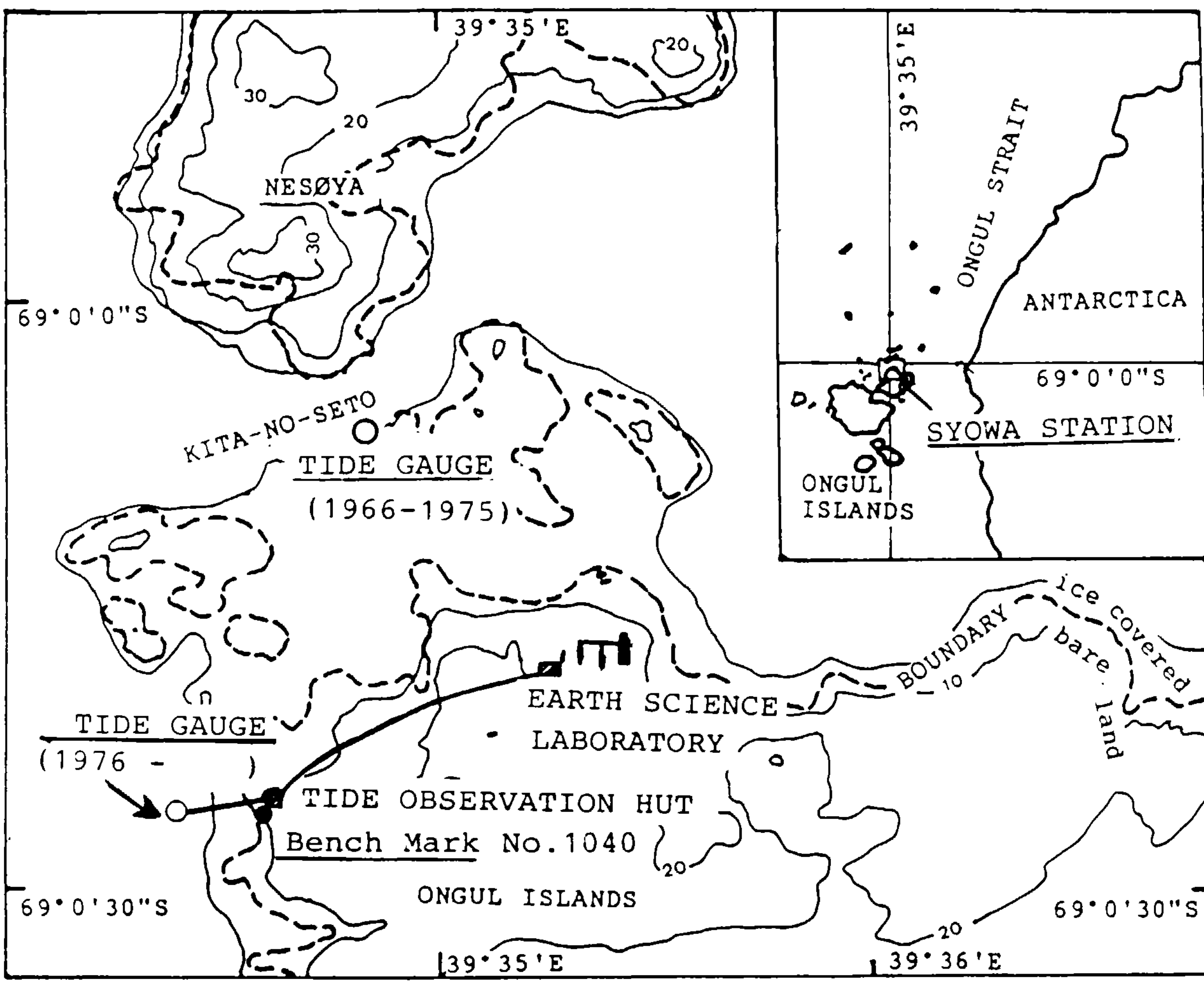



Figure 1 Location of Syowa Station and tide gauge.

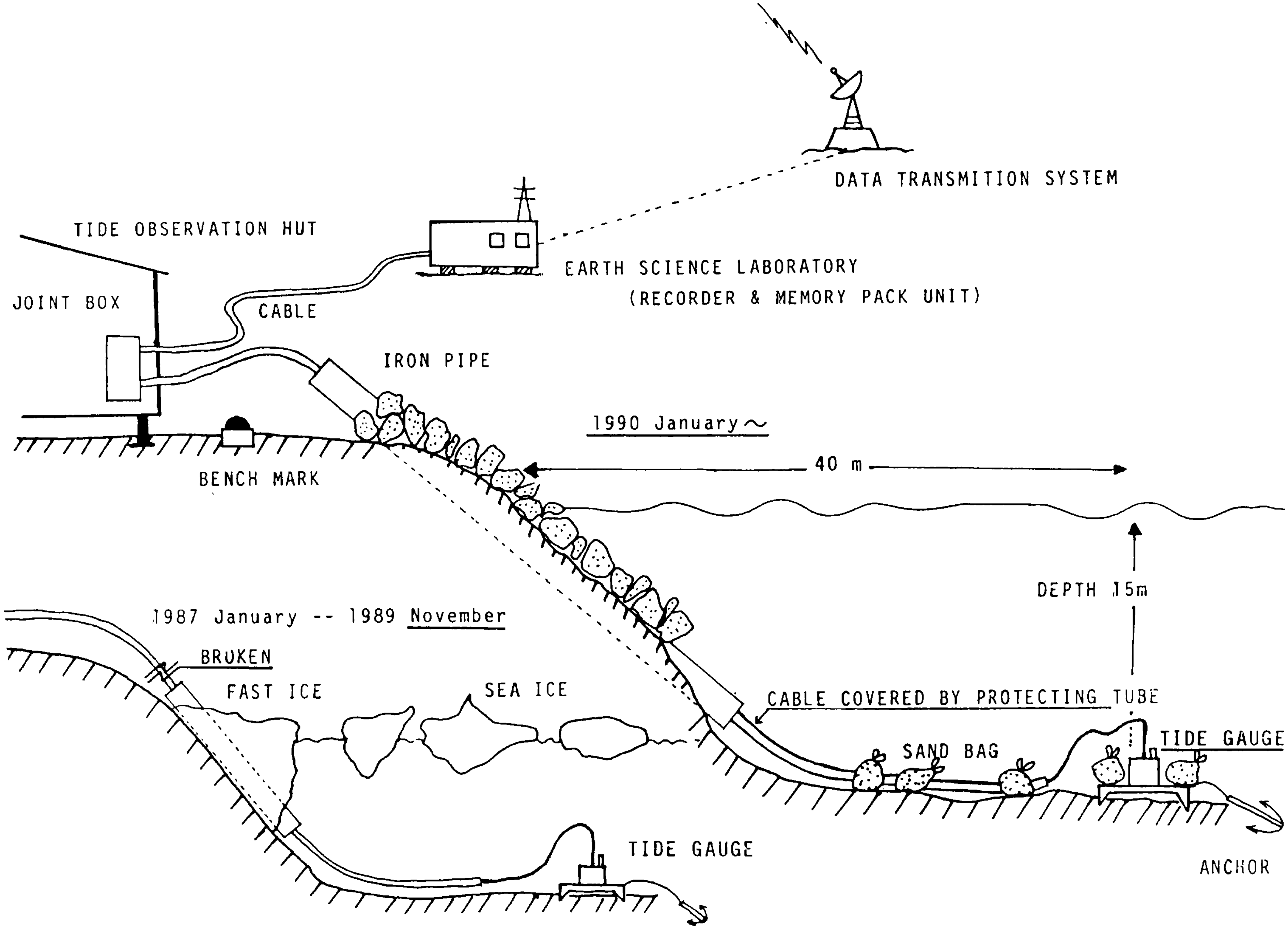



Figure 2 Tidal observation system at Syowa Station.

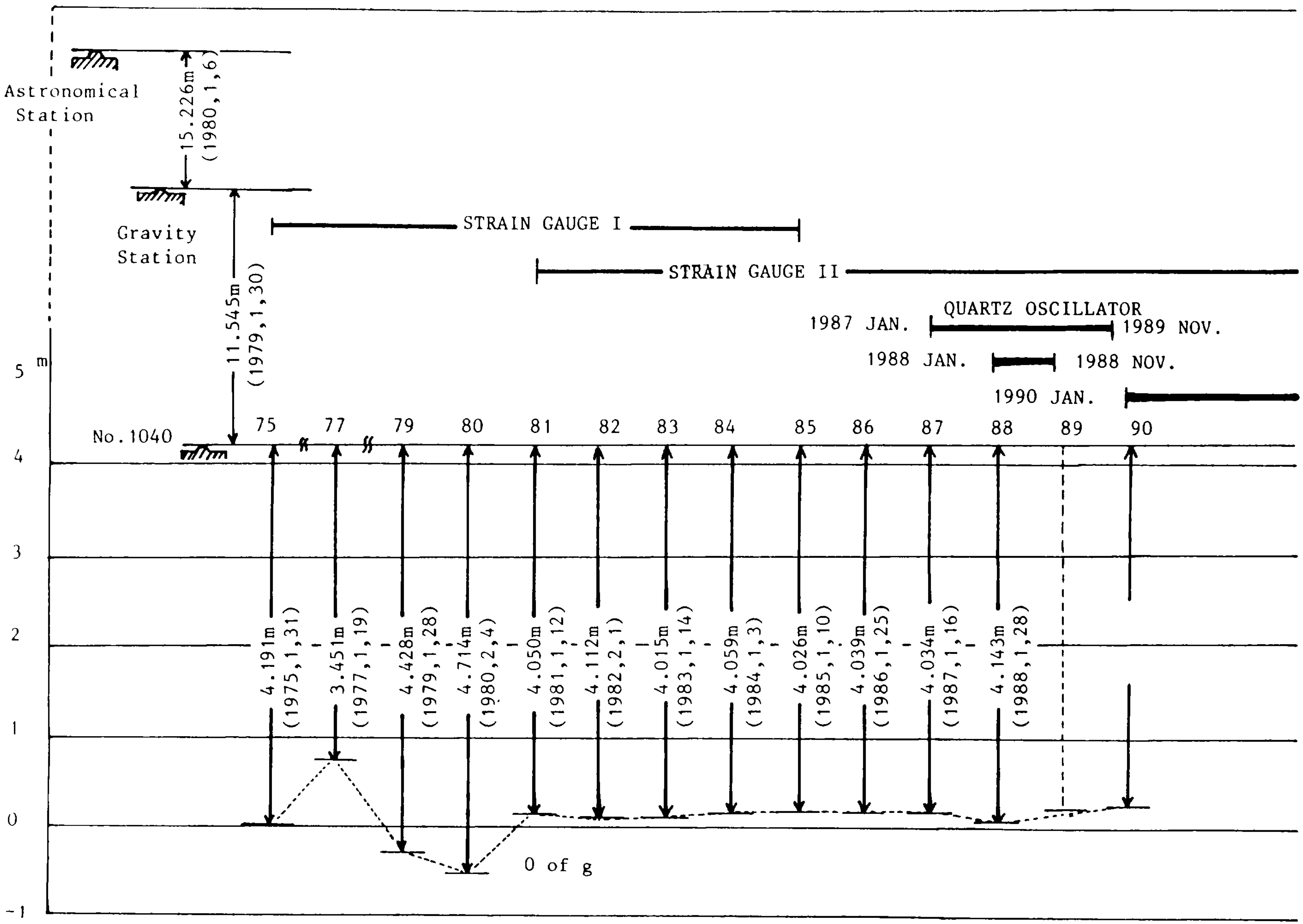
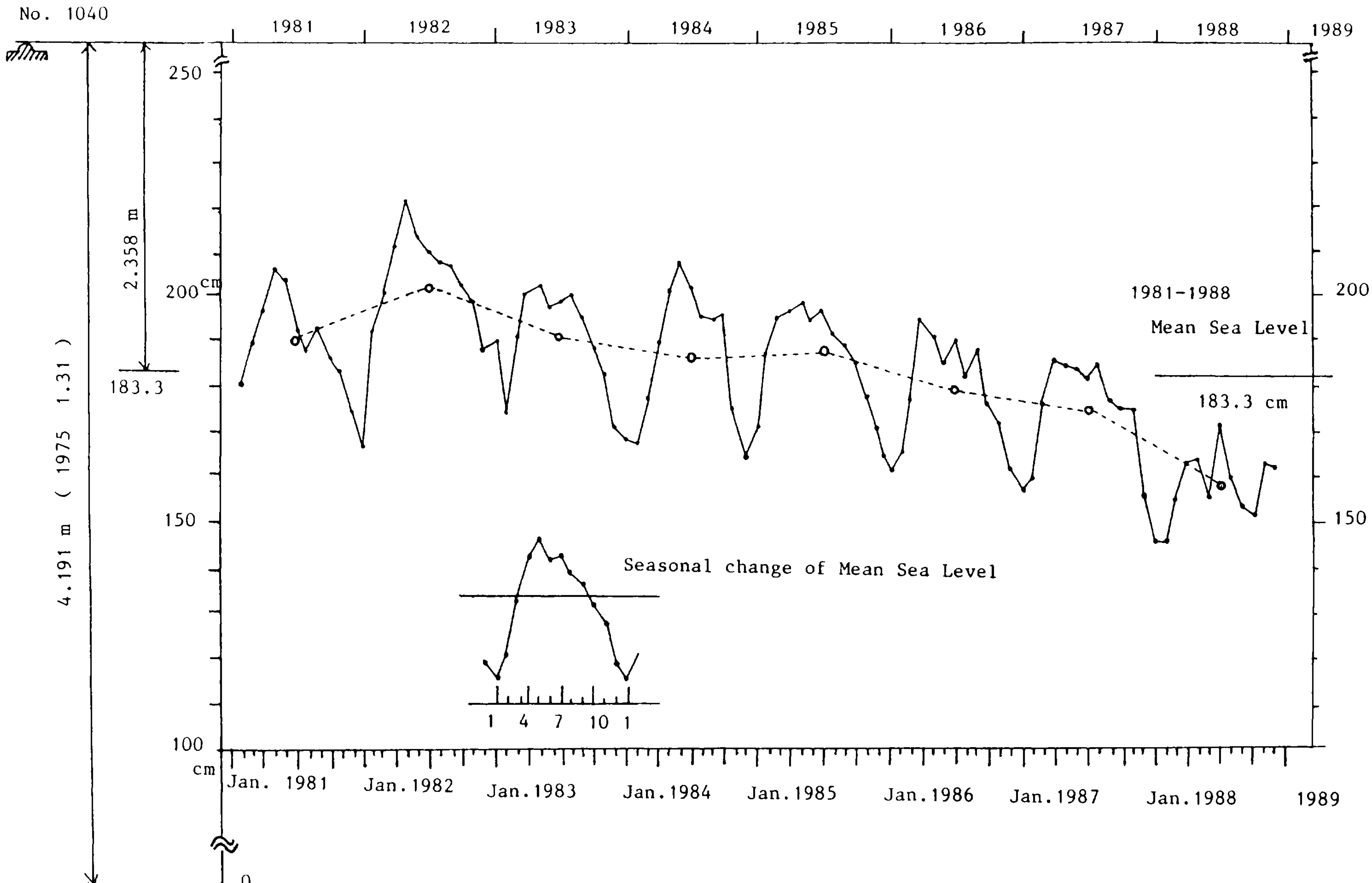



Figure 3 Calibration results of tide gauge datum referred to the Bench Mark.




REFERENCE DATUM IS CORRECTED.

Figure 4 Monthly mean sea level fluctuation from 1981 to 1988
(This figure includes some doubtful data caused by the inconsistent processing in the old days, and will be changed after the recheck of data)

# Tides and Tidal currents around Syowa Station

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## 1. Introduction

Hydrographic Department of Japan has engaged in tidal observation at Syowa Station in Antarctica since 1965. In 1982, first tidal current observation was carried out successfully at the Kita-no-Seto Strait near Syowa Station (Figure 1). The results show remarkable relation of tides and tidal currents concerned with the tidal oscillation system of the Antarctic Sea.

## 2. Tidal current observation

The observation was carried out from January 16th to February 1st 1982. A current meter was moored at the layer of 5 m below surface through the digged ice hole, where depth is 9 m (Figure 2). The attached pressure tide gauge is not working by trouble. Figure 3 shows the observed tidal current, which direction changes twice a day for whole observed period. Its harmonic constants are shown in Table 1 with those of tide. The type of tidal current is semidiurnal, but does not agree with the mixed type of tide at Syowa Station.

## 3. Distribution of tidal phase and amplitude

Figure 4 shows tide stations around Antarctica and Figure 5 shows the phase and amplitude distributions of M2 tide. In the east of Syowa Station, the M2 tidal phase changes abruptly and the M2 tidal amplitude takes minimum, which mean the existence of a node of tidal oscillation around there. Certainly, the phase of M2 tidal current differs about 90 degree from that of M2 tide in Table 1. On the other hand, the amplitude of K1 tide ( Figure 6 ) is not so varied as that of M2 tide. Accordingly, the disagreement of the types is due to the influence of the node where tidal current amplitude becomes large and tidal amplitude becomes small.

## 4. Conclusion

Current observation is difficult to continue for a long period, but definitly useful to understand tidal oscillating system as mentioned above. Then, the author considers that it is better to observe tidal current with tide even though for a short period.

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Table 1

Harmonic Constants of tides and tidal currents around Syowa Station.

Tide : Syowa Station (39-35'E, 69-00'S)

| | amplitude | phase |
|---|---|---|
| M2 : | 23cm, | 165 , |
| S2 : | 19cm, | 181 , |
| K1 : | 22cm, | 4 , |
| O1 : | 23cm, | 352 . |

Tidal Current : Kita-no-Seto (39-35'00"E, 69-00'00"S)

| | | direction | amplitude | phase |
|---|---|---|---|---|
| M2 : | (L) | 278 , | 6.6cm/s, | 298 |
| | (S) | 8 , | 0.2 , | 208 |
| S2 : | (L) | 279 , | 6.3 , | 306 |
| | (S) | 9 , | 0.2 , | 216 |
| K1 : | (L) | 279 , | 2.3 , | 19 |
| | (S) | 9 , | 0.0 , | 109 |
| O1 : | (L) | 273 , | 1.0 , | 218 |
| | (S) | 3 , | 0.0 , | 128 |

Tidal Current : Ongul Strait (39-40'42"E, 68-59'46"S) *

| | | direction | amplitude | phase |
|---|---|---|---|---|
| M2 : | (L) | 6 , | 4.3cm/s, | 268 |
| | (S) | 96 , | 0.6 , | 358 |
| S2 : | (L) | 22 , | 2.5 , | 287 |
| | (S) | 112 , | 0.9 , | 17 |
| K1 : | (L) | 321 , | 1.6 , | 159 |
| | (S) | 51 , | 0.4 , | 69 |
| O1 : | (L) | 293 , | 2.6 , | 283 |
| | (S) | 23 , | 0.5 , | 193 |

(L): Long axis, (S): Short axis of tidal current ellipse.
Phase lags are referred to the local transit time.
* Using the data obtained by Fukuchi et.al.(1985), the harmonic constants are calculated by the author.

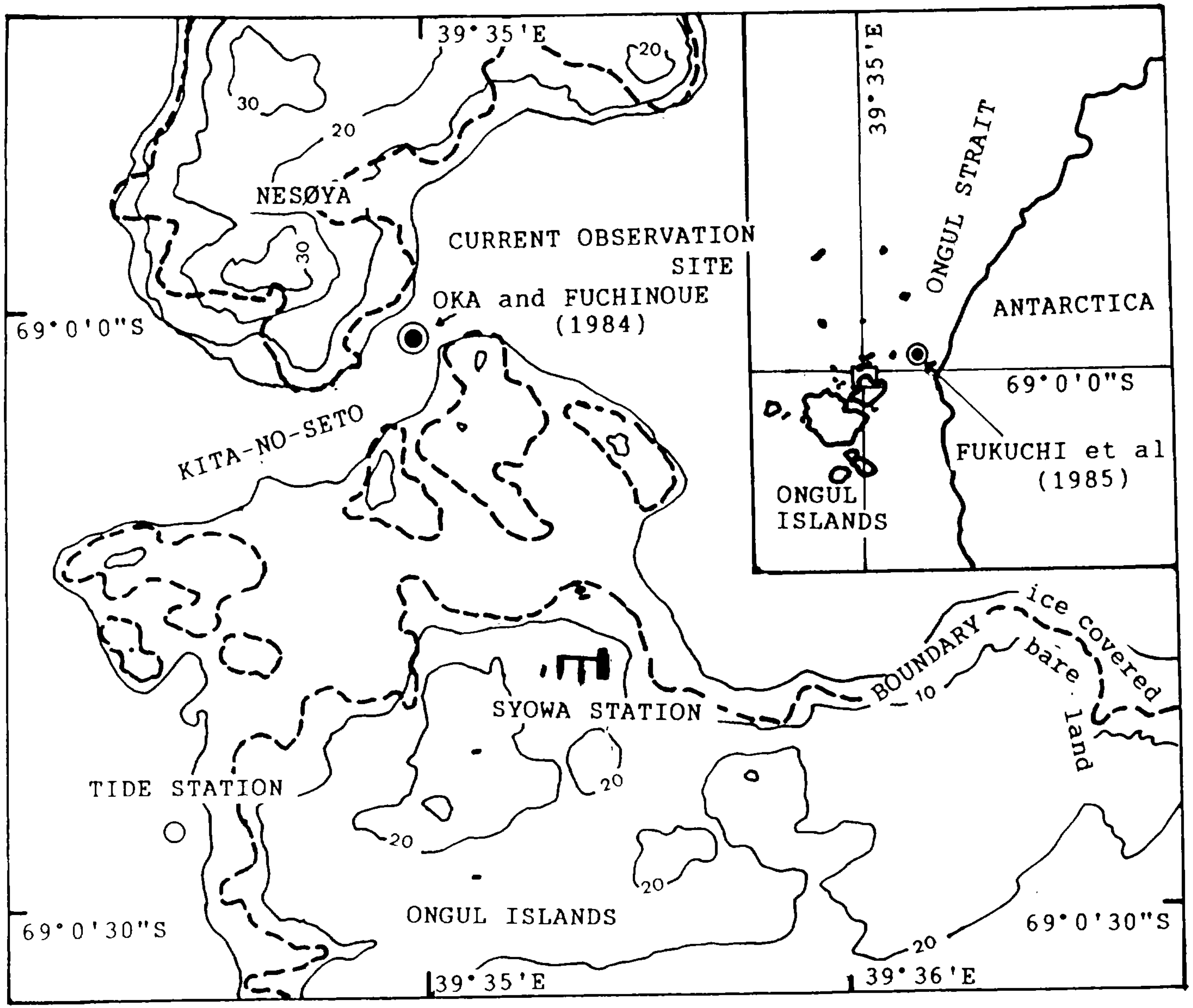


Figure 1  Location of tidal current station.

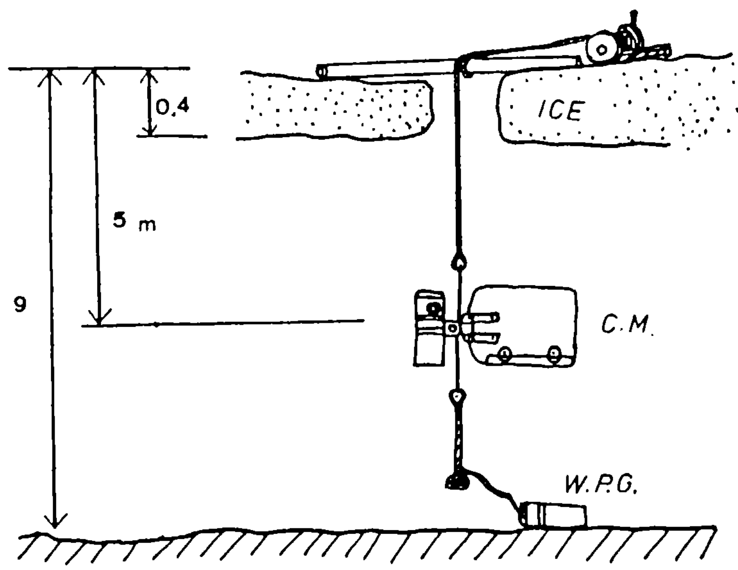


Figure 2  Mooring system of current meter.

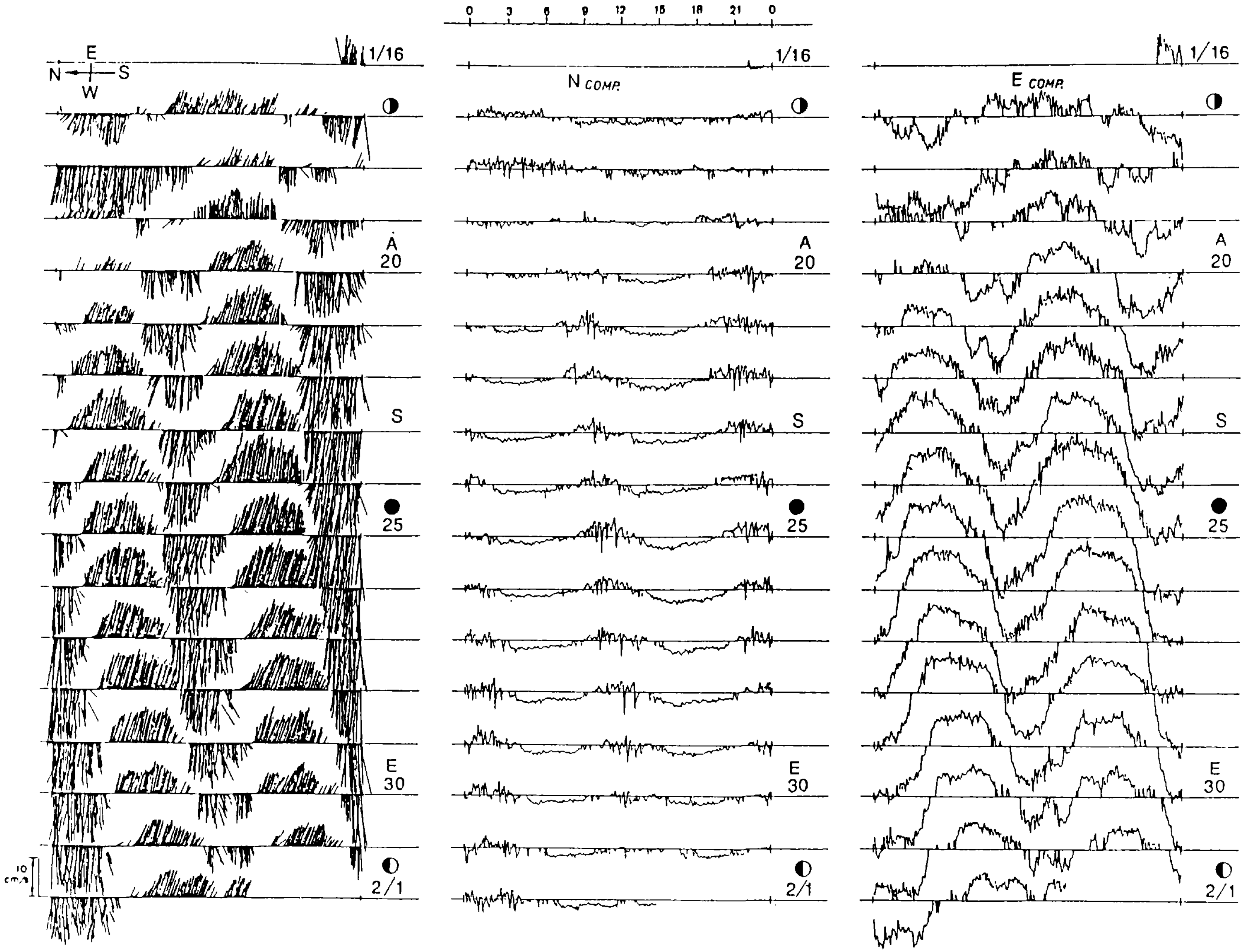


Figure 3 Tidal current observed at the Kita-no-Seto Strait.

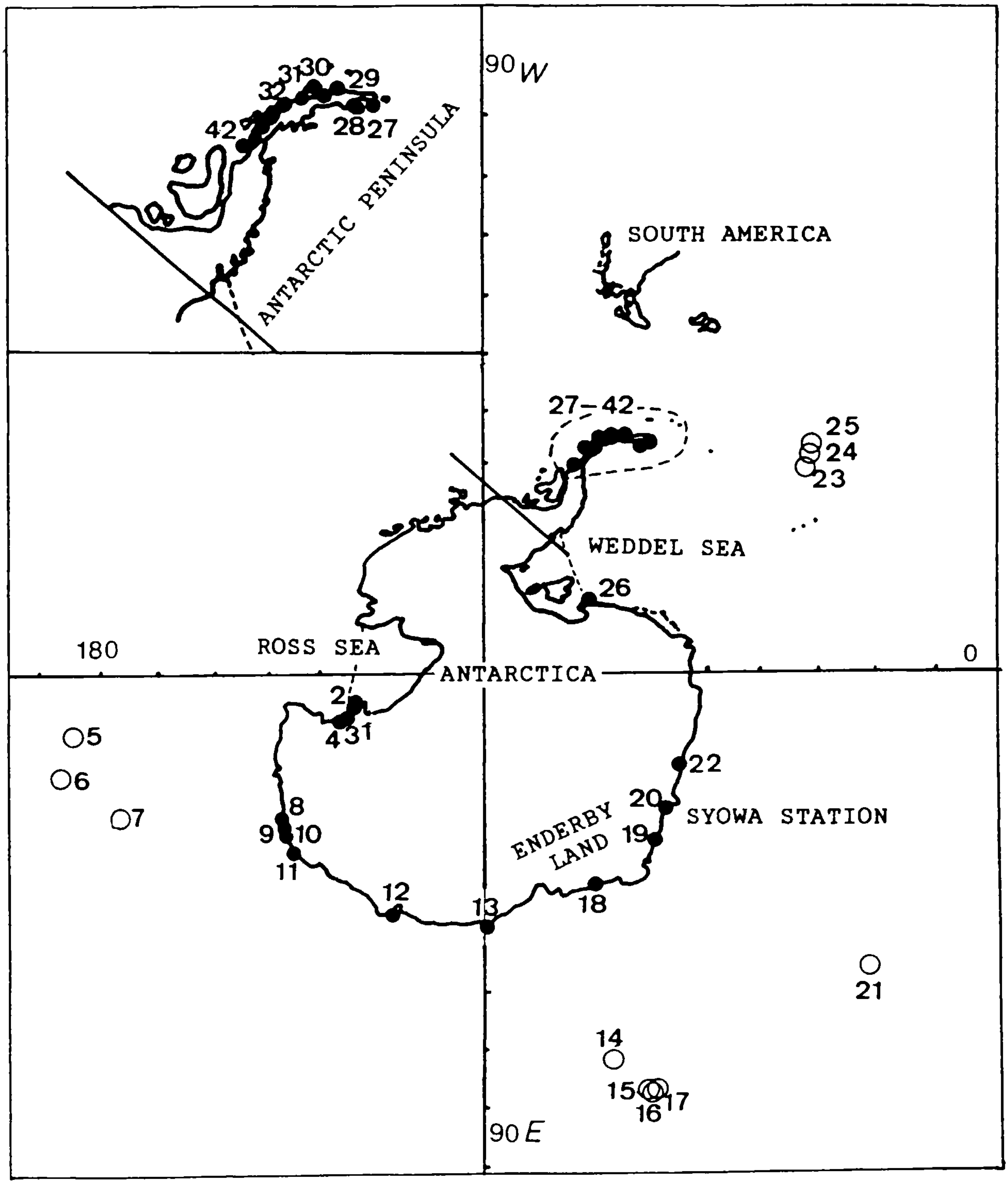


Figure 4 Tide Stations around Antarctica.

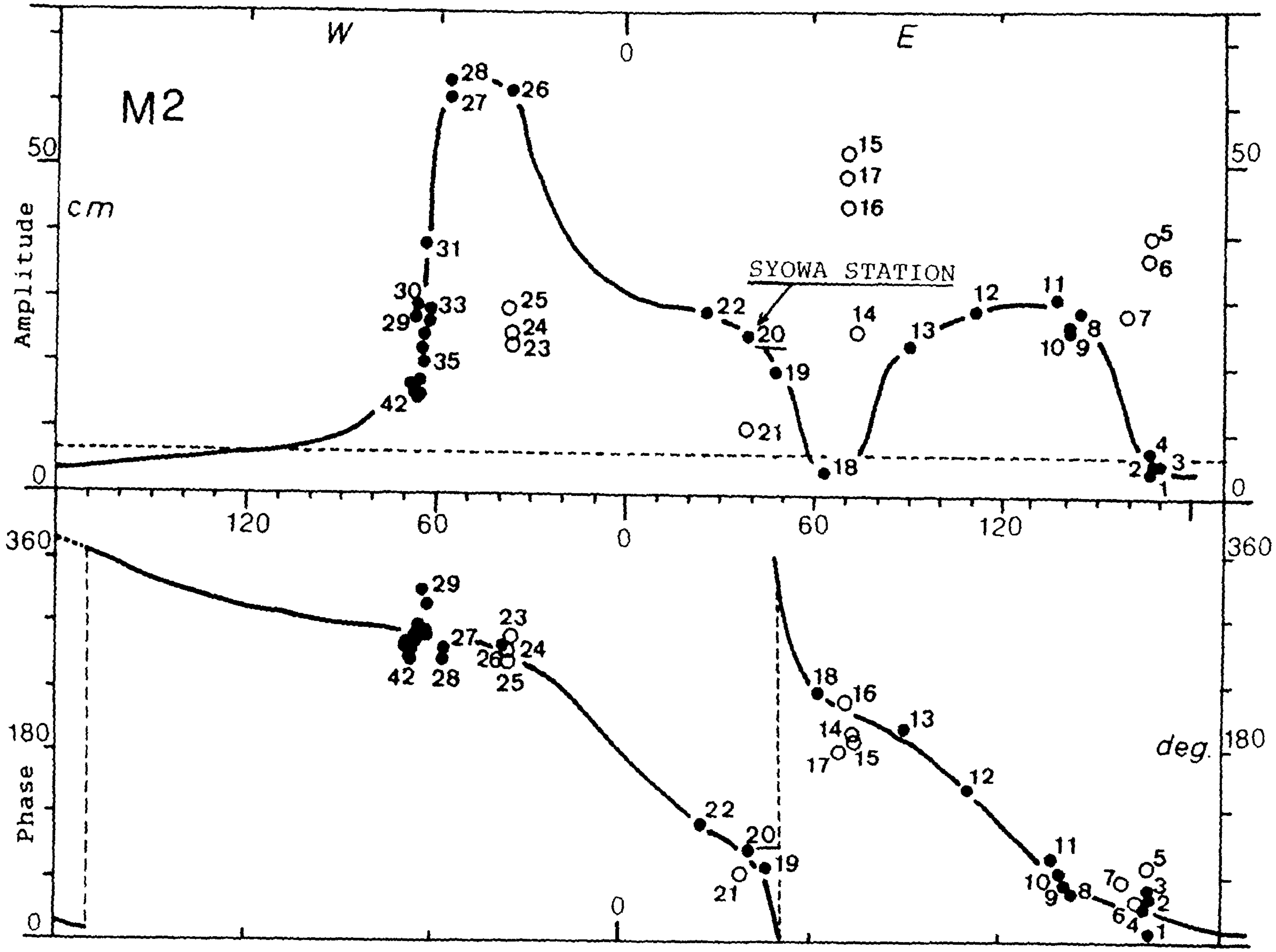


Figure 5 Amplitudes (upper) and phase lags referred to Greenwich (lower) for M2 tide around Antarctica. Numerals correspond with the station numbers in Figure 4. Dashed line in the upper part indicates the M2 amplitude of equilibrium tide along 60 S, 6.1cm.

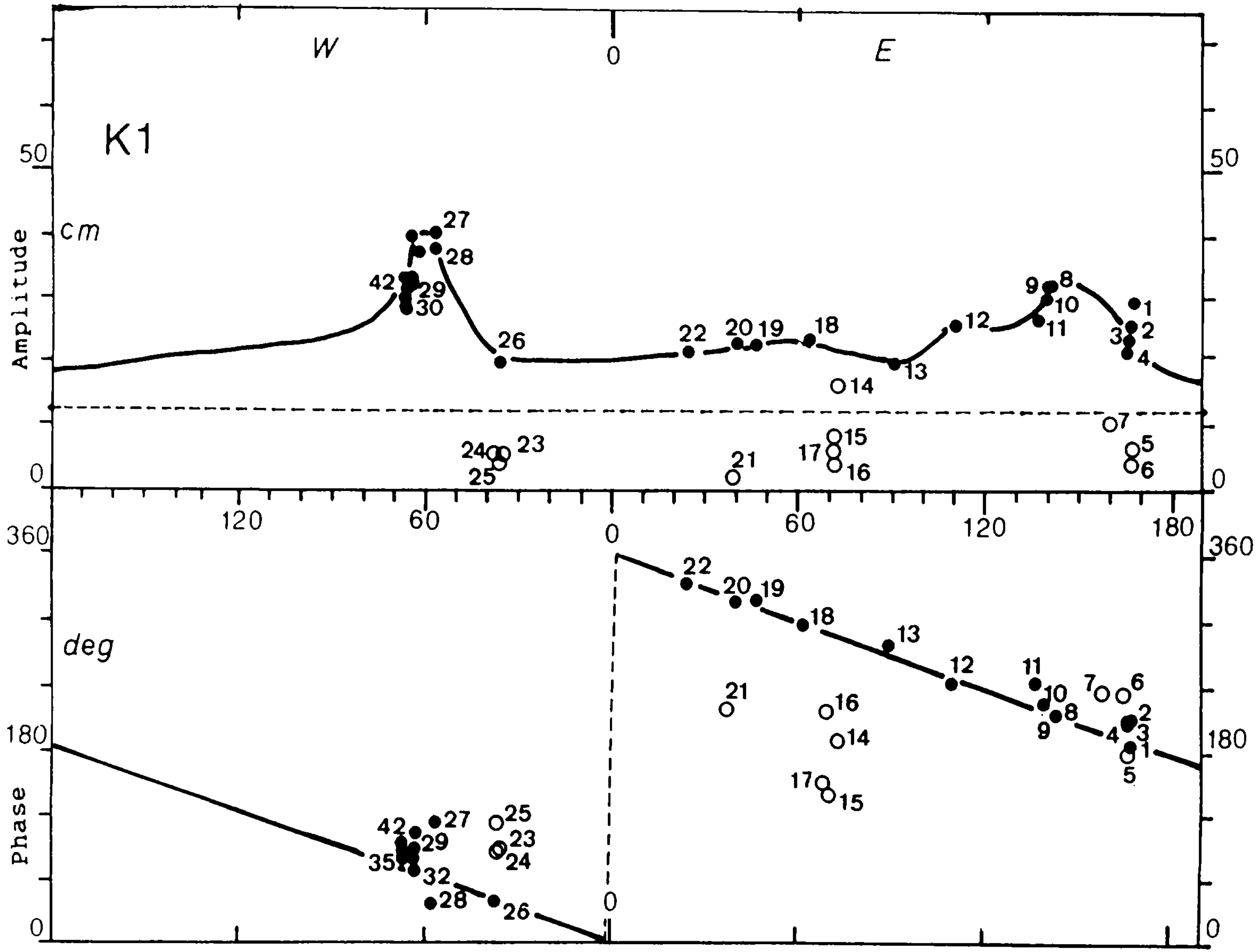


Figure 6 Same as Figure 5 but for K1. Dashed line indicates the K1 amplitude of equilibrium tide, 12.3cm.

## Experiences with water level measurements in the Weddel Sea

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### Introduction and aims

There are very few locations where water level measurements with reference to benchmarks can be performed at the coast of the Antarctic continent. Pressure measurements at the sea floor are carried out more easily. Without a fixed reference they can be used to study a number of processes associated with sea level fluctuations like tides, shelf waves and variations of the Antarctic Circumpolar Current and its Antarctic Gyres.

The maintenance of a pressure measuring device on the continental shelf in Antactia requires the logistical ability to a regular exchange of the mooring, e.g. by ice breaking research or supply vessels in transit to research camps. Secondly, the availability of air pressure data from the vicinity of the mooring is a necessary prerequisite. Both demands are met in Atka Bight close to the Georg-von-Neumayer station, where the AWI maintains a mooring since 1987 in addition to a second one near Vestkapp.

The scientific aims of the measurements are

- to analyze the records for the longer period tidal constituents
- to study the propagation of shelf waves
- to monitor the seasonal and interannual fluctuations to the Antarctic Coastal Current and of the Weddell Gyre
- to provide imput data for numerical models
- to contribute to the network of tide gauges in the Southern Ocean

### Experiences and some preliminary results

The mooring consists of a pressure recorder and two current meters, all of Aanderaa type. The pressure sensor is mounted in a cylindrical container within the bottom weight of the mooring which consists of two train wheels soldered together (fig. 1). The water depth is typically 450 - 500 m. This arrangement proved to work very satisfactorily. Although being placed in a hostile environment close to an ice shelf no particular difficulties were encountered compared with moorings in moderate latitudes.

Due to the frequent presence of the coastal polynia the site is easily accessible to exchange the instruments once a year.

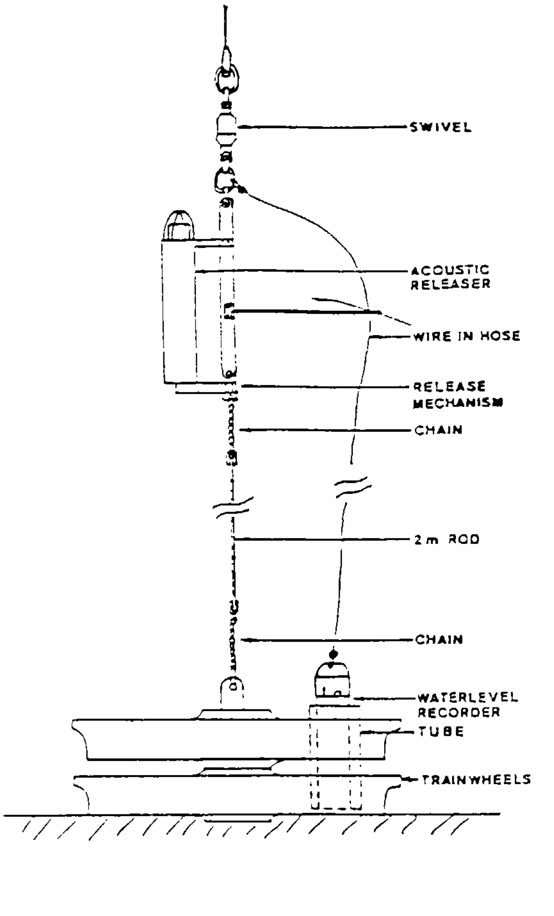


Fig. 1: Near-bottom details of the mooring.

Fig. 2 shows time series of hourly values of sea and air pressure, measured at the Georg-von-Neumayer camp with a Paroscientific Digiquartz sensor to an accuracy of 0.1 h Pa.

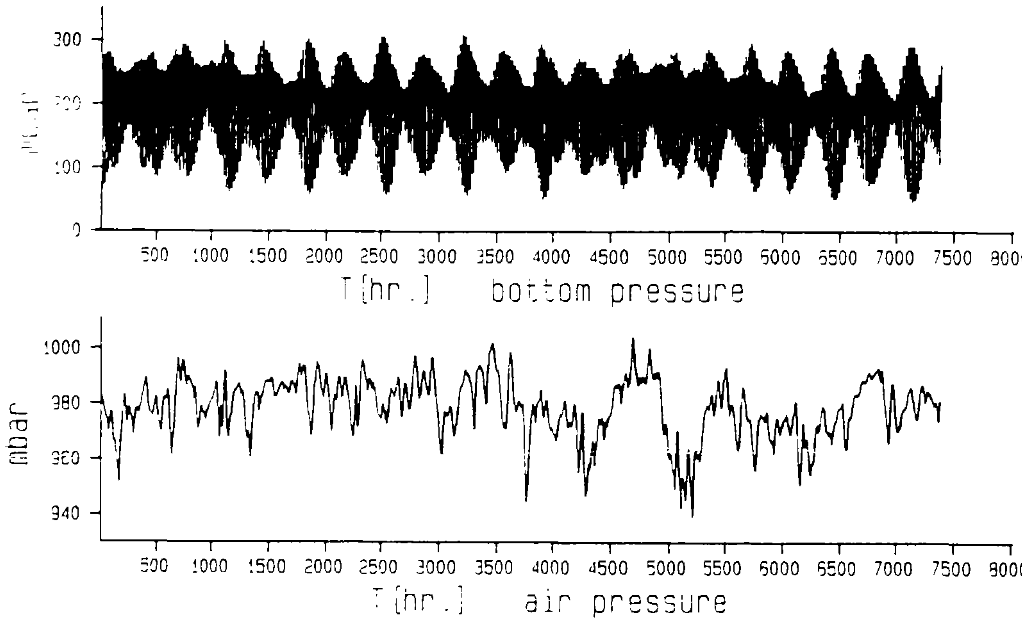


Fig. 2: Original data from Atka Bight.

The results of tidal analysis are summarized in table. 1. Most of the tidal constituents are in remarkably good agreement with the predictions of the Schwiderski model.

Table 1: Harmonic constants for Atka Bight

| Tide | angular sped degree/ hour | 1 measured H | g | 2 after Schwiderski H | g |
|---|---|---|---|---|---|
| MM | 0.54453 | 3 | 183 | - | - |
| MSF | 1.0158 | 1 | 129 | 2 | 196 |
| Q1 | 13.3986 | 7 | 338 | 6 | 337 |
| 0 1 | 13.9430 | 29 | 345 | 29 | 343 |
| P1 | 14.9589 | 9 | 354 | 8 | 350 |
| K1 | 15.0410 | 27 | 354 | 23 | 353 |
| MU2 | 27.9682 | 1 | 176 | - | - |
| N2 | 28.4397 | 7 | 180 | 7 | 186 |
| M2 | 28.9841 | 41 | 190 | 34 | 191 |
| T2 | 29.9589 | 2 | 212 | - | - |
| S2 | 30.0000 | 30 | 212 | 28 | 224 |
| K 2 | 30.0821 | 8 | 212 | 8 | 228 |

H: height in cm g: phase in degrees

*E.W. Schwiderski (1979): Global oceanic tides - Atlas of tidal charts and maps. Naval Surface Weapons Center, Dahlgren, Virginia.*

After low-pass filtering (fig. 3) the sea level fluctuations have been computed. The predominant phenomenon is still a tidal constituent (MM,631h), but there are also indications of atmospheric forcing. The sea level record displays no drift.

Results of more detailed analyses employing current meter data and records from a second station, approx. 500 km downstream along the Antarctic Coastal Curent will be published elsewhere.

Summarizing the experience with the measuring technique one can state that - given the prerequisites of regular mooring exchange and availability of air pressure data - pressure measurements and conversion to sea level on the shelf of the Weddell Sea provide no particular difficulties.

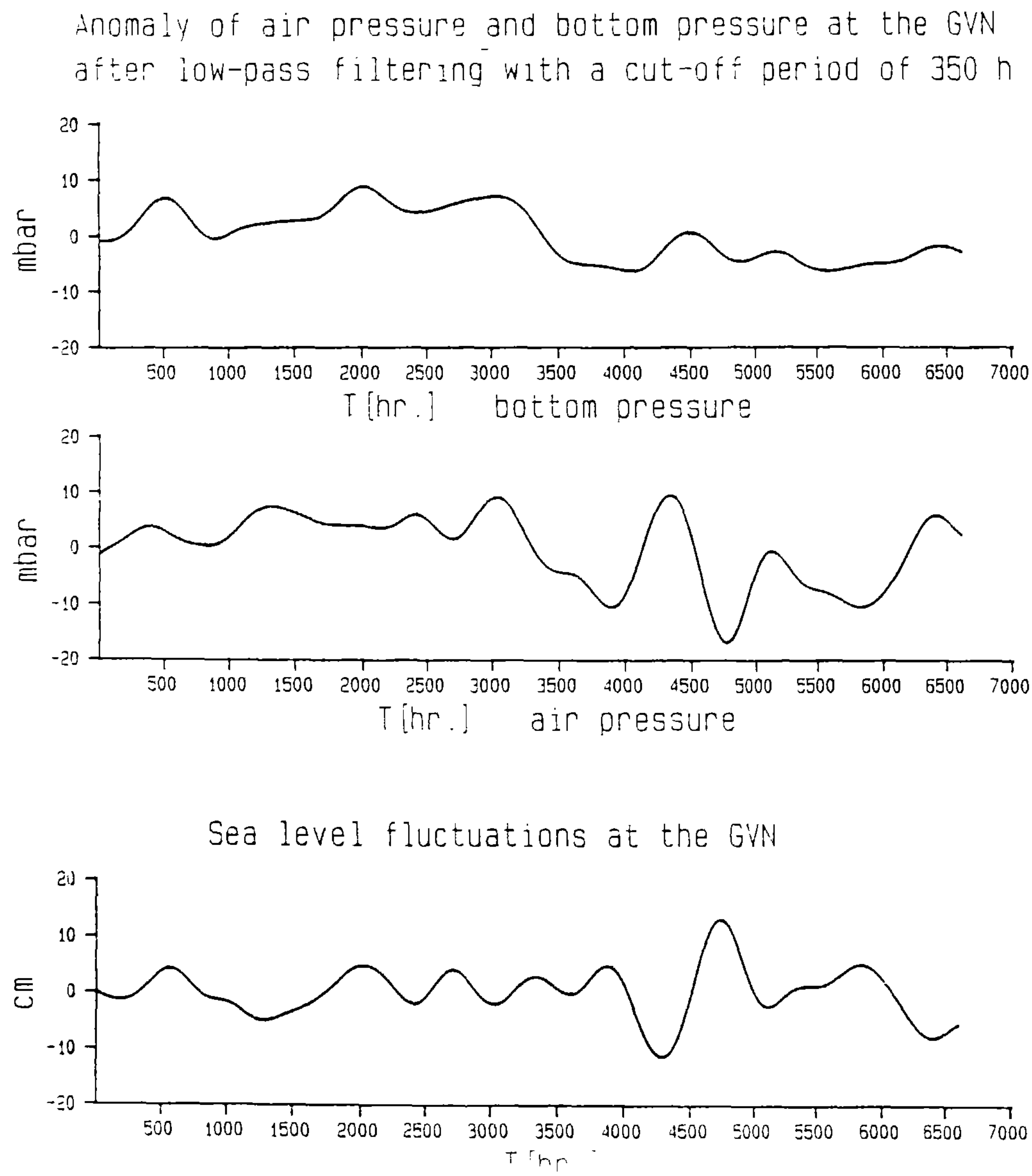


Fig. 3: Long-term fluctuations

# NOAA EXPERIENCE IN HOSTILE ENVIRONMENT TIDE MEASUREMENTS AND THE NEXT GENERATION WATER LEVEL MEASUREMENT SYSTEM

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The National Oceanic and Atmospheric Administration (NOAA) in the Department of Commerce, U.S.A., has operated and maintained a National Water Level Observation Network (NWLON) along United States coastal regions along the Atlantic and Pacific coasts, the Gulf of Mexico, in the Great Lakes, in Alaska, and in Pacific and south Atlantic island locations. NOAA's mission is to measure, collect, analyze, and disseminate tide and water level data. The program serves U.S. federal, state, and local government requirements for tidal and water level data for use in boundary determination, marine navigation, storm and tsunami warnings, environmental protection, resource management, will engineering, and scientific research. The NWLON includes about 200 permanent stations. The NWLON system's products and services are given in Table I. Table II lists the stations from which monthly mean sea level data values have been provided to the Permanent Services for Mean Sea Level. For all but 6 of these 128 stations, data has been provided on 9-track magnetic tape through 1988. A list of primary bench marks and their elevation related to staff "zero" at each location has also been provided.

The existing NWLON system is composed of several different types of measurement and recording systems, several different automatic data processing systems, and associated computer software. The primary measurement systems for the past 125 years has been the float operated mechanical system. This equipment and related facilities are obsolete and are not capable of satisfying current and future National Ocean Service (NOS) and other user needs for better quality data, multiple methods of data transmission, and additional oceanographic and meteorological sensors.

TABLE I

National Water Level Observation Network

Products and Services

1. Datums used for international-Federal, Federal-State, and State-private boundary determinations.

2. Tidal correctors which are used to reduce soundings collected during hydrographic surveys to chart datum on nautical charts.

3. Harmonic constants used to predict tides which facilitate safe and efficient navigation.

4. "Real-time" data for storm surge and tsunami warnings issued by the National Weather Service.

5. Great Lakes water elevation reports to the Corps of Engineers and other reports used in Great Lakes water management.

6. Reports and tabulations used in coastal zone management, determining coastal hazards, and coastal engineering.

7. Basic tidal and sea level information which supports pollution assessments, environmental research, and research on long-term sea levels and phenomena such as "El Nino."

8. Monthly means of high and low water values, and hourly water level values supporting final tidal datums computation, harmonic analyses, and a variety of research applications.

TABLE II

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE
NATIONAL WATER LEVEL OBSERVATION NETWORK STATIONS
PROVIDING MEAN SEA LEVEL DATA TO
PERMANENT SERVICE FOR MEAN SEA LEVEL

| STATION NUMBER | STATION NAME | STATION NUMBER | STATION NAME |
|---|---|---|---|
| 161-1400 | NAWILIWILI, HI | 851-6990 | WILLETS PT., NY |
| 161-2340 | HONOLULU, HI | 851-8750 | THE BATTERY, NY |
| 161-5680 | KAHULUI, HI | 851-9483 | BERGEN PT., NY |
| 161-7760 | HILO, HI | 853-1680 | SANDY HOOK, NJ |
| 161-9000 | JOHNSTON ISLAND, N. PAC. | 853-1991 | LONG BRANCH PIER, NJ |
| 161-9910 | SAND ISLAND, MIDWAY IS. | 853-3615 | BARNEGAT INLET, NJ |
| 163-0000 | APRA HARBOR, GUAM IS. | 853-4770 | VENTNOR CITY, NJ |
| 177-0000 | PAGO PAGO, AMER. SAMOA IS. | 853-6110 | CAPE MAY, NJ |
| 182-0000 | KWAJALEIN, MARSHALL IS. | 853-9993 | TRENTON, NJ |
| 184-0000 | MOEN ISLAND, TRUK ATOLL | 854-5530 | PHILADELPHIA, PA |
| 189-0000 | WAKE ISLAND, N. PAC. | 855-1910 | REEDY PT., DE |
| 269-5535 | ST. GEORGES, BERMUDA | 855-7380 | LEWES, DE |
| 841-0140 | EASTPORT, ME | 857-0280 | OCEAN CITY, MD |
| 841-1250 | CUTLER, ME | 857-1892 | CAMBRIDGE, MD |
| 841-3320 | BAR HARBOR, ME | 857-3903 | TOWN POINT, MD |
| 841-5490 | ROCKLAND, ME | 857-4070 | HAVRE DE GRACE, MD |
| 841-8150 | PORTLAND, ME | 857-4680 | BALTIMORE, MD |
| 844-3970 | BOSTON, MA | 857-5512 | ANNAPOLIS, MD |
| 844-7930 | WOODS HOLE, MA | 857-7330 | SOLOMONS IS., MD |
| 844-9130 | NANTUCKET, MA | 859-4900 | WASHINGTON, DC |
| 845-2660 | NEWPORT, RI | 863-1044 | WACHAPREAGUE, VA |
| 845-4000 | PROVIDENCE, RI | 863-2200 | KIPTOPEAKE BCH, VA |
| 846-1490 | NEW LONDON, CT | 863-5150 | COLONIAL BCH, VA |
| 846-7150 | BRIDGEPORT, CT | 863-5750 | LEWISETTA, VA |
| 851-0560 | MONTAUK, FORT POND BAY, NY | 863-7624 | GLOUCESTER PT., VA |
| 851-4560 | PORT JEFFERSON, NY | 863-8610 | HAMPTON RDS., VA |

TABLE II (Continued)

| STATION NUMBER | STATION NAME | STATION NUMBER | STATION NAME |
|---|---|---|---|
| 863-8660 | PORTSMOUTH, VA | 877-8490 | PORT MANSFIELD, TX |
| 863-8863 | CHESAPEAKE BBT, VA | 877-9750 | SOUTH PADRE IS., TX |
| 865-1370 | DUCK PIER (OUTSIDE), NC | 877-9770 | PORT ISABEL, TX |
| 865-4400 | CAPE HATTERAS, NC | 941-0170 | SAN DIEGO, CA |
| 865-6483 | BEAUFORT, DUKE MAR. LAB, NC | 941-0230 | LA JOLLA, CA |
| 865-8120 | WILMINGTON, NC | 941-0580 | NEWPORT BEACH, CA |
| 865-9084 | SOUTHPORT, NC | 941-0660 | LOS ANGELES, BERTH 60, CA |
| 866-1070 | SPRINGMAID PIER, SC | 941-0680 | LONG BEACH, CA |
| 866-1139 | BUCKSPORT, SC | 941-0840 | SANTA MONICA, CA |
| 866-5530 | CHARLESTON, SC | 941-1270 | RINCON ISLAND, CA |
| 867-0870 | FT. PULASKI, GA | 941-2110 | PORT SAN LUIS, CA |
| 872-0030 | FERNANDINA BCH., FL | 941-3450 | MONTEREY, CA |
| 872-0220 | MAYPORT, FL | 941-4290 | SAN FRANCISCO, CA |
| 872-3080 | HAULOVER PIER, FL | 941-4750 | ALAMEDA, CA |
| 872-3170 | MIAMI BEACH, FL | 941-5144 | PORT CHICAGO, CA |
| 872-3962 | KEY COLONY BCH., FL | 941-8767 | HUMBOLDT BAY, CA |
| 872-3970 | VACA KEY, FL | 941-9750 | CRESCENT CITY, CA |
| 872-4580 | KEY WEST, FL | 943-1647 | PORT ORFORD, OR |
| 872-5110 | NAPLES, FL | 943-5380 | SOUTH BEACH, OR |
| 872-6520 | ST. PETERSBURG, FL | 943-9040 | ASTORIA, OR |
| 872-6724 | CLEARWATER BCH., FL | 944-0910 | TOKE POINT, WA |
| 872-7520 | CEDAR KEY, FL | 944-3090 | NEAH BAY, WA |
| 872-8690 | APALACHICOLA, FL | 944-4090 | PORT ANGELES, WA |
| 872-9108 | PANAMA CITY, FL | 944-4900 | PORT TOWNSEND, WA |
| 872-9678 | NAVARRE BCH., FL | 944-7130 | SEATTLE, WA |
| 872-9840 | PENSACOLA, FL | 944-9424 | CHERRY POINT, WA |
| 873-5180 | DAUPHIN ISLAND, AL | 944-9880 | FRIDAY HARBOR, WA |
| 876-1724 | GRAND ISLE, EAST PT., LA | 945-0460 | KETCHIKAN, AK |
| 877-1450 | GALVESTON, PIER 21, TX | 945-1600 | SITKA, AK |
| 877-1510 | GALVESTON, PLEASURE PIER, TX | 945-2200 | JUNEAU, AK |
| 877-2440 | FREEPORT, TX | 945-2400 | SKAGWAY, AK |
| 877-4770 | ROCKPORT, TX | 945-3220 | YAKUTAT, AK |
| 877-5870 | CORPUS CHRISTI, TX | 945-4050 | CORDOVA, AK |

TABLE II (Continued)

| STATION NUMBER | STATION NAME |
|---|---|
| 945-4240 | VALDEZ, AK |
| 945-5090 | SEWARD, AK |
| 945-5500 | SELDOVIA, AK |
| 945-5920 | ANCHORAGE, AK |
| 946-7292 | KODIAK, AK |
| 945-1380 | ADAK, SWEEPERS COVE, AK |
| 946-2620 | UNALASKA, AK |
| 971-2712 | CAT CAY, BAHAMAS |
| 975-5371 | SAN JUAN, PUERTO RICO |
| 975-9110 | MAGUEYES, PUERTO RICO |

Since 1984, NOS has been in the process of replacing its NWLON with modernized "Next Generation Water Level Measurement System" (NGWLMS). The NGWLMS will include new technology sensors; a microprocessor-based data collection and recording subsystem which will improve data quality and collect data quality assurance parameters; frequent data transmissions to the central office via the Geostationary Operational Environmental Satellite System (GOES); and auxiliary telemetering capabilities via telephone transmission and a modern processing, analysis, and dissemination subsystem at NOS headquarters in Rockville, Maryland. This system will reduce data defects and permit more timely production of products and services. It represents a major upgrade of existing capability through application of technology advances of the last decade.

However, the development of the NGWLMS will do little for the collection of tide data in hostile conditions such as in the Antarctica as this system utilizes a protective pipe similar to that of a stilling well for float operated gauges, and thus has the same limitations that float actuated gauges have in the attempt to collect data in locations with no piers, wharves, and in areas of hostile conditions.

To meet the requirement for vertical control for hydrographic surveys, and environmental studies related to the development of oil, gas, and other mineral deposits along Alaska's West and North Coasts (Bering Sea, Chukchi Sea, and Beaufort sea), a requirement has existed to collect tidal data of a high accuracy that is connected to a network of stable bench marks.

The stability of bench marks in polar regions, with permafrost soil and heaving due to frost as a major problem complicated in many cases by the lack of bedrock. One approach under investigation is the use of thermo bench marks, a technique developed by Arctic Foundation, Inc. A discussion of this technique is given in Appendix A.

Six thermo bench marks were procured in June 1988 from AFI for testing and evaluation. Port Moller was selected as one test site (for 3 thermo bench marks) as three of the five existing deep rod bench marks there were exhibiting instability due to frost jacking. Prudhoe Bay was selected as another test site (for 2 thermo bench marks) due to bench mark instability and different soil conditions. Anchorage was selected as a test site for the last thermo bench mark due to its accessibility. All six thermo bench marks were installed during the 1988 field season.

At this time it is too soon to draw any conclusions on thermo bench mark stability as they have been in less than two years and have only one level connection subsequent to their installation. Initial results, however, show stability over one year at the thermo bench marks in Port Moller and Anchorage. Slight initial movement was anticipated the Prudhoe Bay sites due to the soil conditions (coarse gravel) and different method of installation (augured hole). One thermo bench mark exhibited initial movement while the other remained stable.

## STILLING WELLS

The installation of tidal recording instruments utilizing the float-stilling well in open waters of the Arctic can be accomplished, but has been proven to be extremely costly. In 1980, the NOS installed and operated two such stations for a one-year period at Cross Island and Narwhal Island. These islands are located about five miles north of the Prudhoe Bay oilfield in the Beaufort Sea. Steel pilings were driven into the ocean floor during the summer open-water period approximately 150 meters offshore in a somewhat protected bay. A small steel shelter and a stilling pipe was then welded to the pilings. Daily comparative observations were made with a tide staff that was leveled to the bench mark network weekly to preserve and verify the tide data that was being collected. A back-up gas purging (bubbler) tide gauge was also installed and maintained. During the winter months an insulated blanket was wrapped around the tide shelter and a heater kept the water beneath the shelter from freezing. During the spring break-up the two stations had to be monitored very carefully from ice floes and bergs. In fact, a third station at Dinkum Sands was destroyed by an ice floe shortly after it was installed. Dinkum Sands does not have a protective bay as did the Cross and Narwhal Island stations. No attempt was made to reinstall Dinkum Sands. The bench mark network consisted of stainless steel rods being driven into the permafrost and were insulated with paraffin oil in the upper three meters.

The cost of obtaining the one year of tide data utilizing stilling wells was found to be prohibitively high in that a technician crew supported by a helicopter had to make almost daily visits to the tide stations throughout the year. This type of data collection could not have been possible had not the islands had a protective bay and an airport just five miles away.

NOAA has operated, on a seasonal basis, a gas-purging bubbler tide gauge at the Prudhoe Bay Seawater Treatment Plant owned by the ARCO. Beginning in 1976, the gauge was operated through 1988 for about 76 days a season--the average installation date being July 13 and the removal date September 27.

The ARCO STP is a massive barge sunk in place at the end of West Dock, surrounded on three sides by gravel, with the fourth side fronting into a small, sheltered, bay. The STP is used to process seawater before it is pumped underground to facilitate oil removal. Two bubbler gauges were installed at the STP in August of 1988 to determine the feasibility of operating a year-round water level station at Prudhoe Bay. The instruments are located inside the reservoir room at the southern end of the barge, which is where the large water intakes are located. One orifice was installed inside the barge, just inside one of the large intakes to the western reservoir.

The purpose of two gages was to determine whether or not the water level in the western reservoir truly reflects the outside water level, so that it might provide a protected environment for the establishment of a permanent station using standard equipment. It was initially thought that the outside orifice would not survive the severe winter conditions.

After a year of operation it has been determined that the inside water level does reflect the outside water level. Another result of the test is that the outside orifice survived the winter conditions so well that it is now believed that an outside pressure sensor can be maintained permanently.

A comparison was also performed on simultaneous data between the STP gauges and the seasonal Prudhoe Bay station. The comparison shows that the STP site time and range are identical to the seasonal station. A 0.3 foot difference in datum elevation is present, but the difference is constant, and is attributed to problems experienced with the STP gauges and observers, rather than an actual difference in datum elevations. The level connection between the stations is also suspect.

NOAA plans to install a NGWLMS this field season at the Prudhoe Bay STP as a year round NWLON station. The seasonal station would be run this field season (1990) but discontinued after it if comparisons show no significant difference.

The STP station would be configured with a NGWLMS field unit including:
The Aquatrak water level sensor installed in the western reservoir with a back-up pressure sensor and data logger to provide backup data as well as a continuing check that the inside water level was the same as outside. Consideration is also being given to installing a Paroscientific differential pressure transducer and conductivity sensor mounted at the outside location. This would provide a separate six-minute data stream. The data would be transmitted back via GOES with the possibility of telephone transmission examined. Levels would be run between the STP and seasonal stations to link the data series.

It is expected that the data collected in standard NGWLMS format would provide year round measurement data with substantial reduction in maintenance costs.

The Bottom Pressure Recorder (BPR) is the logical choise for gathering data in areas of hostile conditions. The BPR has been used to collect data in many areas of the world. NOS has not utilized the BPR except for research purposes. The inherent accuracy of the BPR is excellent, but since total pressure is measured, it is necessary to subtract the atmospheric pressure to obtain the hydrostatic pressure. BPR's presently must be deployed where a warm environment exists so that barometric pressure can be obtained. Since an all-weather digital barometer that could operate unattended for on year does not exist, the deployment of BPR's in the arctic where winter temperatures frequently reach -50 degrees, the data from such a BPR becomes contaminated by barometric pressure changes.

By the end of May, NOAA will have received and accepted 150 NGWLMS field units with 50 more to be received by the end of 1990. Table III shows the locations of the 70 installed through May 25, 1990.

Figure 1 shows the locations of the NGWLMS field units installed in the Pacific region, together with the tide stations of the Tsunami Warning System/Toga programs. The NOAA National Weather Service's Pacific Tsunami Warning Center receives water level data from all the stations shown via the GOES satellite.

As part of NOAA's Climate and Global Change Program, the NGWLMS is being complemented with Very Long Baseline Interferometry (VLBI) and Global Positioning Systems (GPS) technologies resulting in expanded capabilities that include the establishment of a worldwide geodetic absolute reference form. These combined capabilities have applications in monitoring absolute global sea level and its connection to the monitoring and prediction of global climate change.

TABLE III

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NGWLMS PRODUCTION FIELD UNITS

STATION LOCATIONS
SYSTEMS ARE NOT IN OPERATIONAL STATUS

| STATION NUMBER | STATION NAME | LATITUDE | LONGITUDE | INSTALLATION DATE |
|---|---|---|---|---|
| 85573801 | LEWES, DE | 38 46.9N | 75 07.2W | 07/22/88 |
| 86513701 | DUCK, NC | 36 11.0N | 75 44.8W | 07/27/88 |
| 86388631 | BAY BRIDGE TUNNEL, VA | 36 58.1N | 76 06.8W | 07/29/88 |
| 87230821 | HAULOVER, FL | 25 54.2N | 80 07.2W | 08/16/88 |
| 87226711 | LAKE WORTH, FL | 26 36.7N | 80 02.0W | 08/17/88 |
| 94142901 | FORT POINT, CA | 37 48.4N | 122 27.9W | 09/01/88 |
| 94471301 | SEATTLE, WA | 47 36.2N | 122 20.2W | 09/13/88 |
| 94134501 | MONTEREY HARBOR, CA | 36 36.3N | 121 53.3W | 09/14/88 |
| 94102301 | LA JOLLA, CA | 32 52.0N | 117 15.4W | 09/20/88 |
| 94197501 | CRESENT CITY, CA | 41 44.7N | 123 11.0W | 09/26/88 |
| 84439701 | BOSTON, MA | 42 21.3N | 71 03.0W | 11/16/88 |
| 84479301 | WOODS HOLE, MA | 41 31.5N | 70 40.4W | 11/17/88 |
| 85755121 | ANNAPOLIS, MD | 38 59.0N | 76 28.8W | 12/13/88 |
| 16123401 | HONOLULU, OAHU, HI | 21 18.4N | 151 52.0W | 01/20/89 |
| 18900001 | WAKE ISLAND | 19 17.4N | 116 37.8E | 01/20/89 |
| 16124801 | MOKUOLOE, OAHU, HI | 21 26.2N | 157 47.4W | 01/22/89 |
| 16199101 | SAND ISLAND, MIDWAY | 28 12.7N | 177 21.6W | 01/28/89 |
| 16156801 | KAHULUI, MAUAI, HI | 20 53.9N | 156 28.3W | 01/30/89 |
| 16174331 | KAWAIHAE, HAWAII, HI | 20 02.3N | 155 49.8W | 02/06/89 |
| 16177601 | HILO, KUHIO BAY, HI | 19 44.0N | 155 03.5W | 02/13/89 |
| 16113471 | PORT ALLEN, KAUAI, HI | 21 54.1N | 159 35.4W | 02/15/89 |
| 17700001 | PAGO PAGO, US SAMOA | 14 16.7S | 170 40.9W | 02/20/89 |
| 18400001 | TRUK ATOLL, CAROLINE IS. | 7 26.8N | 151 50.7E | 02/20/89 |
| 16300001 | APRA HARBOR, GUAM | 13 26.5N | 144 39.2E | 02/28/89 |
| 19100001 | SUVA, FIJI | 18 0.0S | 178 30.0E | 02/28/89 |
| 97553711 | SAN JUAN, PUERTO RICO | 18 27.6N | 66 07.0W | 03/25/89 |
| 97591101 | MAGUEYES IS, PUERTO RICO | 17 58.3N | 67 02.8W | 03/25/89 |
| 87758701 | CORPUS CHRISTI, TX | 27 34.8N | 97 13.0W | 05/19/89 |
| 26955351 | BERMUDA, BIO STATION | 32 22.2N | 64 41.7W | 05/27/89 |
| 26955401 | BERMUDA, ESSO | 32 22.4N | 64 42.2W | 05/30/89 |
| 44005001 | HOLYHEAD,WALES (DEMO) | 53 19.0N | 4 37.0W | 06/15/89 |
| 94550901 | SEWARD, ALASKA | 60 7.2N | 149 25.6W | 06/25/89 |
| 94516001 | SITKA, ALASKA | 57 3.1N | 135 20.3W | 07/15/89 |
| 94542401 | VALDEZ, ALASKA | 61 7.5N | 146 21.4W | 07/20/89 |
| 94626201 | UNALASKA ISLAND | 53 52.8N | 166 32.3W | 07/27/89 |
| 94409101 | TOKE POINT, WA | 46 42.4N | 123 57.9W | 08/17/89 |
| 94430901 | NEAH BAY, WA | 48 22.1N | 124 37.0W | 08/24/89 |
| 84101401 | EASTPORT, ME | 44 54.2N | 66 59.1W | 09/01/89 |
| 90870571 | MILWAUKEE, WI | 43 0.1N | 87 53.2W | 09/01/89 |
| 94498801 | FRIDAY HARBOR, WA | 48 22.1N | 124 37.0W | 09/07/89 |
| 84671501 | BRIDGEPORT CT | 41 10.4N | 73 10.9W | 09/08/89 |
| 85455301 | PHILADELPHIA, PA | 30 56.0N | 75 8.5W | 09/08/89 |
| 85746801 | BALTIMORE, MD | 39 16.0N | 76 34.7W | 09/12/89 |
| 85187501 | BATTERY, NYC, NY | 40 42.0N | 74 5.5W | 09/14/89 |
| 85105601 | MONTAUK, NY | 41 2.9N | 71 57.6W | 09/20/89 |

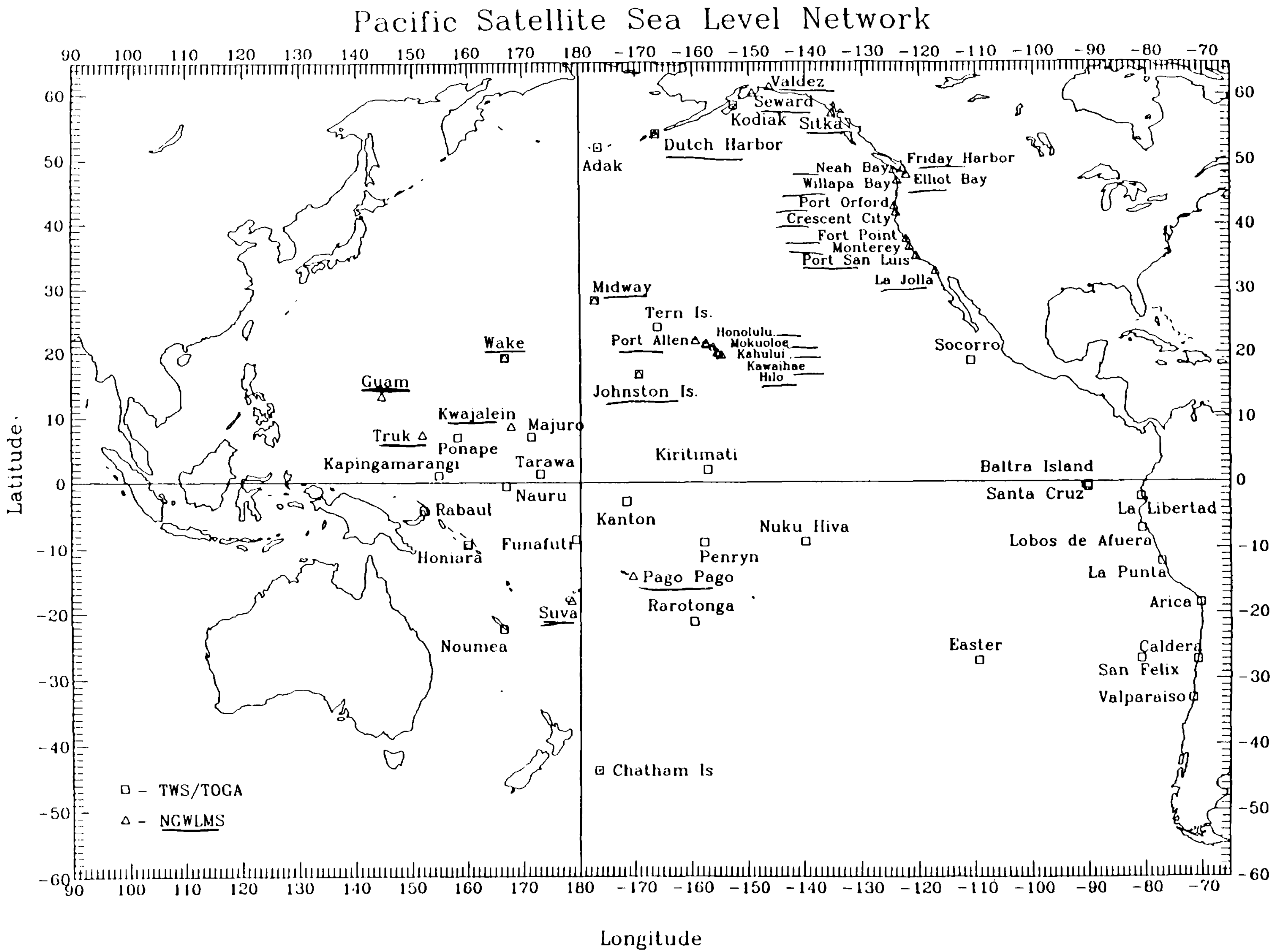
TABLE III (Continued)

Page No. 2
05/23/90

NGWLMS PRODUCTION FIELD UNITS

STATION LOCATIONS
SYSTEMS ARE NOT IN OPERATIONAL STATUS

| STATION NUMBER | STATION NAME | LATITUDE | LONGITUDE | INSTALLATION DATE |
|---|---|---|---|---|
| 87292101 | PANAMA CITY BEACH, FLA | 30 12.8N | 85 52.8W | 09/20/89 |
| 87286901 | APALACHICOLA, FL | 29 43.4N | 84 58.8W | 09/22/89 |
| 94316471 | PORT ORFORD, OR | 42 44.4N | 124 29.8W | 09/22/89 |
| 85316801 | SANDY HOOK, NJ | 40 28.0N | 74 0.1W | 09/26/89 |
| 94121101 | PORT SAN LUIS, CA | 35 10.2N | 120 45.1W | 10/16/89 |
| 90440201 | GIBRALTAR, MI | 42 5.5N | 83 11.2W | 11/08/89 |
| 90630281 | STURGEON POINT, NY | 42 41.4N | 79 2.9W | 12/05/89 |
| 16190001 | JOHNSTON ISLAND | 16 41.4N | 169 31.8W | 01/29/90 |
| 87797701 | PORT ISABEL, TX | 26 3.6N | 97 12.9W | 02/06/90 |
| 87784901 | PORT MANSFIELD, TX | 26 33.3N | 97 25.8W | 02/09/90 |
| 18200001 | KWAJALEIN, MARSHALL IS | 8 44.2N | 167 44.3E | 02/11/90 |
| 87747701 | ROCKPORT, TX | 28 1.3N | 97 2.8W | 02/28/90 |
| 87757921 | PACKERY CHANNEL, TX | 27 38.0N | 97 13.3W | 03/03/90 |
| 87705701 | SABINE PASS NORTH, TX | 29 43.8N | 93 52.2W | 03/08/90 |
| 87778121 | RINCON DEL SAN JOSE, TX | 26 49.5N | 97 29.5W | 03/08/90 |
| 87766871 | YARBROUGH PASS, TX | 27 12.0N | 97 26.0W | 03/12/90 |
| 87617241 | GRAND ISLE, EAST PT. LA | 29 16.5N | 89 57.5W | 04/05/90 |
| 94449001 | PORT TOWNSEND, WA | 48- 6.9N | 122-45.0W | 04/13/90 |
| 86655301 | CHARLESTON, SC | 32 46.9N | 79 55.5W | 04/25/90 |
| 94106601 | LOS ANGELES, CA | 33 43.2N | 118 16.3W | 05/08/90 |
| 94101701 | SAN DIEGO, CA | 32 42.8N | 117 10.4W | 05/09/90 |
| 94150201 | POINT REYES, CA | 37 59.8N | 122 58.5W | 05/15/90 |
| 86708701 | FORT PULASKI, GA | 32 2.0N | 80 54.1W | 05/16/90 |
| 21220601 | DARWIN, AUSTRALIA | 12 28.0S | 130 51.0E | 05/20/90 |
| 21479201 | ADELAIDE, AUSTRALIA | 34 51.0S | 138 30.0E | / / |



Pacific Satellite Sea Level Network
Latitude
Longitude
Valdez
Seward
Kodiak
Sitka
Dutch Harbor
Adak
Friday Harbor
Neah Bay
Elliot Bay
Willapa Bay
Port Orford
Crescent City
Fort Point
Monterey
Port San Luis
La Jolla
Midway
Tern Is.
Honolulu
Port Allen
Mokuoloe
Kahului
Kawaihae
Hilo
Socorro
Johnston Is.
Wake
Guam
Kwajalein
Majuro
Truk
Ponape
Kapingamarangi
Tarawa
Kiritimati
Baltra Island
Santa Cruz
Nauru
Rabaul
Kanton
La Libertad
Nuku Hiva
Lobos de Afuera
Funafuti
Honiara
Penryn
La Punta
Pago Pago
Rarotonga
Arica
Suva
Noumea
Easter
Caldera
San Felix
Valparaiso
Chatham Is
□ – TWS/TOGA
△ – NGWLMS


**Figure 1**

# THERMOPILE BENCH MARK DESCRIPTION AND INSTALLATION PROCEDURE

The thermopile bench mark is a type of bench mark specifically designed to resist the frost heave (vertical) forces generated by seasonal freeze/thaw cycles, particularly in Arctic regions. The thermopile bench mark should be used in areas that do not have bedrock or large stable man-made structures in which to establish standard types of bench marks. The thermopile bench mark can be an alternative to the sleeved type deep rod mark, commonly called the Canadian type deep rod mark, when used under the proper conditions. It can be installed in remote areas without large support equipment and at less cost than the sleeved deep rod. The thermopile bench mark has been developed by Artic Foundation, Inc.

The thermopile bench mark consists of the following components:

- a 10.5 foot long, 1.315 inch diameter, steel pipe with fusion epoxy over flame sprayed aluminum,
- a Bernsten TSD-12 driving tip,
- an unstamped Bernsten TSD-14 aluminum bench mark disk,
- a 7/16 inch diameter threaded coupler with two lock washers (to fasten disk to pipe).

The total unit weighs about 25 pounds. Figure 2 is a schematic of the thermopile bench mark.

The thermopile bench mark operates on a heat transfer mechanism and is generically known as a two-phase closed thermosyphon. Ten feet of the pipe is sealed and pressurized to 600 psi with $CO_2$ gas. The process is activated only when the air temperature is colder than the ground temperature. The temperature differential can be as small as one degree. The temperature differential starts an evaporation/condensation cycle within the pipe. The material within the pipe is in both liquid and gas state due to being charged with a refrigerant. Heat is absorbed from the ground through evaporation of the liquid which rises to the top of the pipe. The rising gas meets the colder air temperature and condenses, radiating heat out from the upper half foot of pipe. Gravity pulls the condensate back down the pipe to the bottom and thermopile at a uniform temperature over its entire length. This will reduce the thermal expansion/contraction effects and result in freezing occurring radially about the thermopile. Ice lenses and other associated pressures will develop radially and therefore not in the vertical direction necessary to cause heaving.

In most cases the installation of a thermopile bench mark is similar to standard deep rod bench mark installations, depending upon the soil type. The thermopile bench mark may be harder to drive, however, due to its larger diameter. In areas with very hard or rocky soil, it may not be possible to drive a thermopile bench mark. A hole may have to be augered in some cases, although this is typically not possible in remote areas. A more feasible option is to alternately drive and pull out a short section of regular hollow open-ended pipe, being sure to knock out the soil in the pipe before driving again. This effectively bores a pilot hole for the mark, although some type of jack is needed to pull the hollow pipe back up out of the ground.

In most areas, however, only a gas impact drill, a tripod, a ladder, and driving heads are required. A location for the mark should be selected according to the standard criteria governing life span and recoverability of the mark covered in the "USERS GUIDE FOR THE INSTALLATION OF BENCHMARKS AND LEVELING REQUIREMENTS FOR WATER LEVEL STATIONS." The thermopile bench mark is then installed according to the following procedure (see Figure 2). Damage to the special epoxy coating should be avoided as the coating reduces the susceptibility of the pipe to the vertical forces.

1. A one-foot diameter pilot hole is dug and should be about one or two feet deep. Because the thermopile bench mark is 10.5 feet long, the tripod must be set up quite high. A deeper hole lessens the height that the gas drill must be elevated in order to sit on top of the pipe.

2. The driving tip is attached tightly to the bottom of the pipe.

3. The driving head is attached tightly to the top of the pipe.

4. The pipe is then driven so that the weld mark is at grade, i.e., the top 1/2 foot of pipe is above ground. The top of the pipe has a weld mark 1/2 foot from the end. The pipe is pressurized along the ten-foot section from the weld mark to the bottom. The top 1/2 foot is not pressurized and radiates the heat.

5. The driving head is removed, and the bench mark disk (previously stamped) is tightly screwed onto the threaded stud, using the two lock washers.

6. (a) If the location selected is protected, such that the protruding bench mark is not exposed to being hit by vehicles, then the hole is backfilled and compacted so that the pipe is surrounded by soil from the weld mark down. If it is not protected, then:

(b) Cut a 6-inch diameter piece of PVC pipe to the depth of the hole plus 3/4 foot more, so that the PVC pipe will extend up around and past the mark about 1/4 foot. Place the PVC pipe around the mark and backfill dirt into the inside of the pipe, compacting it as you go, so that it comes up to the weld mark. Backfill some soil around the outside of the PVC pipe. Then pour one bag of cement around the outside of the PVC pipe making sure that no cement comes in contact with the end piles. Fill the rest of the outside hole with soil. Finally, drill a 1-inch diameter (or more) hole in the side of the pipe just above ground level. This is to allow the insertion of a temperature probe (explained below).

7. Describe the bench mark according to standard procedures.

The thermopile bench mark requires no more maintenance than other deep rod marks. The gas will not run out so long as the pipe remains sealed and pressurized. If there is some doubt as to whether or not this is the case, then the mark can be tested to see if it is operating properly. A day must be selected during which the air temperature is known to be colder than the ground temperature. A temperature probe is used to measure the ambient temperature of several objects on the ground, such as rocks. The probe is then used to measure the temperature of the upper 1/2 foot of the pipe. If the thermopile mark is operating properly, the temperature of the pipe will be higher than ambient. Other heat measuring devices, such as an infrared camera, can also be used to determine whether or not the thermopile is functioning.

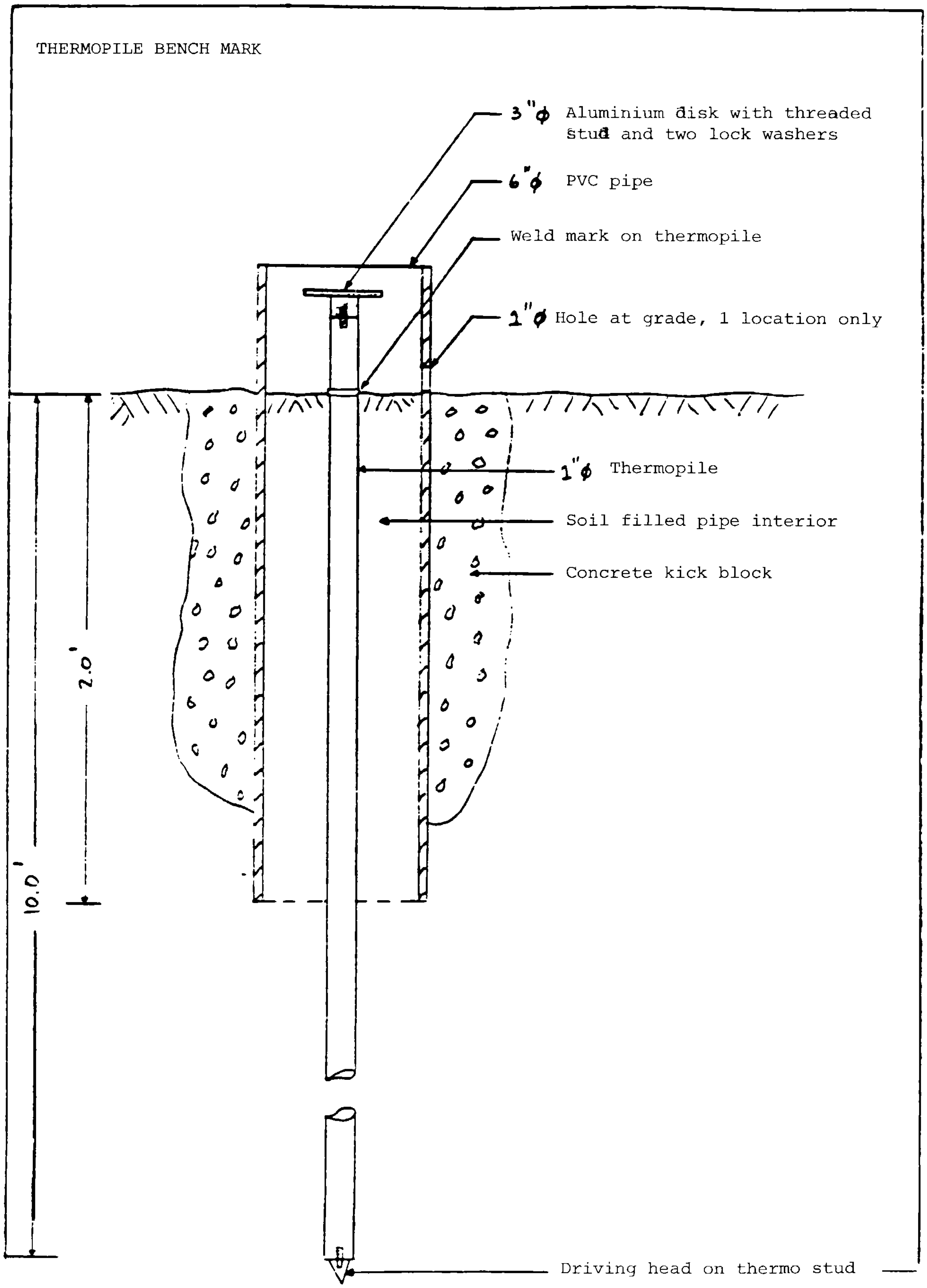
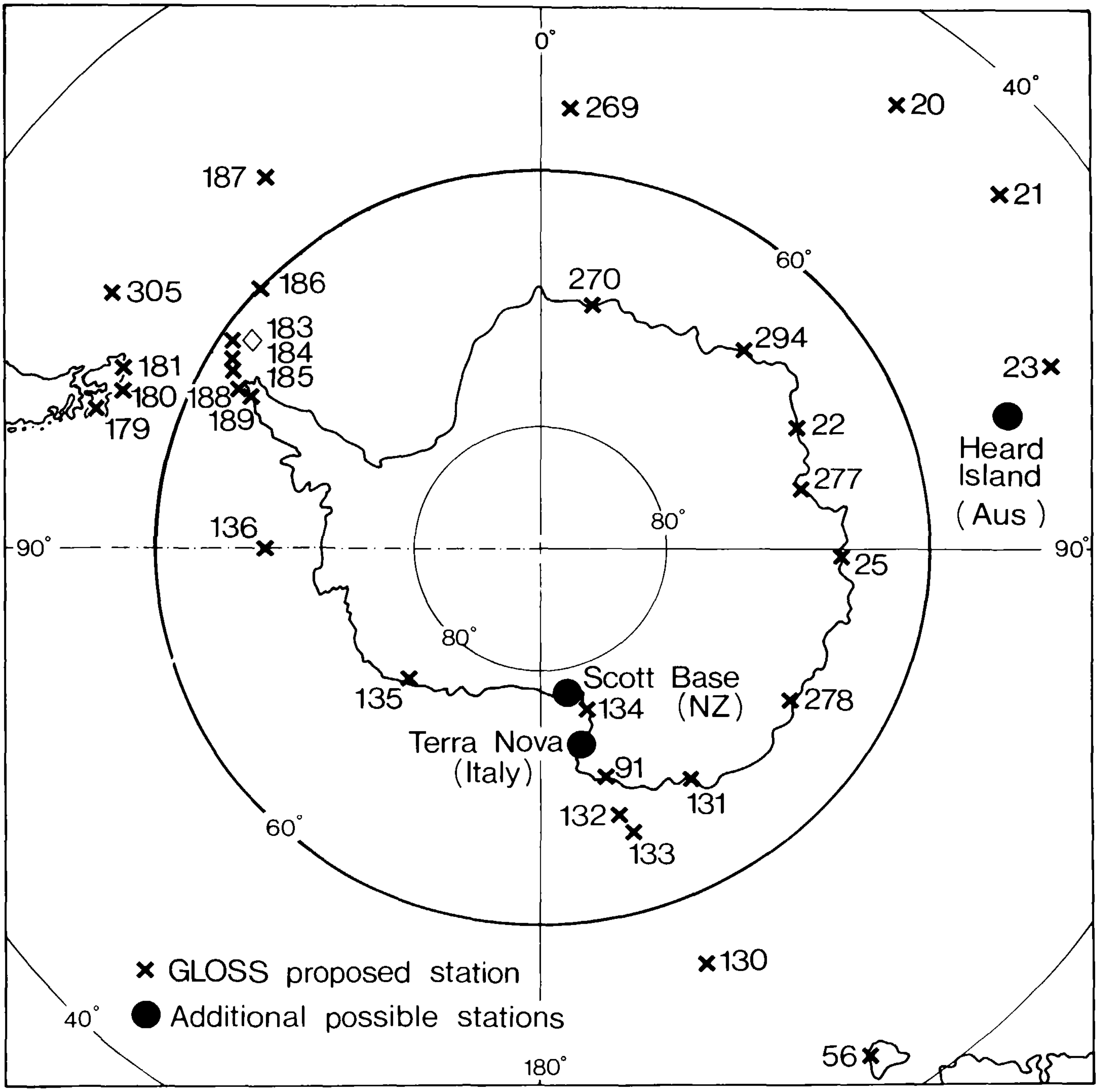

THERMOPILE BENCH MARK
3"ϕ Aluminium disk with threaded stud and two lock washers
6"ϕ PVC pipe
Weld mark on thermopile
1"ϕ Hole at grade, 1 location only
1"ϕ Thermopile
Soil filled pipe interior
Concrete kick block
2.0'
10.0'
Driving head on thermo stud

**Figure 2**

## APPENDIX 1

## SOUTHERN OCEAN GLOSS Proposed Stations (1989)

| | | |
|---|---|---|
| 269 | Bouvet | Norway |
| 270 | Novolazarevskaya | USSR |
| 20 | Marion Is. | S.A. |
| 21 | Crozet | France |
| 294 | Molodezhnaya | USSR |
| 22 | Mawson | Australia |
| 23 | Kerguelen | France |
| 277 | Davis | Australia |
| 25 | Mirny | USSR |
| 278 | Casey | Australia |
| 131 | Dumont d'Urville | France |
| 91 | Leningradskay | USSR |
| 130 | Macquarie | Australia |
| 56 | Hobart | Australia |
| 132 | Balleny | |
| 133 | Scott Is. | |
| 134 | McMurdo | USA |
| 135 | Russkaya | USSR |
| 136 | Peter I. | Norway |
| 179 | Punta Arenas | Chile |
| 181 | Ushuaia | Argentina |
| 180 | Puerto Williams | Chile |
| 183 | Palmer | USA |
| 184 | Jubany | Argentina |
| 185 | Esperanza | Argentina |
| 186 | Bahia Scotia | Argentina |
| 187 | South Georgia | UK |
| 188 | Faraday | UK |
| 189 | Base Antarctica | Chile |
| 305 | Falklands/Malvinas | |
| 306 | South Orkney | UK |


0°
269
20
40°
187
21
60°
270
186
305
183
294
184
181
185
23
180
188
189
179
22
Heard Island (Aus)
277
136
80°
90°
25
90°
80°
Scott Base (NZ)
135
134
278
Terra Nova (Italy)
91
131
132
133
60°
130
GLOSS proposed station
Additional possible stations
40°
180°
56

# APPENDIX 2

## Summary of Sea Level Measurements in the Antarctic

prepared by Dr P D Clarkson - Executive Secretary SCAR
and Dr D T Pugh - Chairman GLOSS

# Sea Level Measurements in the Antarctic

## Summary of SCAR Review

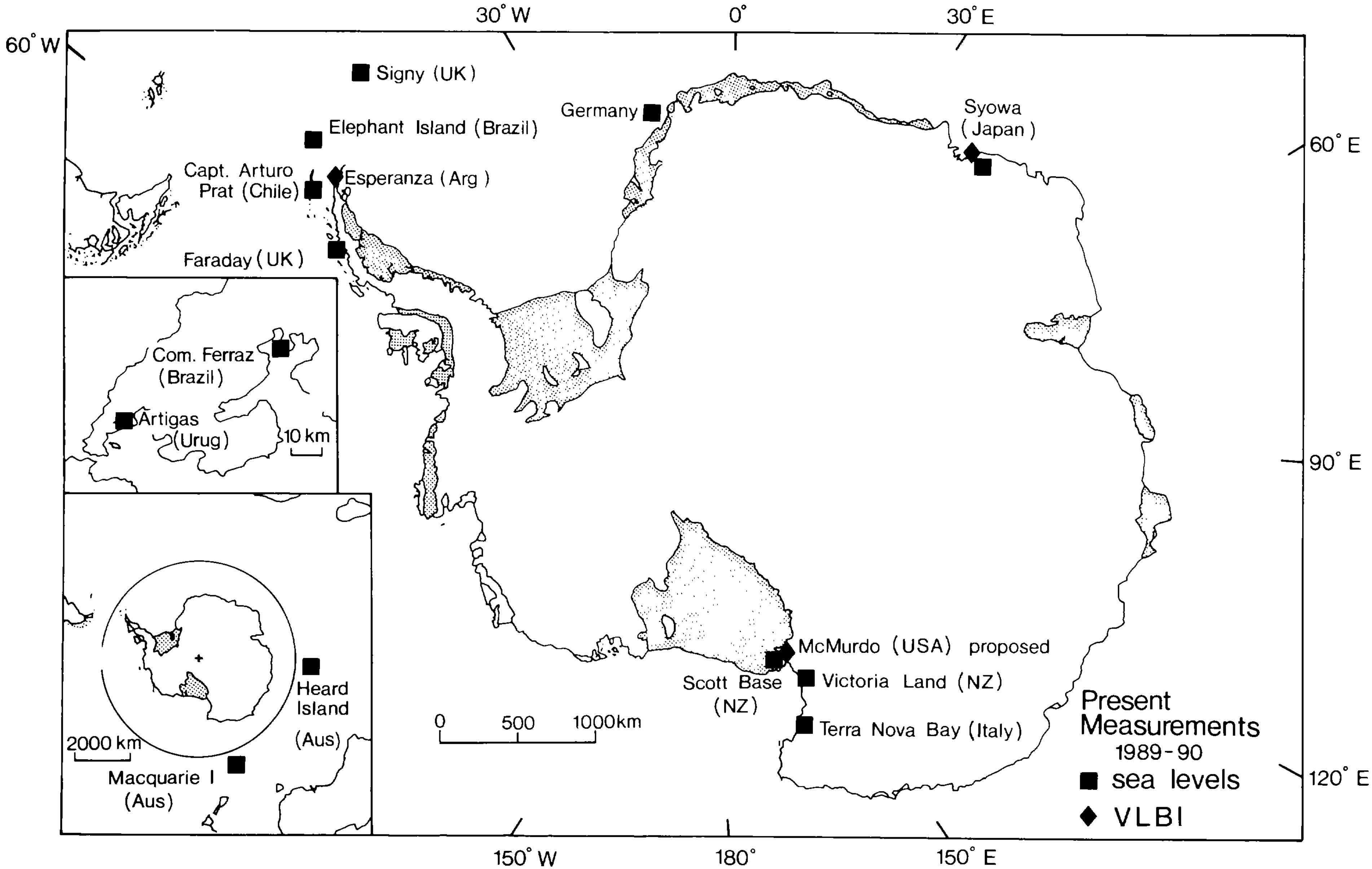
| Country | 1<br>Current Gauge Deploy-ment | 2<br>Location | 3<br>Type of Gauge | 4<br>Organisation and Officer | 5<br>Data Stored by | 6<br>Organisation using data<br>*[If different from Col4]* | 7<br>Scientific Programmes | 8<br>Other Information | 9<br>Other Gauge Locations | 10<br>Person completing questionnaire |
|---|---|---|---|---|---|---|---|---|---|---|
| Argentina | No | | | Instituto Antarctico Argentino<br>Lic José Gallo<br>Sr Martin C Roese | | | | | Jubany<br>62°15'S, 58°41'W<br>28.12.87-10.2.88<br>Camara<br>62°35'S, 59°53'W<br>6.1.89-15.2.89<br>Camara<br>Jan-Mar90 | Lic José Gallo |
| Australia | Yes | Macquarie Islands<br>54°30S, 159°00E<br>Heard Island<br>53°S, 72°35E | Aanderaa | Flinders Univ Tidal Lab<br>Prof G W Lennon | | | Circumpolar current of Australia and Antarctica<br>Shelf tidal mod. due to sea ice<br>South Ocean, re ENSO events | | Planned for Mawson and Davis stations | R Williams<br>Australia-Antarctic Division, Channel Highway, Kingston, Tasmania |
| Brazil | Yes | Comandante Ferraz<br>62°06'S<br>58°24'W<br>Ilha Elefante<br>61°17'S<br>55°13'W | Aanderaa WRL 7 | Diretoria de Hydrografia E Navigação<br>Dept de Serviços Oceanicos | | | Hydrographic Surveying | Deployed for short periods simultaneously with surveying | Will be in future when hydrographic surveying | Marco Antonio de Carvalho Oliveira<br>Diretoria de Hydrografia E Navigação<br>Dept de Serviços Oceanicos |
| Chile | Yes | Antarctica Chilena, Bahia Chile, Arturo Prat<br>62°29S, 59°38W | Gas purged MK Metercraft | Inst Hydrografico de la Armada<br>Capt Rudolfo Camacho | | | IGOSS-SLP, Chilean Antarctic Cartographic Tidal Datum | | Isla Rey Jorge, Bahia Fildes, 1979-1983<br>62°11'S, 58°54'W<br>Tierra de O'Higgins, Rada Covadaiga, 1975-77<br>63°19'S, 57°55'W | Lt Félix R Espinoza<br>Inst Hydrografico de la Armada<br>Casilla 324, Valporaiso, Chile |

| Country | 1<br>Current Gauge Deploy-ment | 2<br>Location | 3<br>Type of Gauge | 4<br>Organisation and Officer | 5<br>Data Stored by | 6<br>Organisation using data [If different from Col4] | 7<br>Scientific Programmes | 8<br>Other Information | 9<br>Other Gauge Locations | 10<br>Person completing questionnaire |
|---|---|---|---|---|---|---|---|---|---|---|
| Finland | No | | | | | | | | None | Hannu Grónvall<br>Inst of Marine Research |
| FRG | Yes | Vestkapp<br>Weddell Sea<br>71°02S, 11°45W | Aanderaa plus inverted echo sounder with pressure transducer | Alfred-Wegener Inst for Polar and Marine Research<br>Prof G Krause | | | Tides in Weddell Sea<br>Weddell Gyre and Coastal Current | First deployment Feb87 | One year in Atka Bight<br>Will be continued during WOCE | Prof G Krause<br>Alfred-Wegener Inst for Polar and Marine Research |
| GDR | No | | | | | | | | Planned for 1991 near Georg Forster Station (11°E, 79°S) | Hans-Jurgen Paech<br>Central Inst for Physics of the Earth |
| India | No | | | | | | | | Contemplated in Antarctica, but no definite plans | Prof V K Gaur<br>Dept Ocean Development, New Delhi |
| Italy | Yes | Terra Nova Bay<br>74°42S, 164°08'E | BTH 700 (Valeport Marine UK) | Programma Nazion, DI Ricerche in Antartide<br>Ing Mario Zucchelli | Inst der L'automazione Naval CMR | | Climate change<br>Bathymetry<br>Geodesy<br>Geomorphology | Gauge operates during summer only | None in past; will be in future | Prof Carlo Stocchino<br>Inst der L'automazione Naval CMR |
| Japan | Yes | Syowa Station<br>69°00'S, 39°34'E | Pressure type using crystal | Ocean Survey Div, Maritime Safety Agency<br>Director of Ocean Survey Div | | | Japanese Antarctic Research Expedition | | | Iwao Noguchi<br>Ocean Survey Div, Maritime Safety Agency |
| New Zealand | Yes | Ross Island<br>77°51'S, 166°45'E<br>Victoria Land<br>77°02'S, 163°11'E | Vibrating wire pressure transducer | Dept of Survey and Land Information<br>G H Rowe | | | Tide prediction for Scott Base; mean sea level; rate of sea level change | Gauge established 1988 as long term<br>Data logged every 10 minutes | Same locations 1957-58<br>If gauge at Cape Roberts survived 1989 winter, would be interested in further operation | G H Rowe<br>Dept of Survey and Land Information |

| Country | 1<br>Current Gauge Deploy-ment | 2<br>Location | 3<br>Type of Gauge | 4<br>Organisation and Officer | 5<br>Data Stored by [If different from Col4] | 6<br>Organisation using data | 7<br>Scientific Programmes | 8<br>Other Information | 9<br>Other Gauge Locations | 10<br>Person completing questionnaire |
|---|---|---|---|---|---|---|---|---|---|---|
| Norway | No | | | | | | | | Norway Station 3°W approx 1957-59<br>Bouvetøya 54°S, 3°E, 1979<br>Possible data from Jan/Feb90 from Jatalstraumen 71°30'S, 0°E | Prof Olav Orheim<br>Norwegian Polar Research Institute |
| South Africa | No | | | | | | | | Marion Island - tide gauge<br>Sea level planned for 1991/92 in Antarctica | D J Van Schalkwyk<br>Dept of Environmental Affairs, Pretoria |
| United Kingdom | Yes | Faraday Station 65°15'S, 64°16'W<br>Signy Island (BAS base) 60°43'S, 45°36'W<br>Port Stanley 51°41'S, 57°50'W<br>South of Falkland Is 53°32'S, 57°1'W<br>Scotia Sea 56°42'S, 52°32'W | Munro IH log<br>Portable Water Level Recorder<br>} Cable to underwater pressure transducer }<br>} Bottom Pressure Recorder } | BAS Cambridge - Dr J G Paren<br>Proudman Oceanographic Laboratory (POL)<br>POL<br>POL<br>POL | British Oceano-graphic Data Centre (BODC), POL | BODC, POL | Faraday - Dynamics of W Antarctica Ice Sheet. US programme on flow through Drake Passage<br>Signy, P/Stanley, Falkland and Scotia - related to WOCE and GLOSS | Faraday proposed as primary GLOSS site<br>Depth 2800m<br>Depth 3150m | 69°58'S, 68°51'W<br>73°10'S, 71°40'W<br>73°08'S, 72°32'W<br>(16, 45 and 357 days)<br>Planned for centre of Ronne Ice Shelf, Dec90 | Faraday: J G Paren, BAS Cambridge<br>Signy, P/Stanley, Falkland and Scotia: Ian Vassie, POL |

| Country | 1<br>Current Gauge Deploy-ment | 2<br>Location | 3<br>Type of Gauge | 4<br>Organisation and Officer | 5<br>Data Stored by | 6<br>Organisation using data<br>*[If different from Col4]* | 7<br>Scientific Programmes | 8<br>Other Information | 9<br>Other Gauge Locations | 10<br>Person completing questionnaire |
|---|---|---|---|---|---|---|---|---|---|---|
| United States of America | No | | | | | | | | Stonington Island, Apr47-Feb48<br>Little America V, Jun-Jul57<br>Wilkes Station, Nov58-Feb59<br>Hallett Station, Mar-Apr59<br>McMurdo Station, Jan-Dec77<br>Palmer Station, Feb71-Oct73<br>Ross Ice Shelf (various), summers 1973-78<br>62°28'S, 60°27'W, Feb-May75<br>56°02'S, 67°06'W Feb-Mar75<br>Palmer Station, Feb75-Oct76<br>56°32'S, 66°59'W, Feb-Jul76<br>62°28'S, 60°27'W, Feb-Nov76<br>62°06'S, 60°35'W Feb76-Jan79<br>56°32'S, 66°59'W Jan77-Jan79<br>No presently planned measurements | B Lettan<br>NSF/Div of Polar Programmes, Washington |

| Country | 1<br>Current Gauge Deploy-ment | 2<br>Location | 3<br>Type of Gauge | 4<br>Organisation and Officer | 5<br>Data Stored by | 6<br>Organisation using data<br>*[If different from Col4]* | 7<br>Scientific Programmes | 8<br>Other Information | 9<br>Other Gauge Locations | 10<br>Person completing questionnaire |
|---|---|---|---|---|---|---|---|---|---|---|
| USSR | No | | | | | | | | Molodezhnaya<br>67°40'S, 45°50'E<br>1963-71<br>Mirny<br>66°33'S, 93°01'E<br>1957-58, 1962,<br>1965-71<br>Novolazarevskays<br>67°40'S, 11°50'E<br>1964, 1966-67, 1969,<br>1972<br>Bellingshausen<br>62°12'S, 58°56'W<br>1968-69, 1972, 1989<br>Seasonal measure-ments, not permanent<br>Planning for Mirny and Molodezhnaya from 1993 | Dr V Kaliazin<br>Arctic and Antarctic Research Institute, Leningrad |
| Uruguay | Yes | King George Island<br>62°11'S, 58°52'W | Aanderaa WLR 7 | Oceanography, Hydrography and Met Service of Navy (SOHMA)<br>Commanding Officer | | | Study of Tides in Antarctica | Measurements correspond to Antarctic summer<br>1988-89 | | A/N (CG)<br>I Barreira<br>SOHMA, Montevideo |



30° W
0°
30° E
60° W
60° E
90° E
120° E
150° W
180°
150° E
Signy (UK)
Elephant Island (Brazil)
Capt. Arturo Prat (Chile)
Esperanza (Arg)
Faraday (UK)
Germany
Syowa (Japan)
Com. Ferraz (Brazil)
Artigas (Urug)
10 km
McMurdo (USA) proposed
Scott Base (NZ)
Victoria Land (NZ)
Terra Nova Bay (Italy)
0 500 1000km
Heard Island (Aus)
2000 km
Macquarie I (Aus)
Present Measurements 1989-90
sea levels
VLBI

| No. | Title | Languages |
| --- | --- | --- |
| 64 | Second IOC-FAO Workshop on Recruitment of Penaeid Prawns in the Indo-West Pacific Region (PREP), Phuket, Thailand, 25-31 September 1989 | E |
| 65 | Second IOC Workshop on Sardine/Anchovy Recruitment Project (SARP) in the Southwest Atlantic, Montevideo, Uruguay, 21-23 August 1989 | E |
| 66 | IOC *ad hoc* Expert Consultation on Sardine/Anchovy Recruitment Programme, La Jolla, California, USA, 1989 | E |
| 67 | Interdisciplinary Seminar on Research Problems in the IOCARIBE Region, Caracas, Venezuela, 28 November - 1 December 1989 | E |
| 68 | International Workshop on Marine Acoustics. Beijing, China, 26-30 March 1990 | E |