INTERGOVERNMENTAL OCEANOGRAPHIC COMMISSION (OF UNESCO)

WORLD METEOROLOGICAL ORGANIZATION

DATA BUOY COOPERATION PANEL

DEVELOPMENTS IN MOORED AND DRIFTING BUOY DESIGN, PROGRAMMES, SENSORS, AND COMMUNICATIONS

PRESENTATIONS AT THE DBCP TECHNICAL WORKSHOP

(Wellington, New Zealand, October 1999)

DBCP Technical Document No. 17

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NOTE

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FOREWORD

The success of the technical workshops, beginning at the eleventh session of the Data Buoy Co-operation Panel (DBCP), encouraged the panel to make such workshops a regular feature of its annual session, as a practical means of promoting cooperation and information exchange amongst all sections of the global buoy community, including buoy deployers, data users and communication systems providers.

Consequently, a technical workshop on *Developments in Buoy Design and Programmes, Data Requirements and Case Studies and SVPBW Minimet Evaluations* took place during the first day and a half of the fifteenth session of the panel, held in Wellington, New Zealand, October 1999. Twenty-five papers were presented to more than fifty participants during the workshop. The texts of twenty-three papers and two abstracts are included in this DBCP technical publication. In all cases the papers have been reprinted as received, without additional editorial intervention.

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VENUE: Wellington, NZ
DATE : October 26-27, 1999

THEME: DEVELOPMENTS IN BUOY TECHNOLOGY, COMMUNICATIONS AND DATA APPLICATIONS

WORKSHOP CHAIR: Ron McLaren, Pacific and Yukon Region, Meteorological Service of Canada.

Tuesday, October 26, 1999

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Chair - Ron McLaren, Meteorological Service of Canada.

The PROVOR Float
Philippe Marchand, IFREMER, Centre de Brest, France

Timeliness and Availability of Buoy Data on the GTS
Pierre Blouch, Meteo-France, France

A Practical Approach for use of the Argos Downlink
Christian Ortega, Argos, Oceanographic Applications, France

Meteo-France's Moored Buoys in Deep Sea off the French West Indies
J. Rolland and P. Blouch, Meteo-France, France

Towards an Australian Ocean Observing System
Phil Parker, National Programme Manager, Marine Weather & Oceanography Services
Bureau of Meteorology, Australia

The CORIOLIS Proposal
Philippe Marchand, IFREMER, Centre de Brest, France

Developments in Quality Control Techniques for Buoy and other Marine Observations
A.E. Guymer, Data Management, National Climate Centre, Bureau of Meteorology, Australia

A Review of New PMEL North Pacific Mooring Experiments
Paul Freitag, Hugh Milburn, NOAA/PMEL, USA

Ice Drift and Meteorological Observations in the Antarctic Sea Ice Zone: the International Programme for Antarctic Buoys (IPAB).
Ian Allison, IPAB Coordinator, Antarctic CRC and Australian Antarctic Division, Australia

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David Meldrum, CCMS - Dunstaffnage Marine Laboratory, Scotland

The Use of Autonomous Solar Electric Research Vessels to Obtain Oceanographic Data
Peter Thomas, Department of Software & Electronic Engineering, Central Institute of Technology, New Zealand

Session II **Data requirements, applications and case studies relating to operational oceanography and meteorology, including in particular weather forecasting in the Southern Hemisphere.**
Chair - Wynn Jones, UK Met. Office

Are Moored Buoy Winds Too Low in High Seas?
Rex Hervey, National Data Buoy Center, Technical Services Contractor, John C. Stennis Space Center, Mississippi, USA
Presented by Eric Meindl

The Storm Wave Studies - An investigation into the Data Recovered From a 6m Moored NOMAD Buoy on Canada's East and West Coasts.
Simon G.P. Skey, Kent Berger-North, Mark Blaseckie – Axys Environmental Systems
Val Swail, Ron McLaren – Environment Canada. Presented by Mark Blaseckie

The Use of Drifting Buoy Observations in the National Meteorological Operations Centre, Melbourne
Terry Hart, Graham Warren and Bob Seaman, Bureau of Meteorology, Melbourne, Australia

Drifting Buoy Observations and Explosive Cyclogenesis over the Tasman Sea
Erick M. Brenstrum, Lead Forecaster, Meteorological Service of New Zealand Ltd., New Zealand

The Moored FGGE Wind Buoy in St. Vincent Gulf, South Australia, Some Applications to Marine Wind Forecasting.
Andrew Watson and Bruce Brooks, Bureau of Meteorology, South Australian Regional Office

The Impact of Drifting Buoy Data
Graeme S. Ball, Senior Meteorologist, Marine Observations Unit, Bureau of Meteorology, Australia

The New Phase of Drifter Experiment in the Black Sea
S.V. Motyzhev*, P.M. Poulain**, A.G. Zatsepin***, C. Fayos**, A.G. Kostianoy***, N.A. Maximenko***, S.G. Poyarkov***, D.M. Soloviev* and S.V. Stanichny*
* Marine Hydrophysical Institute, Sevastopol, Ukraine
** Department of Oceanography, Monterey, CA, USA
*** P.P. Shirshov Institute of Oceanology, Moscow, Russia

An Error in the Initialisation of the NCEP ENSO Predictions
Mark S. Swenson and Hugo Bezdek, National Oceanic and Atmospheric Administration, AOML, USA

Wednesday, October 27, 1999

Session III **DBCP SVPBW/Minimet Evaluation**
Chair - Elizabeth Horton, U.S. Naval Oceanographic Office, U.S.A.

An Assessment of the Uncertainty in Drifting and Moored Buoy Observations
D W Jones, H Tanner, P Blouch, UK Met. Office, UK

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PRESENTATIONS

PROVOR AND CORIOLIS DATA CENTER
A STEP TOWARDS OPERATIONNAL OCEANOGRAPHY

Gérard LOAEC*, Thierry CARVAL*, Serge LE RESTE*, Gilbert MAUDIRE*

*IFREMER - Brest - Marine Technology and Information Systems Division

1 - INTRODUCTION

At the beginning of the nineties, initially within the framework of WOCE program, many tens of multicycle subsurface MARVOR floats have been launched in South Atlantic. Then, with close relationship with the Hydrographic Service of the French Navy, some others have been deployed in North Atlantic. More than 150 MARVOR floats have been running since 1994, giving a better description of the water circulation at depth. These floats typically drift at a given pressure level, being regularly located by acoustics, and come up to the surface every two or three months to achieve ARGOS data transmission. These data are then processed and results are given through scientific publications many months after raw data acquisition.
More recently, the need to get oceanic data that could be introduced in real time into prediction models of the climate evolution, or for defense applications, has been growing up (ARGO and associated programs). PROVOR profiling float has been developped for this use. PROVOR has got benefit from MARVOR improvements and technology has been demonstrated. However, it is necessary to distribute the validated data very quickly after their capture at sea. That is the aim of the CORIOLIS Data Center.

2 – PROVOR DESCRIPTION

PROVOR is a free drifting profiler which uses most of the electronic or mechanical parts which were designed for MARVOR, and takes advantage of its improvements. PROVOR is designed to drift at depth for 5 years and come up to the surface every ten days. Data are then transmitted and the float is localizated, using ARGOS satellite system. During the trips between the surface and the depth, profiles of temperature and conductivity of the upper layer of the ocean are gathered. The typical operating cycle is shown on figure 1.

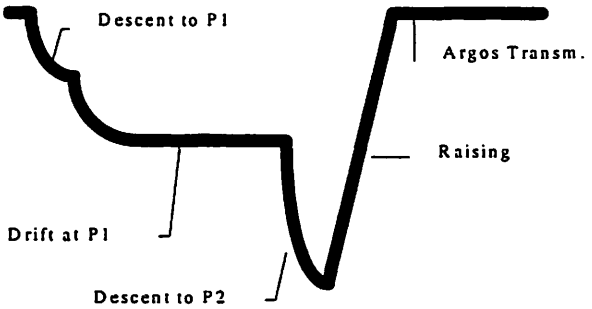


Fig. 1 - Operating cycle of PROVOR float

The float executes identical cycles which are programmed by the user before launching. During the descent phase, the float reaches the drifting level (P1) by light adjustements of the volume of the external ballast, each time the float stabilizes. There is no control of the speed which is about 2.4 cm/s. T or CT measurements can be conducted and the period of data acquisition can be as low as 10 seconds. After the float stabilizes at the desired pressure, it drifts with the surrounding water, until the date of the second descent to the profile pressure (P2), where it stays for a few hours, waiting for the hour of start of profile. The typical duration of the drifting phase is 10 days and the maximum pressure 2000 dbars. As PROVOR is able to adjust its volume, it can drift at a given pressure to identify the circulation of the water and dives to a higher depth before raising to the surface, to provide CTD informations all over the water column. The speed of the float is controlled during the raising and is typically set to 5.5 m/mn. After PROVOR reaches the surface, it tranfers the necessary volume of oil to the ballast to provide a sufficient enough stability to ensure good data transmission results. The number of cycles that can be achieved is a function of the operating pressure and the volume of data that is to be transmitted. Taking into account a 24 (PROVOR-Temperature profiler fitted with SEASCAN sensors) or 26 (PROVOR-CT Conductivity/temperature profiler fitted with FSI sensors) lithium cells battery pack, the number of cycles is about 150, giving 300 T or CT profiles.

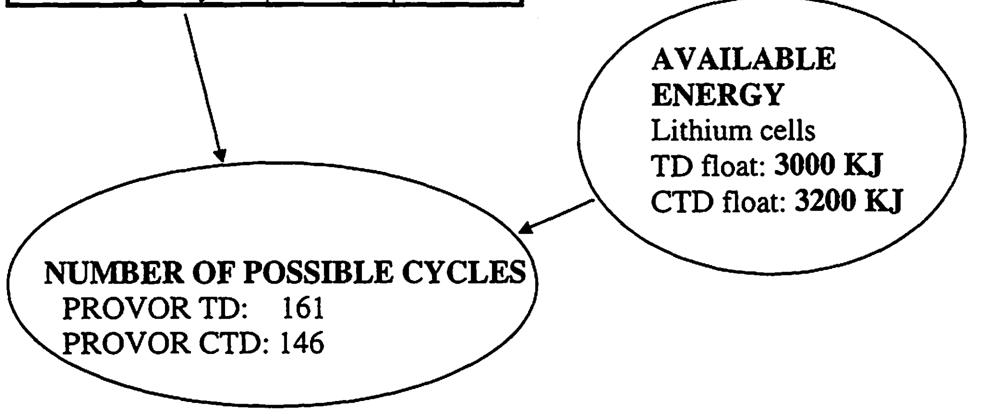
PROVOR ENERGY BUDGET

Conditions:

- Buoyancy control: 400 cm3
- 1week cycle : descent, drifting at 1000m, descent to 2000m, rise.
- Measurements during descent an rise: T or CT F, 1 sample/m
- Measurement during drifting: 1 sample / 6 hours
- Data compression using XBT algorithms: 100 pts for descent, 100pts for rise.
- ARGOS Satellite transmission: 4 hours (PROVOR-T) or 6 hours (PROVOR-CT)

ENERGY REQUIRED PER CYCLE

PHASE	TD	CTD
Buoyancy control	13.9 KJ	13.9 KJ
Satellite transmission	2.5 KJ	3.8KJ
Electronics	2.0 KJ	2.0 KJ
Measurements	0.2 KJ	1.9 KJ
TOTAL per cycle	**18.6 KJ**	**21.9 KJ**



2 - DATA ACQUISITION

It is necessary to keep the time spent at the surface as low as possible for many reasons :
- the environment is much harsher at the surface than at depth (swell effects in rough sea, risks of collision...),
- the float aims to describe the subsurface water circulation and its drift at the surface must be low, compared with the drift at depth,
- a long stay at the surface means a great energy consumption, as the floats comes up to the surface to transmit data via ARGOS.

For all these reasons, it is necessary to reduce the volume of data to transmit and to choose correctly the most pertinent informations, according to the aims of the final user of the equipments. On PROVOR, CTD measurements are gathered function of time and then processed to extract temperature and conductivity profiles which are functions of the pressure. As the sampling period may be as low as 10 seconds, the number of measurement points over 2000 meters during the raising phase may reach 2000. The resolution of the different measurements is 0.01°C, 0.01 mS/cm and 1 dbar respectively for Temperature, Conductivity and Pressure. That means that the raw data is stored on about 6000 bytes.

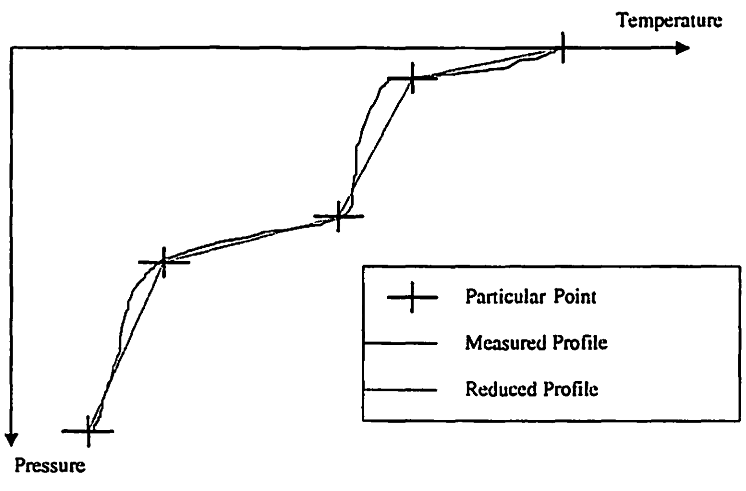
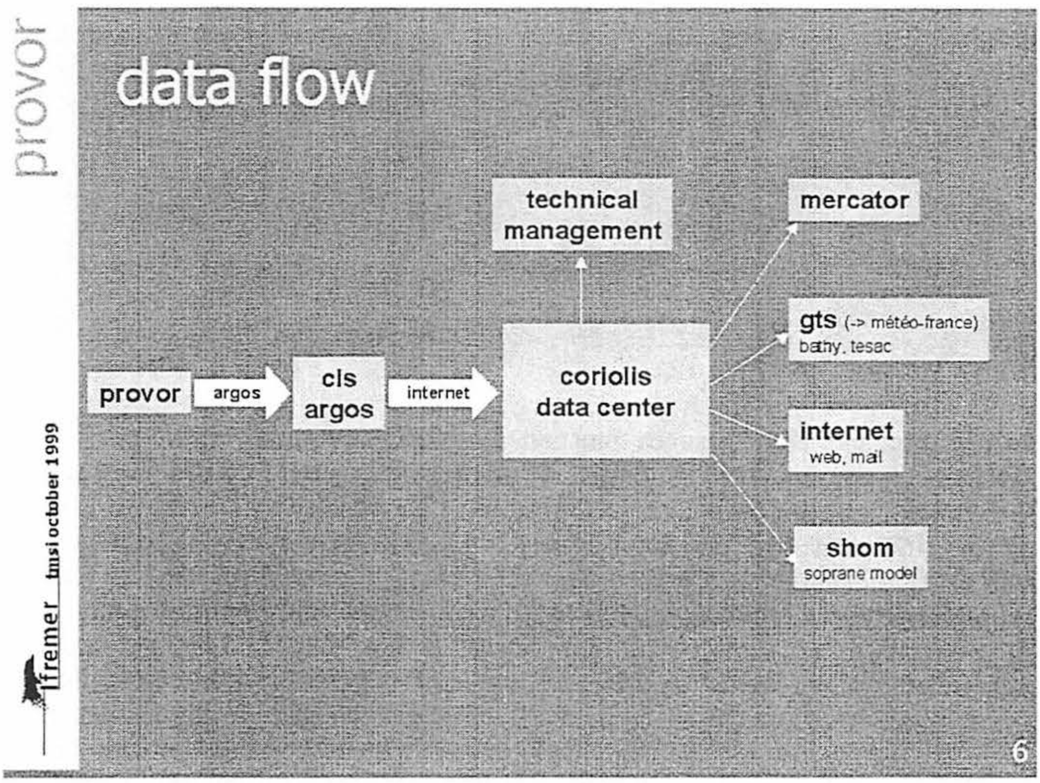


Fig 2 - illustration of the reduction method

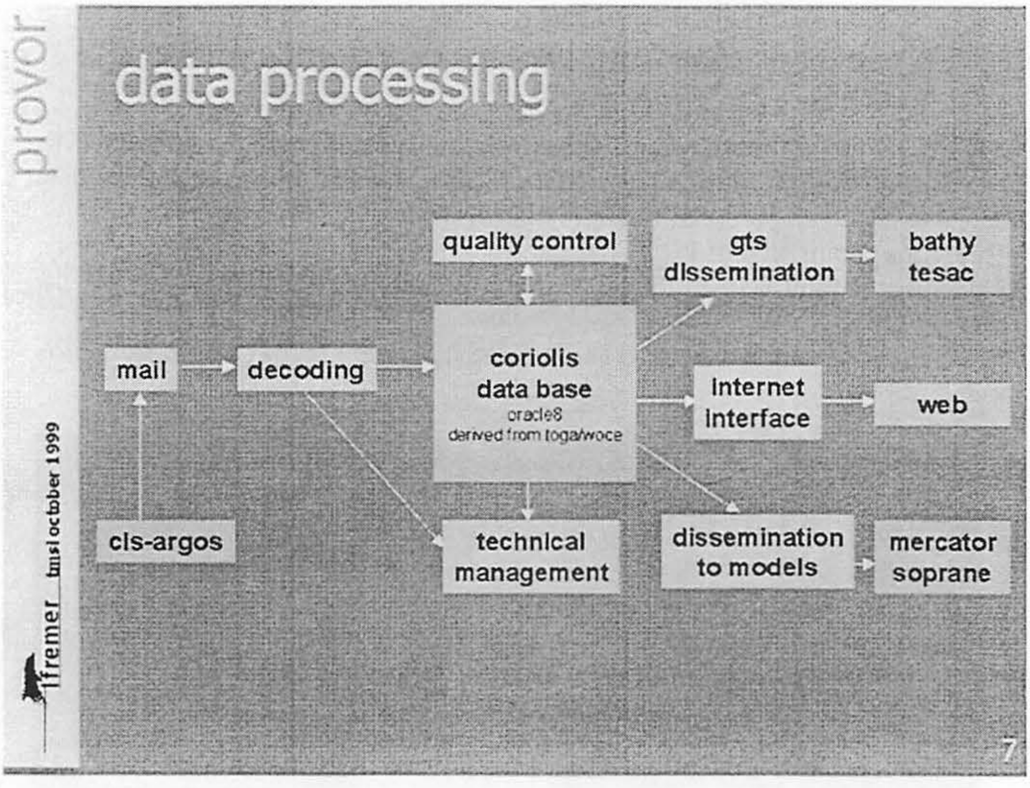
Without any treatment, 4 days would be neccessary to transmit all these data. It is possible to reduce the volume of raw data by keeping only some particular points in such a way that, if a stright line is draught between 2 particular points, the difference between the real T or C measurements and the interpolated values is lower than a maximum error which is defined during the programming phase of the float.
This data processing method was already used to reduce the volume of data provided by XBT sensors and is illustrated on figure 2. As the variability of T and C is much higher in the upper layer of the water column, it is possible to define two differents areas with a specific maximum error in each area, for exemple 0.1°C in the upper side and 0.03°C in the lower side.

3 - CORIOLIS DATA CENTER

CORIOLIS is the data center for operationnal oceanography in IFREMER. Data issued from all PROVOR floats are processed by the CORIOLIS data center. CORIOLIS performs the following features :
-Real time acquisition of PROVOR data
- Decoding and uploading of the data in the CORIOLIS database
- Quality control
- Dissemination of the data on GTS, INTERNET (web, mail) for insertion into models

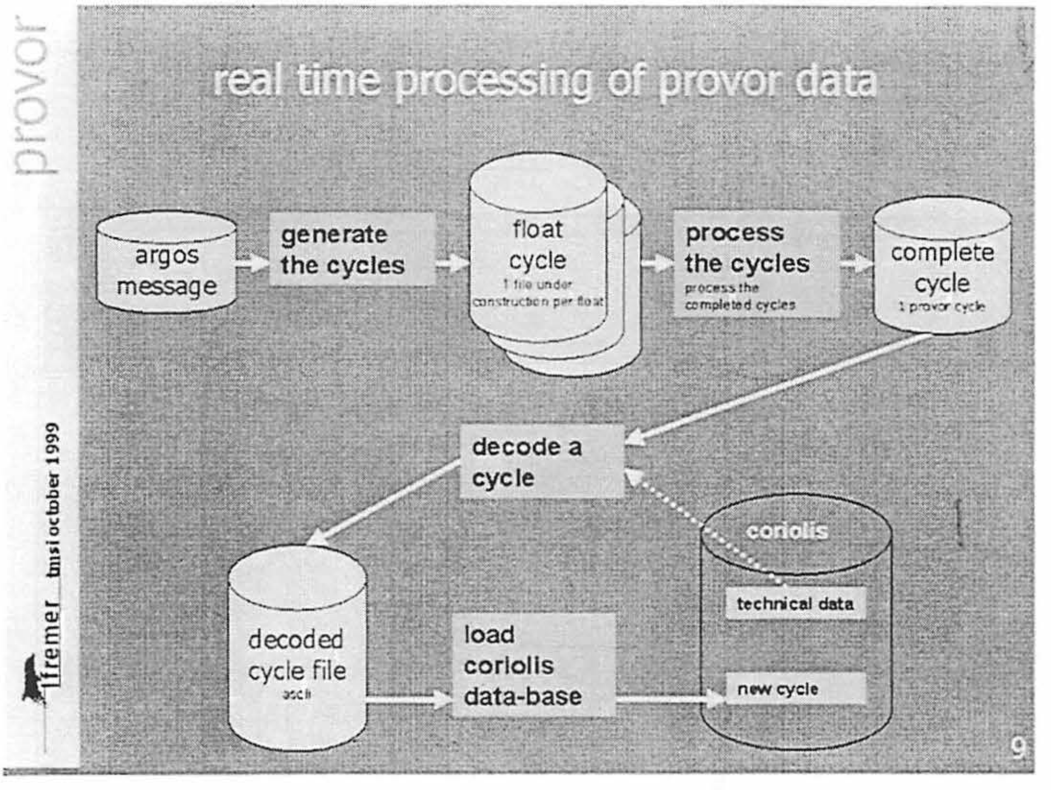


The CORIOLIS data center is an evolution of the TOGA/WOCE database (14 years of data collection, 600000 profiles) . CORIOLIS is based on three major infrastructures :
- INTERNET mail for the real time processing of incoming PROVOR data.
- ORACLE 8 for the data and quality controls
- INTERNET (web, ftp) for the data dissemination.



Information and data messages transmitted by PROVOR are collected by CLS-ARGOS. Through ADS (Automatic Distribution Service), ARGOS messages are immediatly forwarded to CORIOLIS Data Center in IFREMER, by INTERNET mail. The mail address used by CLS-ARGOS is associated with an automatic processing performed at every message delivery and messages are automatically processed as soon as they arrive. There is no need to maintain a system that will regularly check a new arrival of data. This function is naturally performed ; it is a robust solution. Mail service is probably the most critical information infrastructure at IFREMER. The maintenance of the service is therefore a priority for the exploitation team. In case of trouble with one component of the transmission (server, network or electrical failure), the mail protocol will naturally perform the needed retransmission. The mail protocol also guaranty that the received mails are complete.

A PROVOR cycle contains four profiles (descending, ascending, immersion and surface) and technical data. The data of a PROVOR cycle are transmitted in small messages to CLS-ARGOS. For each PROVOR float, messages are gathered to create a complete cycle data file. The cycle data file is then decoded. The four profiles and the technical datas of the cycle are uploaded into the CORIOLIS database.



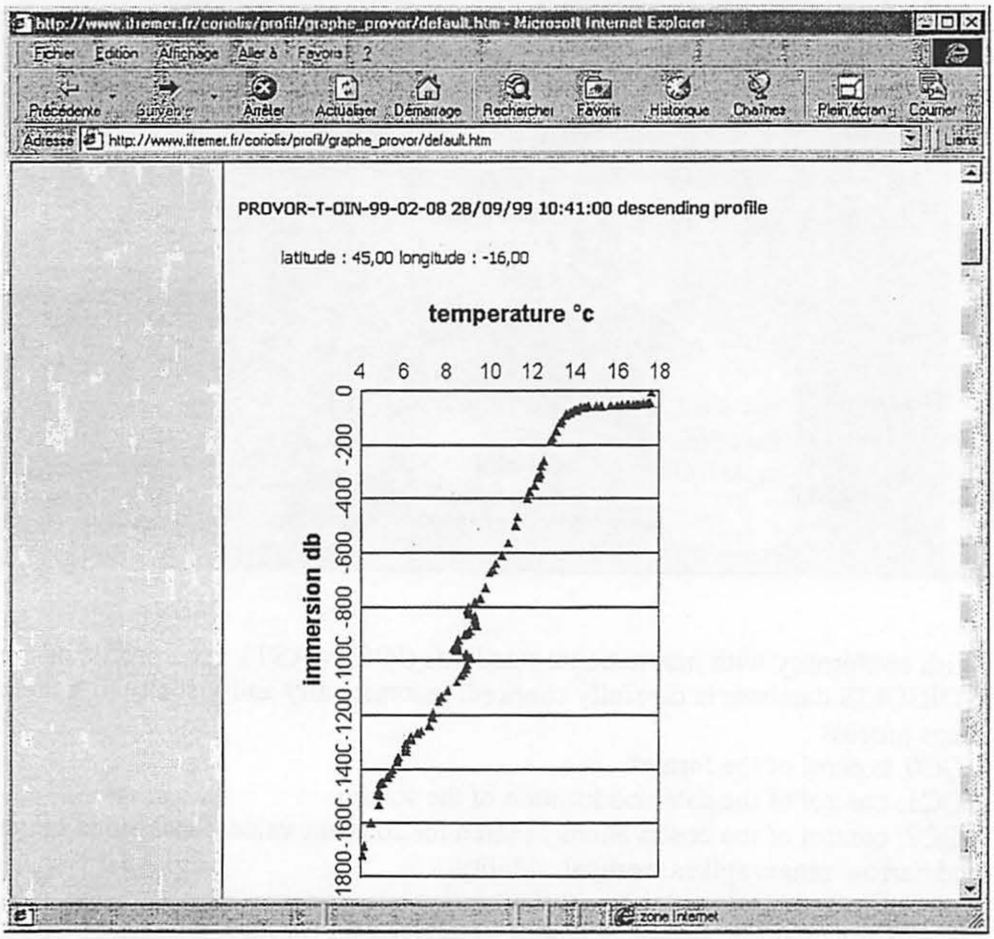
With conformity with international standards (IOC, MAST), each profile of the CORIOLIS database is carefully checked, automatically and visually in a three steps process :
- QC0: control of the format
- QC1: control of the date and location of the station
- QC2: control of the observations : search for constant value, local broad range and narrow range, spikes, vertical stability.

As a result of these checks, a quality flag is added on each numerical value. The flag value complies to the IGOSS scale from the internationnal GTSPP program. The good data are flagged to 1, and the flag value increases with the severity level of the detected anomalies.

IGOSS scale
1 : good value
2 : probably good value
3 : probably bad value
4 : bad value
5 : interpolated or corrected value
9 : lack of value

Following the Quality Control, the PROVOR profiles are disseminated on two main channels which are INTERNET and GTS.

The CORIOLIS web server address is www.ifremer.fr/coriolis .



All PROVOR profiles are available
- in ascii format
- in medatlas format
- in graphic charts

The drift of each PROVOR float is available on a geographic (and soon interactive) map.

The PROVOR profiles, after the quality control procedure are transmitted to a mailing list. All users people registered on the mailing list receive in their personnal mailbox the new profiles available.

After the quality control procedure, all new PROVOR profiles are gathered in a file, using TESAC format. This file is then transmitted by way of FTP to our GTS operator, METEO-FRANCE. GTS is the Global Telecommunication Service of the World Meteorological Organisation (WMO).

4 -CONCLUSION

PROVOR-T is now produced by series, by MARTEC company and the PROVOR-CT will be ready at the beginning of 1999. The first operationnal floats are cycling every week or every two weeks through POMMIER experiment which is conducted by the Hydrographic Service of the French Navy. Raw data are collected every monday morning and validated data are available on tuesday. This experiment aims to validate equipments and data processing software which will be used in next operational programs like CORIOLIS-Atlantic which represents the French contribution to ARGO program.

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Timeliness and Availability of Buoy Data on the GTS

Pierre Blouch, Centre de Météorologie Marine
Météo-France, October 1999

Abstract

For meteorological purposes, data timeliness and data availability are two parameters as important as data quality but less studied until now. Graphs representing the percentage of data received within a given delay are computed for individual buoys or for groups of buoys having the same characteristics (e.g. area, type, sampling scheme). More the curve is close to the y-axis, better the timeliness is; more the curve is close to the 100% level, better the availability is. These graphs are useful to assess the interest of local receiving stations, to test different sampling schemes aboard the buoys, to check possible mistakes in the GTS technical files, etc... We can consider them as a tool to help operators to improve the performances of their buoys for a better use of the data. Soon, they will be also useful to compare the various communication systems between themselves when others than Argos are available.

Background

Numerical models require observations regularly spread out in space and time (typically 8 obs./day in each cell). The data assimilations are generally done twice a day. In a same way, forecasters needs the most recent observations, as soon as possible. Even if data timeliness is more crucial for forecasters, it should be reasonable for models. Data timeliness and data availability are two parameters as important as data quality but less studied until now.

Data coming from moored buoys have generally a good timeliness and a good availability because they use geostationary satellites or direct radio links to be transmitted. So they are received within short delays after observation times.

Data timeliness and availability with Argos

With drifting buoys, it's different. Most of them use the Argos System to transmit their data. Now, this system is based on two LEO satellites which receive the data of buoys when these latest are in sight of them. Later, the data are downloaded to one of the three main ground stations when the satellites are in sight of them (global coverage). The use of local stations (LUT) allows to get the data more quickly. The satellites are able to relay immediately the messages coming from the buoys to a local station if it can see both of them at the same time (regional coverage).

For meteorological purposes, it is not difficult to get a good data availability with drifting buoys. Observations must just be stored aboard the buoys by waiting a satellite pass. It's more difficult to get a good timeliness.

Data timeliness and data availability with Argos system depend on :

- the latitude - satellites are more often in sight of buoys at high latitudes (North or South);
- the number of satellites used - now we can use more than 2 satellites conditionally ;
- the vicinity of LUT's - transmission delays can be reduced when they are used ;
- the measurement sampling and the data storage schemes aboard the buoys.

Besides the drawback of the system, bad results in data timeliness are often due to errors in the algorithm used to retrieve observation times. For buoys reporting stored data, bad results in availability can be due to wrong declarations in the GTS Technical files at Argos (e.g. bad use of the checksum, wrong format...). As buoy operators we must take care of these problems.

To test different sampling schemes, to measure the advantages brought by the implementation of new LUTs or the use of more than 2 satellites, to check the possible mistakes in the technical description of Argos messages, we need a simple tool to assess the buoy performances.

How to represent data timeliness and availability

The method consists in graphs representing the percentage of data received (y-axis) within a given delay (x-axis). Only one observation per buoy and per hour is considered. In case several observations are carried out within one hour, only this with the shorter reception delay is kept. So, 100% corresponds to 24 hourly observations (done at + or – half an hour) or 8 synoptic ones a day. 100% doesn't represent the total number of observations reported by a buoy.

More the curve is close to the y-axis, better the timeliness is. More the curve is close to the 100% level, better the availability is. For moored buoys, the curve climbs to reach about 100% quickly.

Results

Excepted for one curve on figure 1, the graphs were computed for hourly observations (air pressure). 100% corresponds to 24 observations a day, regularly distributed. When synoptic observations are studied, the curves are similar but less smooth because most of the buoys carried out asynoptic or hourly observations. Synoptic observations are not privileged.

Each curve corresponds to an average of several buoys having similar characteristics such as area, Argos message format, measurement sampling scheme, buoy type... Reception delays are those observed at Meteo-France during the period 10 Sept – 10 Oct 1999.

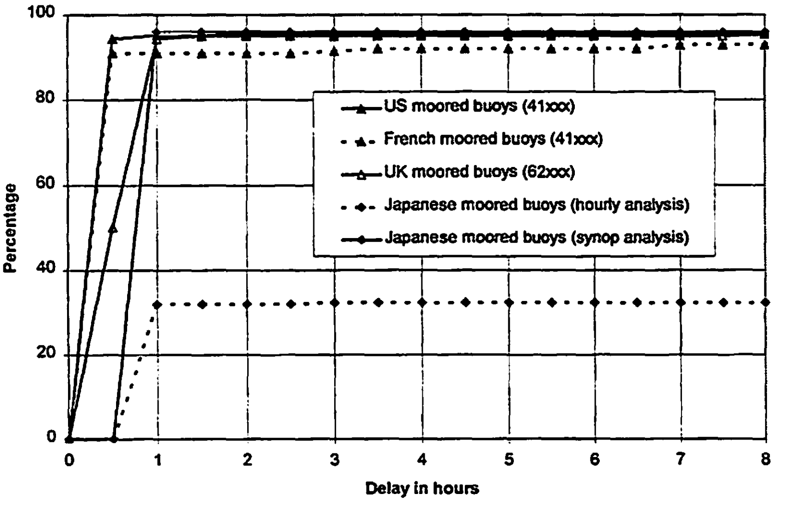


Figure 1 - Percentage of AP data received from moored buoys at Meteo-France, within a given delay

Moored buoys

As expected, timeliness and availability are excellent for moored buoy data. Figure 1 shows some examples. More than 90% of the data are received within one hour after they are measured. The Japanese moored buoys report only synoptic data. This explain why the performance appear weak when hourly observations are analysed. Performances appears as good as for other buoys when synoptic observations are considered only.

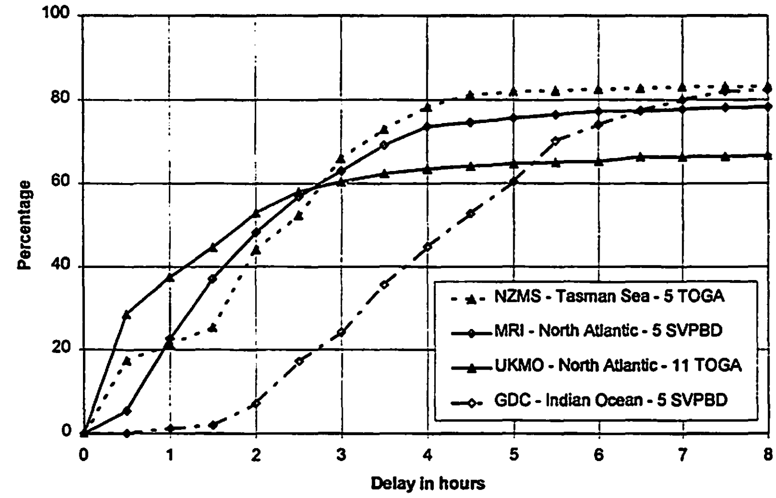


Figure 2 - Percentage of AP data received from drifting buoys at Meteo-France, within a given delay

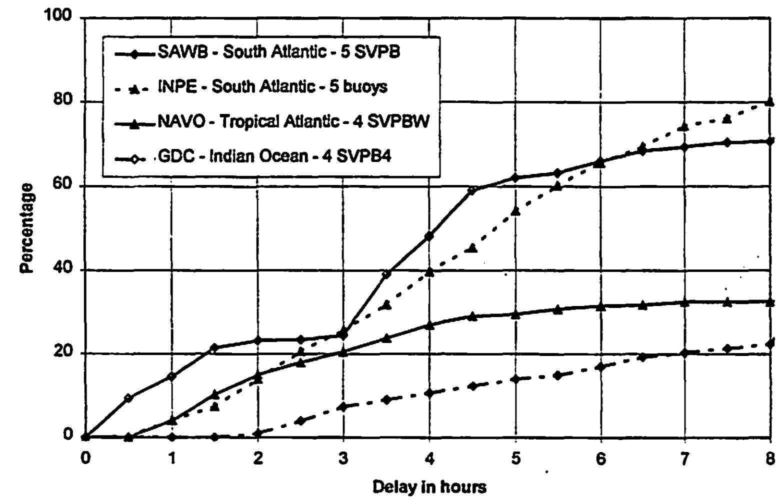


Figure 3 - Percentage of AP data received from drifting buoys at Meteo-France, within a given delay

Drifting buoys

Figures 2 and 3 show the timeliness and the availability for several sets of drifting buoys.

On figure 2, we can see differences for buoys having the same format but drifting in different areas. It's the case for SVP-B drifters having the DBCP-M1 format. Those drifting in the North Atlantic, and owned by MRI, have shorter delays than those drifting in the Indian Ocean, and owned by GDC. Reception delays are longer in the Indian Ocean than in North Atlantic and perhaps the LUT of La Reunion was not correctly operating during the period of the study.

On figure 2, differences between buoys drifting in the same area but having different formats appear too. It's the case for SVP-B drifters owned by MRI and TOGA buoys owned by UKMO, both drifting in North Atlantic. The curve climbs more rapidly for UKMO buoys because they report asynoptic data. Availability is less high after 3 hours for these buoys than for buoys owned by MRI because the latest report stored observations with an interval of 60 minutes instead of 90 minutes.

Old SVP-B drifters having the 1/3 duty cycle and owned by GDC had poor results as seen on figure 3. SVP-BW drifters, deployed by Navoceano in the Tropical Atlantic, reports only the most recent hourly observation. There are no storage aboard. This explains their unsatisfactory performance.

LUT of La Reunion

The LUT of La Reunion has been operational since September 1998. Figure 4 shows the effect of this implementation on the performances of some types of buoy drifting in the area at this time. Thin curves shows the reception characteristics before the LUT implementation (August 1998); thick curves shows the buoy performances after the LUT implementation (October 1998).

It is obvious the delays have been reduced from about 60 minutes after the LUT implementation for two kind of buoys. It is not the case for the third one : there was no change for SVP-B drifters having the SVPB2 format, now called DBCP-O2. Although old observations are stored aboard these drifters,

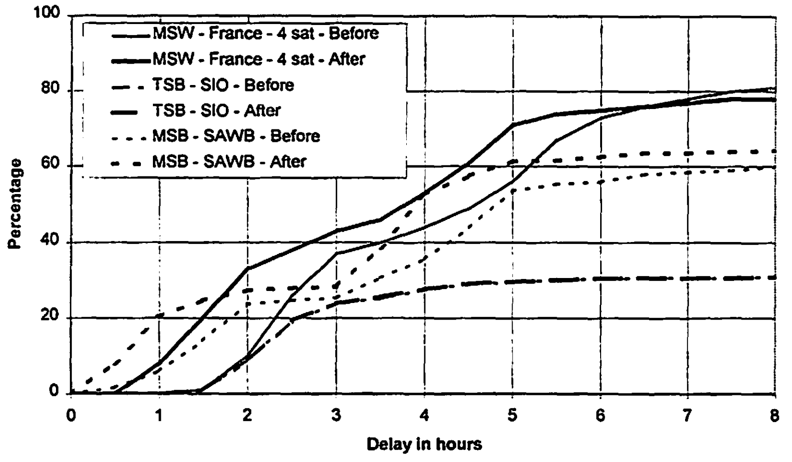


Figure 4 - Percentage of AP data received within a given delay before (98/08) and after (98/10) the LUT implementation in La Reunion

only the most recent ones are transmitted on the GTS. These buoys should provide a better availability than 30% of the maximum possible.

Beyond a certain delay, data availability is unchanged. The data which are not recovered by a local station are recovered later thanks to the global coverage from the moment they are received by the satellites.

Conclusion

On the GTS, the performances in data timeliness and data availability are various for the buoys, even when they drift in a same area. The worst results are sometimes due to the buoys themselves - those which transmit only the most recent observations for instance, as at the beginning of 80's. However, they are often due to mistakes. But it's not obvious to realize that without studying the GTS data flew carefully to see whether the reports received from the buoys are those expected. The problem is the same than for data quality: most of the buoy operators have no access to the GTS data.

In the future, such studies will be useful to compare the communication systems between themselves when Argos will be no more alone on the market. We will have to take in account the data timeliness and the data availability in our choices, at the same level than the communication price and the transmitter consumption for instance, assuming the volume of data will remain more or less stable.

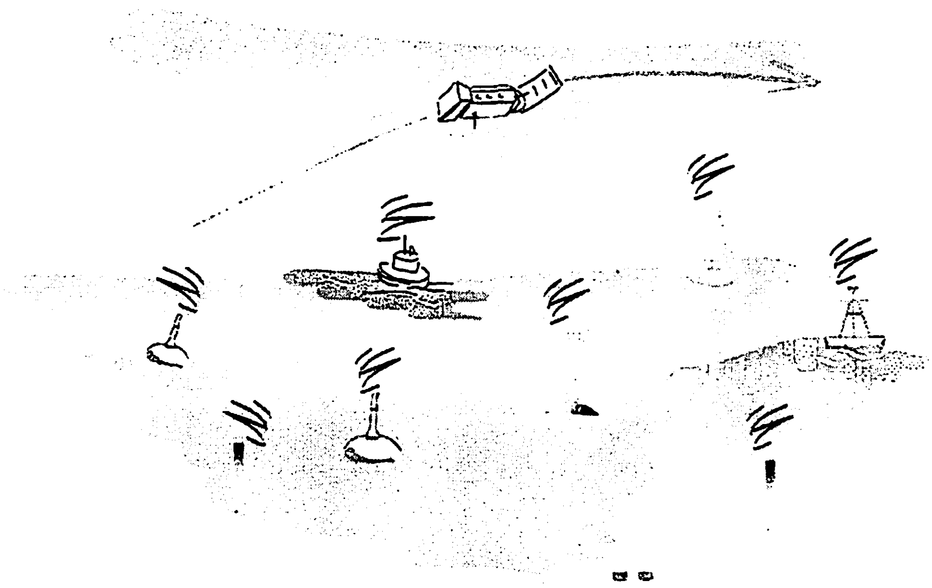
Individual graphs, computed thanks to the data received at Meteo-France for each buoy, should be soon available on the Web. This should help operators to improve the performances of their buoys.

A Practical approach for use of the Argos Downlink

Christian Ortega
Argos, Head Scientific Applications
E-mail: christian.ortega@cls.fr

Data buoys and Argos

The world's oceans contain almost 3000 drifting buoys, moored buoys, floats and other platforms monitored by the Argos satellite-based location and data collection system. Following successful deployments in such programs as WOCE and TOGA, Argos is now going through fundamental changes to better meet the needs of its main users: oceanographers. New features include two-way communication, increased data transmission capacity and fully customized access to data and results. Designed for and with its scientific users, Argos will remain the world's only satellite-based system dedicated to monitoring and protecting the environment.



Ocean platforms using Argos

Overview of Argos Downlink

The Japanese satellite ADEOS-I presents the first opportunity to implement a two-way capability into the Argos system. Beyond ADEOS-II, the Argos-3 instrument will also incorporate downlink messaging along with other improvements such as a 4.8 kbyte high data rate channel.

The Argos Downlink will provide three capabilities:

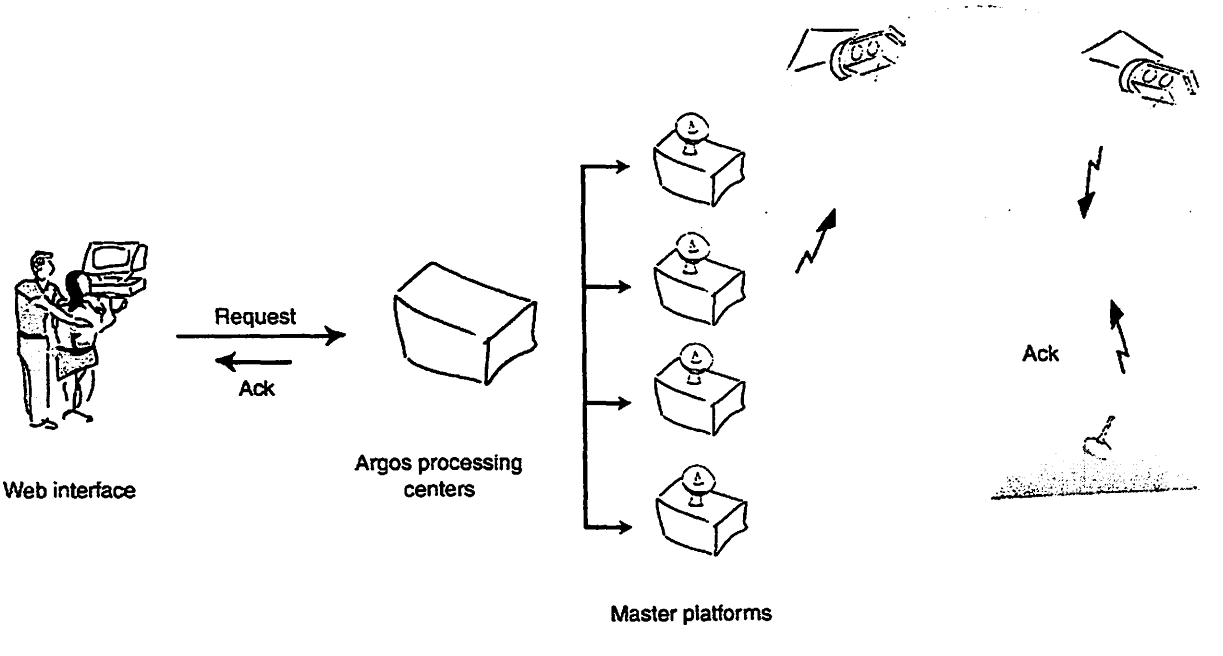
- Downlink messaging: will enable users to send brief commands to their platforms. The commands will be used to simply turn transmitters on or off, or to perform more complicated tasks. For example, sensors could be modified, operating modes could be changed, or transmitters could be programmed.

- Managing platform transmissions: generic messages such as orbit predictions, constellation configuration, will be regularly downlinked to the platforms so they can schedule next satellite passes. By transmitting only when a satellite is in view, platforms will reduce their power consumption and hence increase their lifetime. In addition, the downlink signal will be permanent so it could be used by the platforms to detect the arrival of the satellite.

- Interactive data collection mode: under this mode satellites will confirm to the platform the good reception of the data messages. This will contribute to more efficient platform management by reducing the number of uplinked messages and allow the transfer of higher volumes of data .

Downlink messaging

Two-way communication with Argos transmitters, also known as Downlink messaging, is built on the simple Argos one-way link. Short Downlink messages, lasting less than a second, are transmitted at a fixed frequency, 435 MHz. When the satellite flies over a platform, it repeats the messages several times to make sure they are collected.



Sending messages to platforms

Users will connect to Argos servers via the web, and program the information they want their platforms to receive. The servers will relay these instructions to the satellites via four Master Platforms. Once a satellite "sees" the platform anywhere in the world, it will start downlinking the instructions. The platform will then confirm message reception to the satellite, which will relay an acknowledgment to the user.

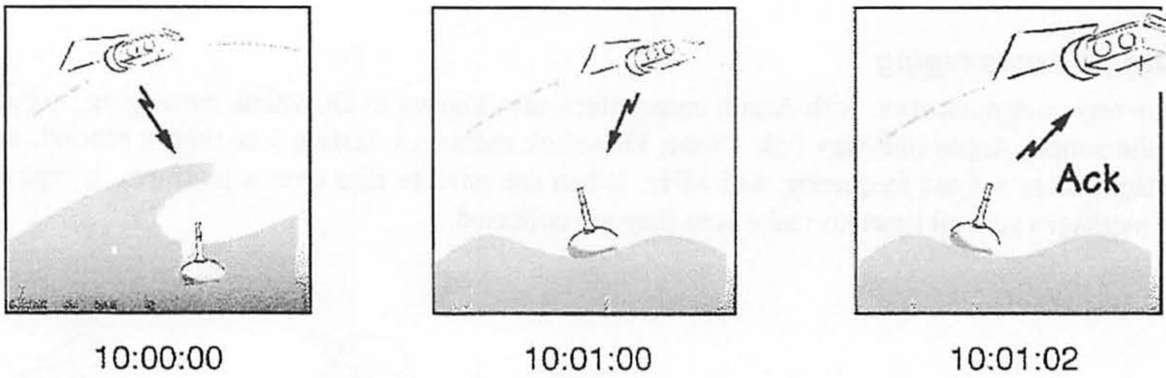
Users will be able to send the message to a given platform or a group of platforms. Each platform may have several group numbers – for example: owner group, international program group such as IABP or ISABP…

Users will also be able to program Downlink messages up to one month in advance.

A set of pre-defined messages, with basic functions which may impact the system such as platform ON/OFF, reset, repetition rate or duty cycle modifications, will use fixed formats pre-defined by Argos. Free format messages will be defined by users and manufacturers to address their specific needs. Downlink message lengths ranges from 8 to 128 bits.

To address the various operating modes of the Argos platforms, two (user selectable) transmissions modes are provided:

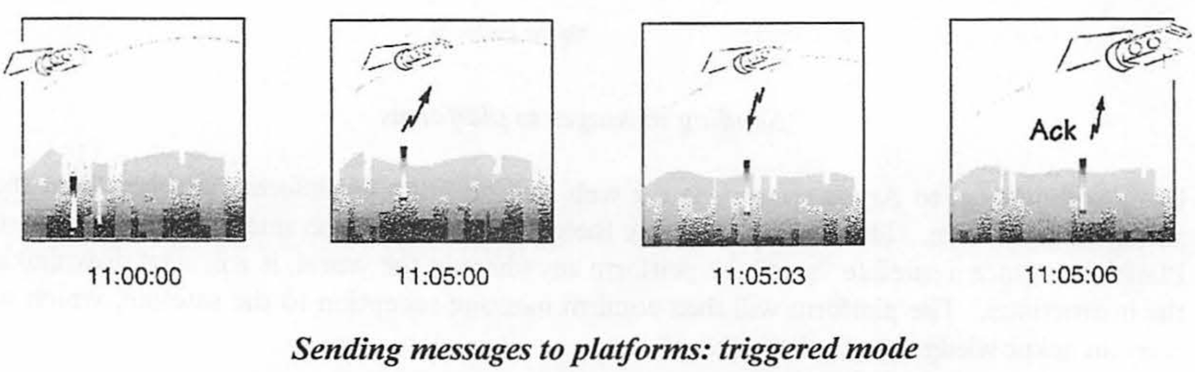
- the "programmed" mode: requires that the platform is available at any time and that its location is known.



Sending messages to platforms: programmed mode

The satellite starts downlinking the user message at a programmed time, computed by the processing center using platform location and satellite orbit – the expected time at which the satellite will start flying over the platform. The message is repeated several times to make sure it is collected. The platform sends an acknowledgment to the satellite which then stops repeating the message. If the satellite does not receive an acknowledgment, it simply sends the programmed number of repetitions.

- The "triggered" mode: more appropriate for platforms with duty cycles or popping up and down in the oceans such as the subsurface floats.



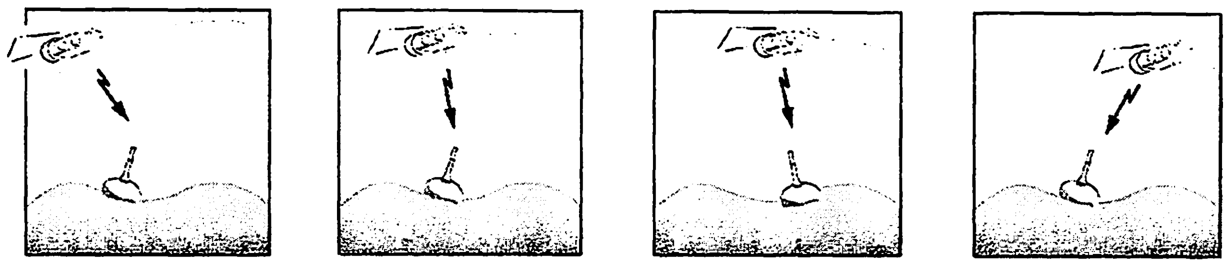
Sending messages to platforms: triggered mode

Downlink message is kept in memory on board the satellite, possibly for several days, until it receives any message from the target platform. This trigger will make the satellite "fire" the

Downlink message at the platform. Any new signal from the platform will trigger again this Downlink message until an acknowledgment from the platform is received.

Managing platform transmissions

With the Argos Downlink platforms will be able to forecast next satellites passes and hence to optimize power consumption by transmitting only when a satellite is in view. Pass prediction software are already implemented today in some Argos platforms, but the quality of the predictions decreases with the time. Regular updates of the orbit parameters and knowledge of the platform position are needed to maintain the accuracy.



04:08:10 Satellite configuration | 04:09:30 Satellite ephemeris | 04:09:42 UTC time | 04:14:01 Platform location

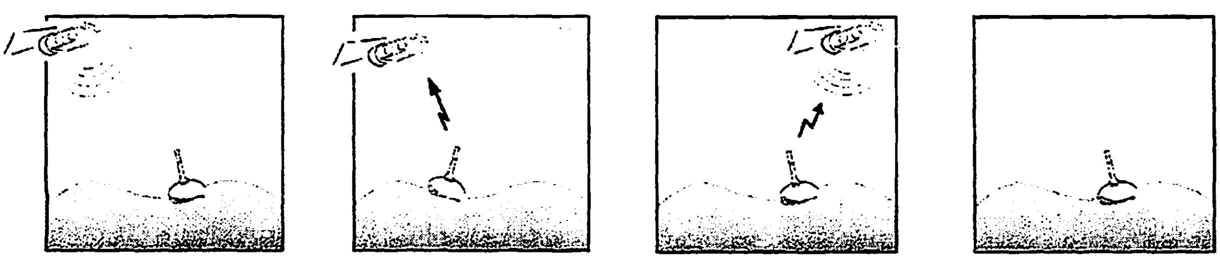
Updating pass prediction parameters

The Argos Downlink will regularly relay messages containing the necessary updates. Those messages includes:

- satellite configuration: indicates the operational satellites with Argos onboard,
- satellite ephemeris: one message per satellite containing simplified orbit parameters,
- UTC time: UTC time is provided with 0.1 second accuracy,

In addition, platforms which are not equipped with a GPS receiver, can receive their previous location at time interval programmed by the user..

The Downlink signal is permanent so it can be used by the platforms to detect the arrival of the satellite. This capability will be even more useful when more than one satellite is equipped with the Downlink.

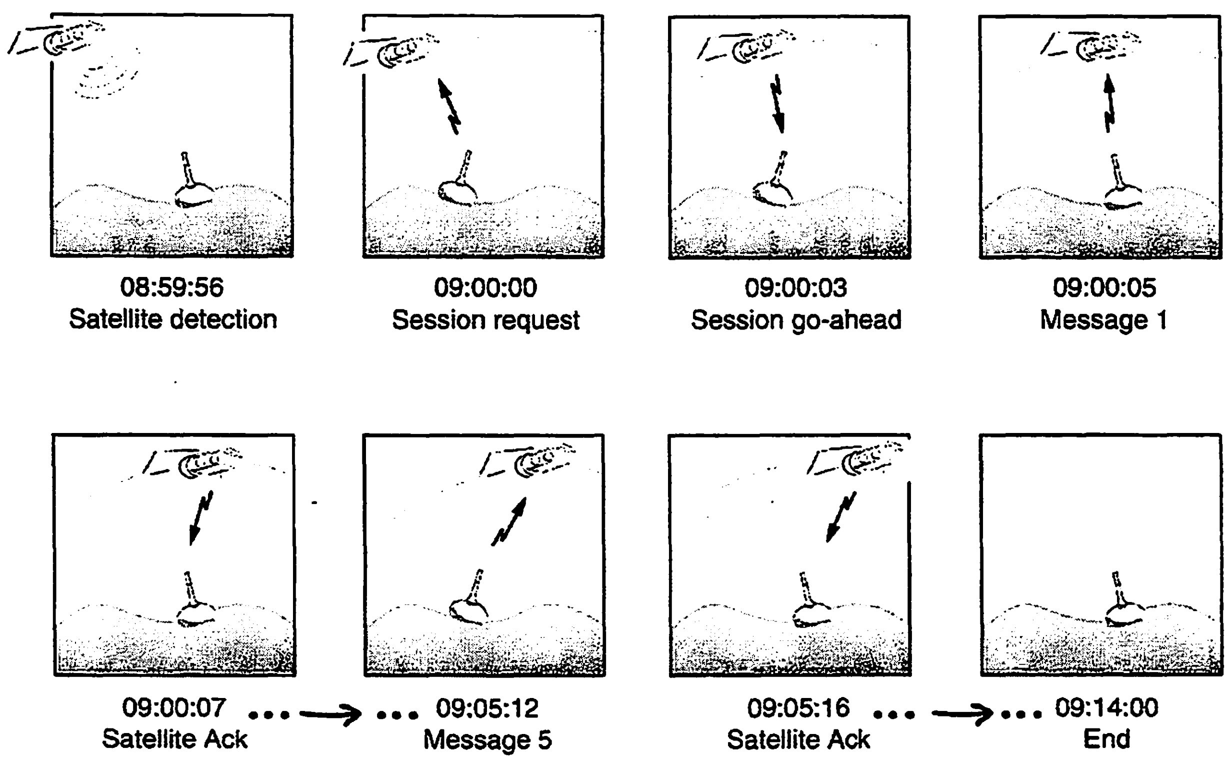


08:01:00 | 08:01:02 | 08:11:00 | 08:15:07

Detecting satellite arrival

Interactive data collection mode

The Argos system in use today includes redundant transmissions to increase the probability of error-free data receipt by the satellite. The two-way communication capability outlined above will enable the number of repetitive messages to be reduced by a factor of 2 by including an "Acknowledgement" signal which will indicate when the data has been successfully received by the satellite. This will enable a greater amount of data to be transmitted in a fixed period of time.



Interactive data collection

When a platform which is fitted with the interactive option detects the arrival of the satellite it sends a Session request message to start the dialogue. The satellite answers with a go-ahead message and the platforms then starts sending the data messages. The dialogue is stopped when the satellite loses sight of the platform. Any Interactive platform will still be able to use the traditional random access data collection mode for example to send data to the previous generation satellites.

Summary

In September 1999, CLS and SAI organized a meeting with the Argos platform manufacturers to prepare with them the implementation of the Downlink. The goal is to provide this capability to users as soon it is available –i.e. soon after the launch of ADEOS-II in 2001.

This requires the development of appropriate receivers, their integration with Argos transmission electronics and the coding of the messaging functions. General specifications of the Downlink were provided to manufacturers.

In parallel, to guarantee the availability of receiver units before the launch, CNES started the development of a slave receiver which will be easily integrated with existing electronics. The characteristics of this unit were presented at the meeting and discussed. Contacts with Manufacturers will be maintained to help them build their own Rx/Tx units or integrate the receivers.

Users interested in this new capability are invited to contact CLS or SAI to discuss the implementation of pilot operations.

Meteo-France's Moored Buoys in Deep Sea off the French West Indies

by J. Rolland, P. Blouch, J.P Jullien - Meteo-France
Centre de Meteorologie Marine - BP 7302 - 29273 Brest Cedex - France

ABSTRACT

Surface observations from specific areas are of great interest and importance for Meteo-France. The area off French West Indies is such an area. This paper describes a project to moor and maintain two open ocean buoys at more than 200 nautical miles from Guadeloupe and Martinique. After a description of the buoys, some data are shown and discussed.

INTRODUCTION

In addition to the cooperation with the UK Meteorological Office to operate two open ocean meteorological data buoy in Biscay Bay: Brittany and Gascogne buoys, Meteo-France is engaged on its own data buoy programme. Two buoys were moored off French West Indies in a water depth of 5500 metres by 21-22 february 1999.

These buoys are quite similar to the UK Meteorological Office: same structure built by Balmoral Company in Scotland, same equipment, same principle of transmission. However we can note two differences:

Photo - ODAS 01 FR and ODAS 02 FR

- the assembly was entrusted to the french company CEIS-TM following an invitation to tender. The first three buoys were delivered to the end of 1998;

- these buoys produce omnidirectional wave height spectra.

It is planned to use three buoys to maintain two points. The lifetime of the mooring lines is estimated between two and six years. A servicing visit is planned every 10 to 12 months for a change of external sensors.

OPEN OCEAN BUOY

The open-ocean buoy has been designed to operate in water depth down to 6000 metres. It weights 3.7 tonnes, has a hull diameter of 2.8 metres and an overhall height of 6.0 metres (**cf Photo**). The buoy has three components:

- a yellow float made of closed cell foam protected by elastomer skin;
- a cylindrical steel foot;
- a three metres high superstructure manufactured from marine grade stainless steel.

Each buoy carries an identifier painted on the float: «ODAS xx FR», where ODAS means Ocean Data Acquisition System. «xx» is a number with 2 digits, characteristic of the buoy and not of the site on which it is anchored.

Each buoy is equipped with two independent sensor and electronic systems which have their own battery packs, each charged by solar panels. Fully charged batteries have sufficient capacity to power the buoy for six months in case of failure of the solar charging system. Every hour each data acquisition system carries out its observations with its own sensors. All sensors except the wave sensor, sea temperature and housekeeping are mounted externally and are located at 3-4 metres above sea level.

SENSORS	RANGE	SENSOR ACCURACY	FIELD ACCURACY
AIR SB2A aneroid barometer	800 -1060 hPa	< 0.5 hPa	+:/- 0.5 hPa
VECTOR A100L2 cup anemometer	0-150 kt	+/-1%	+/-5%
VECTOR SRW1G-M self-referencing windvane	0-360°	+/-5°	+/-10°
ROTRONIC PT100 BAV 99 air thermometer in a Young shield	-40°C - +70°C	+/- 0.1°C	+/-0.2°C
ROTRONIC HYGROMER CK 60 humidity sensor	0 -100%	+/- 1%	+/- 5%
PT100 Engelhard Pyrocontrole SST	-40°C - +70°C	+/-0.1°C	+/-0.2%
HEAVE SENSOR MarkII - DATAWELL	+/-10 m	2%	+/-10%

Table 1- Sensors

The sea temperatures sensors (SST) are in the metallic part of the hull, about 1 metre below the sea level. Housekeeping data, as internal humidity and temperature of the electronics, navigation lamp status, hull dry or flooded, and various supply voltages are reported.

The wave sensor is not duplicated. It is located inside the hull. Both acquisition systems get the raw data and calculate the significant period (T1/3) and height (H1/3) by the statistic method. In addition a wave height spectrum is calculated by each system thanks to a Fast Fourier Transform algorithm. The energy is reported in 30 frequency bands of predetermined width from 2.62 seconds to 24.69 seconds.

The buoys report location using two GPS. An Argos beacon, which the antenna is directly located on the float, enables the location, even in case of superstructure loss.

For security, the buoys are equipped with a single yellow navigation lamp to meet the international requirements (5 flashes every 20 seconds) and two radar reflectors. They are also plotted on marine charts.

DEPLOYMENT AREA

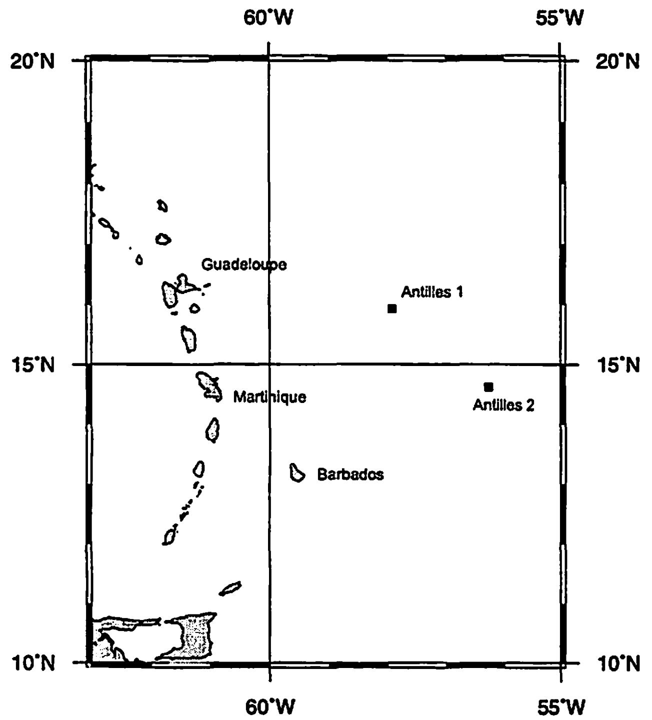


Figure 1 - Buoys location

The buoys ODAS 01FR and ODAS 02 FR were moored off the French West Indies on february the 21 an 22 thanks to the research vessel D'Entrecasteaux operated by the French Navy. The northern buoy is with approximately 210 nautical miles in the east of Guadeloupe, the southern one with 270 nautical miles in the east of Martinique (**Figure 1**). The technique consisted in initially deploys the buoy, to lay out the kilometers of synthetic ropes then to release the clump. One operation lasted about three hours.

NAME	WMO NUMBER	POSITION
ANTILLES 1 Guadeloupe	41100	15.9°N - 57.9°W (5494 m)
ANTILLES 2 Martinique	41101	14.6°N - 56.2°W (5481 m)

Table 2- WMO numbers and positions of the buoys

MOORING LINE

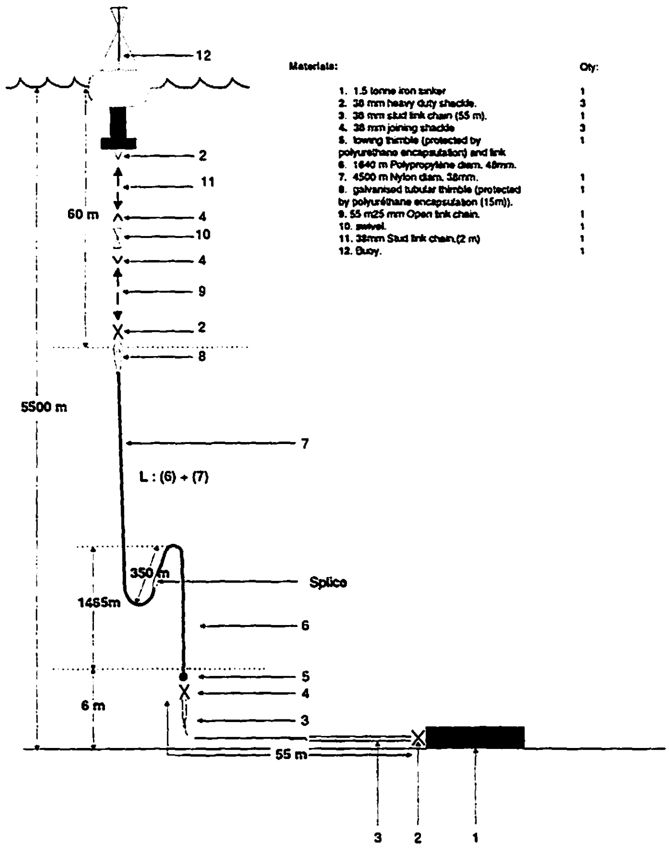


Figure 2 - Mooring line

The mooring line is an inverse catenary type (**Figure 2**), used widespread and originally designed by the NDBC.

From the sea bed to the surface there are:

- a 1,5 tonne iron sinker;
- 55 m of 38 mm stud link chain;
- 6140 m of synthetic ropescomposed of 1640 m of polypropylene (which provides the buoyancy required to form the inverse loop and support the lower chain from the bottom) and 4500 m of nylon;
- 55 m of 25 mm open link chain;
- 2 m of 38 mm stud link chain;
- the buoy.

This slack mooring line lets the buoy to have an excursion radius of about 3000 metres for a depth of 5500 metres (**Figure 3**).

It is planned to change the upper mooring chain after two years at sea and all the mooring line after six years.

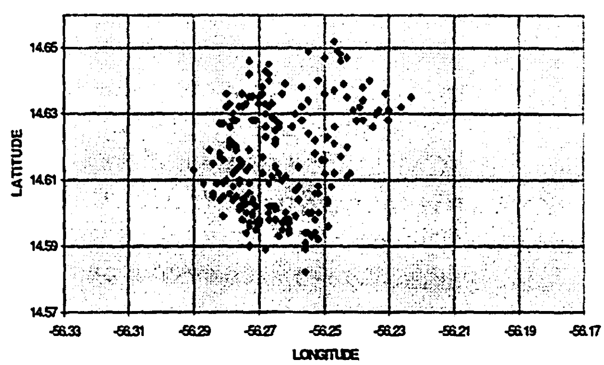


Figure 3 - Martinique buoy positions

DATA TRANSMISSION

Each buoy has two Meteosat DCP (Data Collection Platform) which transmit their data at a selected time slot. The antenna are omni-directional. To ensure availability, each transmission contains data from both suites of sensors in a single message according to a specific format. Wave spectra are transmitted once only.

Raw data are received at Darmstadt from where they are forwarded to Meteo-France at Toulouse via the GTS (Global Transmission System). There, they are transcribed into WMO **SHIP** (FM 13-XI) and **WAVEOB** (FM 65-XI) codes for transmission on the GTS.

Messages	Hours	Bulletin headers
SHIP	Main Synoptic	SMVD01 LFPW
SHIP	Secondary Synoptic	SIVD21 LFPW
SHIP	Others	SNVD41 LFPW
WAVEOB	All	SOVD12 LFPW

Table 3 - Bulletin headers

Although there are two acquisitions systems on each buoy, a single SHIP message and a single WAVEOB one are transmitted every hour. A status file provides to the program the elements needed to code the messages: choice of the sensor, calibration values... This file is updated each time a modification is necessary.

DATA QUALITY CONTROL

The raw data received in Toulouse are forwarded in real time to CMM in Brest where the duplicated data can be checked for individual observations and graphically as a time series. These daily checks also include monitoring of buoy location and housekeeping data.

Once a week, SHIP observations are compared against model outputs. Similar process produces monthly statistics. These statistics provided by four centres: (ECMWF, Meteo-France (CMM), NOAA (NCEP), and UKMO) are available on the Web at: **http://www.shom.fr/meteo/rechstat**.

All the data of each system on board the buoys are archived at CMM.

Information on the status of those buoys is available on the Web at: **http://www.shom.fr/meteo/antilles.htm**

RESULTS

The buoys provided about 10.000 observations of meteorological data from the mooring date by end of February to beginning of october 1999.

MONTH 1999	Number of OBS on GTS ANT1	ANT2	Percentage	
March	716	691	96%	93%
April	698	681	97%	95%
May	717	700	94%	90%
June	676	652	94%	90%
July	710	696	95%	93%
August	706	691	95%	93%
September	544	537	76%	75%

Table 4 - Observations on the GTS

Generalities about some parameters:

The circulation in the area is driven by the trade winds. The prevailing winds are from sector E, blowing at 10/20 kts gusting at 25 kts (**Figure 4**), with a maximum during the night.

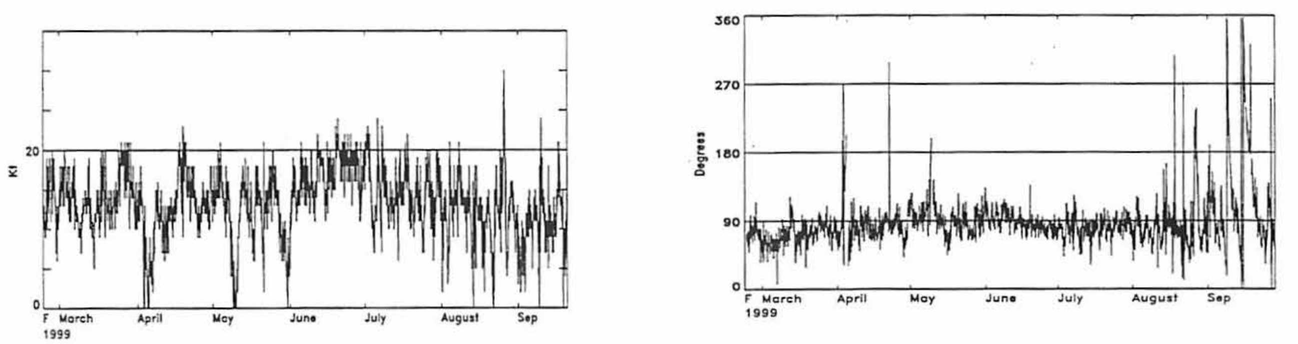


Figure 4 - Wind Speed and Direction

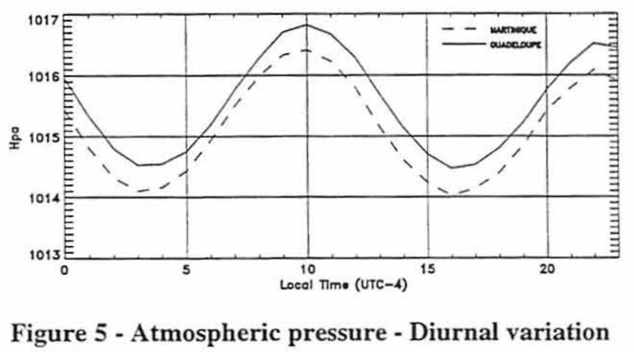


Figure 5 - Atmospheric pressure - Diurnal variation

Atmospheric pressure is close to 1015 hPa and presents a classic semi-diurnal tide variation with 2 maxima: the first one by 10 a.m and a second one by 10 p.m. The mimima are by 4 a.m and 4 p.m.(**Figure 5**)

Air temperature presents a mimimum by 4 -5 a.m, then increases to reach its maximum by 3 p.m (**Figure 6**). Generally this amplitude is less than 1°C, but sometimes under rain showers the temperature can decrease by 2 to 4°C.

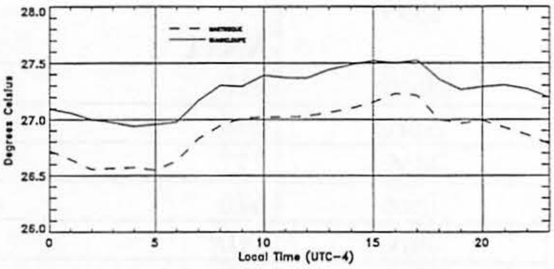


Figure 6 - Air temperature - Diurnal variation

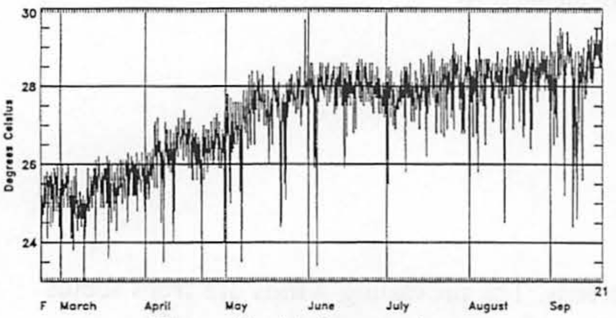


Figure 7 - Air temperature

Air temperature is comprised between 25°C to 29°C from february to september (**Figure 7**).

The mean diurnal amplitude of the sea surface temperature SST is about 0.2°C with a maximum by 2-3 p.m. The diurnal amplitude can increase to 1.2°C when the wind is weak (e.g beginning of april 99).The SST increases from 25/26°C in february to 29/30°C in september (**Figure 8**).

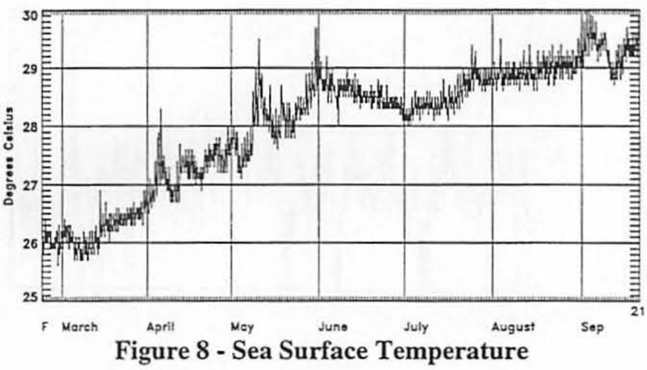


Figure 8 - Sea Surface Temperature

The wave height is usually comprised between 1.5 metres and 2.5 metres with a 7 seconds to 9 seconds period.

Examples of meteorological situations

1- 26 August 1999

The tropical storm EMILY passed just between the two buoys from south to north on 26 of August. The wind turned clockwise from North-East to South-West on Martinique buoy. That means the center of the storm was on its left. The wind speed was about 20 to 30 knots with gusts 30 to 45 knots up to the evening. The maximum of wind was observed from 09UTC to 12 UTC. The lowest atmospheric pressure reported was 1008 hPa at 07 UTC with more than 95% humidity from 06 to 09 UTC. The waves were 6s, 1.5 m to 2.5 m.

HOURS UTC	DD °	FF kts	Gust kts	Ta °C	SST °C	Humidity %	PPP hPa	T1/3 s	H1/3 m
00:00	43	18	22	28.0	28.7	90.6	1011.4	6	1.6
03:00	52	19	30	27.3	28.7	93.6	1012.2	6	1.8
06:00	95	26	35	26.5	28.6	95.0	1009.6	6	2.0
09:00	177	30	45	26.3	28.6	97.8	1009.6	6	2.0
12:00	212	25	35	26.8	28.5	91.9	1013.0	6	2.2
15:00	214	21	29	27.9	28.6	84.2	1014.2	6	2.2
18:00	204	21	32	26.7	28.6	86.6	1013.2	6	2.5
21:00	229	15	19	27.5	28.7	86.8	1013.8	7	2.1

Table 5 - Synoptic data -Martinique buoy- 26/08/99 - (Emily)

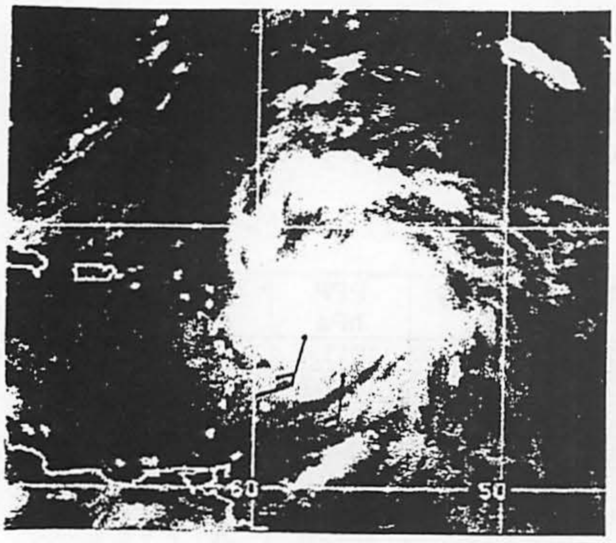
On Guadeloupe buoy the wind turned anticlockwise from North-East to West, then later West to South. The center of the storm was on its right. The wind speed reported was lower than on Martinique buoy: 10 to 15 knots with gusts at 20 to 25 knots. The lowest atmospheric pressure was 1011.8 hPa at 9 UTC. The wave height measured was about 1,5 metres with a 6seconds to 7 seconds period.

HOURS UTC	DD °	FF kts	Gust kts	Ta °C	SST °C	Humidity %	PPP hPa	T1/3 s	H1/3 m
00:00	64	15	20	28.4	29.1	79.4	1013.0	6	1.5
03:00	62	14	18	28.2	29.0	81.2	1014.2	6	1.4
06:00	51	13	20	28.4	29.1	80.5	1012.2	6	1.5
09:00	46	13	16	28.0	29.0	81.0	1011.8	6	1.4
12:00	43	12	15	28.3	28.9	79.1	1013.2	7	1.4
15:00	05	11	14	28.4	29.0	80.3	1013.2	7	1.4
18:00	323	12	18	28.5	29.1	79.9	1012.0	7	1.4
21:00	286	11	14	28.4	29.1	81.7	1012.4	8	1.4

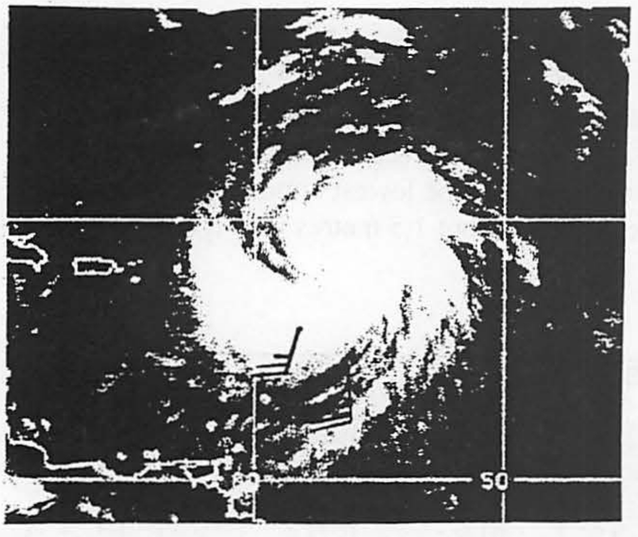
Table 6 - Synoptic data -Guadeloupe buoy- 26/08/99 - (Emily)

2- 9/10 September 1999

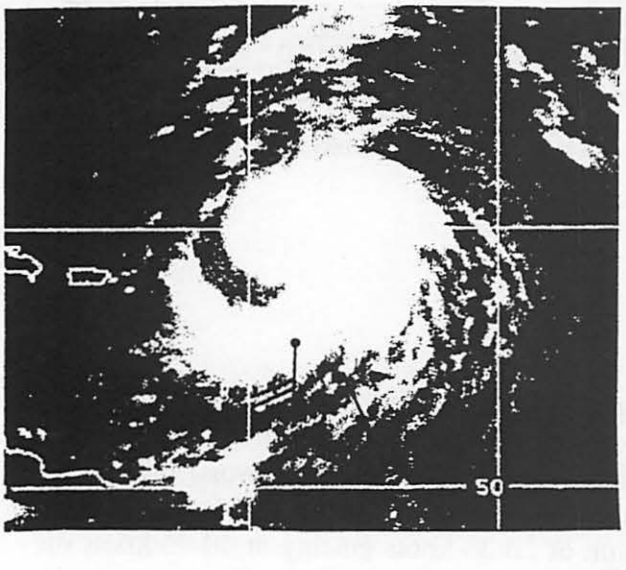
The tropical storm FLOYD, which became hurricane later, was in the area by 9 and 10 of september. The trajectory of FLOYD was about 100 nautical miles more north than the buoy area. But its presence was felt (**Figure 9**) and the weather conditions were worst on Guadeloupe buoy than on Martinique one. On both buoys we can observe the anticlockwise rotation of the wind from North to South, with a maximum of 20-30 knots gusting at 40-45 knots on 10 september, as long as the wind blowed from South on the northern buoy. The atmospheric pressure was about 1007 hPa during all the night on Guadeloupe buoy. The waves increased from 1.5 m to 2.5 m with a 7 seconds period.



00 UTC	WMO :41100	WMO:41101
DDD (Deg)	219	192
FFF (Kt)	16	16
FFF max (kt)	25	21
Tair (DegC)	26.55	28.4
SST (Deg C)	29.15	29
H (%)	91.7	83.7
P (Hpa)	1007.6	1009.4
T1/3 (s)	7	6
H1/3 (m)	1.6	1.4



06 UTC	WMO :41100	WMO:41101
DDD (Deg)	217	177
FFF (Kt)	26	19
FFF max (kt)	40	27
Tair (DegC)	27.4	28.6
SST (Deg C)	29.25	28.8
H (%)	90.1	87.5
P (Hpa)	1007.4	1009.4
T1/3 (s)	6	6
H1/3 (m)	1.9	1.5



13 UTC	WMO :41100	WMO:41101
DDD (Deg)	184	161
FFF (Kt)	27	16
FFF max (kt)	44	21
Tair (DegC)	27.2	28.2
SST (Deg C)	29	28.7
H (%)	89.6	87.3
P (Hpa)	1009.3	1012.0
T1/3 (s)	6	6
H1/3 (m)	1.9	1.7

Figure 9 - **TROPICAL STORM FLOYD - 10/09/1999**

NOAA-GOES8-IR Imagery **BUOYS DATA**

3- 16/17 September 1999

The hurricane GERT trajectory was more north than FLOYD one. However 3.5 to 5 metres waves (**Figure 10**) with a 12-13 seconds period were measured whereas the hurricane was at 300 nautical miles in the NE of the buoys

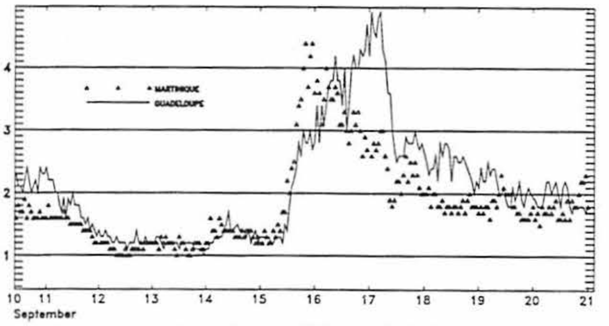


Figure 10 - Significant Wave Height - H1/3

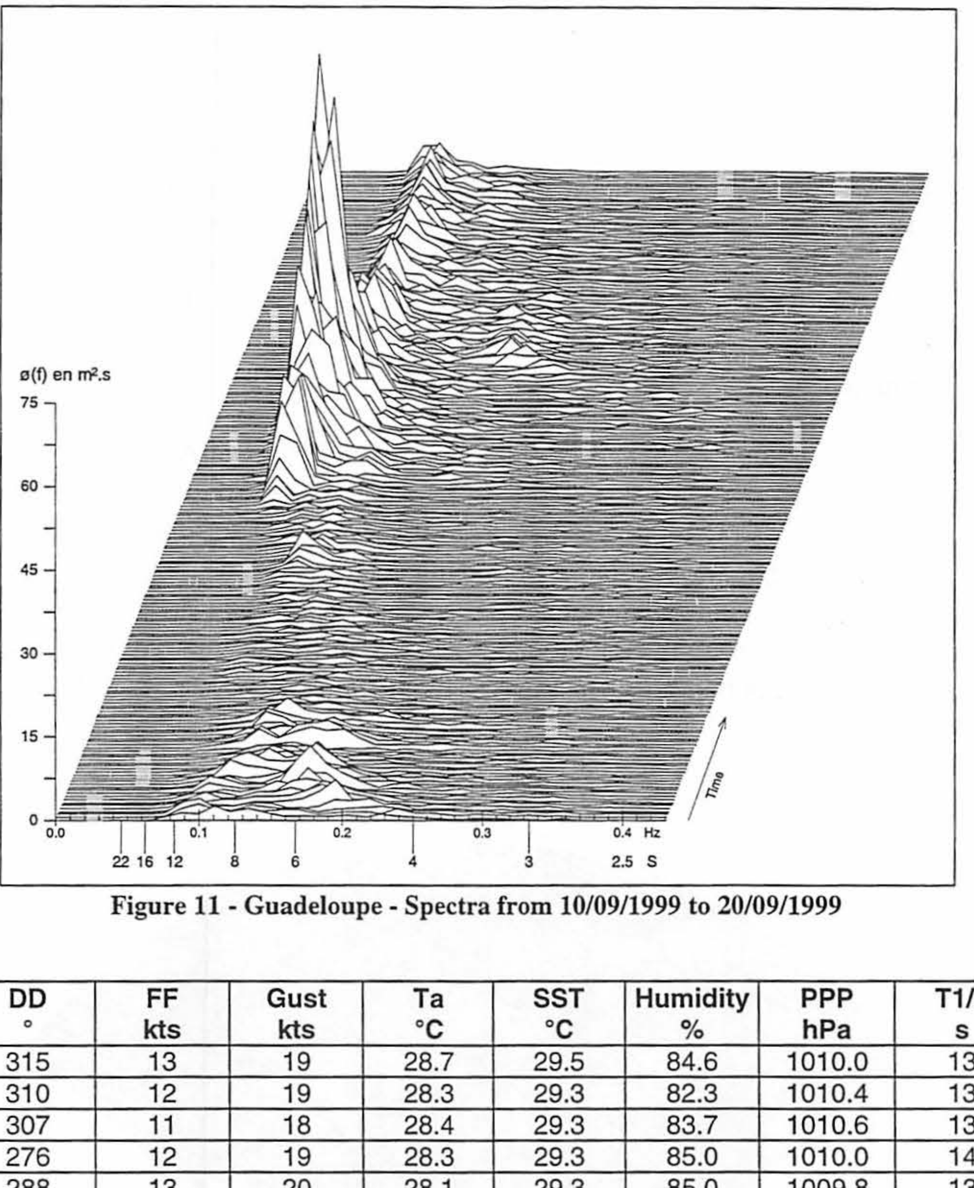


Figure 11 - Guadeloupe - Spectra from 10/09/1999 to 20/09/1999

HOURS UTC	DD °	FF kts	Gust kts	Ta °C	SST °C	Humidity %	PPP hPa	T1/3 s	H1/3 m
00:00	315	13	19	28.7	29.5	84.6	1010.0	13	4.2
01:00	310	12	19	28.3	29.3	82.3	1010.4	13	4.9
02:00	307	11	18	28.4	29.3	83.7	1010.6	13	4.6
03:00	276	12	19	28.3	29.3	85.0	1010.0	14	4.5
04:00	288	13	20	28.1	29.3	85.0	1009.8	13	4.8
05:00	257	13	22	28.4	29.5	87.1	1009.2	14	4.9
06:00	262	14	19	28.3	29.5	87.2	1008.6	13	4.3

Table 7 - Hourly data -Guadeloupe buoy - 17/09/99 - (Gert)

CONCLUSION

The project demonstrated the feasibility of operating ODAS stations in the deep waters off French West Indies. The data reliability by Meteosat transmission is about 95% and the data are useful in an area where they are generally rare. However the operations on these buoys are costly and it would be very interesting if a joint venture programme could be set up.

Towards an Australian Ocean Observing System

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Introduction

The development of the Global Ocean Observing System (GOOS) in Australia has been boosted over the last 12-18 months following several major recent marine policy initiatives by the Australian government. The policies dealing with the use of the oceans and developing marine science and technology capabilities, have both identified the need for a regional ocean observing system as part of an essential national knowledge, information, science and technology infrastructure. At the same time the global effort towards establishing GOOS more broadly has provided added impetus to plans in Australia for more concrete steps towards implementation of an Australian Ocean Observing System (AOOS).

Policy developments

The Australian government established its National Oceans Policy (EA, 1998) in December 1998, partly in response to needs associated with managing Australia's large EEZ which is of order 16 million km^2 (see Fig. 1). Under the stewardship of the Department of the Environment, the policy primarily focuses on the management of the ocean environment within an ecologically sustainable framework. It acknowledges the importance of improved understanding of the marine environment, including baseline survey and monitoring activities, as a major component of infrastructure that is necessary to support the main objectives of the Policy.

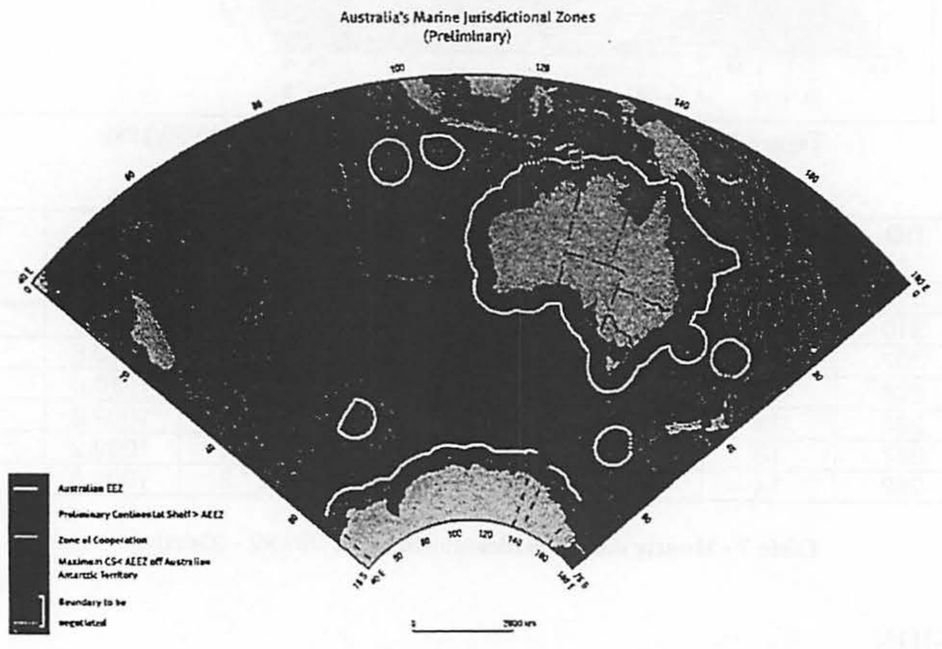

Figure 1. Australia's EEZ.

The Marine Science and Technology (MST) Plan (DISR, 1999) was developed as a daughter plan of the Oceans Policy, and deals with aspects of the Policy that require a science and technology focus. The Plan has been prepared by the Department of Industry, Science and Resources and was released in June 1999.

Both policies give endorsement to the establishment and development of an AOOS, which will be in fact the regional implementation in Australia of the GOOS. The Oceans Policy says "The Government will promote and support the Australian, Pacific and Global Ocean Observing Systems as mechanisms to develop the oceans-related data capture and exchange necessary for improving prediction and management." The third Program of the MST Plan, *Infrastructure for understanding and utilising the marine environment*, also covers AOOS directly in its objective to "Implement an Australian Ocean Observing System (AOOS), designed to improve marine observing capability, links between existing facilities, and to support participation in international oceanographic and meteorological observing programs such as GOOS". The Plan also states that the "AOOS should support international efforts to improve observations in the South Pacific, Indian and Southern Oceans".

Facilitating arrangements

The established inter-agency arrangements for coordination of marine activities at the national level in Australia are complex. The new arrangements being put in place in support of the implementation of the Oceans Policy and MST Plan provide a stronger policy focus and the potential to improve coordination across programs and activities. On the Oceans Policy side, the government has established the:

- National Oceans Ministerial Board to provide oversight of Policy implementation;
- National Oceans Advisory Group to provide multidisciplinary expert advice;
- National Oceans Office to provide core administrative support.

On the MST side a Marine Science Advisory Group has been created to monitor and report on progress towards implementation of the Plan. Its core comprises the heads of the three DISR portfolio agencies: the Australian Geological Survey Organisation (AGSO), Australian Institute of Marine Science (AIMS) and CSIRO Marine Research (CMR). Reporting will be channelled through the National Oceans Ministerial Board.

A schematic representation of proposed new structure for marine activities within Australia and the position of ocean observing activities within it is shown in Fig. 2. The connection to international GOOS activities comes through a Joint Working Group for Australian GOOS/GCOS as well as direct involvement in international activities such as the Global Ocean Data Assimilation Experiment (GODAE)[1], Argo[2] float project, the, etc. Practices, protocols and standards will be developed in accordance with best international practice and GOOS guidelines.

[1]GOADE's objectives are (i) The application of state-of-the-art ocean models and assimilation methods for ocean, coastal and climate forecasts and boundary conditions; and (ii) Global ocean (re-)analyses and an improved global ocean observing system.

[2]Argo is an initiative of GODAE and CLIVAR to populate the global oceans with ~3000 profiling floats, and is expected to revolutionize operational oceanography.

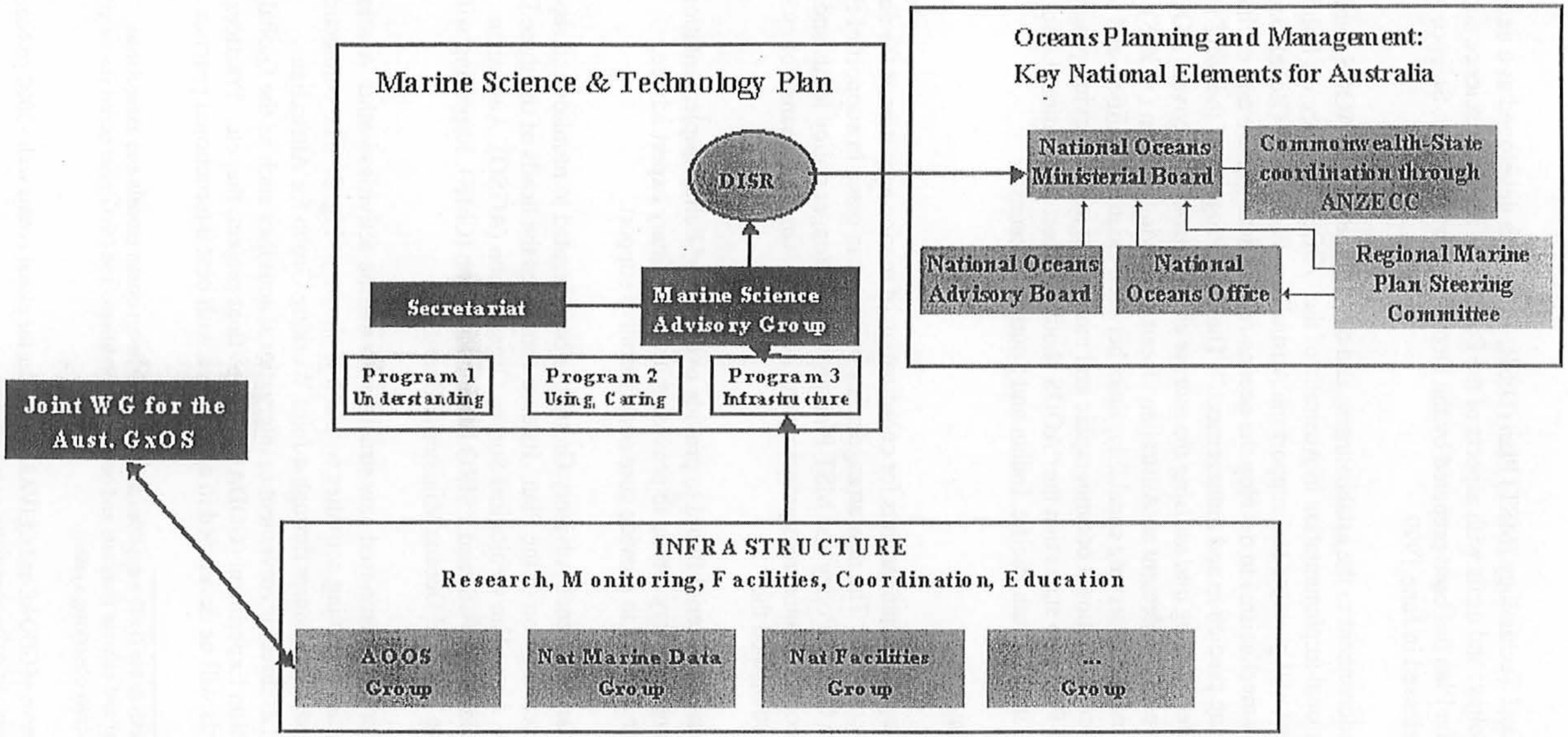

Figure 2. Schematic intended relationships and structure for marine activities within Australia.

Interests and priorities

The main interests and priority areas for the Policy are:

- Biodiversity, ecosystems and marine resources in southern temperate and northern tropical waters;
- Surveys and inventories of key marine habitats;
- Monitoring and assessment of change and variability in the marine environment and coastal zone;
- Marine services and marine data;
- Ocean and climate monitoring and prediction.

Specific initiatives

The Policy seeks to:

- Further develop and strengthen the existing base (capabilities and expertise);
- Upgrade research vessels and permit extended use (to around 200 extra days);
- Implement an AOOS;
- Develop better practices for management of marine data.

Overview of AOOS elements

The AOOS will be implemented within the framework and context of GOOS, and will include:

- The Cooperative Ocean Observing Experiment (COOE). This multi-agency project is already underway in the seas off Australia's west and north-west, and involves physical, biological and chemical monitoring using voluntary observing vessels and high density XBT lines. A number of Argo floats are being deployed in north-western waters;
- A comprehensive sea state observation program;
- Measurement protocols and benchmarks including marine biodiversity monitoring;
- The sea level network;
- Long term monitoring of the Great Barrier Reef, the North-west Shelf and other strategic locations;
- Ocean data assimilation systems for climate and ocean state estimation and prediction, based on GODAE.

The AOOS would also be planned to:

- Incorporate industry-generated data;
- Link monitoring to marine data coordination and management;
- Link monitoring to State of the Environment reporting;
- Better target data gathering programs for support of ocean/marine construction industry;
- Operate long term monitoring stations;
- Integrate historical data into the developing real-time/operational database;
- Contribute to GODAE and Argo as appropriate.

Improving infrastructure - nationally and internationally

Several recent initiatives have been made which strengthen both Australian and international infrastructure for implementing both GOOS and the AOOS. These include:

- Establishment of a Joint CMR/Bureau of Meteorology Research Centre (BMRC) Australian Facility for Ocean Observing Systems (JAFOOS);
- Hosting by BMRC of the International GODAE Project Office;
- Establishment of the IOC Regional Office in Perth, Western Australia in September 1999. This new Office will have a strong GOOS focus, particularly in the Indian Ocean basin.

Participation

The following agencies/institutions are likely to participate in the development of the AOOS:

- AIMS;
- CMR;
- the Bureau of Meteorology;
- the Centre for Research on Ecological Impacts of Coastal Cities;
- Fisheries Western Australia;
- James Cook University;
- New South Wales Fisheries;
- Primary Industries and Resources South Australia;
- Queensland Department of Primary Industries;
- South Australian Museum;
- University of Tasmania;
- University of Melbourne;
- University of Queensland.

Inter-agency discussions are progressing to better define priorities. Funding for major planks of the Oceans Policy and MST Plan has been identified, or bids have been submitted for consideration, by the Australian Government. The complex policy and interdepartmental situation may not contribute to speedy outcomes, however it is anticipated that the funding situation will be clarified during the early part of 2000.

Acknowledgements

The author would like to thank Dr. Neville Smith of the BMRC, and Director of the GODAE Project Office (amongst his many capacities), for his invaluable advice and background information on the developing AOOS.

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THE CORIOLIS PROPOSAL

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RÉSUMÉ — Les futurs modèles globaux de prévision océanique tels que MERCATOR ou GODAE assimileront des données satellitales et *in situ.* Pour satisfaire les besoins opérationnels en mesures *in situ,* le groupe français CORIOLIS recommande de (1) poursuivre l'effort actuel de mesures en Atlantique, (2) construire un réseau de 600 profileurs T,S lagrangien et eulérien répartis régulièrement dans tout l'Atlantique. Ce réseau devra se mettre en place progressivement dans un cadre internationnal tel qu'ARGO.

ABSTRACT — *The future global ocean prediction models will require to assimilate satellite and in situ data. To satisfy the in situ needs, he French group CORIOLIS recommends to (1) Continue the present in situ monitoring of the Atlantic, (2) Build a new in situ network made of 600 profiling floats T, S of both lagrangian and eulerian type, covering all the Atlantic on a regular space—time grid. Such a network will be deployed progressively in an international framework like ARGO.*

1 — INTRODUCTION

The French working group "CORIOLIS" was formed in 1997 to provide recommendations on the *in situ* data component available for future operational ocean models as the ocean prediction project MERCATOR (part of GODAE) which will assimilate satellite and in situ data. It includes representatives of the main six agencies dealing with oceanography (IFREMER, ORSTOM (IRD), CNES, FMTO, INSU/CNRS, SHOM) and is led by IFREMER The group focused on the Atlantic Ocean.

2 - THE PRESENT SITUATION

2.1 - An ocean under-sampled :

The *in situ* monitoring of the global Ocean and the Atlantic in particular is dramatically insufficient, limited in spatial coverage, in time distribution, in quantity and restricted mainly to temperature measurements. No salinity data are available on a regular basis. In addition, a fraction only of the observations are accessible in real time on the GTS. The observation system is composed mainly of:

- Drifting buoys (SST)
- Expandable XBT : About 600 XBT are collected every month along ship routes in the upper 500m depth range
- The scientific PIRATA network made of 12 buoys collecting T, S data in the 0-500m depth range
- P-floats PALACE deployed in the Atlantic in the framework of international programs
- Conventional ship-based sections and bathysonde profiles, with the big contribution of WOCE

2.2 - New automatic instruments :
The global monitoring is now technically feasible with the development of new autonomous and automatic profiling floats of lifetime exceeding 3 years and able to collect T,S profiles on a regular basis. Among the instruments available or still in development, the CORIOLIS group pointed the two major P-floats developed by IFREMER : the multicycle drifting profiler PROVOR and the expandable eulerian profiler EMMA.

- PROVOR is the profiling version of the successful subsurface drifter MARVOR (170 floats were deployed during the last 5 years, and 70% are still in operation after 4 years at sea). Equipped with T or C, T sensor, it is able to drift at a given depth, then to dive until 2000m and ascent to the surface, delivering it's recorded T, S descent and ascent profiles through the ARGOS satellite system. A new generation of such profiler will be developed, to cope with full operational requirements : minimum cost, deployable from ship of opportunity or aircraft's, with increasing sensor lifetime [Loae 98].

- The expandable lighter-than-water probe EMMA, equipped with CTD sensor will profile the water column from the bottom (i.e. 5000m) to the surface and transmit the data through the ARGOS link when surfacing. A marginal cost per probe is estimated to be less than /$1000 in production quantities [Cono 98]

3 - THE CORIOLIS PROPOSAL

The working group CORIOLIS concludes that it is essential to remedy to the dramatic under-sampling of the ocean [Marc 99]. He considers its contribution as a proposal for the Atlantic to the ARGO proposal and recommends :

1. To continue and improve the existing observing systems such as the VOS-XBT lines, surface drifters operated by Met-offices, PIRATA tropical Array.
2. To implement a new automatic and permanent in situ network covering all the Atlantic and composed of :
- 500 profiling floats (such as PROVOR) as a contribution to the ARGO project, basically on a 5° x 5° grid with denser sampling (2° x 2°) in specific areas.
- 100 eulerian expandable pop up probes EMMA, profiling from top to bottom on a monthly basis on a 10° x 10° grid.

Floats are a cost effective means to collect in situ data over the global ocean. Several advantages can be pointed out when mixing fixed and drifting profilers : (1) EMMA probes will not be ejected from high dynamic zones, they will collect time series of T, S at fixed location and in a synoptic way all over broad areas ; (2) high quality of T, S measurements are expected from EMMA probes because of their protected CTD before poping up ; Calibration of P-float can then be envisaged ; (3) Collecting data in all the water column is useful to evaluate the possible climatic signal of deep waters.

The CORIOLIS proposal (released in December 1998) would represent a significant contribution to ARGO. As a consequence, it is plan presently in France :

- To develop a full operational version of the PROVOR profiler and to develop the EMMA eulerian probe.
- To deploy floats in the North Atlantic as a CORIOLIS contribution to ARGO, including 30 PROVOR in the 1999-2000 period (during the scientific experiment POMME) and 50 floats/year during the 2001-2003 period financed by IFREMER. In addition, the French contribution will be

complemented through a European proposal _Gyroscope" to be submitted to the European Union 5th framework program, which will require a total of 150 additional floats on the same period. We thus envision a French direct contribution to ARGO of about 50 floats per year which could be complemented by 50 additional floats through a EU proposal, giving a total of 100 floats per year and 300 floats at sea in 2003 after 3 years of deployment.

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[Loae 98] G. Loaec et al. : " PROVOR: a hydrographic profiler based on MARVOR technology ", IEEE-*Oceans'98*, Nice, September 1998.

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DEVELOPMENTS IN QUALITY CONTROL TECHNIQUES FOR BUOY AND OTHER MARINE OBSERVATIONS

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1. INTRODUCTION

Meteorological data storage and archival facilities around the world are faced with the unceasing and daunting task of how to adequately quality control (QC) the mountains of data now being collected – usually within existing or shrinking resource budgets. The Australian Bureau of Meteorology's National Climate Centre (NCC) is no exception and the storage of 'buoy' data is a typical example of the problems being faced.

In 1994 , the NCC implemented the Oracle relational database system called the Australian Data Archive for Meteorology (ADAM). At that time, automated data archival procedures were implemented for buoy data to address the existing deficiencies in archival procedures. Since that time, data has been flowing down the real-time 'pipe' from the operational world into the database, but with virtually no inspection of the data possible due to limited resources. This scenario holds true for some other types of observations, including ship data, and is probably typical of the situation in many countries with the explosion of meteorological observation platforms providing a plethora of data, often with very high spatial and/or temporal resolution.

In October 1997, NCC commenced a project to try to reduce the number of rainfall observations requiring close QC inspection and expedite the processing of data which required modification or needed to be flagged in some way. The principle was simple: to develop and implement automatic systems which could identify 'suspect' observations, flag them as suspect and pass them to software which could visualise the data. This would allow human assessment to determine whether the observation was correct and make decisions accordingly thereafter. The theory was that this should reduce the bulk of the work to more manageable proportions. This concept is a part of NCC's 'Quality Monitoring' philosophy embodied in a paper presented at the 2nd European Conference on Applied Climatology (ECAC) 1998 (Plummer et al. 1998).

The work is 'in progress' and this paper discusses adaptation of the concept and systems to marine data.

2. DATA

The meteorological data reported from ships and buoys are retained in the Marine Met data tables. The basic table is the SFC_SHIP. The MOBILE_MARINES table is required in order to identify the source of the data in the SFC_SHIP table. Details of the ship/buoy name, country, thermometers, etc are available via this table. Figure 1 shows the data flow of marine data, whereby real-time messages collected over the Global Telecommunications System are decoded and stored in the Real Time Data Base before being quality controlled and archived in ADAM.

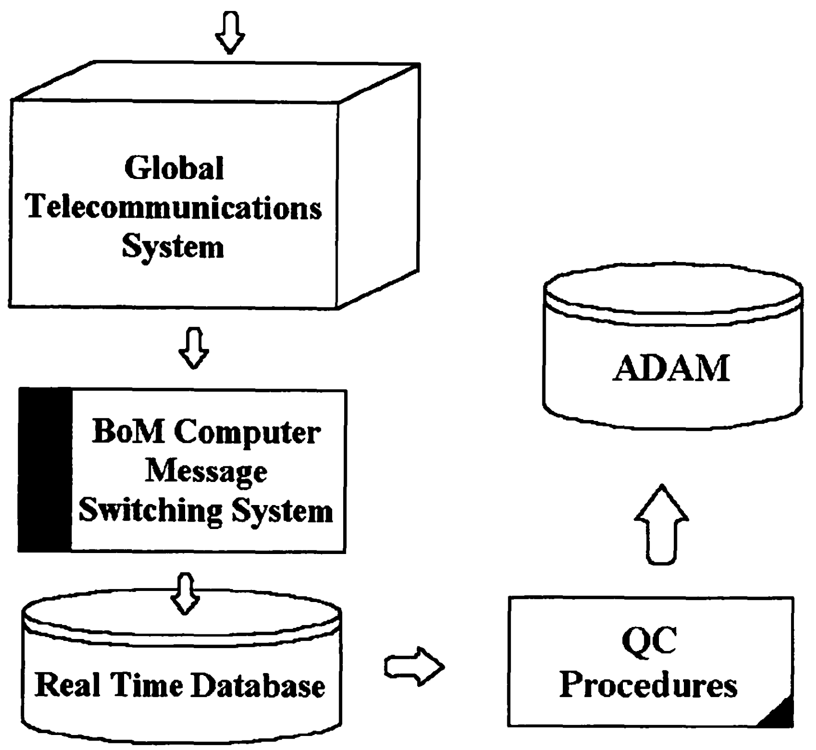


Figure 1. **Data flow – from meteorological message to the climate database.**

The callsign and UTC date/time uniquely identify each record.

2.1 Ship Observations

Surface ship observations are available in the NCC Oracle database from 1931 onwards (Figure 2). These data are accessed using SQL scripts modified to suit the particular requirement. Appendix I lists the parameters which may be reported in the messages and subsequently archived.

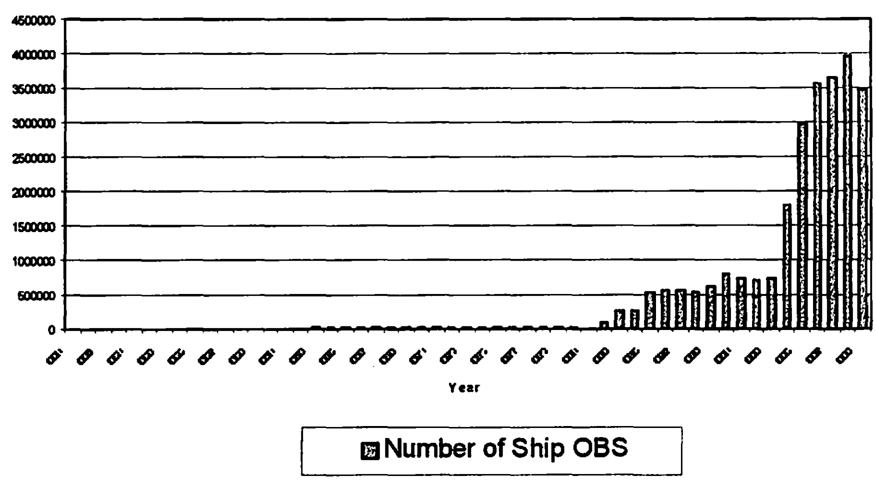


Figure 2. **Archived Surface Ship Observations – 1931 - 1991.**

Figure 3 highlights the ship observations whose archived position is overland – ships of the ‘desert’. Each black dot represents a surface ship or buoy observation. The advent of GIS (Arcview used here) facilitates identification of spatially misreported data.

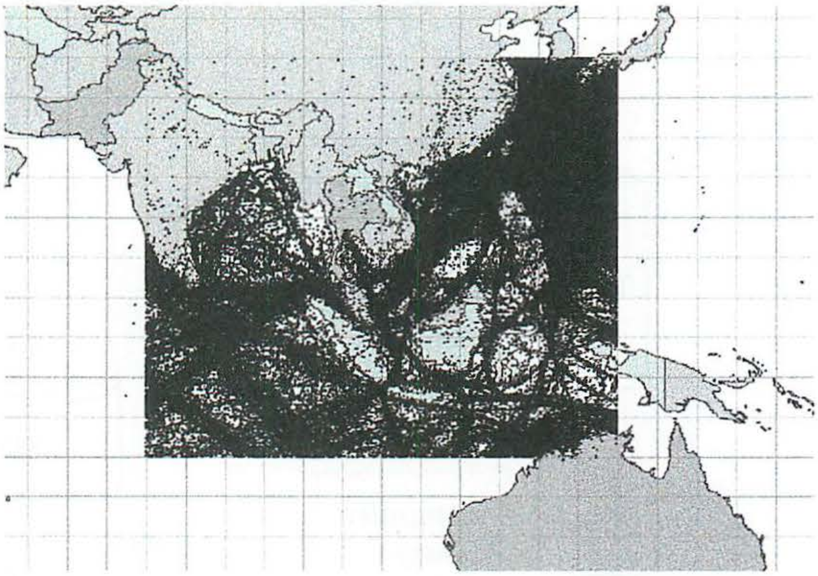


Figure 3. Subset of Archived Surface Ship Observation Positions – 1992 - 1998.

Figure 4. indicates problems with the integrity of the data within observations. These average daily sea surface temperatures (SST) and surface air temperatures (SAT) in the Bay of Bengal are contaminated by negative hourly sea surface temperatures – an unlikely occurrence in the area – but very difficult to pick up without temporal and spatial analysis tools to identify the problem in such large tables in databases. ADAM has 16,840,424 records in its post '91 marine table.

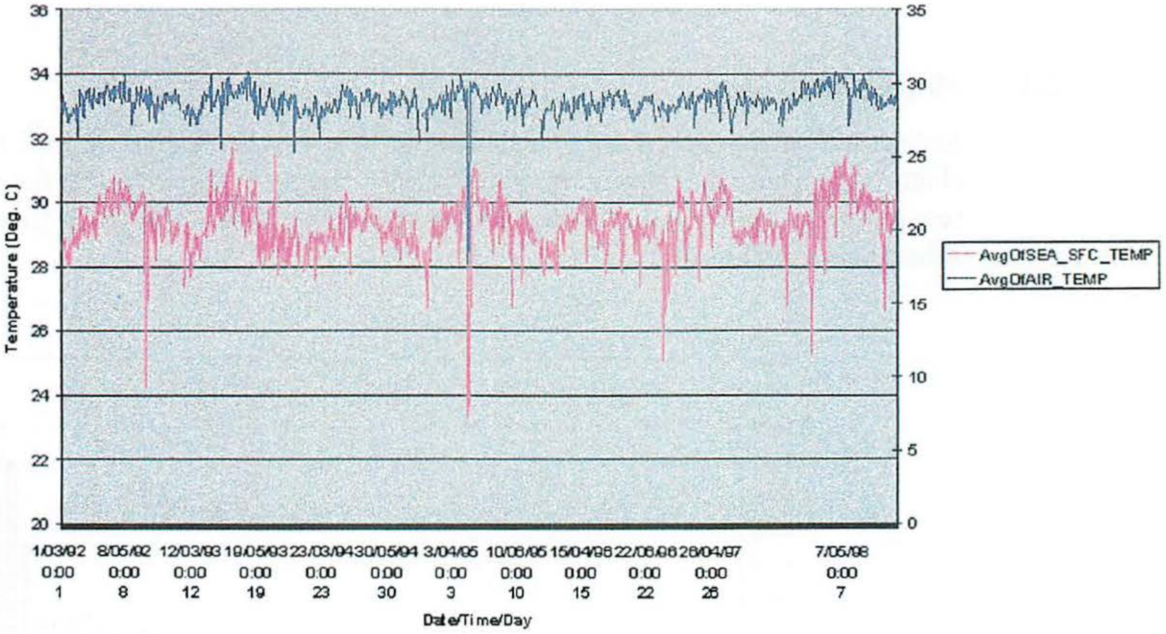


Figure 4. Average Daily SSTs and SATs in the Bay of Bengal from 1992 to 1998 calculated from un-quality controlled data.

2. Drifting Buoy data

Figure 5 shows that drifting buoy data are available from the NCC's ADAM Oracle database from 1994 onwards (3,823,371 records – 1998 incomplete). Appendix II shows the spatial and temporal distribution of these data. Data prior to 1994 has not yet been transferred to ADAM.

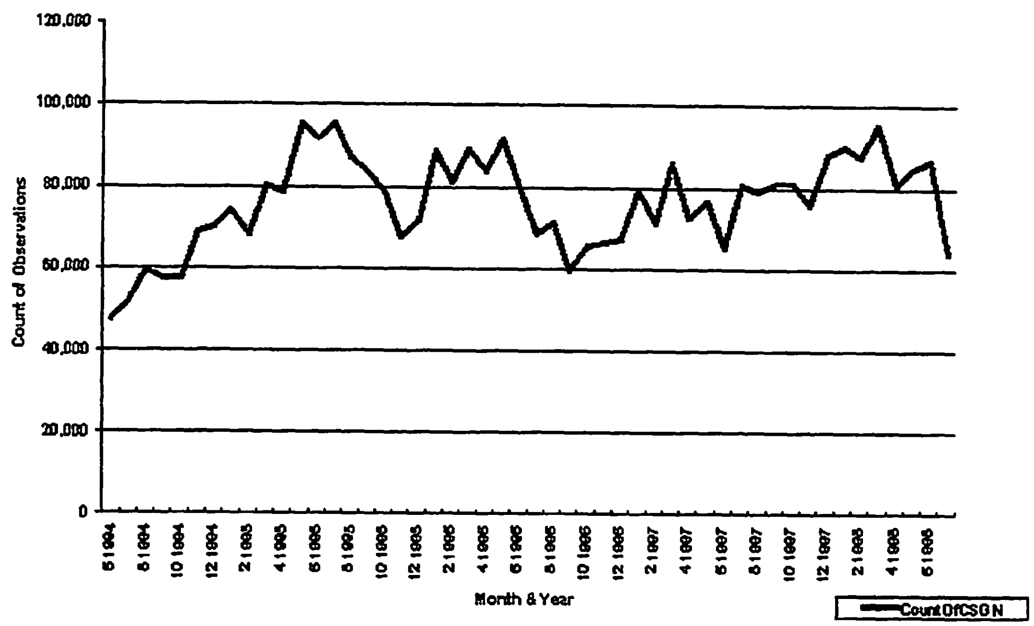


Figure 5. Number of Archived Drifting Buoy Observations – 1994 to July,1998.

Observation frequency is another factor, which can impact adversely on QC procedures. Figure 6 highlights the large variability existing in the frequency with which buoys report. The software developed to QC these data had to be modified to accept the unexpectedly large numbers of wave rider buoy observations in the database.

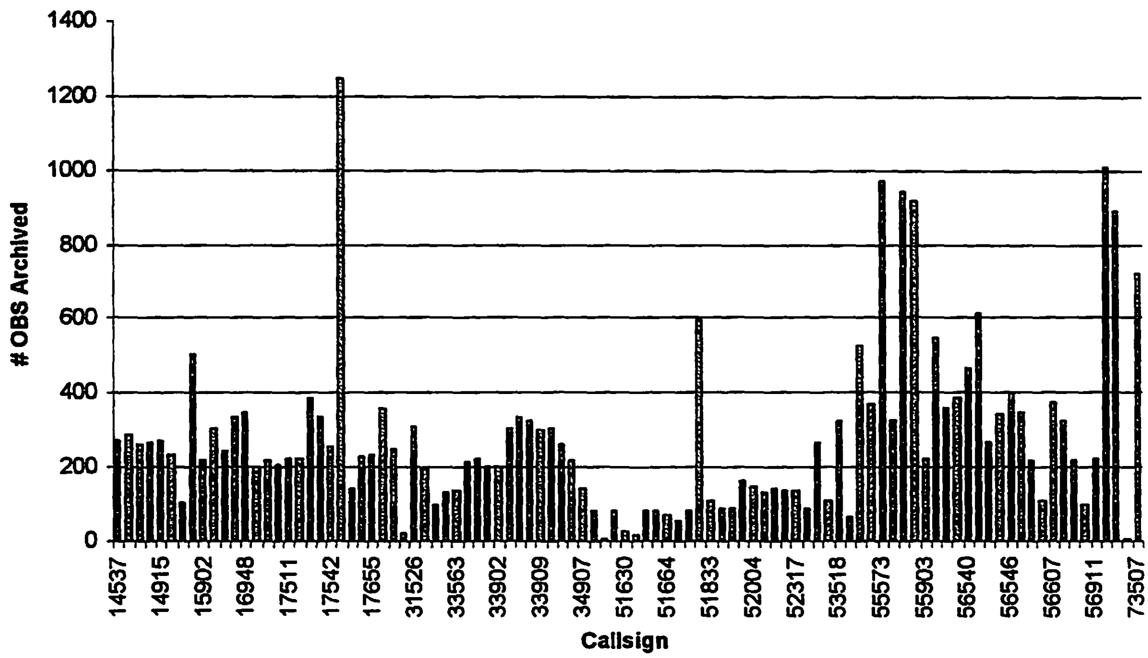


Figure 6. Observations received from each buoy – January, 1990.

3. QC SOFTWARE DEVELOPMENT

Software is being adapted and developed in C, Fortran and IDL for the rain project and these developments will continue to flow into the marine QC procedures with appropriate modification.

'C' routines have been written to compare observations from the same site for successive observations. The 'spike' check determines whether a particular observation exceeds some pre-determined criteria when compared to the observations taken immediately before and immediately after the one being tested.

Similarly, the 'flat line' check tests whether successive observations are repeated and alerts to the possibility of sensor failure.

The Fortran code conducts a 2 pass Barnes analysis on the data which compares any observed value with those from its neighbours (taken at the same time) to determine whether the observation is likely to be correct. Each observation is compared to the weighted mean of the observations from surrounding stations, with the weighting based on the distance of any station from the observation under test.

These tests are designed to identify 'suspect' observations and write the station number, date, time, observed value and a 'flag' to a Data Quality Flag table in the ADAM database. These data constitute a permanent record of the 'suspect' observations received and provide the basis for identifying the suspect values in the next phase of the quality control procedure.

Code written in Research Systems 'IDL' is undergoing a major re-write to accommodate larger data sets and increase the speed of processing and display. Originally data were stored in string arrays and packed and unpacked as needed. This proved to be much too slow in practice and identified a barrier to further development in IDL using this technique: array sizes were regularly exceeding the 280,000 limit in IDL – particularly for rainfall.

Consequently, the code is being re-written using 'arrays of structures' and pointers to subset the data for processing. These techniques show great promise in providing fast, reliable visualisation of the data, identification of suspect values and rapid assessment and correction facilities.

4. IMAGES

The images used are built around a few basic concepts:

Data is displayed on maps (Figure 7) and can be grouped by time or remain ungrouped. This provides the spatial data display;

Suspect observations defined by the automated processes – in this case the Barnes Analysis – are highlighted in a different colour so that the operator can easily focus on these observations, while still being presented with the 'good' data to place the suspect value in context;

Note the topographic presentation on the map of Australia to assist in assessing topographic influence on rainfall distribution (Figure 8);

It is proposed that the black continents on the world map will be used as a mask to automate identification of marine observations reported on land;

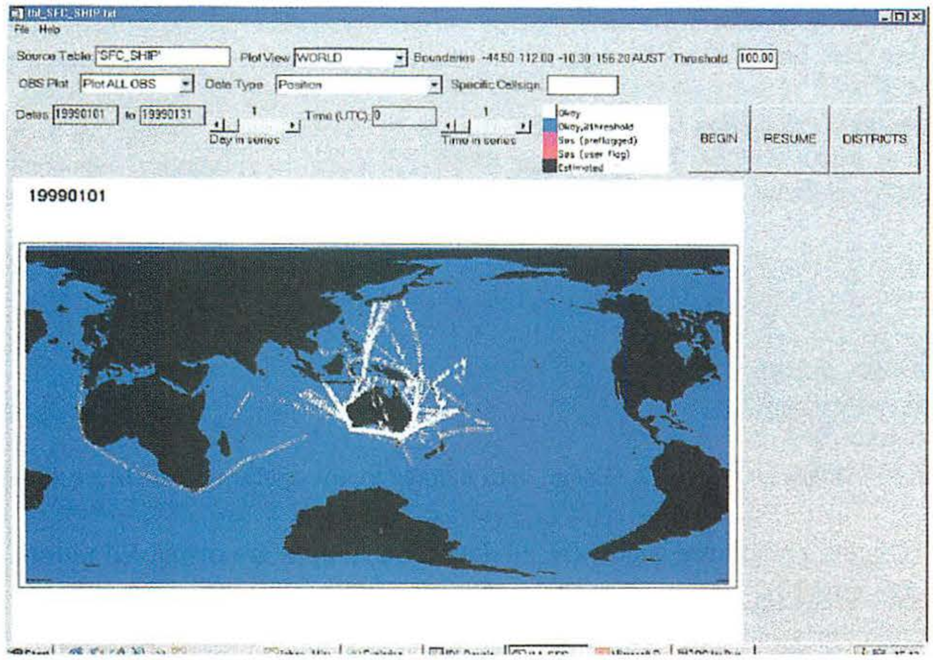


Figure 7. **Example of the Graphical User Interface and Australian VOS observations for January, 1999.**

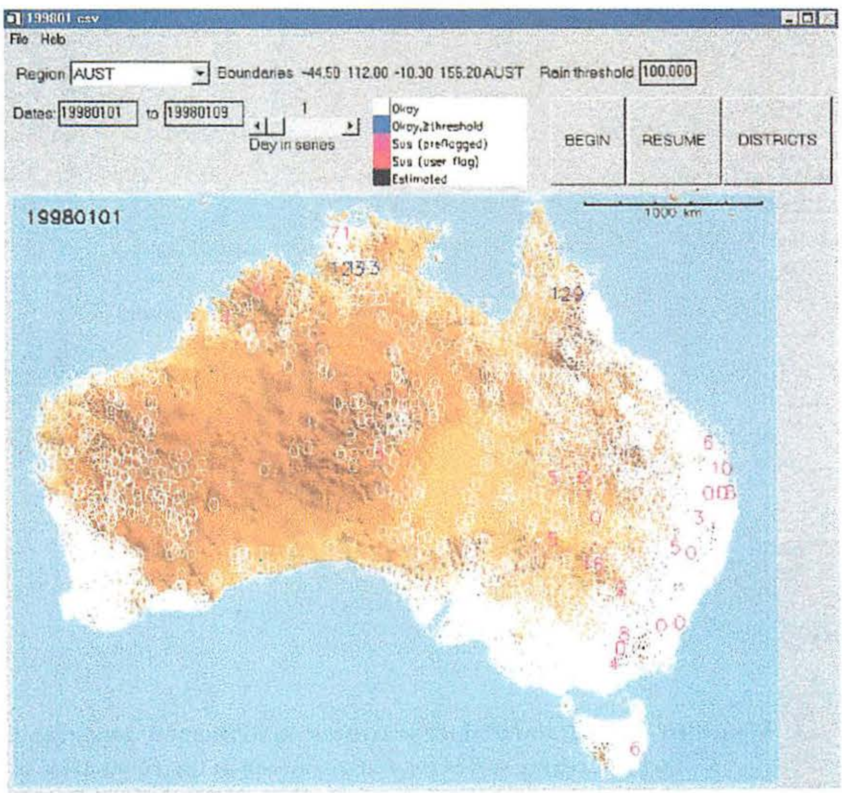


Figure 8. **Rainfall data presented on a high-resolution topographic map with 'suspect' observations presented in purple.**

- The maps can be zoomed to focus on a particular area or group of observations derived from the base map;

Figure 9. A 'Zoom' area defined by the operator – the black square.

- Once a zoom area is chosen, all data for that area are displayed in time series (Figure 10).

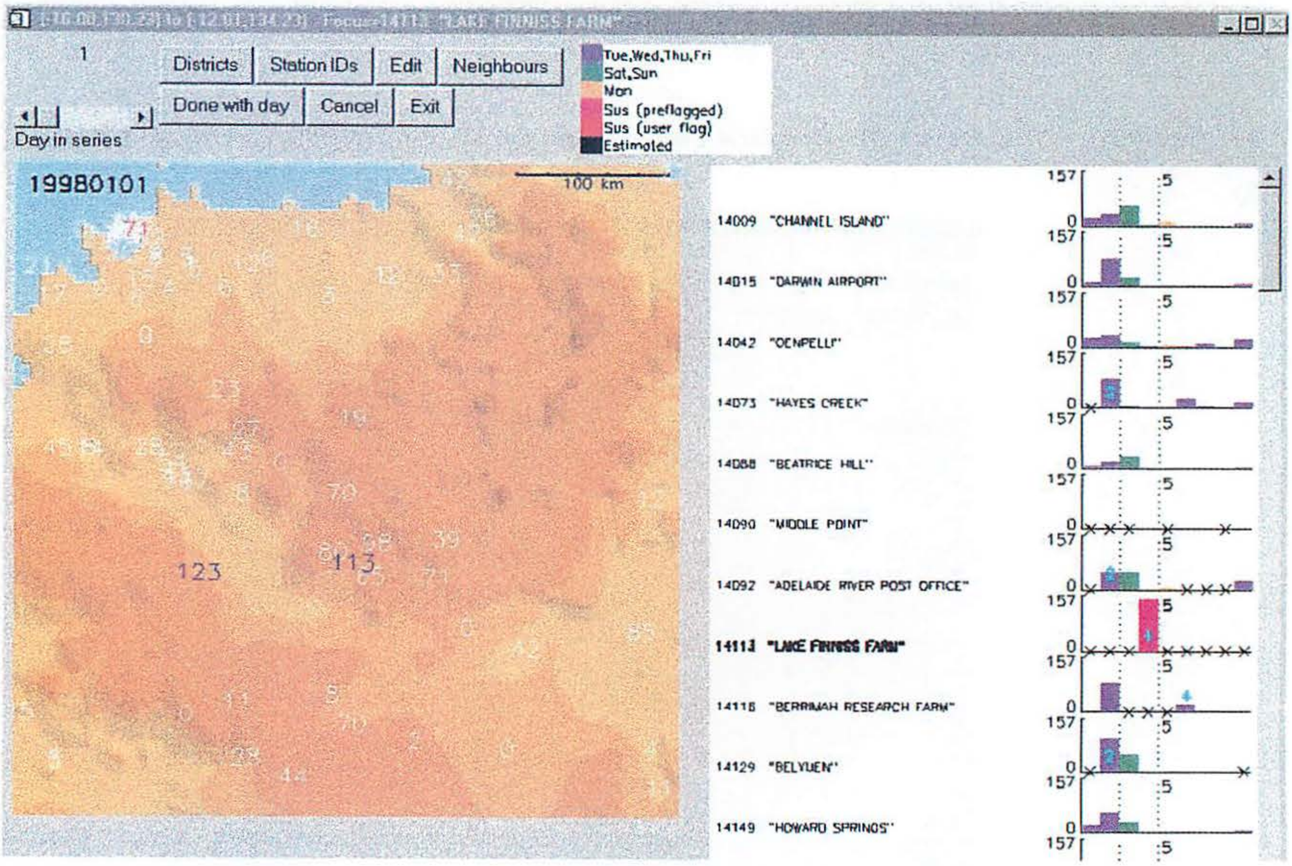
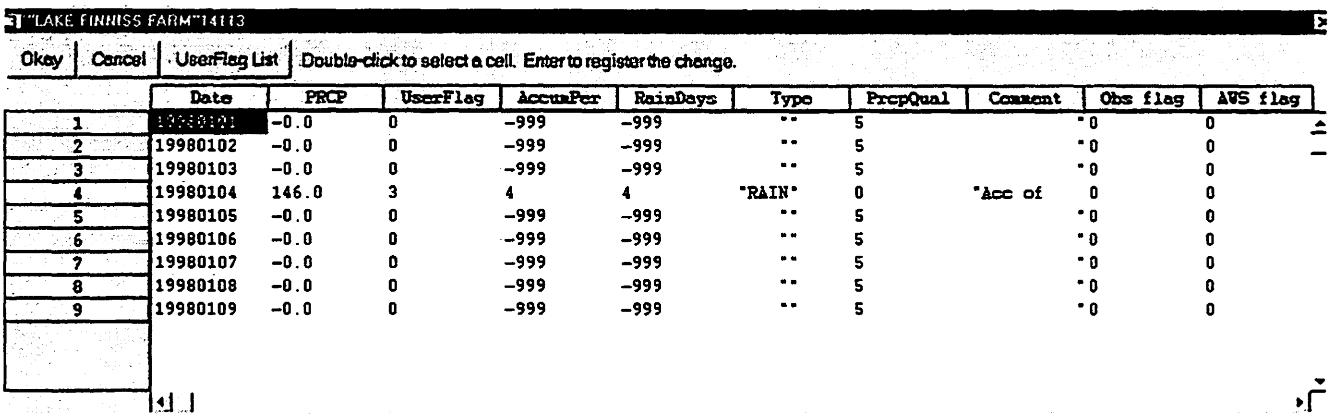


Figure 10. Rainfall data presented on a 'zoomed' topographic map with the time series for those stations in the zoom area at right.

- The relevant spatial display for the particular date/time is derived from actions within the time series.

- Double clicking an observation in the time series brings up an editable window allowing direct interaction with the data (Figure 11.). When such a window closes, modifications to the data are stored in the primary arrays of structures and uploaded to the database at the operators command.



"LAKE FINNISS FARM"14113

Okay | Cancel | UserFlag List | Double-click to select a cell. Enter to register the change.

	Date	PRCP	UserFlag	AccumPer	RainDays	Type	PrcpQual	Comment	Obs flag	AWS flag
1	19980101	-0.0	0	-999	-999	""	5		"0	0
2	19980102	-0.0	0	-999	-999	""	5		"0	0
3	19980103	-0.0	0	-999	-999	""	5		"0	0
4	19980104	146.0	3	4	4	"RAIN"	0	"Acc of	0	0
5	19980105	-0.0	0	-999	-999	""	5		"0	0
6	19980106	-0.0	0	-999	-999	""	5		"0	0
7	19980107	-0.0	0	-999	-999	""	5		"0	0
8	19980108	-0.0	0	-999	-999	""	5		"0	0
9	19980109	-0.0	0	-999	-999	""	5		"0	0

Figure 11. **Edit table within 'RainQC'.**

5. DATA INPUT FORMS

Identification of missing observations requires a strategy for entering such data from the ship log books. An integral part of the project will be the development of appropriate forms to facilitate data entry. These forms will be developed using Developer 2000 and will follow established practices currently employed for surface data and other meteorological parameters. Coarse quality checks will be undertaken while data is keyed in. More sophisticated tests will be undertaken during reprocessing.

6. CONCLUSION

It is anticipated that the application of the methodology and software described herein to data quality control will:

Promote more effective use of human resources in data management;
Expedite the identification of erroneous data;
Facilitate the correction of data and the associated modification of data in the database;
Utilise a new 'flag' system described by the wider 'Quality Monitoring System' and enhance the Bureau's capacity to identify systematic problems with hardware, software and communications; and
Substantially out-perform some of the Bureau's existing QC techniques while providing the opportunity for retrospective analysis of data in the database by using human resources more effectively.

7. REFERENCES

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8. ACKNOWLEDGEMENTS

Dr. E. Ebbert, Bureau of Meteorology Research Centre – for transforming the visualisation concept into reality using IDL.

Dr. G. Weymouth, Bureau of Meteorology Research Centre – who adapted his Barnes analysis routines to this project

Appendix I

Explanation of Terms in the SFC_Ships table -

Date/Times are UTC

lat:	Latitude (-90 to 90)
long:	Longitude E (0 to 360)
oq:	Observation quality flag (0 means the observation has been through quality control, anything else and it has not)
Temp:	Temperature (degrees C)
dew:	Dewpoint (degrees C)
maxt:	Maximum Temperature (degrees C)
mint:	Minimum Temperature (degrees C)
sst:	Sea surface temperature (degrees C)
pres:	Pressure (hPa)
vsby:	Visibility (km)
wdir:	Wind direction (degrees)
wspd:	Wind speed (m/s)
w1:	Present weather id
w2:	Past weather id
c:	Total cloud amount (oktas)
b:	Cloud base height id
t:	Total low/middle cloud amount
l:	Low cloud id
m:	Middle cloud id
h:	High cloud id
s1p:	Swell 1 period (sec) **Note: These values are not correct between July 1994and 11 November 1997**
s1h:	Swell 1 height (m)
s1d:	Swell 1 direction (degrees)
s2p:	Swell 2 period (sec)
s2h:	Swell 2 height (m)
s2d:	Swell 2 direction (degrees)
wp:	Wave period (seconds)
wh:	Wave height (m)
sspd:	Ship speed
sdir:	Ship direction (degrees)
prcp:	Precipitation (mm)
pp:	Precipitation period (hours)
x:	Data source type
	icedata: Ice data ID
o:	Sea observation id
z:	**# (end of line marker)**

Appendix I (cont)

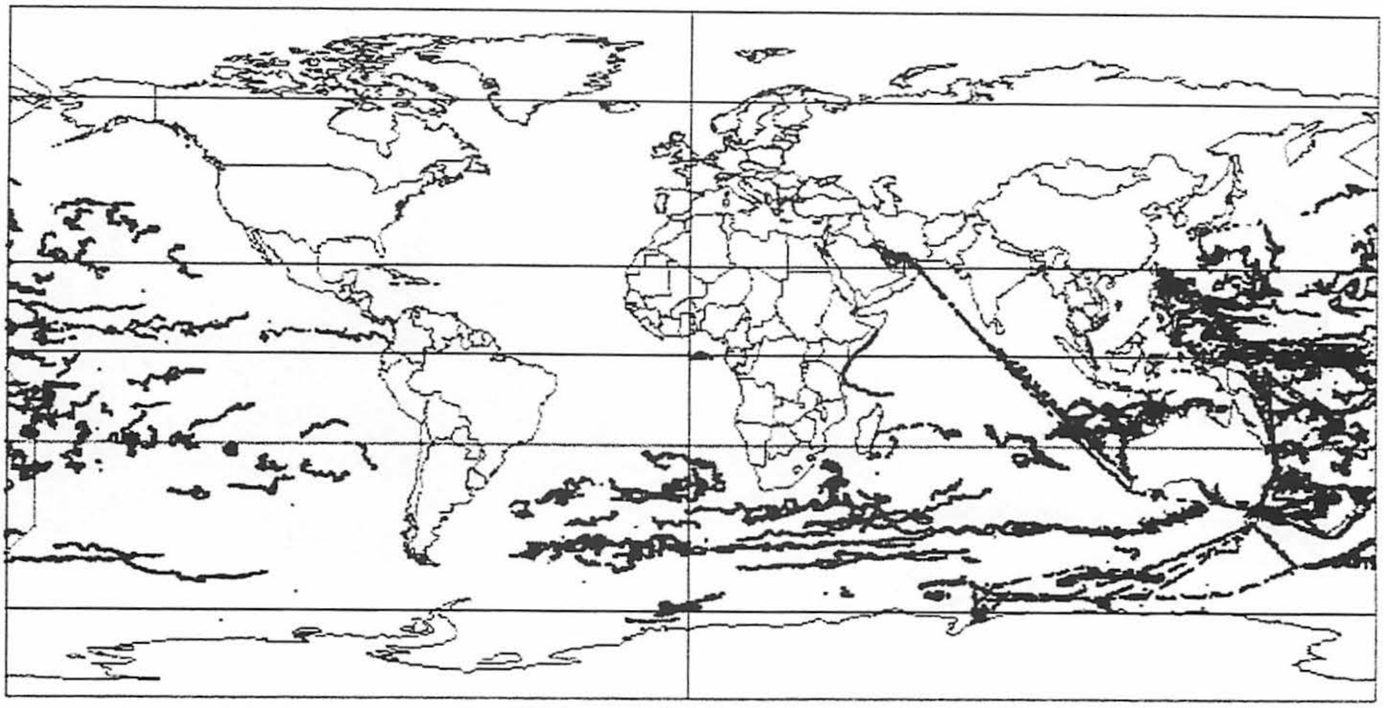
SFC_SHIP Elemental Fields and units

(Note that a blank in the NULL Field indicates "Yes")

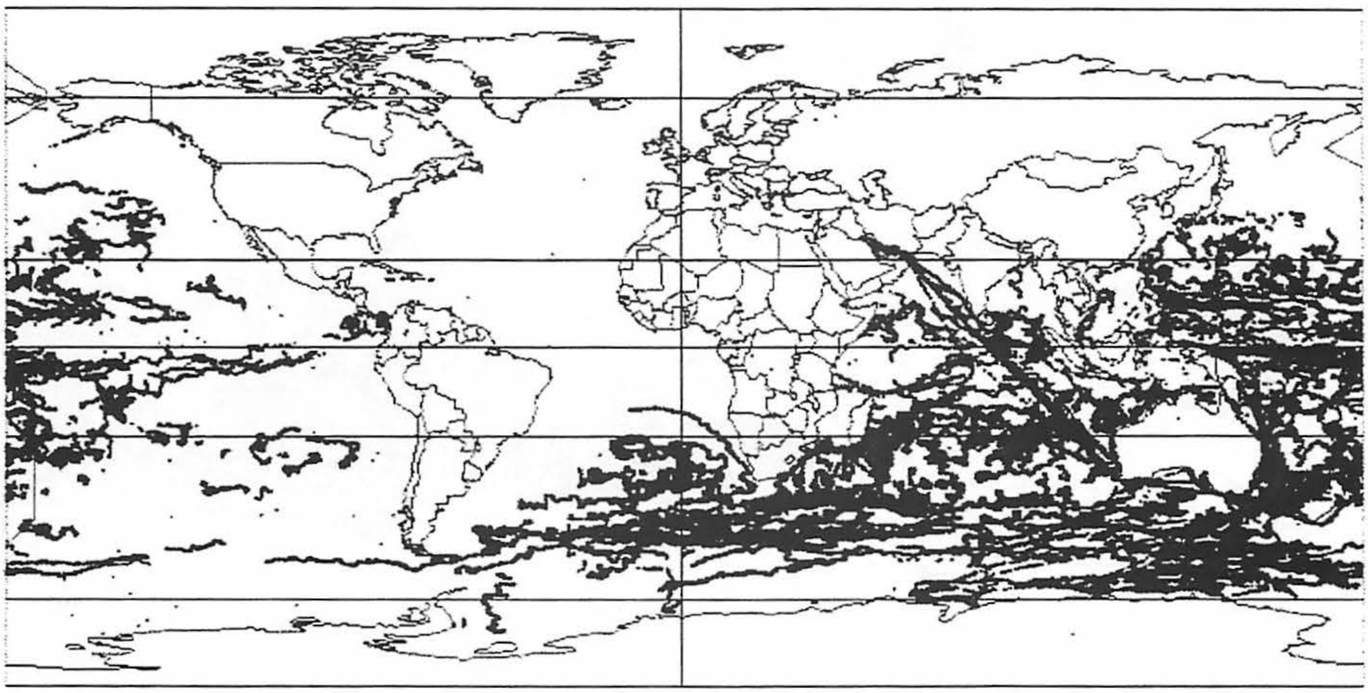
Name	Null?	Type	Units or example
AIR_TEMP		NUMBER(6,1)	deg C to 0.1
AIR_TEMP_QUAL		NUMBER(2)	
CLD_BASE_HT_ID		NUMBER(1)	Code
CLD_BASE_HT_ID_QUAL		NUMBER(2)	
CMT		Varchar2(240)	
CSGN	NO	Varchar2(8)	ABCD
DATA_SRC_TYPE		NUMBER(1)	Code
DWPT		NUMBER(6,1)	deg C to 0.1
DWPT_QUAL		NUMBER(2)	
HI_CLD_ID		NUMBER(1)	Code
HI_CLD_ID_QUAL		NUMBER(2)	
ICE_DATA_ID		Varchar2(11)	Code
LAT	NO	NUMBER(8,4)	lat to 0.1 (-90 to +90)
LAT_LON_QUAL		NUMBER(2)	
LON	NO	NUMBER(8,4)	Lon E (0-360) to 0.1
LOW_CLD_ID		NUMBER(1)	Code
LOW_CLD_ID_QUAL		NUMBER(2)	
MAX_AIR_TEMP		NUMBER(6,1)	deg C to 0.1
MAX_AIR_TEMP_QUAL		NUMBER(2)	
MAX_QUAL_QUAL		NUMBER(2)	
MID_CLD_ID		NUMBER(1)	Code
MID_CLD_ID_QUAL		NUMBER(2)	
MIN_AIR_TEMP		NUMBER(6,1)	deg C to 0.1
MIN_AIR_TEMP_QUAL		NUMBER(2)	
OB_QUAL_FLAG	NO	NUMBER(2)	
PAST_WX_ID		NUMBER(2)	Code
PRCP		NUMBER(6,1)	mm to 0.1
PRCP_PER		NUMBER(2)	hours
PRCP_QUAL		NUMBER(2)	
PRES		NUMBER(7,1)	hPa to 0.1
PRES_QUAL		NUMBER(2)	
PRES_TDCY		NUMBER(4,1)	hPa to 0.1
PRES_TDCY_ID		NUMBER(1)	code
PRES_TDCY_ID_QUAL		NUMBER(2)	
PRES_TDCY_QUAL		NUMBER(2)	
PRST_WX_ID		NUMBER(2)	Code
SEA_OB_ID		NUMBER(1)	Code
SEA_SFC_TEMP		NUMBER(7,1)	deg C to 0.1
SEA_SFC_TEMP_QUAL		NUMBER(2)	
SHIP_DIR		NUMBER(5,1)	degrees (whole)
SHIP_DIR_QUAL		NUMBER(2)	
SHIP_SPD		NUMBER(5,1)	knots
SHIP_SPD_QUAL		NUMBER(2)	
SWL_1_DIR		NUMBER(5,1)	degrees (whole)
SWL_1_HT		NUMBER(4,1)	metres to 0.1
SWL_1_PER		NUMBER(2)	seconds
SWL_2_DIR		NUMBER(5,1)	degrees (whole)
SWL_2_HT		NUMBER(4,1)	metres to 0.1
SWL_2_PER		NUMBER(2)	seconds
TM	NO	DATE	UTC date/time to minutes
TTL_CLD_AMT		NUMBER(1)	Oktas
TTL_CLD_AMT_QUAL		NUMBER(2)	
TTL_LOW_MID_CLD_AMT_QUAL		NUMBER(2)	
TTL_LOW_MID_CLD_AMT		NUMBER(1)	Oktas
VSBY		NUMBER(5,2)	km to 0.01
VSBY_QUAL		NUMBER(2)	
WAV_HT		NUMBER(4,1)	metres to 0.1
WAV_HT_QUAL		NUMBER(2)	
WAV_PER		NUMBER(3,1)	seconds to 0.1
WAV_PER_QUAL		NUMBER(2)	
WND_DIR		NUMBER(5,1)	degrees to whole
WND_DIR_QUAL		NUMBER(2)	
WND_ID		NUMBER(1)	
WND_SPD		NUMBER(5,1)	m/sec to 0.1
WND_SPD_QUAL		NUMBER(2)	
WX_QUAL		NUMBER(2)	

Appendix II

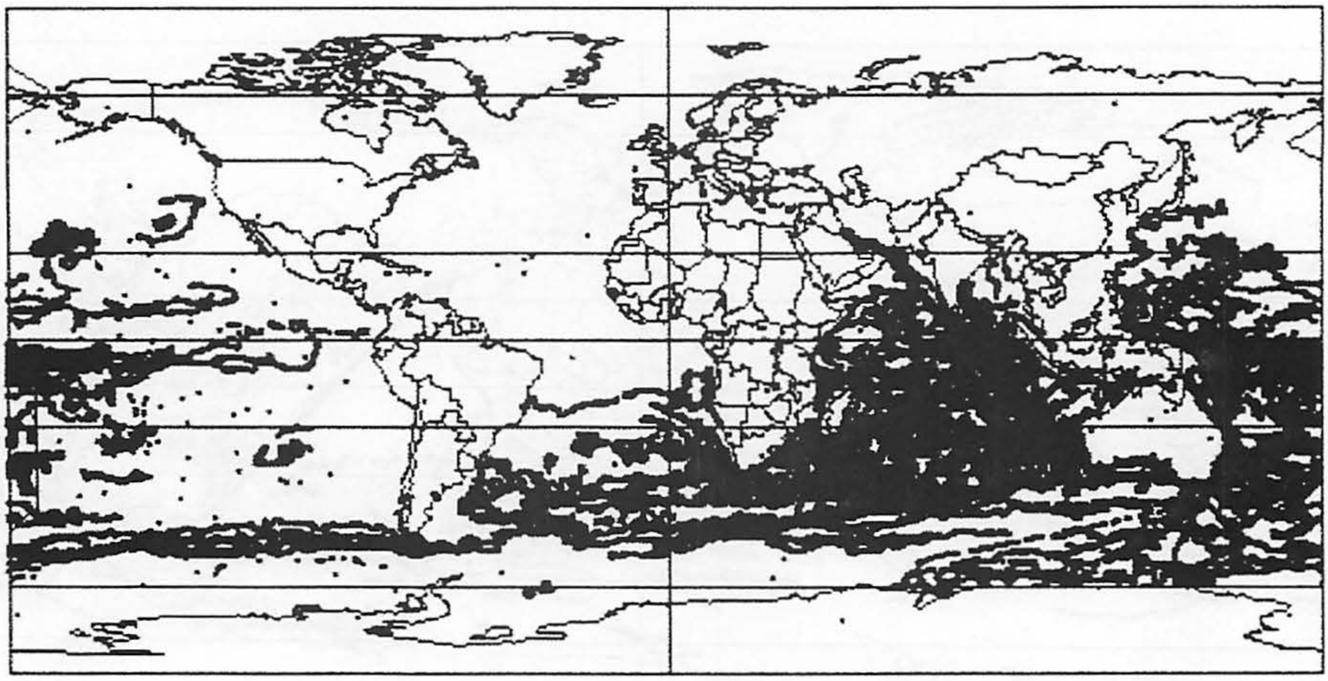
Drifting Buoy Observation Positions by Year



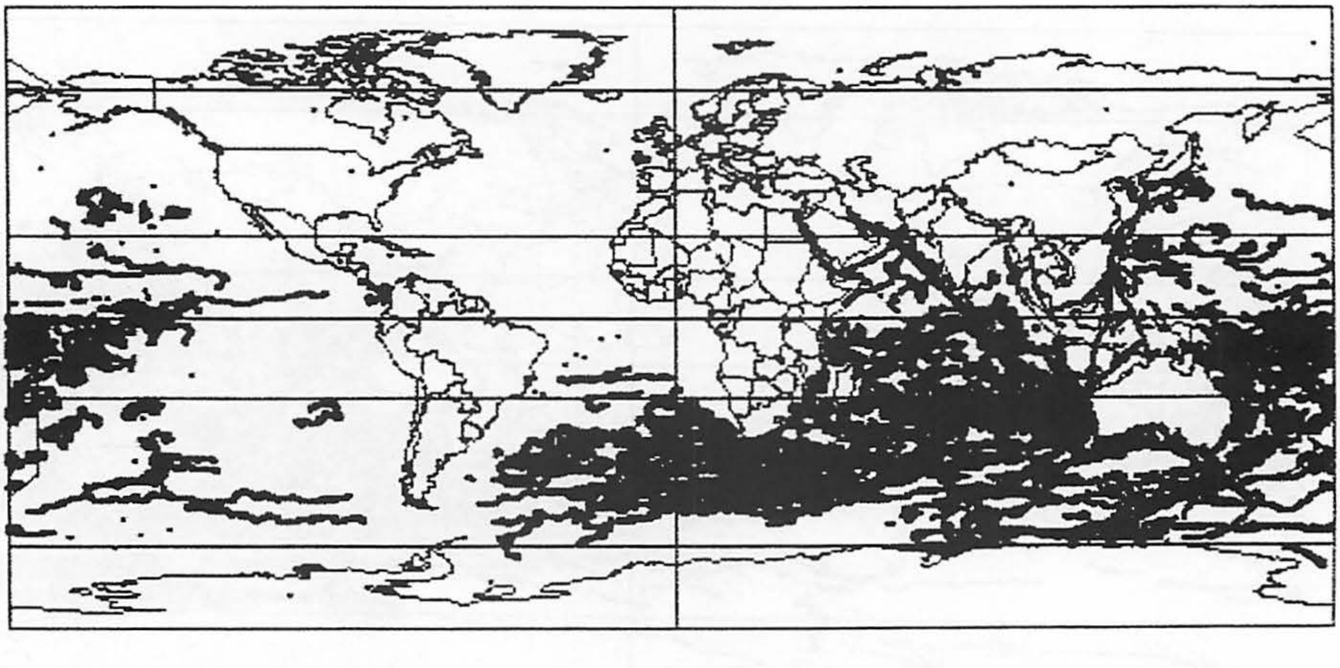
1994 Drifting Buoys



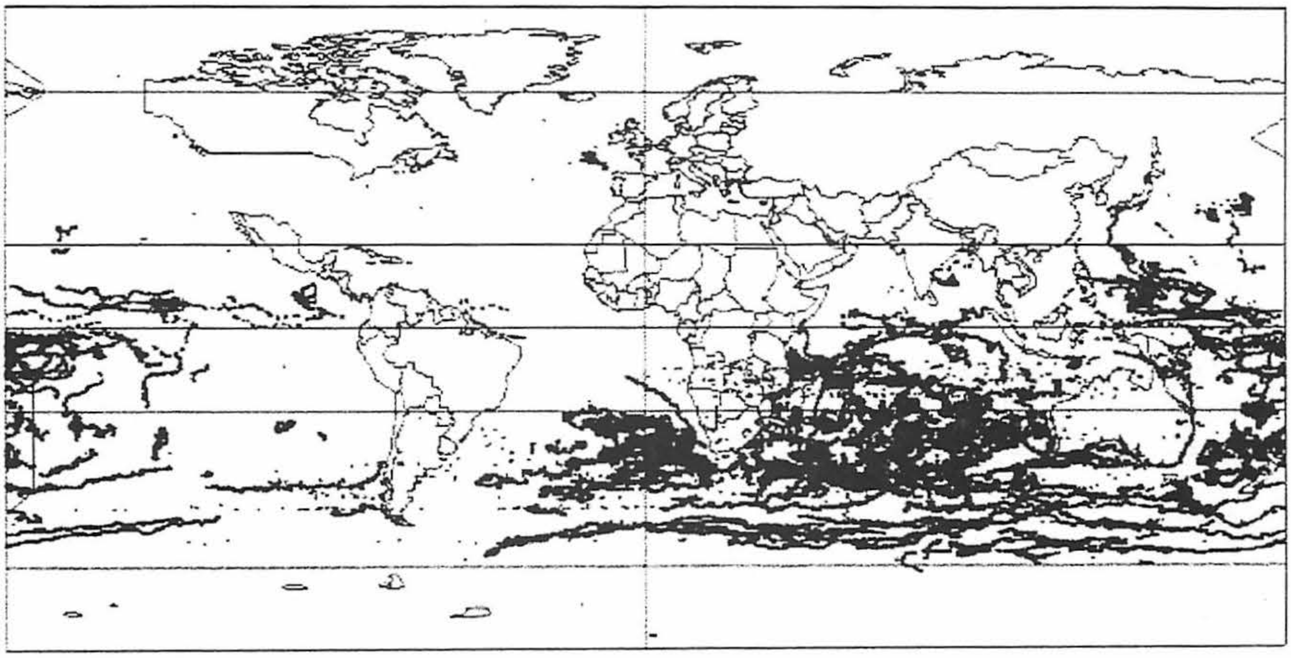
1995 Drifting Buoys



1996 Drifting Buoys



1997 Drifting Buoys



1998 Drifting Buoys

A Review of New PMEL North Pacific Mooring Experiments

Scientific and Technical Workshop of the 15th Data Buoy Cooperation Panel Meeting
Wellington, New Zealand, 26-27 October 1999

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Hugh Milburn

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Abstract

Over the past few years, Pacific Marine Environmental Laboratory (PMEL) has begun several new moored buoy experiments in the North Pacific. These include: two enhanced surface meteorological and upper ocean moorings near Ocean Weather Station PAPA and in the North Pacific subtropical gyre (as participation in the National Ocean Partnership Program); Tsunami real-time reporting moorings; and an Ocean-Systems for Chemical, Optical, and Physical Experiments (O-SCOPE) mooring at PAPA (also within NOPP). The NOPP met/ocean buoys were designed for high-latitude climate studies and to provide surface meteorological and subsurface oceanographic data in a data-sparse region. A first met/ocean buoy was deployed in fall 1998 near PAPA and recovered in summer 1999. Two moorings were deployed in fall 1999; one at station PAPA and a second in the subtropical gyre near 35°N, 165°W. The PMEL Tsunami Program seeks to mitigate tsunami hazards to Hawaii, California, Oregon, Washington and Alaska with real-time reporting of bottom pressure. Three Tsunami moorings with real-time data telemetry were deployed in the Gulf of Alaska in fall 1999. An array of six Tsunami moorings will be in place in the year 2000. The O-SCOPE mooring was deployed in fall 1999 at station PAPA and is instrumented with interdisciplinary sensor suites (e.g., pCO2 sensors, nitrate analyzers, and spectral optical sensors) to quantify seasonal and interannual changes in upper ocean biogeochemical and bio-optical variability and carbon fluxes.

Introduction

Three individual research projects at PMEL have drawn upon a common pool of mooring design, hardware and electronics in order to more efficiently pursue their research goals. Six taut-line surface moorings, designed and integrated by PMEL's Engineering Development Division (EDD), were deployed in fall 1999 from the NOAA Ship Ron Brown in the subtropical Pacific and Gulf of Alaska (Figure 1). All shared the same mooring hardware, basic surface meteorological sensors, and GOES telemetry systems, but differed in their suite of other surface and subsurface sensors (Table 1). The research aims of the three projects are 1) weather and climate studies, 2) Tsunami warning, and 3) real-time interdisciplinary (chemical, bio-optical, and physical) long-term ocean-atmosphere monitoring. All moorings were designed for a nominal 1-year deployment period.

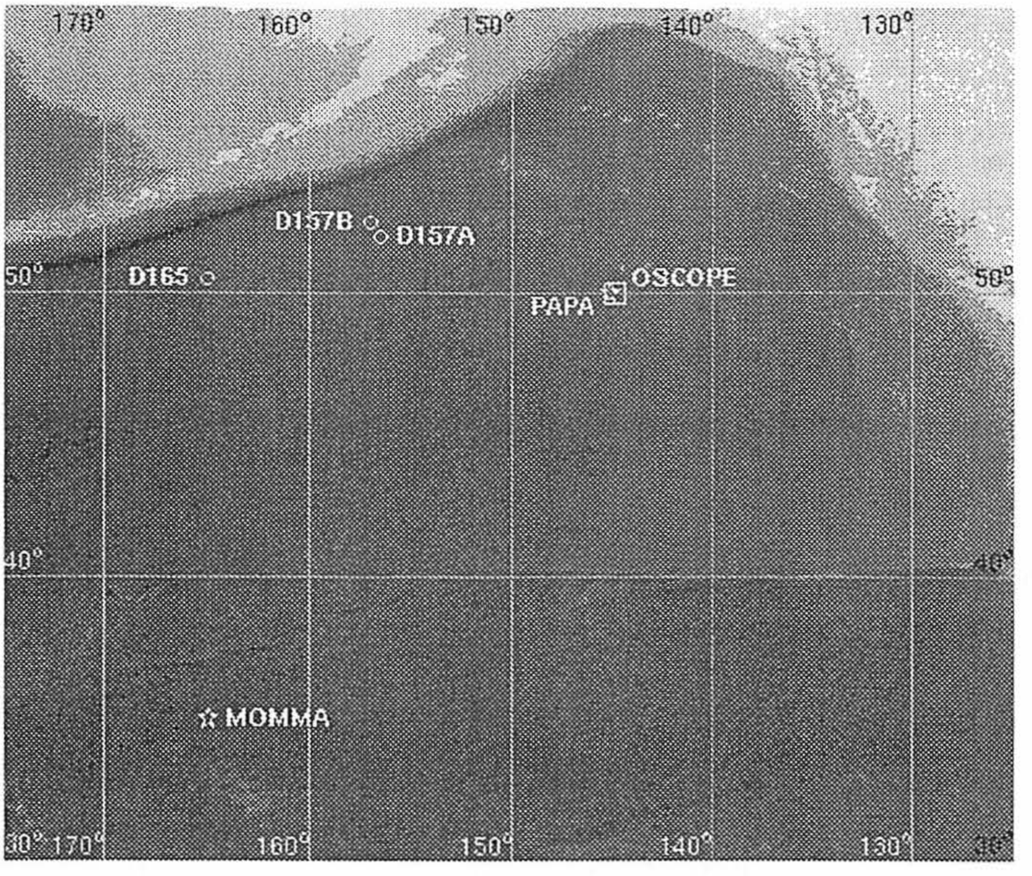

Figure 1. Location of six PMEL moorings deployed in the North Pacific in fall 1999.

Mooring Name	MOMMA	PAPA	D165	D157A	D157B	OSCOPE
Location	34.98°N 164.91°W	49.98°N 145.06°W	50.53°N 164.93°W	52.08°N 156.65°W	52.65°N 156.93°W	50.03°N 144.88°W
Telemetry rate	3 hours	3 hours	1 hour	1 hour	1 hour	1 hour
Surface Sensors	Wind (2) Air Temp (2) RH (2) Water Temp Salinity Rain (2) SWR LWR BP	Wind (2) Air Temp (2) RH (2) Water Temp Salinity Rain (2) SWR LWR BP	Wind Air Temp RH Water Temp Salinity	Wind Air Temp RH Water Temp Salinity	Wind Air Temp RH Water Temp Salinity	Wind Air Temp RH Water Temp Salinity MCR PCO_2 PH Fluorometer Nitrate
Subsurface Sensors	Temp (17) Salinity (9)	Temp (17) Salinity (9)	Bottom Pressure (subsurface mooring)	Bottom Pressure (subsurface mooring)	Bottom Pressure (subsurface mooring)	MCR (2) Fluorometer (2) Nitrate

Table 1. Location, data telemetry rates and sensors on PMEL moorings in the North Pacific. RH = relative humidity, SWR = short-wave radiation, LWR = long-wave radiation, BP = barometric pressure, MCR = multichannel radiometer. Numbers in () are the number of a given sensor type deployed.

Weather and Climate Monitoring Moorings

Two moorings, one near Ocean Weather Station PAPA (50°N, 145°W) in the Gulf of Alaska and the other in the subtropical Pacific near 35°N, 165°W (given the name Mid-Ocean Moored Measurement Array, or MOMMA) are part of an effort of monitoring the North Pacific for improved ocean weather and climate forecasts, supported by the National Ocean Partnership Program. The moorings, modeled after ATLAS moorings which are deployed in the TAO Array (McPhaden, 1995), expand and enhance the available sensor suite (Figure 2) and widen the scope of suitable environmental conditions under which the moorings are used. Standard ATLAS measurements include wind speed and direction, air temperature, relative humidity, sea-surface and 10 subsurface water temperatures. Recent enhancements to ATLAS measurements include short-wave radiation, rainfall and salinity (Milburn, *et al.*, 1996). Additional surface measurements at moorings PAPA and MOMMA include barometric pressure and long-wave radiation. These measurements will soon be optional from ATLAS moorings as well. Given the harsher environmental conditions at moorings PAPA and MOMMA, most surface sensors have been duplicated.

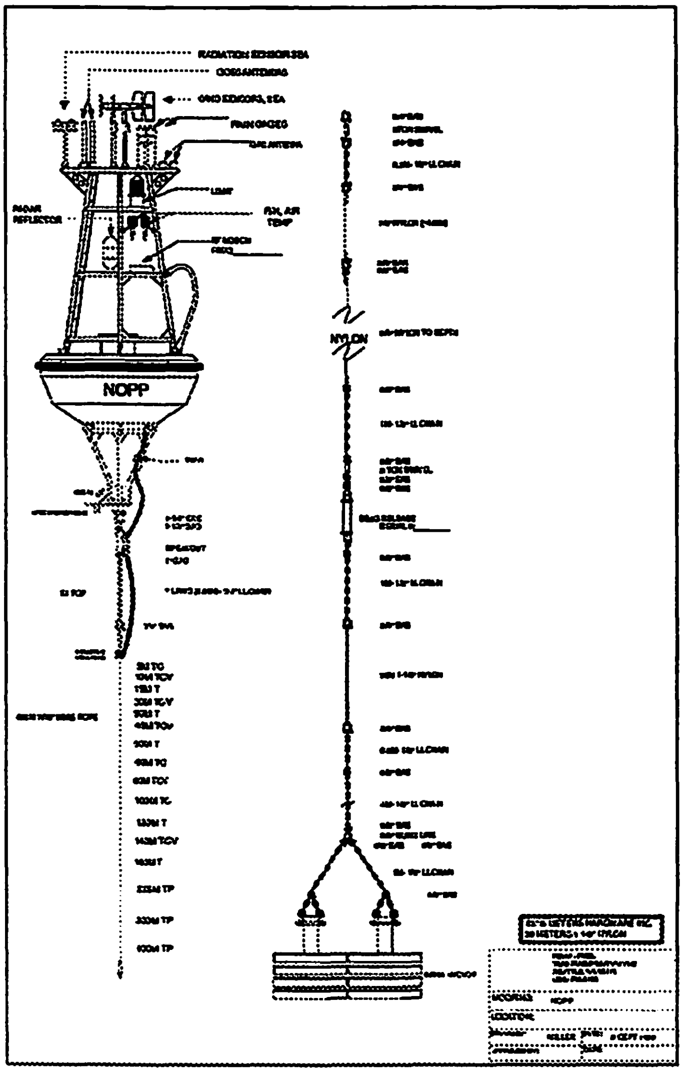

Figure 2: Schematic drawing of the met/ocean PAPA mooring.

With the increased bandwidth of GOES (compared to Service Argos, the method of TAO telemetry), telemetry rates for real-time data are increased from daily to 3-hour intervals (Figure 3), and subsurface measurements are increased from 10 to 17 depth levels. Most data sample at 10-min rates. Exceptions are rainfall (1-min), short- and long-wave radiation (2-min), and barometric pressure (1-hour). These data are stored in memory and available after the moorings are recovered. Data are monitored at PMEL and are available to other researchers or operational weather centers via ftp. Plans are also underway to submit the surface data onto the GTS (Global Telecommunications System).

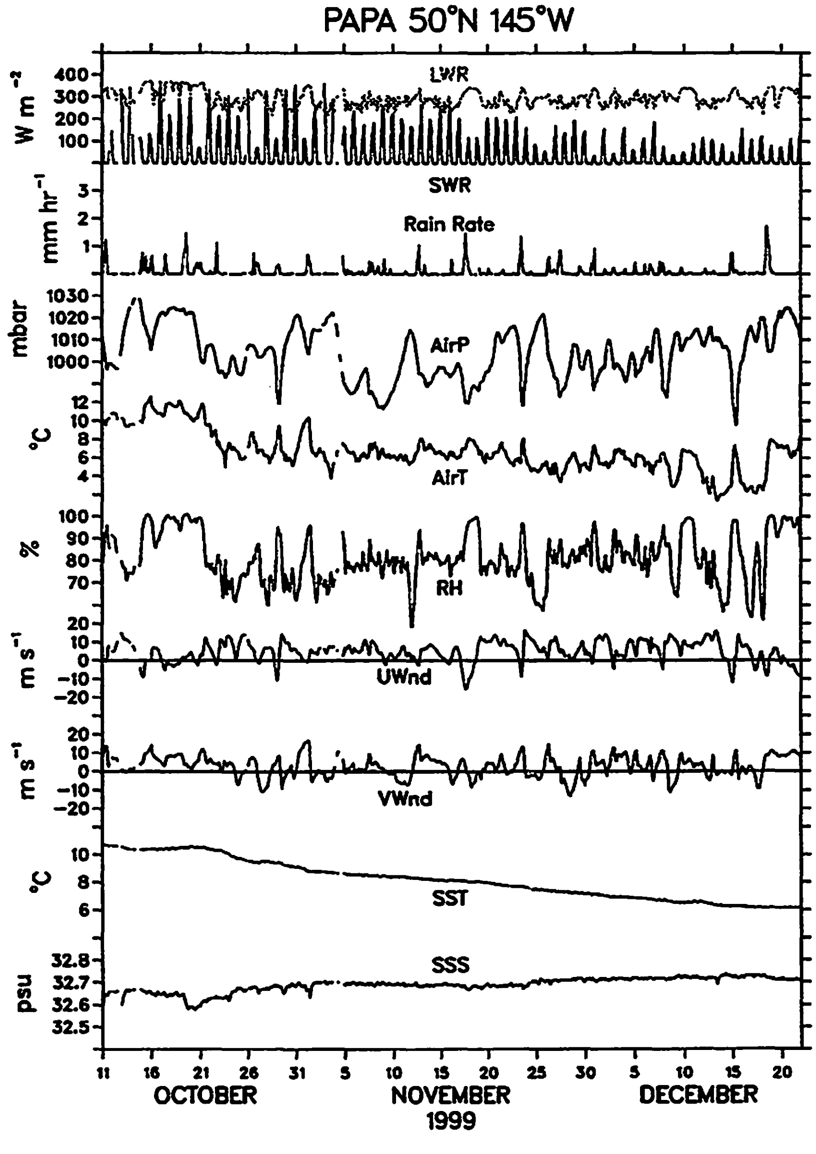

Figure 3. Example of 3-hour average data telemetered from mooring PAPA.

Tsunami Warning Moorings

Tsunami researchers at PMEL have deployed deep-ocean bottom pressure recorders in the northeast Pacific since 1986 and the data recorded have proven to be of high quality and have made significant contributions to the fundamental understanding of tsunamis (Eble and Gonzales, 1991). Recent developments in mooring technology have enabled the expansion of this program beyond a research effort by providing data for operational tsunami warning. The addition of an acoustic modem to the bottom pressure mooring has enabled the telemetry of data to a nearby surface mooring. The surface mooring, using the same mooring hardware as the PAPA and MOMMA moorings, forwards the data to shore via GOES (Figure 4). Three mooring systems were deployed near the Aleutian Trench in October 1999 (Figure 1). The array will be expanded to six systems with the addition of moorings off the Washington-Oregon Coast and within the TAO array in the eastern tropical Pacific.

Deep Ocean Assessment and Reporting of Tsunamis (DART)

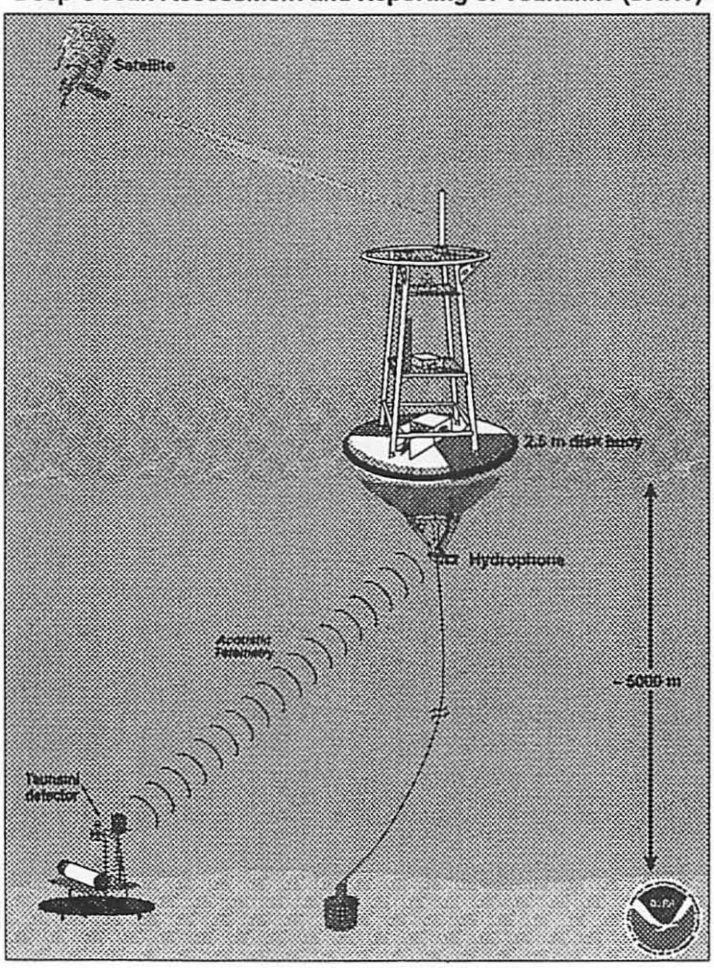

Figure 4. Schematic drawing of tsunami warning mooring system.

Pressure data are sampled and stored at 15-sec intervals. Under monitoring conditions, a subset of these data, sampled at 15-min intervals is transmitted to shore on an hourly basis. If an on-board processor detects a tsunami, 15-sec and 1-min data are transmitted for several hours during and after detection. Data are monitored at PMEL and are also available at the Pacific Tsunami Warning Center in Honolulu, Hawaii, and the West Coast and Alaska Tsunami Warning Center in Palmer, Alaska.

Similar to the PAPA and MOMMA moorings, the surface mooring of the tsunami warning system is also instrumented with meteorological sensors (wind speed and direction, air temperature, relative humidity, barometric pressure), and sea surface temperature and salinity sensors. As meteorological measurements are not the primary purpose of these moorings there is no duplication of met sensors. Meteorological data are transmitted hourly via a separate GOES transmitter and stored internally at 10-min intervals. Telemetered meteorological data are monitored at PMEL and are available to other researchers or operational weather centers via ftp. Plans are also underway to submit meteorological data onto the GTS.

O-SCOPE Mooring

The sixth mooring to be deployed in October 1999 was the O-SCOPE mooring which was deployed near the PAPA site (Figure 1). The mooring hardware was similar to that of the other 5 moorings, but the suite of surface and near-surface instrumentation deployed was designed for the monitoring of biogeochemical and bio-optical processes. In addition to PMEL, institutions involved with the project included the University of California at Santa Barbara, the Atlantic Oceanographic and Meteorological Laboratory, the Monterey Bay Aquarium Research Institute (MBARI), the Bermuda Biological Station for Research, Inc., the University of South Florida, and Western Environmental Technology Laboratories, Inc. Instrumentation on the mooring includes pCO2 and pH sensors, nitrate analyzers, chlorophyll fluorometers, and spectral optical sensors, located at the surface and to a depth of 15 m. MBARI and PMEL have also collaborated in the addition of similar instrumentation onto two moorings within the TAO Array (Chavez, *et al.*, 1999). O-SCOPE data are telemetered in real time via GOES. Data are processed and monitored by the institution responsible for individual sensor types and available on the World Wide Web from PMEL.

Similar to the tsunami moorings, the O-SCOPE mooring is also instrumented with meteorological sensors, sea surface temperature and salinity sensors. Meteorological data are transmitted hourly via a separate GOES transmitter. Telemetered meteorological data are monitored at PMEL and are available to other researchers or operational weather centers via ftp and will be included in future submissions to the GTS.

Summary

Six moorings were designed, constructed and deployed by PMEL for 3 individual research projects. Using a unified approach for mooring hardware, sensor integration, onboard data processing and telemetry, the cost of design and construction were decreased for each project. Having a commonality between systems also standardized the methods of mooring deployment, making better use of ship time. In addition to project specific sensors, all mooring systems have a common suite of meteorological sensors, which provide a unified source of data in a region of fairly sparse data availability. This method of using a common mooring design serves as a good model for decreasing the cost in time, dollars and personnel for research projects that require moored buoy systems.

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Ice drift and meteorological observations in the Antarctic sea ice zone: the International Programme for Antarctic Buoys (IPAB).

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The WCRP/International Programme for Antarctic Buoys (IPAB), an Action Group of DBCP, is a consortium of 18 agencies and institutions with interests in near-surface meteorology and oceanography in the Antarctic and Southern Ocean. It seeks to develop and maintain an observational network of drifter buoys and other appropriate data collection systems south of 55°S, a region within the maximum Antarctic seasonal sea-ice extent.

The majority of IPAB buoy deployments are made to support specific research programs, rather than as part of operational networks, and much of this research is concerned with the movement of Antarctic sea ice. The drift and deformation of the ice, not just thermodynamic processes, determine the thickness and other characteristics of the ice cover which control air-sea interaction at high latitude.

A number of specialised platforms and techniques are used by IPAB members to both suit the environment, and to provide high-resolution ice deformation data. Compilations of IPAB data have provided new insight to the pattern and variability of Antarctic sea ice drift.

Further applications of the IPAB data will be illustrated with results from a recently completed winter research cruise to the Mertz Glacier Polynya. This polynya, an area of open ocean on the Antarctic coast at 145°E, is an area of high sea ice production and export, and is believed to be an important source region for Antarctic Bottom Water.

Dr Ian Allison
Voyage Leader: RSV Aurora Australis, Voyage 1 1999/00
"The Mertz Glacier Polynya Experiment" 66.5S, 143E

Find out about our program at http://www.antdiv.gov.au

A NOVEL ANTARCTIC ICE BUOY

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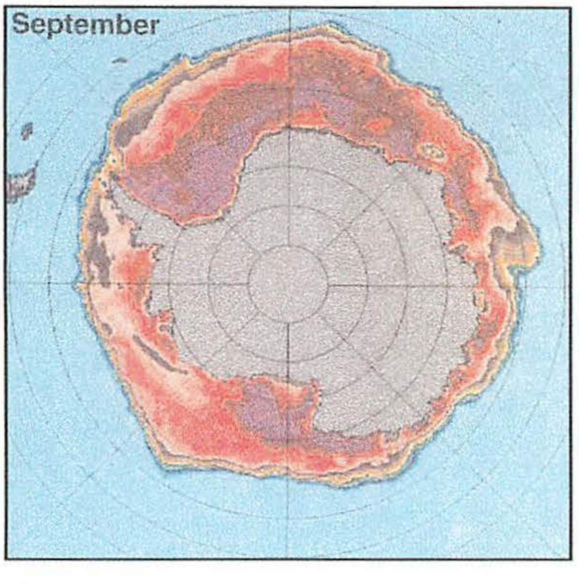
INTRODUCTION

The seasonal variability of the sea ice cover around the Antarctic is one of the most climatically important features of the southern hemisphere and probably the most sensitive to climate change. Yet the processes by which the ice forms, especially in the outer part of the pack, are not well understood. In a NERC funded project, CCMS-DML and the University of Cambridge Scott Polar Research Institute are developing a suite of novel drifting buoys which will be used to clarify the processes involved in the deformation, seasonal variability and dynamics of sea ice in this region. Initial deployments will be made from the RV *Polarstern* at the onset of the year 2000 austral winter. The drifters, especially designed to mimic the characteristics of young 'pancake' ice, will use both the Orbcomm and Argos satellite systems to transmit GPS location data, meteorological observations and wave spectra back to the UK. Through an important collaboration with the UK Meteorological Office, a subset of the observations from this notoriously data-sparse area will be made available to the global weather forecasting community in near real time via the GTS.

RATIONALE

Sea ice influences the Earth's climate in many ways: its high albedo affects the planet's heat budget; its thermal insulation controls heat and mass fluxes between the atmosphere and the polar oceans, and its role in destabilising the water column through brine rejection may drive deep convection. In addition, variations in the seasonal pattern of sea ice distribution are likely to be sensitive indicators of changes in the heat content of the upper ocean, itself a key marker for climatic change (Wadhams, 1991). The area of the planet's surface involved is enormous: the sea ice extent in the Antarctic alone varies from a minimum of 4×10^6 km^2 at the end of summer to a maximum of 19×10^6 km^2 in winter (Figure 1, Gloersen *et al*, 1992). However, the processes governing ice formation, especially in the outer part of



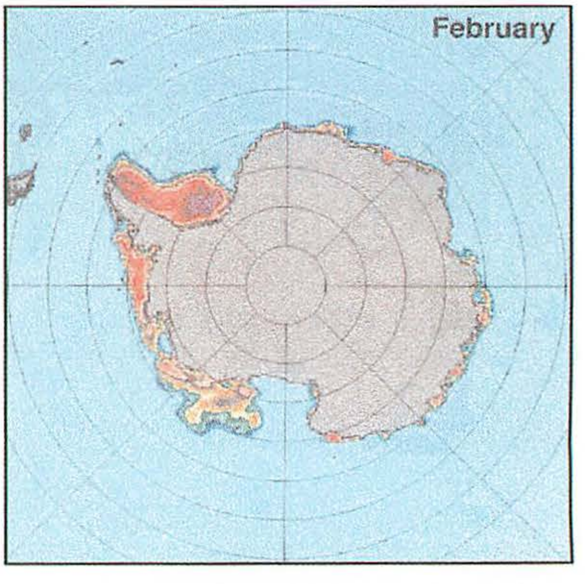


Figure 1. *Passive microwave images of maximum and minimum sea ice extent around Antarctica in 1987 from NASA's Nimbus-7 satellite.*

the pack, are not well understood. Moreover, young ice is not well imaged by satellites, thus placing increased reliance on *in situ* studies such as ours.

In our study, called StiMPI (Short Timescale Motion of Pancake Ice) we will deploy an array of drifters in the Antarctic marginal ice zone (MIZ) during the period of ice formation. The array is designed to measure the deformation of the young ice pack and its response to wind forcing and wave action, thus giving an insight into the mechanisms of sea ice growth, and the likely impact on regional heat and mass fluxes. Using techniques previously developed during the NERC Land-Ocean Interaction Study (Meldrum 1997, 1999), GPS locations will used to yield highly accurate relative displacements and velocities (Figures 2 and 3).

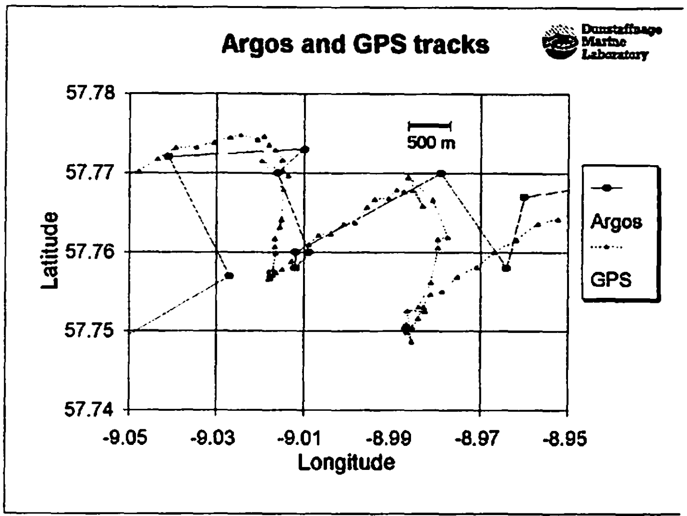


Figure 2. *A comparison between Argos and GPS locations for one of the LOIS drifters. The increased resolution of the GPS locations in both space and time leads to a much better description of mesoscale features.*

A totally independent meteorological package, complete with its own batteries and Argos satellite transmitter, will transmit weather data. These data will be disseminated globally in near real time for use by national meteorological centres. In this respect, the deployment is particularly timely in view of the transition of GCOS and GOOS to their operational phases, and the need for national commitments towards these global programmes and their aims (Ryder, 1998). Data distribution will continue after the drifters have left the ice, entering the Antarctic Circumpolar Current and the open waters of the Southern Ocean (Figure 4).

SEA ICE FORMATION

The general mechanism of Antarctic sea ice formation is as follows. At the approach of austral winter, from March onwards, the sea surface cools and freezing begins seaward of the existing summer ice edge. However, the high turbulence levels in the rough Southern Ocean cause the ice to form as a suspension of small unconsolidated crystals, called frazil or grease ice, which cannot congeal to form a coherent young ice sheet. Cyclic compression in the ocean wave field causes the frazil, as it grows

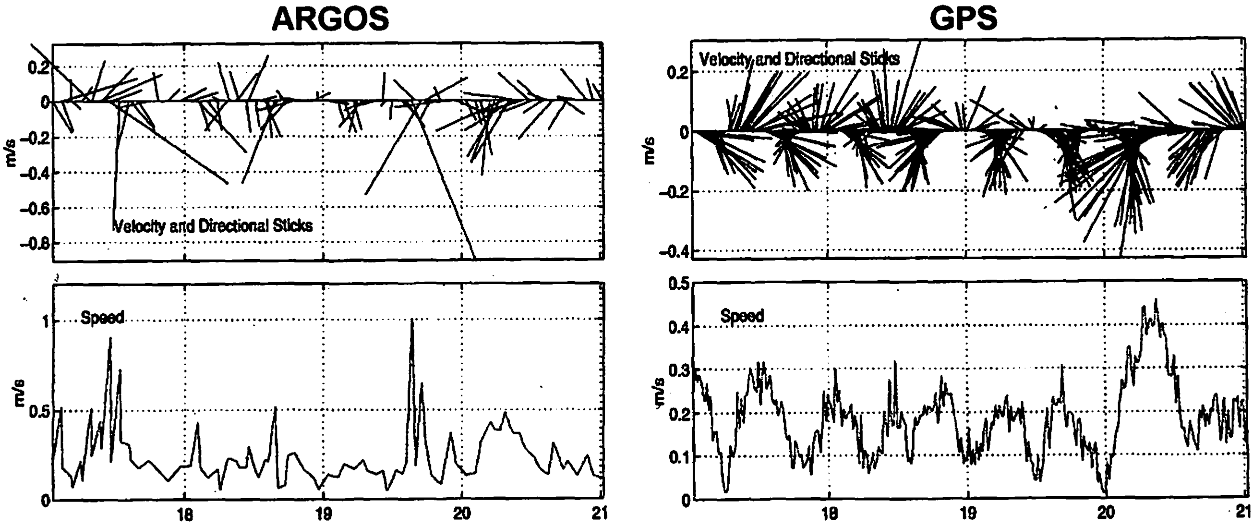


Figure 3. *A comparison between Argos-derived and GPS-derived velocities. The increased resolution and accuracy of GPS locations leads to a much better velocity signal. Post processing of the GPS locations to remove errors associated with Selective Availability will yield a further order of magnitude improvement.*

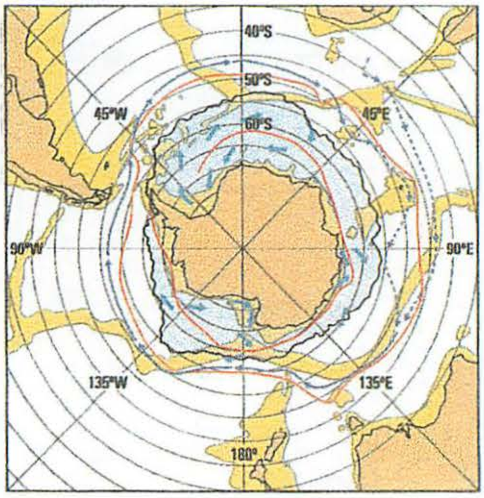


Figure 4. The principal currents in the Southern Ocean, showing the eastward flowing ACC.

Figure 5. Pancake ice in a young icefield. The raised edges are caused by repeated collisions between cakes of frazil ice.

denser, to clump together into small cakes, which acquire raised rims from the pumping of frazil on to their edges during further collisions. This is pancake ice (Figure 5). Initially the cakes are only a few cm in diameter, but grow in size and thickness with distance from the ice edge, until they reach 3-5 m in diameter and a thickness of 50 cm (Wadhams, 1991). As the penetrating wave field moves through this ice edge pancake zone it gradually loses energy, but (in the case of the Weddell Sea) only after some 270 km are the waves damped enough to allow the pancakes to freeze together to form a continuous ice sheet (Wadhams *et al*, 1987). This process of ice sheet formation is called the frazil-pancake cycle (Lange *et al*, 1989) and is responsible for a significant percentage of ice production in the Antarctic. The pack expands until September-October, followed by retreat and break-up due to warmer temperatures and the effects of the wave field.

USE OF SATELLITE TECHNOLOGY

The ice drifters will use three different satellite systems for position determination, data telemetry and control. Two of the systems (Argos and GPS) are well proven, but the third system (Orbcomm) is relatively new and untested. The experiment has therefore been designed to collect as much operational data as possible using the Orbcomm system so that our experience will allow a detailed assessment of its potential for data collection from remote locations.

Argos

The Argos system, carried on board the NOAA weather-imaging satellites, has been the system of choice for low-power environmental data collection and position tracking for more than 20 years. However, the prime purpose of the NOAA polar-orbiting satellites is to collect daytime imagery of the earth and its weather systems, and the orbits of the spacecraft are arranged to image a swath on either side of a given point on the earth's surface at roughly the same local solar times each day. The general picture can be seen in Figure 6, which shows every pass of the two operational NOAA satellites that would have been seen by a drifter at 57°N during September 1995.

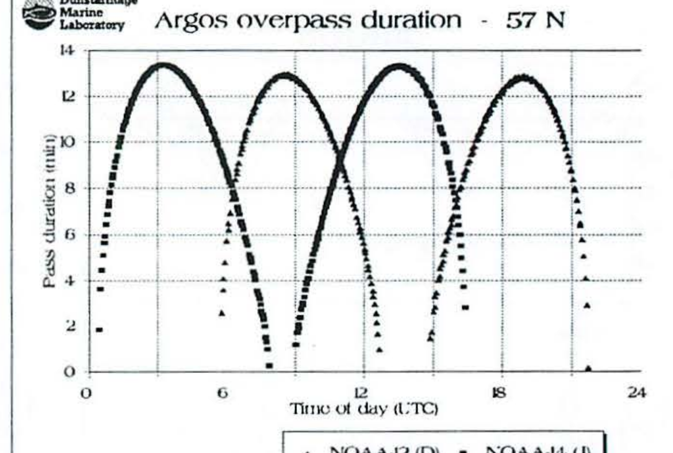


Figure 6. Pass durations at latitude 57° for the two NOAA satellites used by the Argos system in 1995, as a function of local mean time. The several-hour gap around local midnight can be troublesome.

An important feature of the graph, and one of concern to many users of Argos, is the several hour gap in coverage around midnight local time, a direct consequence of the orbital configuration described above. An experiment that aims to recover an uninterrupted time series must therefore ensure that a sufficiently large stack of historical data is transmitted to bridge the largest expected gap in the satellite coverage. The situation is worst at the equator but improves for experiments lying closer to the poles because of the convergence of the sub-satellite tracks of polar orbiters at high latitudes.

Data collection rates are also limited, with a maximum message length of 32 bytes. At the present time, message acknowledgement is not possible with Argos, which means that the user must ensure that sufficient redundancy is built into his data stream to cope with coverage gaps and transmission errors. This limits practical data throughput to about 1 kbyte per day. Significant enhancements to the system are planned which will allow a proper data acknowledgement protocol and increased data rates.

Given a favourable overpass, Argos can also compute platform locations using Doppler measurements combined with accurate satellite orbitography. In practical terms, km-scale location accuracies are achieved, which is perfectly adequate for many purposes, though not for the deformation and dynamics experiment described here. A major advantage of Argos compared to other systems is that its frequency allocation (401.65 MHz) is in a particularly clean part of the spectrum, allowing the use of low power transmitters (0.1W) by animal trackers and the like. The system also offers true global coverage.

GPS

The Global Positioning System (GPS) is a US-operated military satellite navigation system, implemented using a constellation of 24 or more satellites in high orbit to ensure global operability round the clock. The GPS user equipment is passive - unlike Argos it does not transmit. Range from each satellite in view is estimated by measuring the transit time of signals broadcast by the satellites. Ranges thus determined are called pseudo-ranges as the receiver's clock is not initially synchronised to the satellites' clocks. The receiver computes the position of each satellite using a set of orbital parameters (the ephemeris) contained in the broadcast signal, and thus is able to infer its own position. A 2-dimensional solution (latitude, longitude and time) requires ranging to three satellites. The system is currently operated by the US Departments of Defense and Transportation; the former exercising the right to degrade the accuracy available to civilian users by introducing errors into the satellite clocks, the broadcast ephemeris, or both. Full accuracy denial is termed Selective Availability (SA), and currently increases the 2-σ error in computed GPS locations from a few metres to about 100 m. In our application, these errors will largely be removed by differential post-processing techniques (Figure 7). For a fuller description of GPS see, for example, Daly (1993).

Orbcomm

The functionality of this satellite messaging system is similar to Argos, but with much higher data rates (2400 bps) and built-in two-way communication. Satellites consist of discs about one metre in diameter prior to deployment of solar panels and antenna. Satellites are usually launched in batches of eight using a Pegasus rocket piggy-backed on to a Lockheed L-1011 aircraft. After a prolonged period of launcher problems, the last two years have seen considerable progress, with 35 satellites now in orbit.

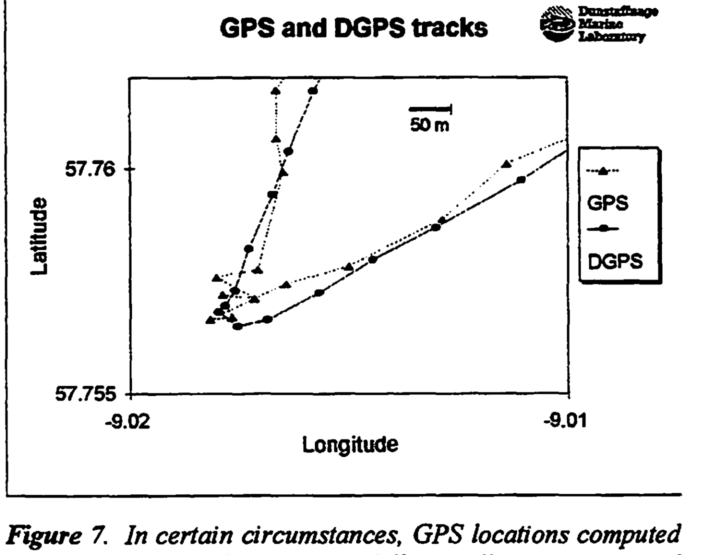


Figure 7. In certain circumstances, GPS locations computed by on board a drifter may be differentially post processed (DGPS) to remove the main error terms. Location and velocity accuracies typically increase by an order of magnitude.

Of these, 24 are operational, with another 7 likely to come on line soon. Most orbit planes are at 45° inclination and therefore have no coverage at polar latitudes: only three satellites, in the F and G planes (~70°), offer a near-polar service (Figure 8). An equatorial plane launch is scheduled in 2000 to improve the coverage in the tropics. No plans have been announced for further near-polar orbit launches, although the company is licensed for 16 satellites in these planes.

The system offers both bent-pipe and store-and-forward two-way messaging capabilities, operating in the VHF (138-150 MHz) band. Although there have been significant problems with interference close to urban areas, this is not expected to impact offshore operations, and some early trials of the system have been encouraging. The message structure currently consists of packets transmitted at 2400 bps, and coverage will be global, and near-continuous at lower latitudes when the full constellation is in place. Messages are acknowledged by the system when correctly received. The platform position is determined, if required, using propagation delay data and doppler shift, or by an on-board GPS receiver. Position accuracy without GPS is expected to be similar to that offered by Argos.

The limitations on the store-and-forward mode messages (known as globalgrams) are beginning to become apparent, with platform-originated messages limited to 229 bytes and platform-terminated messages limited to 182 bytes. Each platform is allowed to send a maximum of 16 globalgrams to a satellite in one pass. It is also thought that some satellites may not be fully enabled for store and forward operation. As our experiment will depend on sending and receiving globalgrams through the three polar orbiters, we have been conducting extensive trials of this mode of operation in order to build confidence. Such trials are not easy to perform as the satellites will only operate in globalgram mode when out of sight of a ground station.

The ground segment has started to expand, and there are now active stations in Italy, Argentina, Brazil, Japan and Korea in addition to the four in the US. Further stations are under construction in Malaysia, Morocco, and Brazil, and potential sites have been identified in Russia, Ukraine, Philippines, Botswana, Australia and Oman. 16 international service distribution partners have been licensed. Non-US

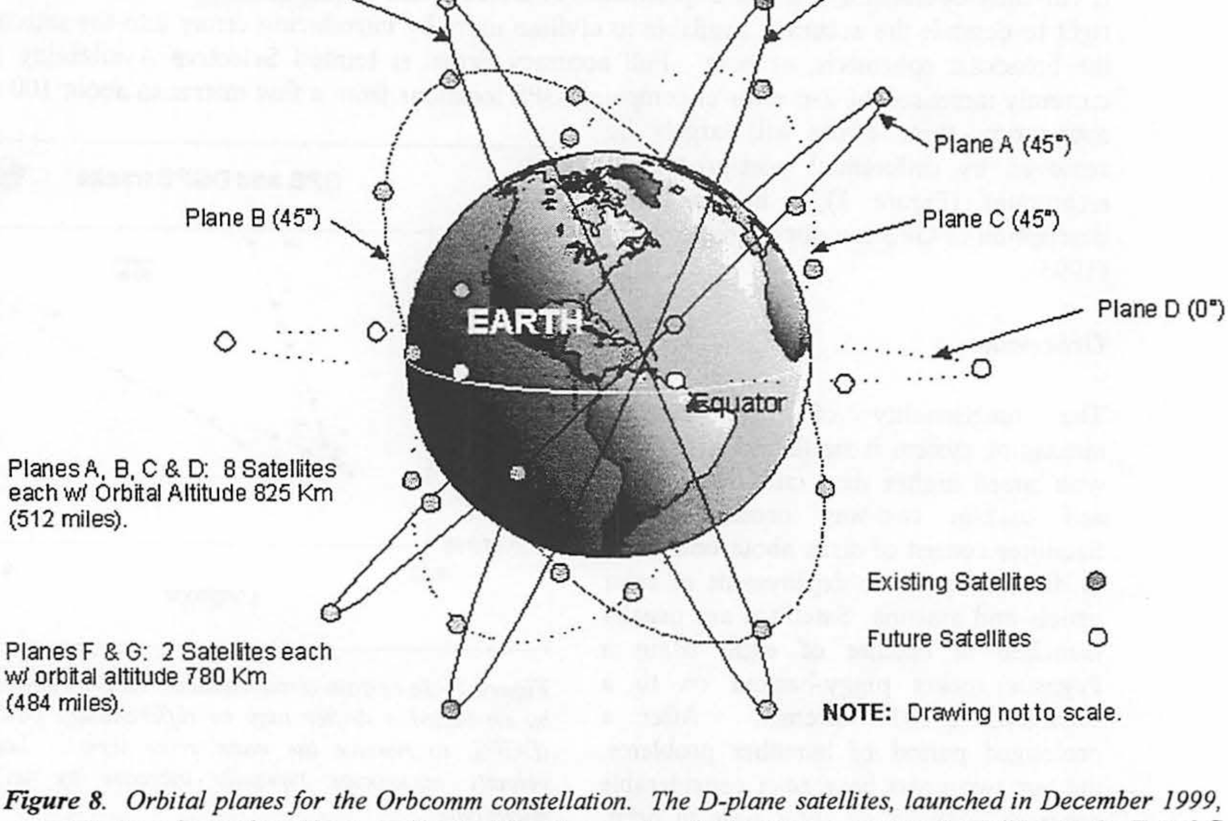


Figure 8. *Orbital planes for the Orbcomm constellation. The D-plane satellites, launched in December 1999, appear to have been placed in an inclined orbit. At present, only the three operational satellites in the F and G planes give polar coverage.*

customers have faced difficulties because of the absence of ground stations, lack of spectrum licensing and the presence of other in-band users. However the situation is improving rapidly. Many operational details, and the costs of using the system, which will mainly be available to users through resellers, are only now starting to become known.

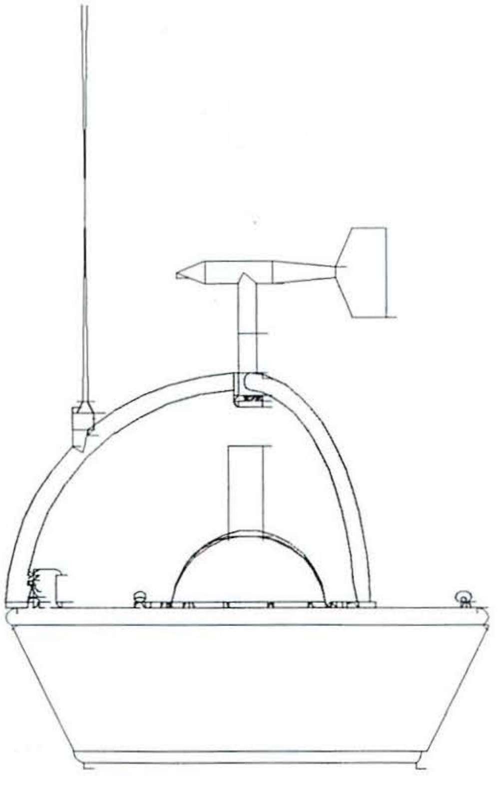
ICE DRIFTER DESIGN

Hulls

The buoy is designed to mimic as closely as practicable the properties of the pancakes being studied. DML and SPRI have already built such a buoy in fibreglass for the Odden region of the Greenland Sea (Meldrum, 1998). Ice conditions in the Antarctic, however, demand a rather different approach since, unlike the Odden, Antarctic pancakes consolidate into large ice sheets that exert a much greater force on the buoy. The design must withstand repeated impacts with pancakes and larger floes, as well as static pressure from convergent ice conditions. The buoy is therefore fabricated from 3 mm thick stainless steel sheet, with sensors and antennae supported by a stainless steel tripod (Figure 9). The design also features sloping sides, allowing the buoy to rise up and avoid being crushed between ice floes.

Sensors

The sensor fit includes three Betatherm thermistors (narrow and wide range sea temperature, air temperature), a Motorola Oncore GPS receiver (position and time), a Crossbow gimballed vertical accelerometer (wave energy spectrum), a KVH fluxgate compass (buoy orientation) and an R M Young anemometer (wind speed and direction). Custom signal conditioning electronics interfaces the analogue sensors to the processor module. Meteorological data (atmospheric pressure and sea surface temperature) are collected and transmitted by an entirely independent package consisting of a standard Metocean WOCE SVP-B drifter hull embedded in a well in the main hull. This has the appealing advantage of minimum engineering effort coupled to a high expectation of data integrity.



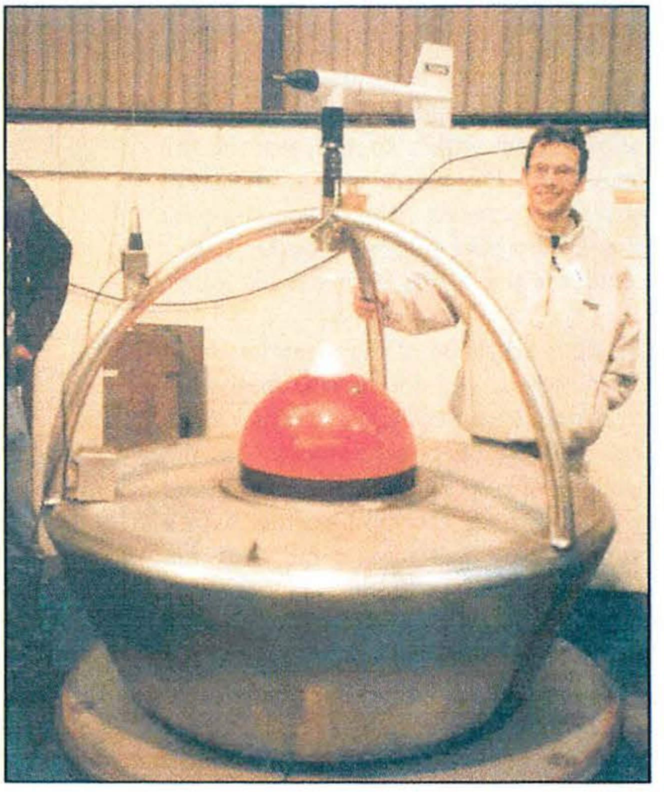


Figure 9. *The ice buoy during construction. Overall diameter is 1.25 m. The main electronics package lies below the central SVP-B meteorological sphere. Sensor and antenna cables will run inside the tripod legs.*

Processor

The Persistor CF1 processor has been chosen because of its computing power, low energy requirements, ease of programming and flexibility as regards memory and interfacing. It is also available in an extended temperature version suitable for use during the polar winter. In addition to sampling the various sensors in appropriate ways, the processor computes the wave spectrum, formats the data, constructs the message stack and controls the Orbcomm transceiver. It is also designed to alter sampling strategy according to latitude, and to respond to a simple set of external commands received from the user over the Orbcomm link.

Communications

The embedded meteorological package will use the Argos system for data transmission. This will allow Argos positions to be used as a fallback in the event of total failure of the GPS subsystem. In recognition of the importance to the operational weather forecasting community of timely atmospheric pressure observations from this notoriously data-sparse area, the meteorological data stream will be inserted on to the World Meteorological Organization's Global Telecommunication System (GTS) by the Argos processing centre at Toulouse.

Orbcomm globalgrams will be used for all other data and command strings. Sensor and status data will be formatted as two globalgrams every three hours. In order to assure correct reception of the data, and to test data throughput and latency for various paths through the Orbcomm ground segment, replicate messages will be interleaved in the message stack and addressed to each of the three Gateway Control Centers in the US, Brazil and Italy.

DEPLOYMENT STRATEGY

A set of six buoys has been built. These will be deployed from the RV *Polarstern* (Figure 10) in the eastern Weddell Sea during her ANT-XVII/3 cruise in April-May 2000. She will be working off Cape Norvegia and will then sail west, following the MIZ, to the east of the Peninsula. The buoys will be deployed during this transect. Space and shiptime have kindly been allocated by Dr Dieter Fütterer of the Alfred Wegener Institute.

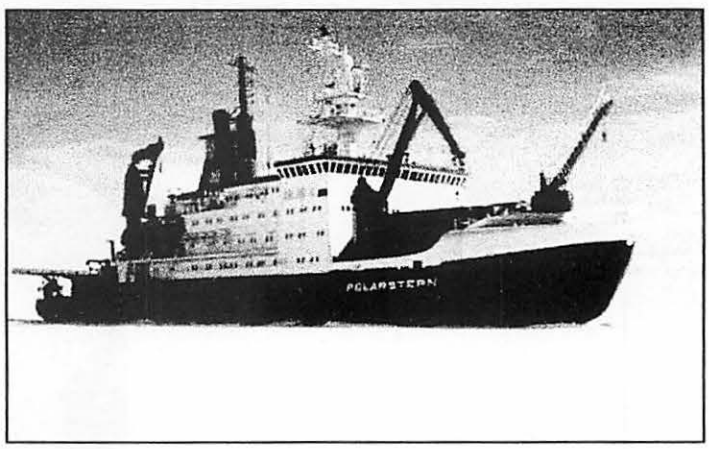


Figure 10. *The RV Polarstern, from which the ice buoys will be deployed in April 2000.*

The planned shape of the array has been found most useful for several mesoscale ice dynamics experiments in other MIZs (e.g. the MIZEX experiments in the Arctic, 1983-9), and consists of a group of 5 buoys on a 150 km baseline, with a further buoy displaced some 800 km along the ice edge (Figure 11). The two outermost buoys will be placed within 50 km of the outer ice edge, in loose pancake. The two innermost buoys will also probably be in pancake ice at the time of deployment, but as winter progresses and the ice edge advances faster than the buoys, each buoy in turn will become embedded in a consolidated

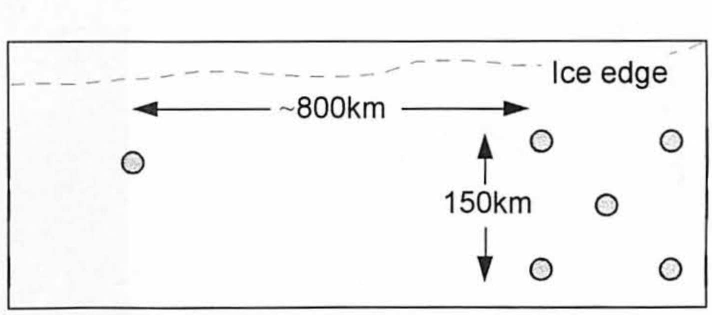


Figure 11. *A sketch of the buoy deployment strategy. The 5-element array will yield the differential parameters of the motion field; the isolated buoy will give an estimate of the lateral coherence scale.*

first-year ice cover, with a resulting change in the nature of the ice dynamics: a reduction in high-frequency energy and transition from free-drift to dynamics with internal friction. The 5-element array will enable differential kinematic parameters (DKPs) for the motion field to be generated (Wadhams *et al*, 1989), with the isolated buoy giving a measure of the scale of coherence in ice motion along the ice edge. The individual triangles in the 5-element array give separate DKP estimates for each of the four regions of the array.

During the deployment period the SPRI/DML personnel on board will carry out an intensive programme of ice physics measurements in collaboration with the AWI personnel. These data will provide a baseline characterisation of pancake and consolidated zones that can be related to the parameters obtained from later array measurements. Measurements will include profiling of temperature, salinity and fabric from ice cores. Oxygen-18 concentrations will be taken to determine the meteoric ice content (Eicken *et al*, 1994) through the ice and overlying snow layer. In the pancake zone, larger pancakes will be examined in the same way where safe, while smaller pancakes will be lifted on board and analysed on deck, as done in the Greenland Sea by SPRI/DML during a March 1997 cruise as part of the European ESOP programme.

Survival of the buoys in open water after ice retreat offers some limited possibility for retrieval, since there is a large number of research and supply ships operating in the Weddell Sea sector in summer. However, the intention is to allow the buoys to continue into the Southern Ocean as operational meteorological and wave climate drifters, with data distribution via the GTS.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the UK Natural Environment Research Council in funding this experiment through research grant GR3/12592, the UK Meteorological Office for material assistance in procuring and operating the SVP-B meteorological packages, the Alfred Wegener Institute, Bremerhaven, for logistical support aboard the RV *Polarstern*, and the UK Defence Evaluation and Research Agency for the loan of shipboard oceanographic equipment.

ABBREVIATIONS AND ACRONYMS

ACC	Antarctic Circumpolar Current
AWI	Alfred Wegener Institute
CCMS	Centre for Coastal and Marine Sciences
DML	Dunstaffnage Marine Laboratory
DKP	Differential Kinetic Parameters
ESOP	European Subpolar Ocean Programme
GCOS	Global Climate Observing System
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GTS	Global Telecommunication System
LOIS	Land-Ocean Interaction Study
NERC	Natural Environment Research Council
MIZ(EX)	Marginal Ice Zone (Experiment)
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
SPRI	Scott Polar Research Institute
STiMPI	Short Timescale Motion of Pancake Ice
SVP	Surface Velocity Programme
VHF	Very High Frequency
WOCE	World Ocean Circulation Experiment

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The Use of Autonomous Solar Electric Research Vessels to Obtain Oceanographic Data

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Abstract: This paper evaluates the potential for gathering oceanographic environmental and climate data from ocean going autonomous solar powered research vessels.

It outlines the requirement for a command and control centre and discusses the opportunities for data gathering made available by this technology.

BACKGROUND:

Scientific data is required about atmospheric and ocean conditions for many purposes. These may include such things as:

(1) Met Service information
(2) Oceanographic information
(3) Fisheries support
(4) Security
(5) Oil exploration

There are several problems associated with gathering data from the surface of the oceans.

These may include:

(a) Obtaining the data from the required position on the ocean.

(b) Making measurements in a hostile environment.

(c) Transmitting the information back to a data processing facility on land.

(d) Reducing the costs associated with these experiments.

The technology in current use includes:

(a) Drifter buoys These are normally taken by a ship or dropped from an aircraft into the ocean close to a point of scientific interest. They often carry some form of drogue to limit their drift due to wind. (Drogues do not help if the drift is due to tidal stream or currents). They also ensure the buoy spends considerable time under water.

After a period the drifter buoy will drift away from the place of scientific interest to a place of non interest and may be recovered or more likely lost. Once the non-rechargeable batteries have run flat the chances of finding them again are remote. Because of power limitations drifter buoys do not carry navigation lights.

(b) Manned ships or aircraft are sometimes used to obtain data. These fall into two categories:

(i) A ship or aircraft on other business may assist data gathering in passing.

(ii) A dedicated manned research vessel may be used.

(c) Moored buoys may be used in relatively shallow coastal waters. However, as the average depth of the ocean is about 2 nautical miles, there are significant costs associated with using a large enough buoy to support a heavy enough chain for the moored buoy to stay moored in deep water.

A new tool has been developed at the Central Institute of Technology. It is a Solar Electric Research Vessel. It is an autonomous surface vessel. It uses the global positioning system to find its position but has an internal dead reckoning back up when satellite coverage fails. Solar panels provide all the electrical energy for instrumentation, control, and propulsion. Surplus solar energy obtained during the day is stored for use at night in sealed deep cycle lead acid batteries so the vessel can run day and night, at a typical cruising speed of 4 knots. On board energy management systems control daily energy consumption to match daily energy received from the sun. Most of the energy is consumed by the propulsion system so daily energy control is achieved by control of the propulsion system, which has both a rapid response loop to respond to rapid weather changes and a slow self learning loop. The self learning loop responds to changes in latitude weather patterns and seasons. An uninterruptible power supply will maintain all essential services in periods of adverse conditions. The vessel is self righting under all conditions and has been designed to be able to stay at sea for periods of up to a year, if necessary.

The idea is that the vessel can leave its home port under its own power and follow a programmed route to a waypoint. There it can use power to maintain station. The vessel uses a split rudder which it can either open to provide a drogue to limit the speed of drift from a waypoint, or close to enable to vessel to steer back to its station under power, should the GPS indicate that it has drifted off by more than a pre prescribed distance. When its work is completed at one station, it may proceed to a new station or may return to its home port for a refit.

It will be obvious from this that the vessel needs a remote Command and Control Centre. This is a shore based control with a 2-way communication link to the boat. It comprises two computers. One of the computers contains electronic charts of the area quilted together. The vessel's present position is marked on this computer. A second computer processes the data being transmitted form the boat. This data can include digital pictures taken by an on-board digital camera.

The third unit in the Command and Control Centre is a manual control panel to enable a shore-based operator to remotely move the vessel and get the vessel to carry out particular tests, gather data and eventually return to its home port or bay and anchor itself.

A single Command and Control Centre should be able to monitor several vessels.

The prototype vessel is running but this is only the start of the research programme. For it to be of use, it must be capable of meeting users' applications.

APPLICATIONS:

We have received a large number of applications from potential users. These applications are quite varied.

Met Services in NZ and overseas require surface data from the ocean. These include measurements of air temperature, water surface temperature, barometric pressure, wind speed and direction, wave height and direction, precipitation levels and pictures of the sky and ocean.

Oceanographers are interested in some of the above but also want salinity measurements, speed and direction of currents and tidal streams.

Security applications may include such things as digital cameras and remote guidance systems.

When assessing scallop beds for nutrients and toxins the biologists can require continuous grid search facilities in shallow water (30 metres) and measurements of salinity, temperature, turbidity, pressure and current flow at layered depths to produce a vertical profile of the sea. This necessitates the production of a winch with transducers on a pod to be lowered to the required depths. They also require the facility to collect water samples for analysis and a remote command and control centre.

Solutions

In each case the solution is not just in the production of a transducer and its electronics. The equipment must be able to make repeatable measurements within the required environment. For example, it is relatively simple to use a PT100 resistance thermometer and its electronics to measure air temperature to the required accuracy, but it is considerably harder to ensure the transducer is not being directly heated by the sun or local radiated heat and also is not having its readings contaminated with water temperature in rough weather.

The problem is to know whether the sampling errors due to external influences are insignificant. Where possible, parallel measurements can be made from a nearby manned vessel at the same time, preferably using different techniques. Which is fine if the answers are substantially the same, but when they are not, we have no means of knowing which is the correct answer. Meteorologists normally apply the "best guess" criteria to all data, ie. is it the answer they would expect, from historical data or data obtained from nearby transducers.

There is value in attempting to make the measurements in a different way to the existing methods. Take for example the measurement of speed and direction of ocean currents. The traditional method is to drop a drifter buoy with drogue attached into the ocean at a known place and time, and see how long it takes to drift to a new position. It is often assumed that either the effect of wind is negligible or the leeway made by the buoy is estimated from other data, preferably obtained using different techniques.

We drive the vessel at a constant water speed in a circle around a fixed waypoint. Say the circle is 0.32 nautical miles radius. We time how long it takes the vessel to complete the circle. The speed through the water is known. The path over the ground taken by the vessel is also known (by GPS and compass). The time taken to complete the circle is measured.

From geometry we can show:

$$\frac{2\pi R}{time \cdot for \cdot one \cdot revolution} = \sqrt{\beta^2 - (A\sin\phi)^2} - A\cos\phi$$

where

R = radius of the circle
P = velocity through the water
A = speed of current
ϕ = angle turned through

R and β are known and ϕ can be averaged over 360° by integration.

By solving the equation we have the magnitude of the current A. The course angle where maximum speed over the ground occurred is the direction of the current.

A similar technique is used to measure wind speed. Identical speakers at each end of the vessel alternatively transmit a tone to each other. The time taken for the sound to complete the journey from one speaker to the other is modified by the speed and direction of the wind. Digital signal processing removes the boat's speed in still air from the calculation.

By turning the boat through 360° and noting the maximum and minimum transmission times, both the speed and direction of the wind can be obtained. In addition, the vessel also has a vertical wind turbine with a fixed outer stator to mechanically measure wind speed. Wind direction is then obtained by application of the drogue so that the vessel points downwind and the wind direction is obtained by compass bearing.

A new method of measuring salinity has been devised. The transducer consists of an eight stage LR phase shift oscillator. The inductors are the leakage reactance of eight salt water cored transformers arranged round a nylon sphere and linked together with a laminated iron toroid. Differences in salinity cause the frequency of the LR oscillator to change: The change in frequency is measured and is a function of salinity.

Oil companies require specific worst case data about potential oil rig sites. They find the use of drifter buoys frustrating because the buoys drift the wrong way, are seldom in the required place and expensive because of high deployment and replacement costs. These costs consume about one third of their budget. They see considerable advantage in a vessel that can deploy itself maintain station and finally return to its home base by itself. They are particularly interested in wave height and wind speed measurement.

The illegal taking of fish from coastal waters is a worldwide problem and is causing depletion of fish stocks, sometimes to non recoverable levels. Some countries have installed high powered radar right round their coasts. They can see foreign fishing boats enter their zone. However, when a vessel or aircraft is deployed at considerable cost to investigate, the offending vessel sees them coming on their own radar. They stop fishing and are simply on innocent passage through the ocean. One advantage seen by fisheries protection of these solar electric research vessels is the fact that they are so small they can be lost in "sea clutter". They maintain station say 100 nautical miles offshore and can be remotely guided towards their target. Once there, they can take time place and date stamped digital pictures of illegal fishing operations and transmit these back to a shore base. The vessel also requires wave height, roll and pitch transducers so that pictures can be obtained from the top of waves when the vessel is horizontal.

The current status of the Solar Electric Research Vessel is a working prototype. A pre-production working model is well in hand. Because of the varied nature of applications for the vessel, it is proposed to produce standard vessels and to fit transducers and communication systems to suit individual customer requirements.

Communication with the vessel at present will remain application specific. Inshore applications such as scallop bed grid search work can be achieved with two way data links by normal cell phone.

For offshore work we look to satellite communications, or mobile satellite systems.

These fall into 3 groups:

GEO (Geostationary earth orbit)35,000 Km MEO (mid-altitude earth orbits) 10,000 Km LEO (low earth orbit) <1000 Km

The farthest away satellites have the largest footprints and require the greatest power to communicate with them.

The closest systems have the smallest footprint need the least power but many more satellites are needed.

The LEOs are divided into big LEOs and little LEOs. Little LEOs offer data only either on a real time direct readout (bent pipe) basis or as a store and forward service.

Big LEOs offer voice fax telex paging and data.

Commercial forces drive satellite deployment, many systems concentrate on land mass and do not offer true global coverage.

Argos is the most common system used for blue water data buoy communications, it is truly global. At present, it is only one way (ship to shore) and has limited bandwidth. It offers data processing facilities. There are plans to make this system 2-way and to increase the bandwidth. It also offers doppler position facilities.

Shortly we can expect to be able to use some of the systems under development. This may include ORBCOM, SAFIR, IRIDIUM, TELEDESK, ICD, INMARSAT D+.

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Development in Satellite Communication Systems

1.11 ARE MOORED BUOY WINDS TOO LOW IN HIGH SEAS?

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1. INTRODUCTION

Wind measurements from buoys operated by the National Data Buoy Center (NDBC) are used extensively by operational forecasters for real-time assessment of ocean conditions and model initialization. The research community relies on buoy winds for a wide variety of purposes such as climatology development, providing ground truth for remotely sensed observations, and numerical model validation. The accuracy of buoy observations is obviously an important consideration to both the operational and research communities, and studies addressing the issue have occasionally been conducted. Buoy measurements were found to be an excellent calibration reference for remotely sensed winds when used with the proper constraints (Gilhousen, 1987). Austin and Pierson (1999) showed that most of the scatter seen in comparisons of scatterometer and buoy winds are a result of mesoscale effects inherent in buoy wind averages. While such studies explore the variability of buoy wind measurements, not much information is available in terms of absolute accuracy.

A striking feature of the Comprehensive Ocean-Atmosphere Data Set (COADS) is that areas with moored buoys appear to have wind speed deficits greater than 2 m/s relative to areas dominated by ship observations (Woodruff and Lubker,1993). While these differences can largely be accounted for by such factors as the poor quality of ship observations and the relatively high placement of ship anemometers (Wilkerson and Earle,1990), it has been suggested that buoy winds may in fact be too low in relation to the "true wind." Thomas (1998) reported that many forecasters within Environment Canada, presumably assuming buoy winds to be low in high sea states, use peak instead of mean buoy wind speed in their marine wind analyses. Large et al. (1995) found buoy neutral stability equivalent 10-m wind speeds were systematically low in relation to numerically modeled wind field analyses and suggested the cause was wave distortion of the wind profile.

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The purpose of this study is to evaluate if wave height does indeed influence the accuracy of buoy wind speeds. To accomplish this, moored buoy wind speed measurements taken during periods of high sea states were compared with those of a nearby coastal site and with numerical model forecast winds.

2. BUOY-SHORE STATION COMPARISON

2.1 Data Set

The Coastal-Marine Automated Network (C-MAN) station, NWPO3, located on the Oregon Coast near Newport and the nearby moored buoy station, 46050, are uniquely situated to provide data for this study. The C-MAN station is low lying but well exposed to onshore winds. The site elevation is 9.1 m above sea level with an anemometer height 9.4 m above site elevation. Buoy 46050 is a 3-m hull with an anemometer height of 5 m above the water line, located 36 km due west of NWPO3. Each station is equipped with redundant R.M. Young propeller anemometers. The distance between stations is large but within limits recommended by Gilhousen (1987) for such comparisons and well within the windows typically used for comparisons of buoy and scatterometer winds. See, for example, Freilich and Dunbar (1999).

Concurrent hourly wind measurements were available from these stations over a 7-year period from 1991 through 1997. Hourly wind speeds of both stations represent scalar means sampled at 1 Hz. However, the length and time of data acquisition are different. The C-MAN station uses a 2-min acquisition period ending on the hour, while the buoy samples over an 8-min period that ends 10 min before the hour. The effects of these differences are likely to be small compared with those caused by spatial separation or orographic effects. To minimize such effects, concurrent measurements used in the study were confined to onshore winds, reported between 200 and 340 degrees by NWPO3 and within 20 degrees of those reported by 46050.

Buoy winds were adjusted to 10 m, assuming neutral stability since many observations were missing air or water temperature, and under high wind and sea conditions, the boundary layer would tend to be neutral in any case (Hsu, 1988). This also allowed for a direct comparison to the method proposed by Large et al. (1995) that accounts for wave height but neglects the effects of stability in high winds and seas. The method of adjusting wind speed to 10 m is just that proposed by Large et al. without the wave height correction. No adjustments were made to NWPO3 wind speeds.

2.2 Analysis

Figure 1 is a scatterplot of all concurrent observations meeting the criteria established for the study. Large markers represent sample averages of bins bounded by lines perpendicular to the 1:1 line at 3-m/s intervals. The scatter is broad about the 1:1 line, but bin averages show good agreement in the mean up to 15 m/s. Above that, buoy wind speeds tend to be less than the C-MAN station, showing a negative 10 percent bias at 20 m/s.

To determine if wave height influenced the results in any systematic way, C-MAN and 10-m buoy wind speed pairs were sorted by wave height and compared. Observation pairs were sorted by observed significant wave height, in 1-m increments, from 3 to 6 m. All observations with wave heights over 6 m were included in one grouping. If wave height is the primary factor contributing to low bias of buoy wind speeds seen in Figure 1, it ought to be apparent in comparisons of wind speeds observed at increasingly higher wave heights. This, however, is not the case. Bin averages of each wave height increment (Figure 2) are tightly grouped and close to the 1:1 line up to 15 m/s, not too different from bin averages of the total sample. At higher wind speeds, they scatter in haphazard fashion showing no relation to wave height. In fact, observation pairs with wave heights above 6 m show the least bias at high wind speeds, although this is likely just a result of small sample size at the higher wind speeds and wave heights. These results suggest that wave height is not a significant factor causing buoy winds to report low at wind speeds up to between 15 to 20 m/s or significant wave heights up to 6 or 7 m.

Large et al. (1995) found a similar but larger bias in comparisons of buoy wind speeds to European Center for Medium Range Weather Forecasts (ECMWF) wind field analyses. They suggested that the cause was failure to account for distortion of the wind profile by waves when adjusting observed buoy winds to 10 m. They proposed an adjustment method that includes the effects of waves, scaled by wave height, analogous to the commonly used stability correction. Their method was applied to the data set using buoy reported wave heights. The results are shown in Figure 3 along with those from Figure 1. Bin averages of the nonadjusted 5-m buoy winds are also included to show the degree of adjustment by each method. Little difference among bin averages is evident up to wind speeds of 10 m/s. Above this, nonadjusted buoy winds are light relative to the C-MAN station. When buoy winds are adjusted to 10 m, assuming neutral conditions, the relationship is closer. However, when winds are adjusted accounting for the effects of waves, buoy wind speeds are high by about as much as the normally adjusted wind speeds are low.

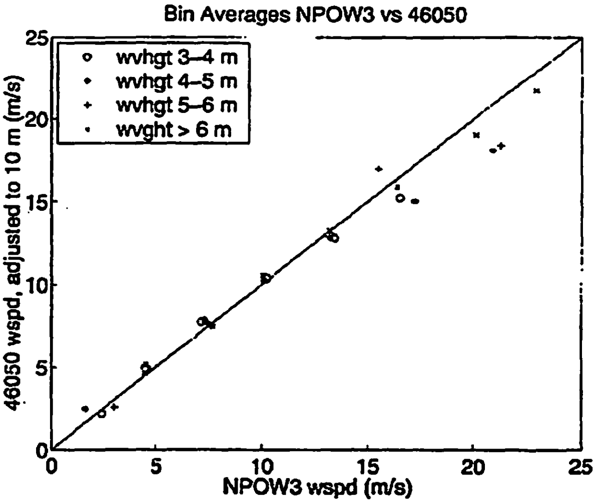

FIG. 2. Bin averages of NWPO3 vs. 46050 wind speeds sorted by significant wave height.

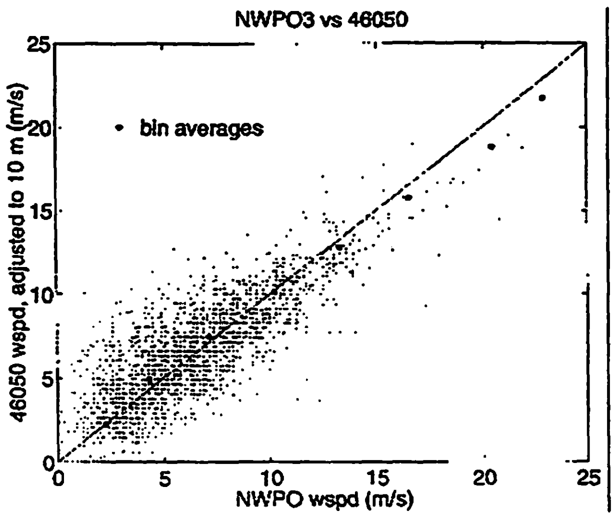

FIG. 1. Scatterplot of NWPO3 vs. 46050 wind speeds adjusted to 10 m with 3-m/s bin averages indicated.

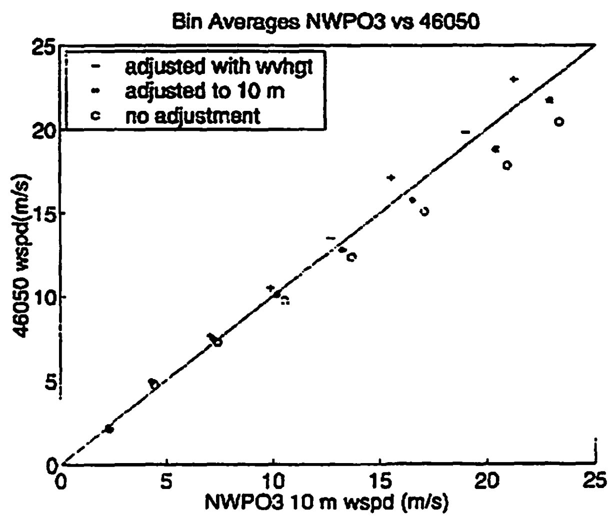

FIG. 3. Bin averages of NPOW3 vs. 46050 wind speeds with no adjustment and adjusted to 10 m, with and without accounting for wave height.

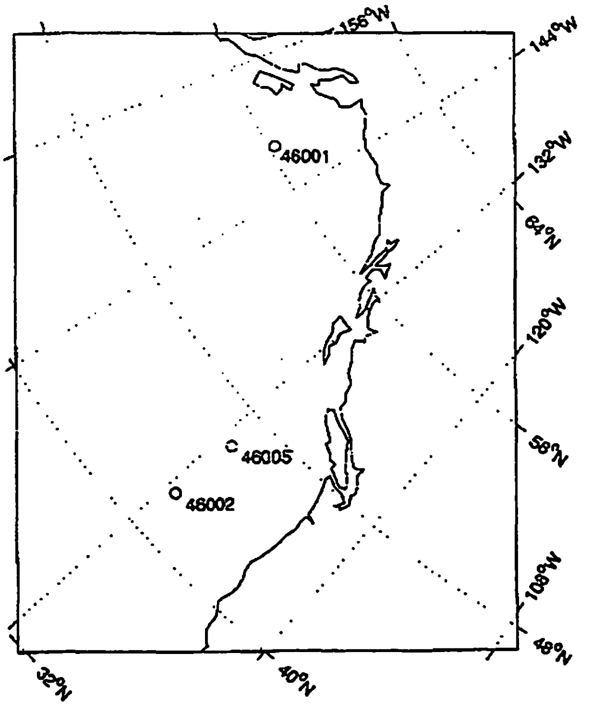

FIG. 4. Map showing location of buoys used in the model versus bouy wind speed comparison.

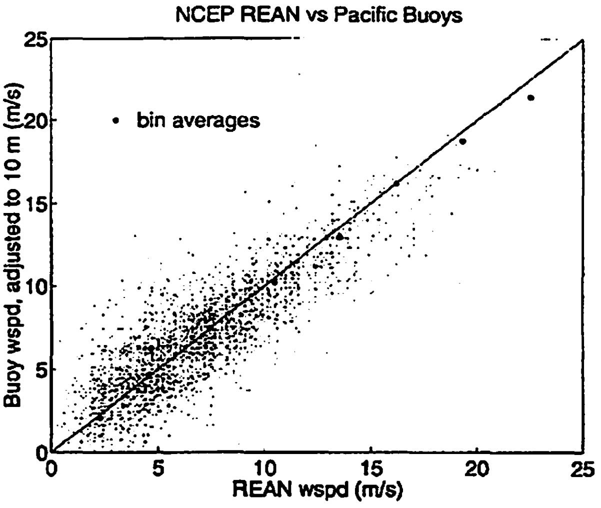

FIG. 5. Scatterplot of reanalysis 6-hr forecasts of 10-m wind speed vs. buoy 10-m wind speed. Bin averages are indicated.

It should be noted that the method suggested by Large et al. is based on a buoy wind speed sample having a much larger bias relative to numerically modeled wind speeds and with wave heights estimated from wind speed rather than actual observations. Swell also made a significant contribution to wave heights observed in this study. If the contribution of swell were eliminated, for instance, the results might have been more favorable. As will be seen in the next section, however, the application of a wave height correction does not appear to be warranted in any case.

3. BUOY-NUMERICAL MODEL COMPARISON

3.1 Data Set

By simply comparing buoy winds with those of a shore station as in Section 2, the actual influence of wave height on the wind profile might be masked in some way. Other factors, like the difference between roughness lengths over land and water, or the anemometer height of the shore station were not considered, but may be playing a role. To eliminate the influence of such factors, a similar study was conducted that compared the wind speeds of open ocean buoys with numerical model wind fields. Wind speeds from three Pacific 6-m buoys were compared with National Center for Environmental Prediction (NCEP) Reanalysis Project 6-hr forecasts of 10-m winds. The buoys, depicted in Figure 4, are located well offshore where the surrounding wind fields should be free of orographic effects. Each buoy has redundant R.M. Young propeller anemometers 5 m above the water line. Data sampling rates and averaging periods of the 6-m buoys are the same as those of the 3-m buoy already described. Buoy wind speeds were adjusted to 10 m in the same manner as in the previous section. Buoy observations were from the entire years of 1996 and 1997. Two observations each day were used, corresponding to model 6-hr forecast times valid at 0600 and 1800 UTC.

The model, described by Kalnay et al. (1996), uses the NCEP T62 grid that has a horizontal resolution of approximately 2 deg. Wind speeds were linearly interpolated from model grid points to buoy locations. Observations from the three buoys were combined into a single sample for collective comparison with model winds. To develop a meaningful sample size, observations from all three buoys were combined into a single sample for collective comparison with model winds. While the buoy observations were presumably included in model initialization, direct influence of the observations on the results of the comparisons should be mostly eliminated by the model's optimization process and the use of 6-hr forecasts.

3.2 Analysis

The results of the buoy and model wind speed comparison are shown in Figure 5. The scatter of points is broad but symmetric about the 1:1 line. Bin averages indicate good agreement between the model and buoy observations at speeds in excess of 15 m/s. To determine if wave heights might be influencing the results, buoy and model wind speed pairs were sorted according to significant wave height and compared in the same manner as in Section 2.2. The results are shown in Figure 6. Results are very similar to those seen in the comparison of buoy and shore station

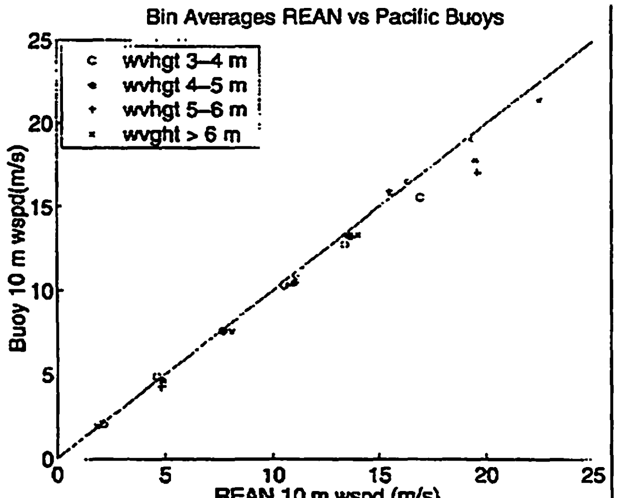

FIG. 6. Bin averages of reanalysis vs. buoy wind speed sorted by observed significant wave height.

winds. Bin averages are tightly grouped and close to the 1:1 line up to beyond 15 m/s. Above that, the bin averages scatter as sample size becomes small, but effects directly attributable to wave height are not evident.

4. CONCLUSION

Buoy wind speeds compared with a nearby coastal station show good agreement in the mean up to speeds of approximately 15 m/s, above which, buoy winds tend to be less than those of the coastal station. The bias at high wind speeds does not appear to be directly related to wave height, since bin averages of observation pairs sorted by wave height behave in a similar fashion to those of the total sample, regardless of wave height. A method to adjust buoy wind speeds to 10 m using observed wave height wind speeds too high.

Although a number of unknown factors may be influencing the buoy and coastal station wind speed comparisons, the results tend to be confirmed through a comparison of open ocean-buoy winds with the NCEP Reanalysis Project wind fields. Good agreement of wind speeds in excess of 15 m/s is again seen, even when only the highest wave heights are considered. Wave height does not appear to produce systematic errors in the accuracy of buoy wind speed measurements over the range of wave heights and wind speeds considered in this study. At wind speeds up to 20 m/s and significant wave heights up to 7 m, buoy wind speeds adjusted in the conventional manner should be considered accurate enough for most purposes. At higher winds and seas wave height may indeed be a factor, but the small sample size makes it difficult to draw firm conclusions.

This study focused on wave height since it is readily available from moored buoys, and has been most often questioned as a factor influencing buoy wind speed accuracy. Wave height, of course, does not tell the entire story on the state of the sea. Similar studies concerning the influence of other factors such as wave period or steepness would also be appropriate.

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THE STORM WIND STUDIES
An investigation into the data recovered from a 6m moored NOMAD buoy on Canada's East and West Coasts

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Introduction

The ability to forecast wave heights accurately during storm conditions is a prime objective for increasing marine and coastal safety. Accurate determination of wave properties during extreme weather is also essential to the development of design criteria for marine vessels, and coastal and offshore structures.

As a result of the uncertainties concerning wind measurements in sea states where the height of the significant wave is greater than the height of the anemometers, the Storm Wave Study-1 (SWS-1) was initiated. A six metre ship-shaped NOMAD weather buoy was equipped with an additional payload designed to gather data (primarily wind speed and direction and wave height and period) at 2 Hz, and store it directly without averaging.

The buoy was successfully deployed and, in the winter of 1994/95, recorded a number of storms, the worst being associated with a significant wave of 9.4 m. The SWS-1 study found some important items with regard to wind and wave measurement and recommendations were made both for changes in the way the Environment Canada buoys report data as well as for a follow-on SWS-2 study to continue the research into areas requiring further study. In summary, the SWS-1 data showed a number of interesting and important results. Some of these were:

- wind speed and direction both demonstrated significant variability over individual waves. The so-called sheltering effect manifested itself with reduced speeds and changes in wind direction in the wave troughs. This variability typically increased with increased wave height. This variability was shown to have linear relationships with wave height;
- the strapped down accelerometer appeared to read approximately 9% lower than the Datawell Mark II sensor under all wave conditions; and,
- the variability of wind and wave conditions within any one-hour was quite large. The data that are reported on the hourly satellite broadcast are thus affected by a combination of factors such as the conditions encountered, the sampling and averaging interval, and the processing algorithms.

One of the main recommendations from SWS-1 was to carry out a follow-on program (SWS-2) on a NOMAD buoy deployed in the vicinity of a fixed platform for additional data verification and inter-comparison. On Saturday October 25th 1997, the SWS-2 program was initiated with the deployment of an Environment Canada NOMAD buoy at 46° 44.05' N. 48° 48.13' W. on the Grand Banks of Newfoundland in 81m of water on an all-chain mooring 1.5 nautical miles to the south-west of the Hibernia platform. The buoy was on station until December 1st when the mooring parted. The buoy was redeployed on February 19th, 1998 and data was recorded until March 15th. The first period of deployment is identified as Phase One, and the second period as Phase Two. Some of the key points of note for SWS-2 are:

- an additional strapped down accelerometer was located as close as possible to the Datawell heave sensor. A Systron Donner motion sensor (3 accelerometers and 3 rate sensors) was installed in the SWS-2 compartment.
- a Solent Windmaster acoustic anemometer, as well as an R. M. Young 05305 AQ anemometer were installed on the aft mast alongside the standard R. M. Young 05106 anemometer;
- sampling at 2Hz was continuous for the period of deployment;
- a 3 Axis Solent Ultrasonic acoustic anemometer was installed on the forward mast as part of a program being run by the Southampton Oceanography Centre;
- a Directional Datawell Waverider and a Minimet Buoy were located in the same vicinity as the SWS-2 NOMAD. The data being measured on the Hibernia platform included wind speed and direction, and wave information from a MIROS wave RADAR.

The paper includes data and analysis of the unique data sets from both SWS-1 and SWS-2. Particular attention is given to the inter-comparison of various wind sensors, the output from the variety of wave sensors tested on the buoy, the variability of wind speed and direction during high seas and the effect that buoy pumping may have on the wind measurements.

Solent Windmaster

A Solent Windmaster acoustic anemometer, as well as an R. M. Young 05305 AQ anemometer was installed on the aft mast alongside the standard R. M. Young 05106 anemometer. The purpose of the installation was to determine if the Windmaster sensor would be an adequate alternative to standard wind sensors, which are susceptible to failure due to water damage and fatigue.

As shown in figure 1, there is good agreement between the R.M. Young 5106 wind sensor and the Windmaster Anemometer during the experiment with a few exceptions. These exceptions can be seen as spikes on the graph of up to 65 m/s on the Windmaster.

Figure 2 shows an expanded time series representing approximately one minute of the 2 Hz data. It can be seen that the data alternates from being reasonable (8 m/s) to quite unreasonable (63 m/s). These periods of poor data quality tended to begin and end quite rapidly.

There has been some speculation that these data anomalies may be caused by precipitation, but that is inconclusive at this point. Weather records from the Hibernia platform may help to clarify this.

There were two Windmaster sensors used on this buoy; the first during Phase One of the SWS-2 experiment, and the second during Phase Two. During Phase One, it was noted that the sensor began to fail over the course of a four hour period, then failed completely. On retrieval (after the mooring parted), it was found that the sensor had separated from its own mounting plate.

During Phase Two, the second Windmaster sensor was lost when the rear mast of the buoy disappeared before recovery. For this reason, it was not possible to investigate the nature of the spiking or to do any post deployment testing or calibration.

Data Intercomparison

Since the SWS-2 experiment was collocated with other moored platforms, it provided a very good means of verification of the buoy data quality.

Figure 3 shows a graph of the intercomparison data between the Bedford Institute of Oceanography's (BIO) Directional Datawell buoy and the NOMAD buoy's calculated Significant Wave Height as reported through the GOES system.

Figure 4 shows a scatter plot of the NOMAD Hs vs. the BIO Datawell buoy Hs. The graph shows that there is a difference of approximately 9% between the two buoys.

One of recommendations following the SWS-1 experiments was to collocate a strapped down accelerometer at a point as close as possible to the Datawell sensor in the NOMAD. This was done on the SWS-2 experiment. A scatter plot of the intercomparison data is shown in figure 5.

The data show that there was less than a 3% difference between the strapped down accelerometer and the much higher priced Datawell sensor.

Wind Sheltering

The SWS-1 experiment brought up many interesting issues. One of the reasons for the conducting the experiment was to determine what effects (if any) the high sea states would have on the wind measured from a buoy when the wave height exceeded the height of the anemometers above the sea level.

Figure 6 illustrates the variability of the relative wind direction as the buoy rides up, over and down the wave crests. This variability can be as much as 70°.

This variability suggests that the absolute wind direction is variable from the peak of the crest to the depth of the trough of the wave. The wind may be traveling through the troughs much as wind travels down mountain valleys. When there is a break in the crests, the wind may break over one crest and carry on through the trough in the next. Figure 7 shows the variability in the buoy heading as the buoy rides over the wave crests. The variability is generally lower here (50°) than it was for the relative wind.

Figure 8 shows the variability in the wind speed from one wave to the next. The data shows that the wind speed is decreasing by over 50% between waves. It can also be seen that there is a correlation between the decreases in the wind speed and the buoy displacement.

Figure 9 shows the mean decrease in wind speed for all storms expressed as a percentage. It shows that there is a linear relationship between increasing wave height and increasing variability in the wind speed.

Figure 10 is a theoretical graph showing the amount of anemometer pumping (potential contamination) that can be expected for various wave periods and various tilt angles for the buoy. This graph assumes that the buoy follows the waves perfectly and does not have a natural period of oscillation of its own.

One of the additional sensors installed on the SWS-2 platform was a Systron-Donner motion sensor, which measured the acceleration of the platform in three axes and the rotation of the platform along those three axis.

The Systron-Donner sensor's output is expressed as degrees/second. By extending the effects of the rotation up to the height of the anemometers, the induced pumping of the wind speed is calculated for various periods of time during the SWS-2 deployment.

Figure 11 shows the wind speed collected at the buoy during a period of time when the significant wave height was 1.3m. The time span for the graph is four minutes. The graph shows that there is a maximum fluctuation in the wind speed variation of about ±2.0 m/s and a frequency identical to that of the pitch axis rate sensor.

Figure 12 shows the wind speed data from the buoy when the significant wave height is 4.5 m. The significant wave height is now 3 times what it was for the lower sea state, and there is only a slight increase in the maximum fluctuation of the wind speed caused by the pumping motion of the buoy to about ± 2.5%.

Figure 13 shows data collected during the height of a storm when the significant wave height was 8m. This data shows that the magnitude of the pumping effect is about ±3%.

Conclusions

The data collected during the SWS-1 and SWS-2 programs provide a unique insight into the behaviour of the NOMAD hull in a variety of sea states.

Specifically, this paper shows that:

The tested acoustic anemometer is not suitable for buoy use at the time of testing.

There was very good agreement between the Datawell Directional Waverider and the Datawell heave sensor mounted in the NOMAD.

There is a great deal of variability in the wind field as the NOMAD rides up and down the waves.

The pumping action of the buoy can affect the buoy winds by approximately ±2.5% in all sea states.

The analysis shown in this paper of the effects of wave height and buoy motion on the measurement of wind speed and direction is very preliminary. More detailed analysis is recommended to fully investigate the problem. The SWS data sets provide an excellent opportunity to carry out this further research.

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Appendix

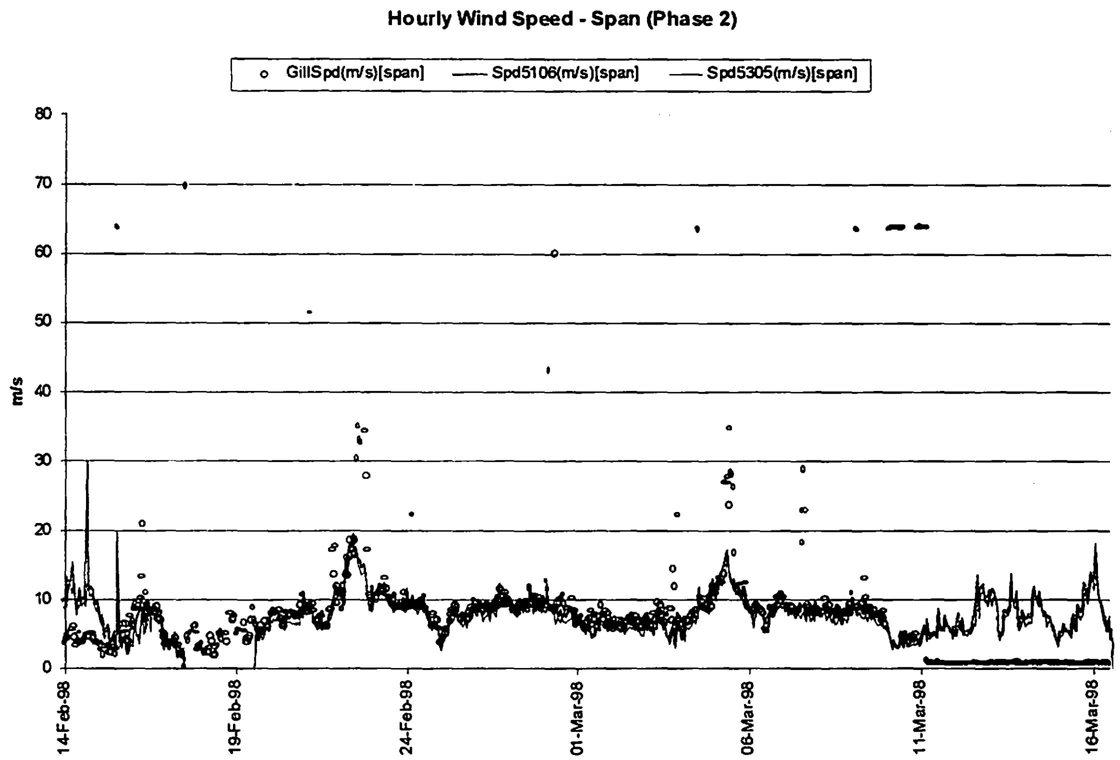
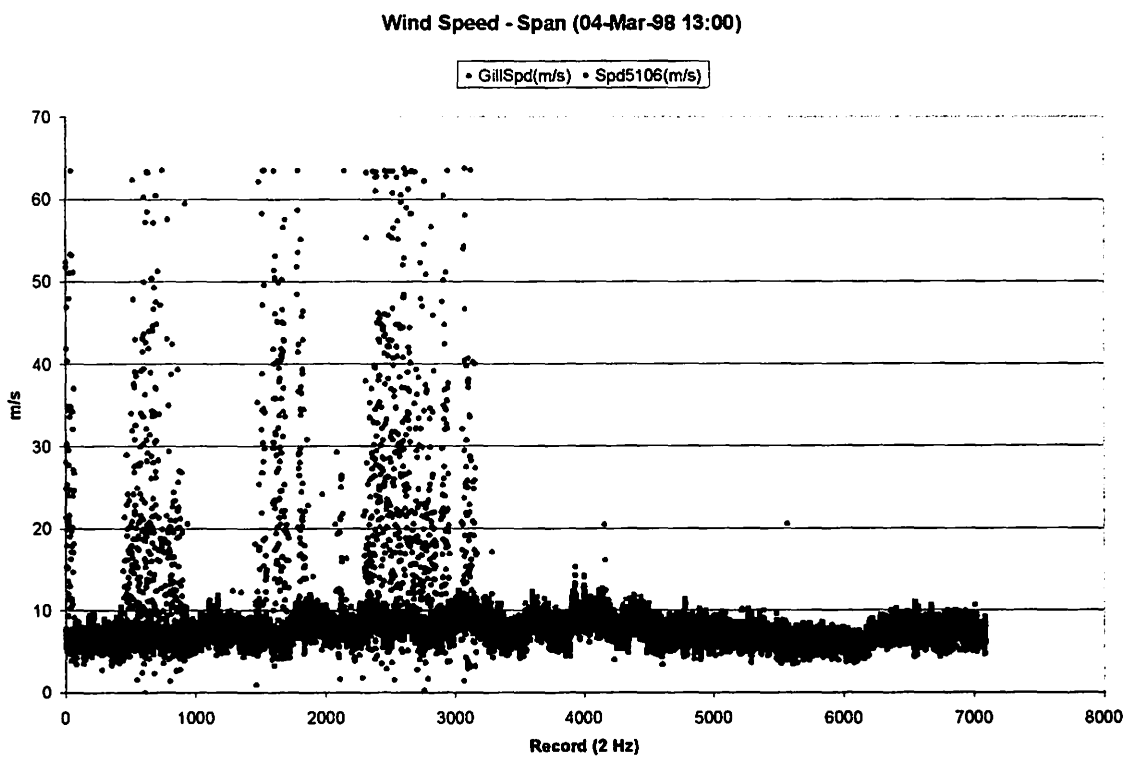


Figure 1



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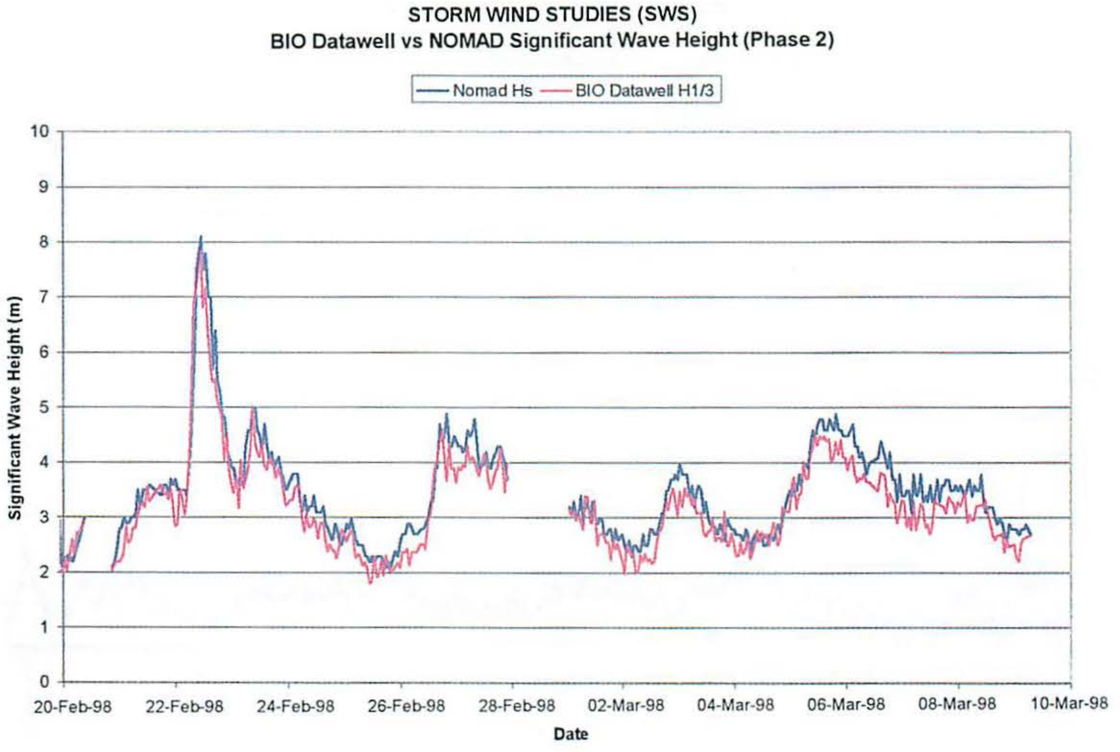

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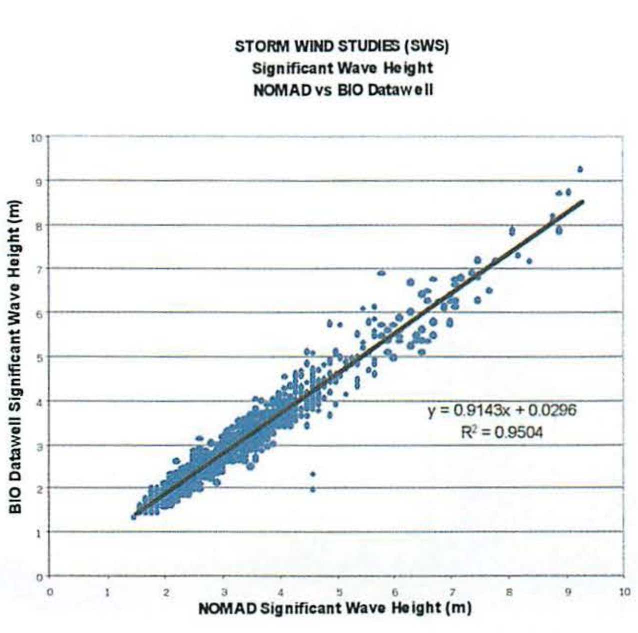

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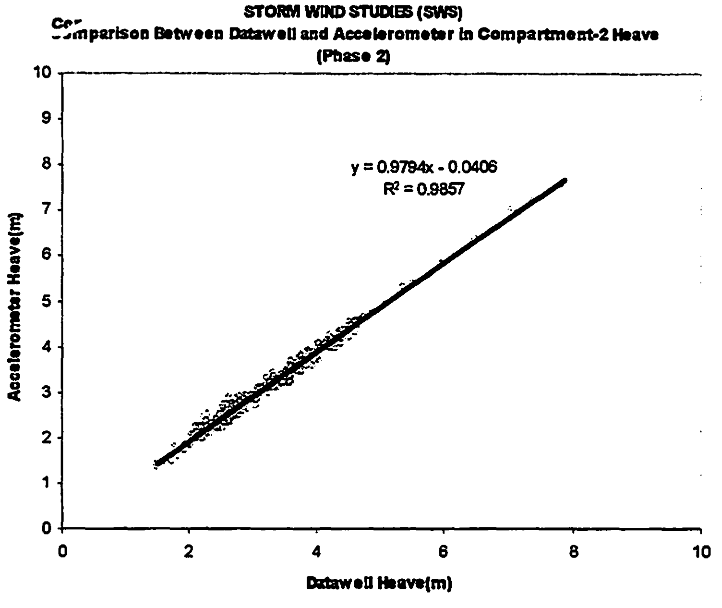

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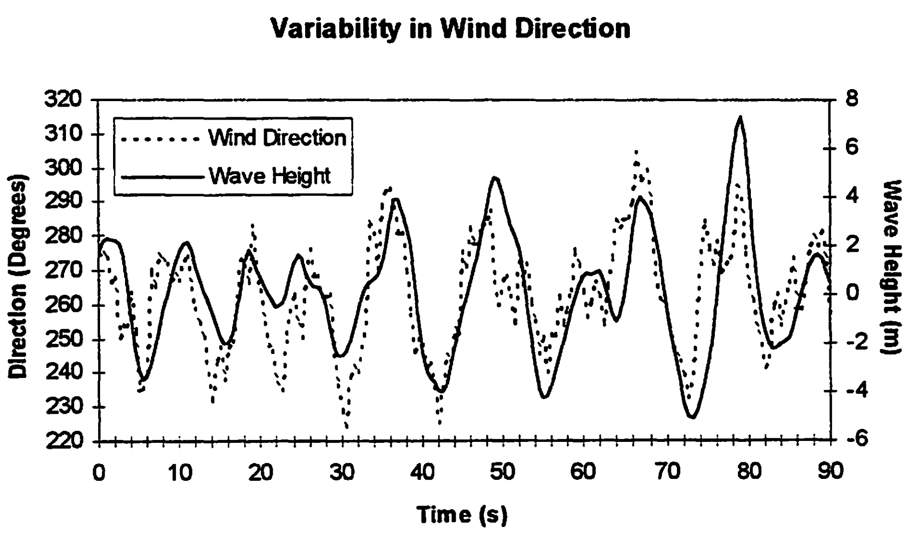


Figure 6

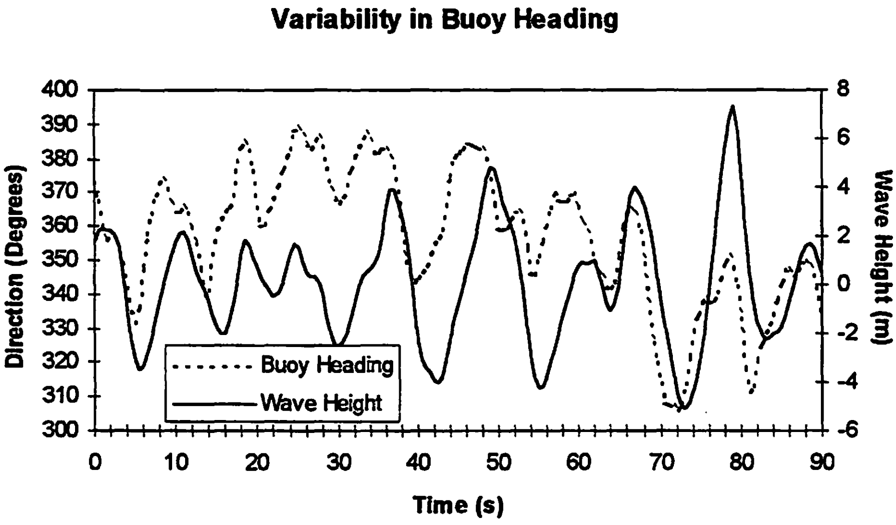


Figure 7

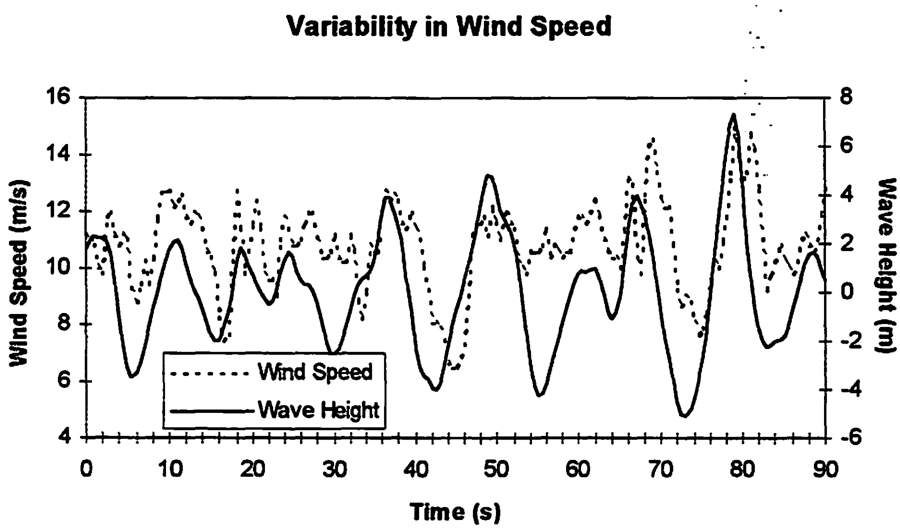


Figure 8

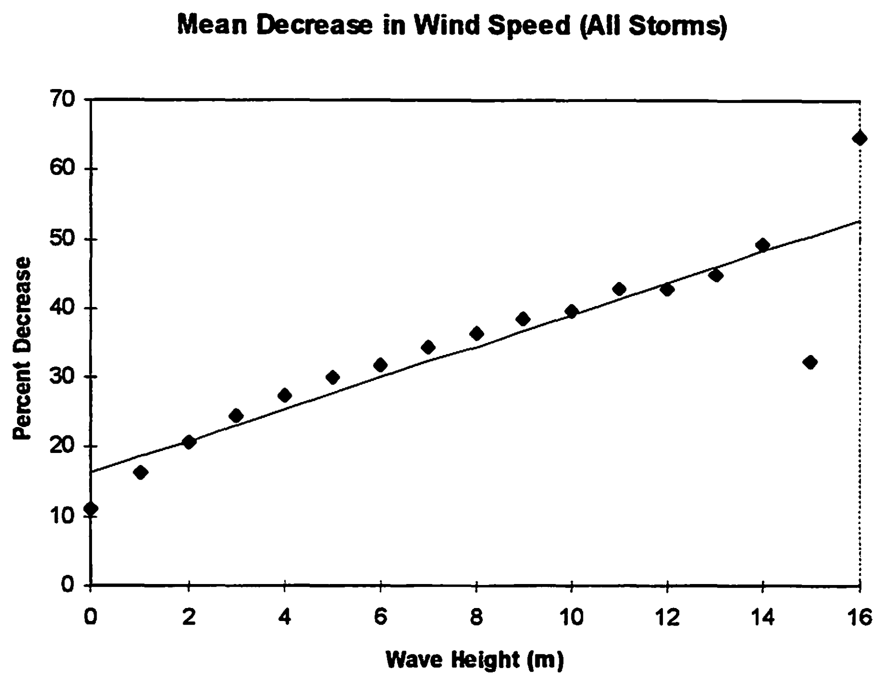


Figure 9

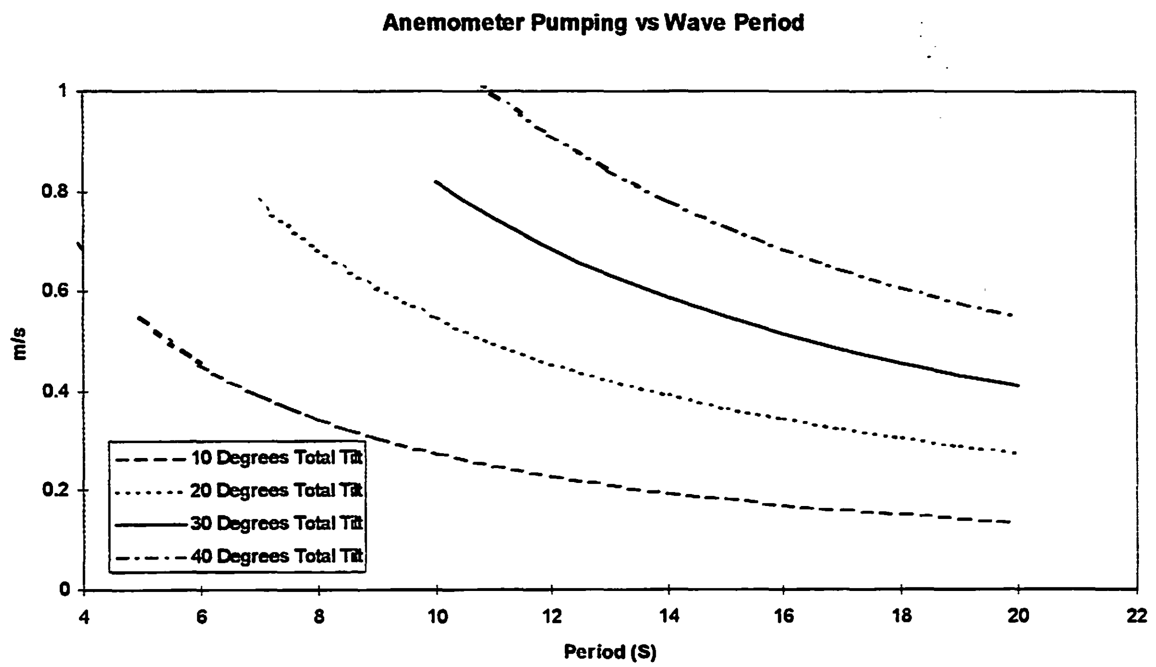


Figure 10

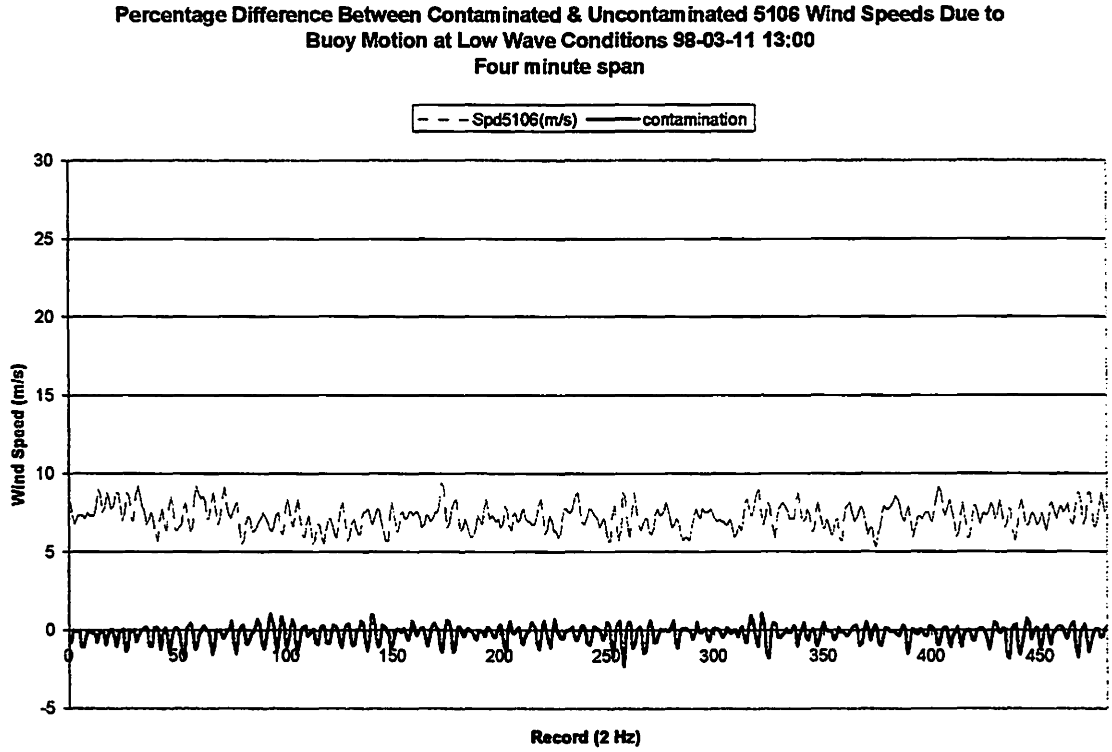
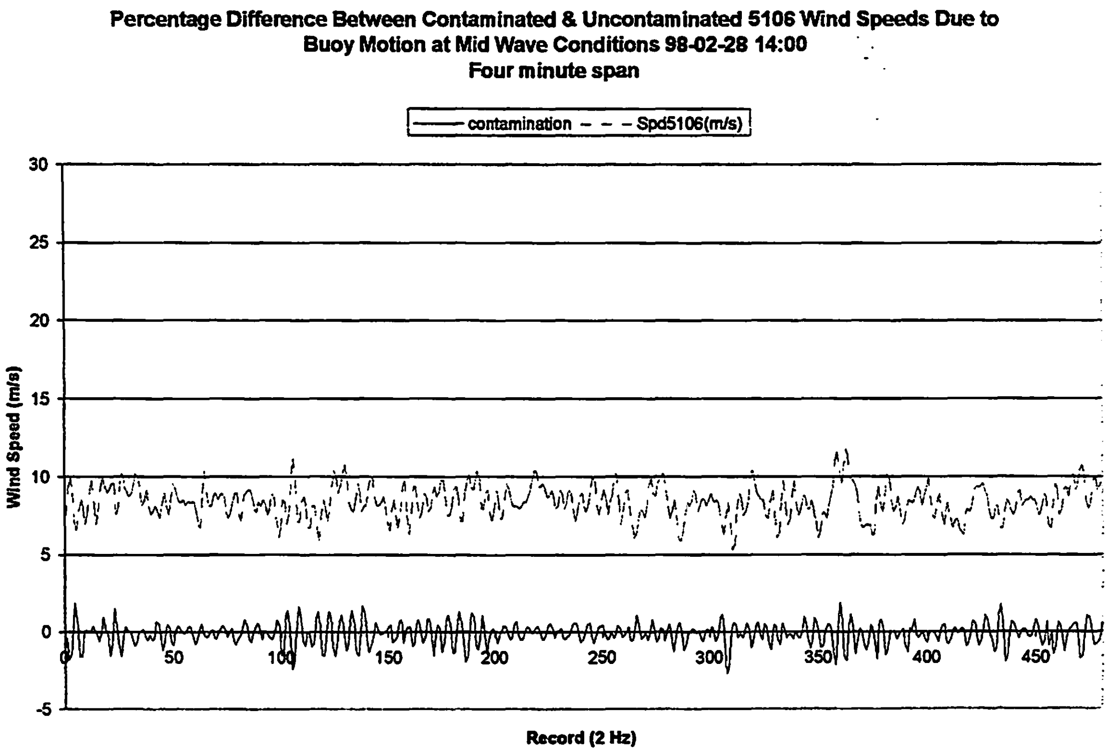


Figure 11



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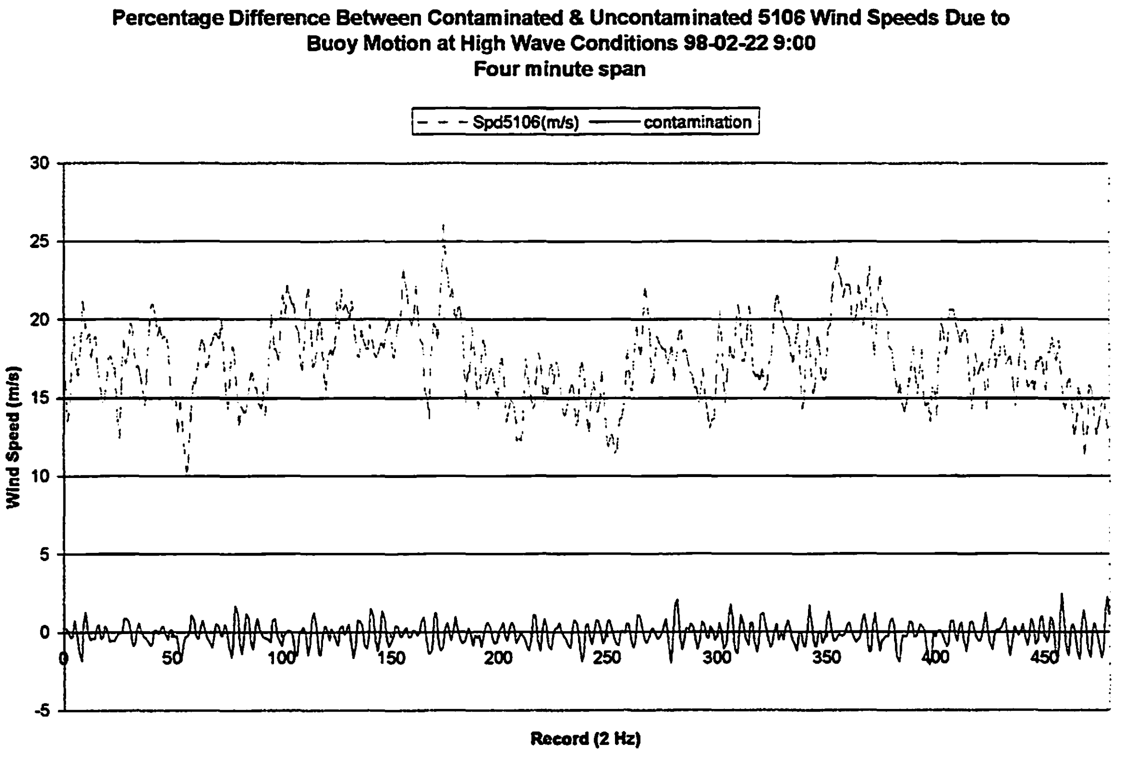
Percentage Difference Between Contaminated & Uncontaminated 5106 Wind Speeds Due to Buoy Motion at High Wave Conditions 98-02-22 9:00
Four minute span
Spd5106(m/s)
contamination
Wind Speed (m/s)
30
25
20
15
10
5
0
-5
0
50
100
150
200
250
300
350
400
450
Record (2 Hz)

Figure 13

The Use of data buoy observations in the National Meteorological Operations Centre, Melbourne

Terry Hart, Graham Warren and Bob Seaman
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Introduction

The National Meteorological Operations Centre (NMOC) of the Australian Bureau of Meteorology, located in Melbourne, has a role as a World Meteorological Centre to prepare analyses for the southern hemisphere. The Bureau's Northern Territory Regional Office in Darwin fulfils a similar role for the tropical region in East Asian and West Pacific longitudes. Data buoys are regarded as a very valuable component of the observation base over the southern and tropical ocean areas.

The extensive coverage of satellite-based observations such as cloud drift winds, scatterometer measurements of wind speed and direction over the ocean and high density soundings of temperature and moisture may belie the southern hemisphere's reputation as a data sparse area. However, numerical weather prediction skill is still lower for the southern than for the northern hemisphere, although the gap is narrowing (e.g. Kalnay et al., 1998). The reason in part is that much of the satellite data provides information on gradients of the thermal structure of the meteorological fields rather than absolute values. Pressure measurements from the drifting buoys with pressure sensors provide sparse reference level information which complements other data sources. Measurements from the data buoys perform a similar role for the analysis of sea surface temperature. This paper describes such uses of buoy data in our operations and their impact on the quality of our products.

Timeliness

For operational use timeliness of observations is an issue. For the southern hemisphere manual analyses a data cut-off of 4-5 hours is used. For our global numerical model the cut-off is 7 hours although other modeling centres, especially those with aviation responsibilities, operate with data cutoffs of less than 3 hours. For the Bureau's regional systems the cut-off is 2 hours. The current data acquisition and distribution processes work very effectively although further reduction in delays would increase the usefulness of the data. A diagram showing the arrival of buoy data relating to the analysis base time is shown in Figure 1.

Manual Analyses

A major output from NMOC is the manual mean sea level pressure (MSLP) analysis for the southern hemisphere, produced twice daily. These charts are based on synoptic observations and interpretation of satellite imagery and show the presence of features such as fronts and low pressure systems. They are disseminated to a range of users including broadcast by radio-facsimile. They are also the basis for the preparation of pseudo-observations prepared in NMOC for use by operational global atmospheric analysis and prediction centres, such as NCEP and ECMWF.

Despite the diverse range of observations now available it is still believed that human analysts and their pattern recognition skills make a unique contribution and can add value to the objective systems. Experiments demonstrating the small but positive impact of these pseudo-observations in the Bureau's global analysis and prediction system are outlined below. The manual analysts have available a broad range of satellite data but consistently report the value of the particular contribution added by the isolated measurements of surface pressure from the data buoys. Over sparse ocean areas such pressure measurements can corroborate the existence of synoptic features suspected as a possibility by signature cloud features. Combined with the estimates of low level winds from satellites even isolated surface pressure observations allow considerable detail of the synoptic pattern to be identified.

Numerical analysis and prediction

Buoy data are also a key input to the Bureau's numerical analysis and prediction systems, which cover several domains, including a global model for medium-range prediction. The numerical analysis scheme used in the Bureau's systems is described in Seaman et al. (1995). Numerical analysis schemes blend observations with a background or 'first guess' field, which is usually a six-hour model prediction from the previous analysis. The aim is to utilise the known covariance properties of the observational and first guess errors in order to find the optimal analysis. Many observations may contribute to the analysis at a grid point with the weight for any observation determined by the relative errors of the observation platform and the first guess, distance from the grid point and any spatial or temporal correlations in the observations. The observational errors are based on information from data producers but also make an allowance for representativeness. The errors assigned for surface pressure observation types used in the Bureau's global analysis and prediction system are:

Synoptic stations	0.8 hPa
Ships or buoys	1.5 hPa
PAOB pseudo-observations	4.0 hPa

In some cases the first guess field for the numerical analyses may depart from the real world to such an extent that isolated observations such as buoy reports may be rejected by the in-built quality control procedures. When faced with observations which differ significantly from the first guess, the objective analysis scheme needs to maintain a balance between detecting either an erroneous observation or a poor first guess. As the model accuracy is improved the errors assigned to the background field are decreased, potentially making the numerical analysis scheme resistant to correction by isolated observations. The insertion of pseudo-observations can provide support to such isolated observations and ensure that the values are paid. The analysis procedures in NMOC have been revised recently to allow the manual analysts more influence in ensuring that pseudo-observations can support isolated observations in the numerical analysis. Where a PAOB is inserted close to a SYNOP, SHIP or buoy observation the normal quality controls are relaxed and the observational error of the PAOB reduced to emphasise the value of the observation.

As a by-product of the analysis system information is available on the impact of individual data platforms and types (Seaman,1994), as measured by the difference in the analysis with and without the particular observation. Average statistics show that drifting buoys at mid- to high southern latitudes are well-represented among the platforms having the highest impacts on the MSLP analyses.

The results for June-Sep 1999 are listed in Table below.

Average impact on the Australian Bureau of Meteorology global numerical analysis of Mean Sea Level Pressure (MSLP) for July-September 1999

Station or Buoy	Lat	Lon	Impact (hPa) rms	max
1. 71557	66	306	3.1	9.6
2. Grytviken	54	324	3.0	7.0
3. Orcadas	61	315	2.9	7.5
4. 71552	70	285	2.5	10.8
5. 56549	56	105	2.4	9.6
6. 74531	66	355	2.3	10.2
7. 56541	62	173	2.3	10.2
8. 74532	55	106	2.3	6.6
9. Crozet Island	46	52	2.1	6.5
10. Belgrano	78	325	2.0	8.0

Impact of buoy data on numerical weather prediction skill
Tests on the impact of the buoy data were carried out with the Bureau's global analysis and prediction system from mid-May to mid-June 1999. The operational system is based on a spectral model (GASP) with triangular wavenumber 239 truncation (T_L239) and 29 vertical levels.

Three assimilation cycles were run, withholding (a) all pseudo-observations (PAOBs), (b) all buoy data, and (c) both PAOBs and buoy data. Forecasts to 7 days were run daily from 30 base times, and compared with the operational GASP forecasts. Verifications were performed versus the operational GASP analyses, and against the standard WMO observational data sets.

The results showed:

(1) Withholding the PAOBs resulted in a small degradation of predictions

(2) Withholding the buoys (but including the PAOBs) also resulted in a small degradation of predictions, of similar magnitude to (1).

(3) Withholding both buoys and PAOBs resulted in a larger degradation of predictions, suggesting a significant although not complete redundancy between PAOBs and buoys, and also confirming the positive impact of buoy data.

Comparison verification statistics are shown in Figure 2 for the southern annulus region 20 - 60^0 S. While the differences may seem relatively small, they represent a significant impact from a relatively few pieces of information. The area covered also includes a large area of the subtropical high pressure belt. The impact is concentrated further to the south in the zone commonly associated with strong westerly flow and mobile low pressure systems.

Analyses of sea surface temperature
NMOC also produces numerical sea surface temperature analyses. For the global analysis an optimal interpolation system is used to blend *in situ* and remote measurements of SST with forecasts based on previous analyses. The key sources of data are polar orbiting AVHRR data

and *in situ* data from ships, moorings and buoys.
The satellite data produce the best spatial coverage but there can be a bias in the retrieved values especially when the atmosphere is contaminated by aerosols such as smoke or volcanic ash. Because of this possible bias, a scheme to correct these data has been implemented.

Firstly, separate coarse analyses of *in situ* and satellite data are performed. These coarse analyses are performed on a 2.5° grid and use broad correlation scales (of the order of 800km). At these scales it is assumed that there are sufficient *in situ* data to perform an accurate analysis. The statistical weights given to the different data types reflect their observational accuracy. In the *in situ* analysis buoy data are given the greatest weight. A difference field is calculated from these two analyses which is interpolated to the location of every satellite observation and used to correct the original observation. Such corrections are only made in areas where *in situ* measurements are available to define the bias field. The final global analysis is performed on a 1° grid at correlation scales of about 150km and uses all *in situ* and corrected satellite data.

This product is updated weekly and is used both by the operational atmospheric models and in the production of climate forecasts and seasonal outlooks.

Verification of surface wind predictions

A program to verify predictions of surface winds by the numerical models is being implemented in NMOC. Surface wind observations from drifting buoys are a particularly valuable source of verifying information for ocean areas.

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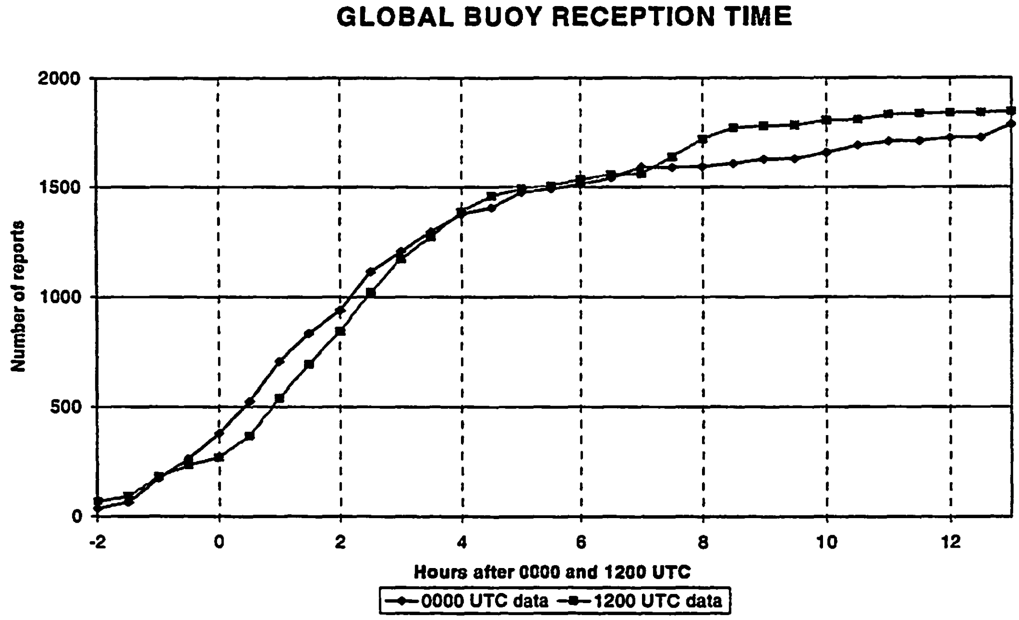

Figure 1. Cumulative buoy reports valid within +/- 3 hours of the nominal analysis time of 00 or12 UTC.

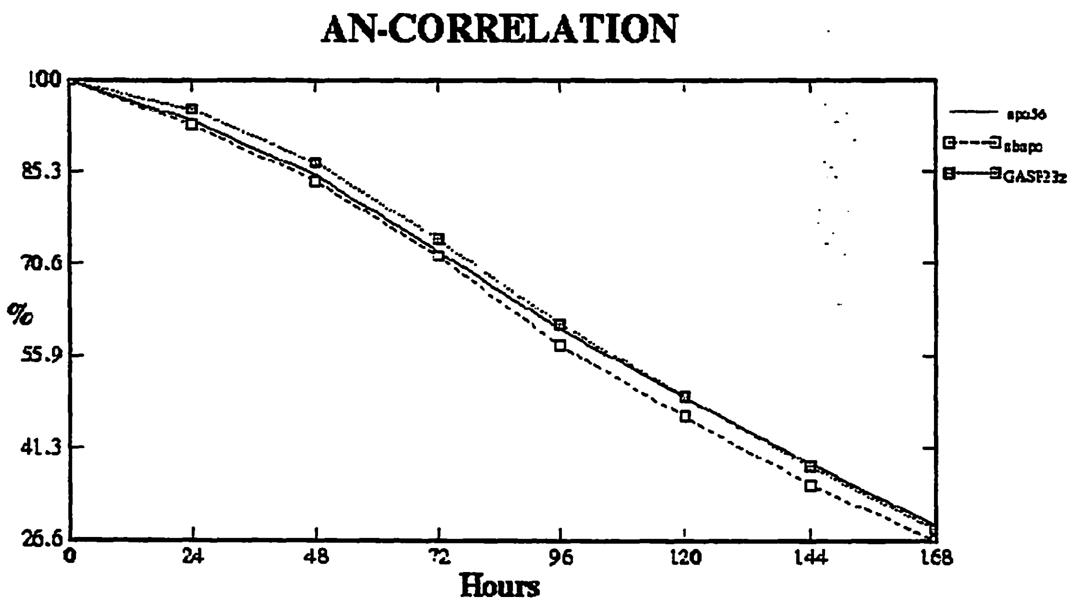

Figure 2. Verification statistics showing the impact of removing buoy data on medium-range prediction with the Bureau's global analysis and prediction system (GASP). The graph shows the correlation of the differences relative to climatology in the predictions and analyses over the southern annulus (20-60°S) for 30 cases run daily from May to June 1999. The dotted line represents the operational system; in the experiment designated by the full line pseudo-observations (PAOBs), which implicitly include buoy information, had been omitted from the analyses, and in the case indicated by the dashed line both pseudo-observations and the buoy observations had been omitted.

Drifting Buoy Observations and Explosive Cyclogenesis over the Tasman Sea

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On 9 May 1998 a depression moving southeast over the data-sparse Tasman Sea passed directly over a drifting buoy 350 km west of Haast on the West Coast of New Zealand's South Island. The pressure fell 9.3hPa in 2 hours and reached a minimum of 981.8hPa indicating that the depression was deepening explosively. As a consequence a storm warning was issued forecasting surface winds of 50 knots near the depression centre.

In addition to the strong pressure gradient close to its centre, the depression developed another characteristic of a tropical cyclone, namely a ring of deep convective clouds surrounding a central eye. Individual cumulonimbus cells appeared to rotate around the centre with a speed of 60 knots, but no surface observations were available to confirm these winds.

No scatterometer pass was available for this depression although other small intense depressions have been captured before.

The depression deepened in association with strong cyclonic vorticity advection aloft ahead of a fast moving upper trough. Although computer models indicated deepening they significantly underestimated it.

This event highlights the importance of drifting buoys and other remote sensing systems for a country like New Zealand surrounded by large oceans from which few ship reports are received.

The Moored FGGE Wind Buoy, St Vincent Gulf, South Australia. Some Applications to Marine Wind Forecasting.

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Abstract

The Australian Bureau of Meteorology has had involvement in drifting buoys since the First GARP Global Experiment (FGGE) in the 1970's. Via the Data Buoy Cooperation Panel, and with the assistance of the Observation and Engineering Section of the Bureau's Melbourne Head Office, an opportunity has recently arisen for the South Australian Regional Office of the Bureau to become involved in the deployment of a moored FGGE wind buoy in St Vincent Gulf, close to Adelaide, the economic and social centre of the state.

The fundamental reason for the deployment of the buoy was to investigate the correlation between the intensity of weather radar detected back scatter from wave action on the waters of St Vincent Gulf, with the height of wind produced sea waves. Side lobe reflectivity from the Adelaide weather radar caused by wave action increases in intensity with wind speed. This radar data is seen as potentially useful in providing an indication of wind speed at the sea surface in southern St Vincent Gulf.

To quantify this relationship, there was a need for wind data in the area from which the radar returns are derived. Data from the buoy, which was deployed in mid March 1999, is currently being continuously transmitted and recorded. Once a sufficiently large database of significant wind events has been obtained, radar reflectivity data will be compared to the wind data from the buoy with the intention of developing a relationship between radar reflectivity and wind speed.

A number of "side benefits" have come out of the buoy deployment. Meteorologists at the South Australian Regional Office now have data from the marine environment not previously available. For the first time ever, forecasters are able to monitor in near real time, wind speed and direction, air pressure and temperature, and sea surface temperature from a point in St Vincent Gulf which is representative of the southern part of the Adelaide metropolitan waters zone. This continuous feedback has already impacted positively on the confidence and quality of coastal waters wind forecasts.

Buoy Wind data has been compared to that from a standard cup anemometer located on the pier at Port Stanvac Oil Refinery, some 16 kilometres to the northeast. Wind data recorded during June, August and September 1999 showed a correlation between buoy wind speed data and that from the refinery anemometer of greater than 0.8. The Root Mean Square (RMS) difference between the wind direction data from the buoy and the refinery anemometer was 24^0. The RMS difference in wind speed was less than 1.5 knots. These comparisons have added confidence that the buoy wind data are a close representation of wind conditions at sea level.

The buoy data has also provided the opportunity to objectively assess the accuracy of wind forecasts for the southern part of St Vincent Gulf. This has not been possible previously. Comparisons indicated RMS errors between forecasts and observations of 4 to 5 knots in June, increasing to 6 to 8 knots in September. There was also a systematic positive bias – that is a tendency to "over-forecast". These results have been fed back to forecasters, and will continue as the part of a new coastal waters verification scheme.

Data from the moored buoy provide both operational and research opportunities not previously available to the meteorological community in South Australia. There is considerable scope to enhance both the understanding of the characteristics of the local marine weather environment, and the quality of the weather service provided by the Bureau to the marine community.

Introduction

Use of Buoys by the Bureau

The Australian Bureau of Meteorology participates on international buoy committees and is currently represented by the Chairman of the Data Buoy Co-operation Panel (DBCP) and separately, by the Chairman of the International Buoy Program for the Indian Ocean (IBPIO).

The Bureau has been involved with drifting buoys since the First GARP Global Experiment (FGGE) in the 1970s. From about the mid 1980's until 1994, the Bureau maintained a modest buoy deployment program of about six buoys per year, supplemented by an equivalent number of buoys deployed in support of the Tropical Ocean Global Atmosphere (TOGA) experiment. Since 1995 (post TOGA), the Bureau has allocated additional capital funds to increase the annual deployment program to about ten buoys. In another cooperative arrangement, the Bureau occasionally deploys buoys to the south and southwest of Australia for the Atlantic Oceanographic Marine Laboratory.

Since the installation of a weather radar on Sellicks Hill, 50 km to the south of Adelaide, South Australia (Figure 1), meteorologists at the South Australian Regional Office of the Bureau have been interested in the reflectivity returns which occur when winds of greater than about 15 knots blow over waters to the immediate west of the radar. It is assumed that these returns are caused by the reflection of the radar beam side lobe from the sea spray from waves generated by the wind over the water. Reflectivity intensity increases as the wind speed increases.

This qualitative data is of some value to forecasters, who use it as a rough guide to the wind speed over the waters of southern St Vincent Gulf. The potential of the radar data as an indicator of wind speed was recognised, but it was clear that before quantitative assessment of the wind speed could be made, sea level wind data from the area of side lobe reflection was required to provide an objective basis by which to quantify the reflectivity intensity.

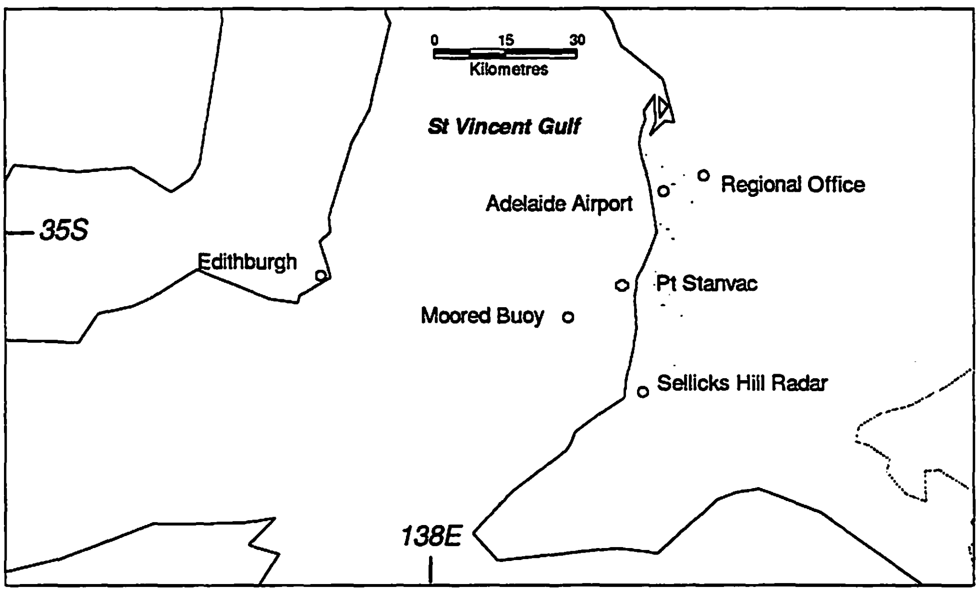

Figure 1 : Location of Moored Buoy

The involvement of the Bureau in the drifting buoy program provided a window of opportunity for a project to be mounted which would assist in obtaining wind data from the area of interest. With the assistance of the Observation and Engineering Section of the Bureau's Head Office, a FGGE wind buoy was obtained for deployment in the St Vincent Gulf.

Buoy Description

Modifications and Deployment

The buoy type used in this project is the FGGE wind buoy, which in standard configuration, comprises sensors for wind speed and wind direction, air pressure, air temperature and sea surface temperature. A schematic of the wind buoy can be seen in Figure 2.

Once it arrived in Adelaide, in cooperation with the Flinders Institute for Atmospheric and Marine Science (FIAMS), modifications were made to the buoy which enabled it to be moored to the sea bed. For the mooring, a 100 metre long neutral-buoyancy line was connected to the mounting pad at the bottom of the buoy. A ships anchor, was attached to the end of the mooring line, providing the mooring point.

With the cooperation of Mobil Oil Australia Port Stanvac Oil Refinery, who provided a suitable transport vessel, deployment was undertaken on 22 March 1999. The buoy was deployed at the point indicated in Figure 1, 16 kilometres southwest of Port Stanvac, and 25 kilometres to the northwest of the Sellicks Hill radar.

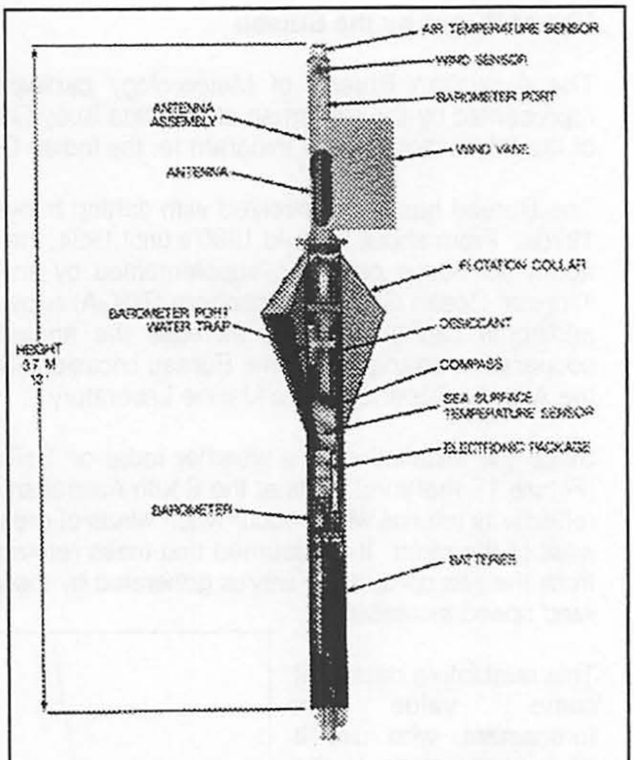

***Figure 2** : Components of FGGE wind buoy*

Communication System

As with all Bureau deployed buoys, the FGGE buoy transmits data using the Argos communication system. The Argos system utilizes both ground and satellite-based resources to accomplish its mission. This includes instruments carried aboard the NOAA Polar Orbiting Environmental Satellites (POES), receiving stations around the world and major processing facilities in France and the United States. This fully integrated system works to conveniently locate and deliver data from the most remote platforms to the user's desktop, often in near real-time.

The transmitter on the buoy sends signals continuously from a small transmitter weighing less than 20 grams, with an average daily power consumption of a few milliamps. The POES satellites collect the data and retransmit it to the Argos centres for processing. Data can be accessed from anywhere in the world by public data networks, often within 20 minutes of transmission.

The Argos receivers are carried on board the NOAA series satellites. At least two satellites are simultaneously in service on polar, sun-synchronous, circular orbits at 850 km altitude, providing full global coverage.

Immediately the buoy was deployed, it commenced the successful transmission of data via the ARGOS communication system. These transmissions have continued uninterrupted up to this point of time (late October 1999). Data is being logged continuously, with the most recent 50 observations available in near real time throughout the Bureau via an intranet. The data is accessed routinely by forecasters in the South Australian Regional Office to assist the task of marine forecasting. A typical (partial) data sequence as displayed on the office Intranet is shown in Table 1.

Date (UTC)	Time (UTC)	Pressure (hPa)	Pressure Trend (hPa)	Air Temp	Sea Temp	Wind Direction	Wind Speed (knots)
1999/07/14	12:04	1021.6	0.0 S	13.4	13.8	067	11
1999/07/14	11:34	1021.6	0.0 S	13.4	13.8	075	10
1999/07/14	10:25	1021.6	0.4 R	13.4	14.0	070	10
1999/07/14	08:47	1021.3	0.1 R	14.2	14.2	098	6
1999/07/14	08:16	1021.2	0.2 F	14.8	14.2	119	2
1999/07/14	07:02	1021.0	1.0 F	17.0	14.3	163	0
1999/07/14	06:37	1021.2	1.2 F	17.6	14.3	170	0
1999/07/14	04:57	1022.1	1.5 F	19.6	14.2	163	0
1999/07/14	01:18	1024.3	0.1 R	14.8	13.7	108	11
1999/07/13	23:18	1024.3	0.7 R	12.8	13.6	101	14
1999/07/13	22:02	1023.7	0.2 R	12.2	13.6	108	13
1999/07/13	21:36	1023.6	0.2 R	12.0	13.6	109	15
1999/07/13	20:28	1023.6	0.1 F	12.4	13.6	118	8
1999/07/13	18:48	1023.6	0.6 F	12.6	13.6	126	5

***Table 1** : Buoy data for a 24 hour period, as displayed on SA Regional Office Intranet.*

Wind Data Comparisons

Buoy Data versus Port Stanvac Anemometer

This is the first time that near real time surface wind speed and direction data from the marine environment have been routinely available to forecasters in South Australia. To assess the validity of the data from the buoy, and therefore its value as a platform for providing reliable wind observations from the marine environment, data was compared to observations from a conventional anemometer located on the pier at Port Stanvac Oil Refinery, about 16 kilometres to the northeast of the buoy. The anemometer head is approximately 15 metres above mean sea level, but is recognised by pilots at Port Stanvac and Bureau forecasters as providing representative wind data for the location.

A subset of the wind data transmitted by the buoy during the months of June, August and September 1999 was compared with data from the Port Stanvac anemometer. Data at 2330 UTC (0900 CST) and at 0530 UTC (1500 CST) from Port Stanvac were compared with buoy data as close as possible to these times, and always within one hour. Results of the comparison are shown in Table 2 and graphically (wind speed, June only) in Figure 3.

	June		August		September	
	Direction	Speed (kts)	Direction	Speed (kts)	Direction	Speed (kts)
RMS Difference	19^0	3.7	24^0	3.7	28^0	4.5
Bias		+0.8		-1.8		-2.0
Correlation		0.86		0.90		0.84

***Table 2** : Comparison of Buoy Winds with Pt Stanvac Anemometer Winds.*

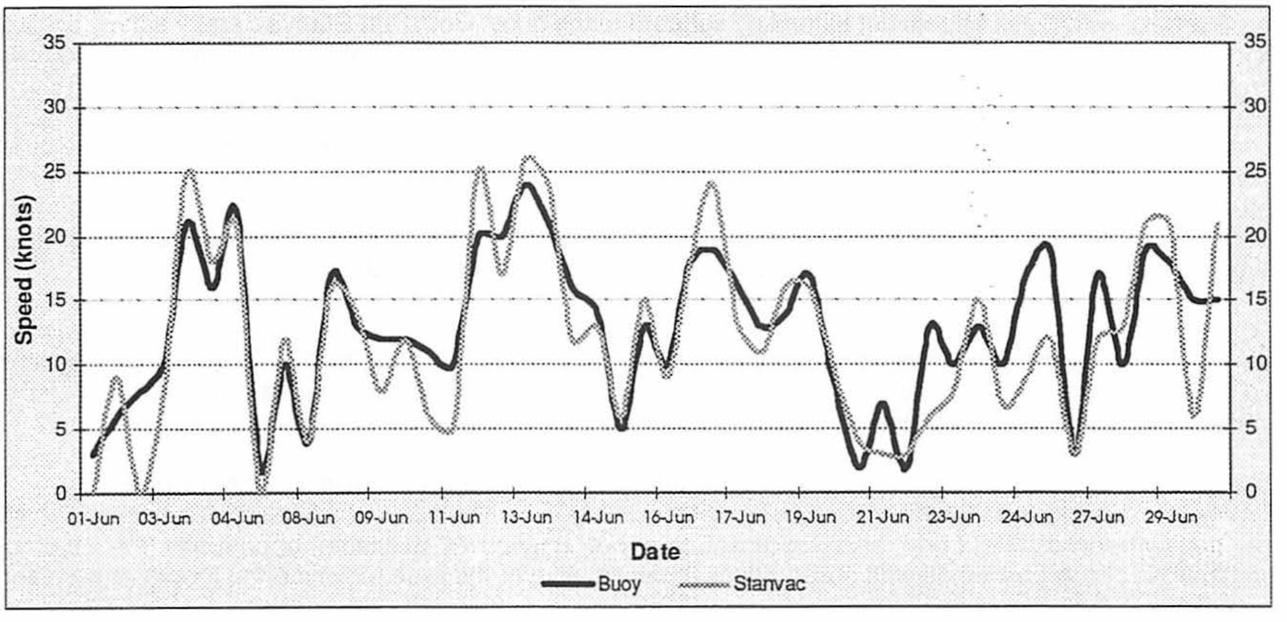

***Figure 3** : Graphical Comparison of Buoy Winds with Pt Stanvac Anemometer Winds : June 1999.*

The correlation coefficient for wind speed was 0.84 or better in each month. In June, the RMS difference in wind speed was 3.7 knots with the buoy winds being slightly stronger (a positive bias of less than 1 knot). The RMS directional difference was less than 20^0. On the assumption that the wind climatology of the respective locations are very similar, these results provided early confidence that the buoy data is representative of wind conditions in the area.

In August and September, the RMS difference in wind direction was slightly, though not significantly higher, at 24^0 and 28^0 respectively. The RMS difference in wind speed was 3.7 and 4.8 knots respectively. A negative bias of close to 2 knots was observed in both months. This was a significantly different result to that seen in June, which could be rationalized in two ways.

1. The impellor on the buoy is becoming worn or contaminated with salt or dirt, and not responding accurately to the real wind.

2. During the warmer months of August and September there are more frequent variations of the marine wind compared to the wind over land. This effect results from stable stratification of the low level atmosphere over the Gulf, which occurs when the air temperature becomes higher than the sea surface temperature. This reduces the efficiency of vertical mixing, with the marine wind speed decreasing, and becoming lower than the wind over adjacent land. Such local spatial variations are not common during the colder months, like June.

The coastline adjacent to Port Stanvac rises fairly abruptly to the east. To analyse whether there were coastal effects at Port Stanvac which might bias that data in comparison to the open, exposed location of the buoy in the Gulf, the data was stratified into the four wind quadrants - North East (NE), South East (SE), South West (SW) and North West (NW). The wind direction at the buoy was the basis for the stratification. Table 3 shows the RMS differences in wind speed and direction, the bias and correlation for each wind quadrant.

	RMSD Spd	Bias Spd	RMSD Dir	Correlation (wind speed)
NE	4.6	-0.9	20	0.83
SE	4.2	-0.5	19	0.61
SW	3.6	-0.8	29	0.84
NW	3.9	-1.9	24	0.92

***Table 3** : Comparison of Buoy wind data with Pt Stanvac data for the four wind quadrants, all data. RMSD = RMS Difference*

This data shows that the greatest RMS difference in wind speed between the buoy and Port Stanvac occurred when the wind was from the northeast quadrant (4.6 knots), and the least when the wind was from the southwest quadrant (3.6 knots). This suggests that coastal effects do have an influence on the winds at Port Stanvac, with these effects not extending seaward to the buoy. Both Port Stanvac and the buoy are well exposed to winds from the southwest, with the speed of this flow unlikely to be affected by coastal topography.

In northwesterly winds, wind strength at Port Stanvac was more consistently stronger than winds at the buoy, shown by the bias of almost –2 knots. This difference may be attributed to the low level stabilisation which occurs in winds from the northwest. Stable stratification of the flow in this regime often results in air mass "blocking" of the flow near the coast, and an along shore acceleration due to convergence. This zone of accelerated flow apparently does not extend seaward as far as the buoy location.

With regard to wind direction, there was less than 20^0 RMS variation in off shore (easterly) streams, which was lower than for on shore (westerly) streams, where the difference was up to 29^0. This may be attributed to a climatological effect, where the topography of the coastal zone tends to channel winds into a preferred direction, with this effect apparently extending seaward at least as far as the buoy location.

Forecasts versus Buoy, Adelaide Airport, Edithburgh and Port Stanvac Wind Observations

The deployment of the buoy also represented a not previously available opportunity for objective comparisons of forecast winds with observations representative of the area for which the forecasts are valid.

To this end, a scheme for objective comparison of forecasts against observations was developed. For the months of June, August and September 1999, forecast winds for the Adelaide Metropolitan Waters were compared to wind observations from the buoy, and from Adelaide Airport, Edithburgh and Port Stanvac anemometers. The basis of the comparison scheme was :

- *The forecast issued at 1700 local time (0730 UTC) was verified against 0900 data (2330 UTC) the following day.*
- *The forecast issued at 0500 local time (2030 UTC) was verified against 1500 (0530 UTC) data.*
- *The **mid point** of the forecast direction and speed range was the datum which was compared to the observation.*
- *"% in range" is the percentage of observations which fell within a **45^0 and 5 knot range** around the mid point of the forecast.*

Table 3 summarises the comparisons, with Figure 4 showing graphical representation.

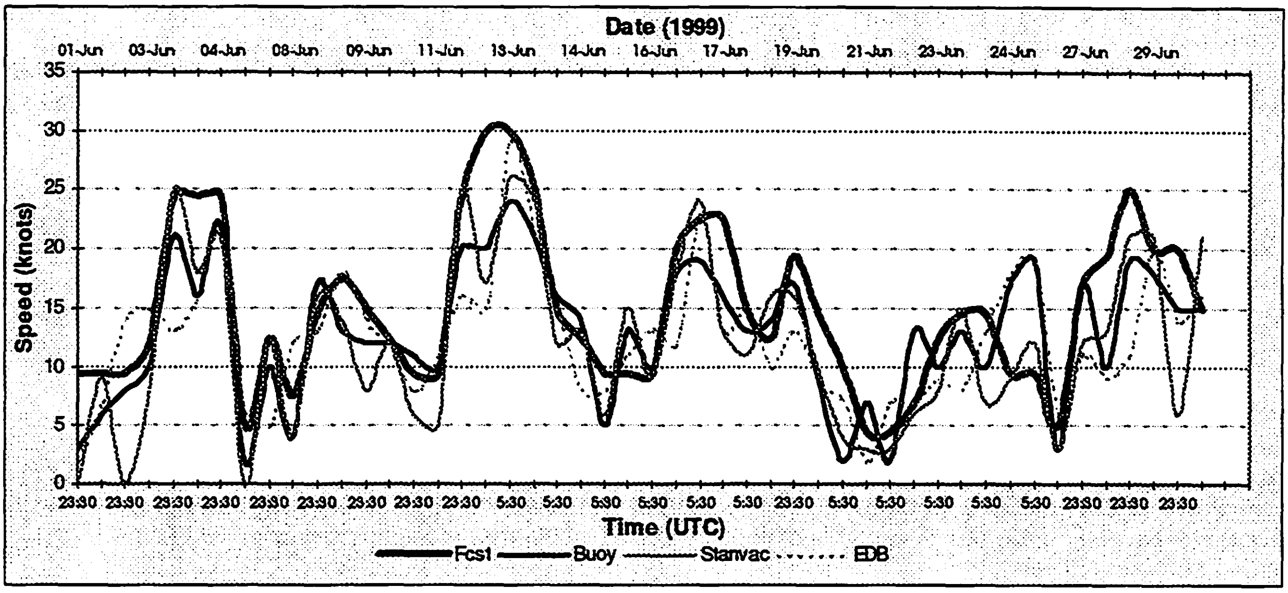

***Figure 4** : Graphical Comparison of Wind Speed Forecasts and Observations from Buoy, Pt Stanvac and Edithburgh Anemometers : June 1999*

	Buoy		Adelaide A/P		Edithburgh		Pt Stanvac	
	Direction	Speed (kts)	Direction	Speed	Direction	Speed	Direction	Speed
Mean		12.8		9.0		12.4		12.0
RMS Error	30^0	4.5	38^0	7.3	46^0	5.8	39^0	5.1
Bias		2.1		6.0		2.6		2.9
Correlation		0.81		0.78		0.65		0.82
Fcst within range	52%	48%	46%	35%	58%	46%	38%	40%

Table 3a** : Comparison of Wind Forecasts with Buoy, Pt Stanvac and Edithburgh AWS data : **June 1999

	Buoy		Adelaide A/P		Edithburgh		Pt Stanvac	
	Direction	Speed (kts)	Direction	Speed	Direction	Speed	Direction	Speed
Mean		8.9		8.8		11.4		10.7
RMS Error	37^0	6.2	46^0	6.1	64^0	5.0	36^0	5.3
Bias		4.1		4.2		1.6		2.3
Correlation		0.73		0.72		0.66		0.76
Fcst within range	52%	33%	51%	40%	40%	41%	48%	33%

Table 3b** : Comparison of Wind Forecasts with Buoy, Pt Stanvac and Edithburgh AWS data : **August 1999

	Buoy		Adelaide A/P		Edithburgh		Pt Stanvac	
	Direction	Speed (kts)	Direction	Speed	Direction	Speed	Direction	Speed
Mean		9.6		10.4		12.6		11.9
RMS Error	41^0	7.8	60^0	6.6	64^0	5.3	55^0	6.1
Bias		5.5		4.7		2.5		4.8
Correlation		0.67		0.72		0.70		0.75
Fcst within range	57%	22%	43%	27%	50%	45%	42%	33%

Table 3c** : Comparison of Wind Forecasts with Buoy, Pt Stanvac and Edithburgh AWS data : **September 1999

These comparisons show that in June, the RMS difference between forecast wind direction and that observed by the buoy was 30^0, and the difference in speed was less than 5 knots. Observations fell within the 45^0 and 5 knot forecast ranges on close to 50% of occasions and forecasts had a slight positive bias of 2.1 knots. Forecasts were slightly more accurate with respect to the buoy data than they were for Port Stanvac, and significantly more accurate than for both Adelaide Airport and Edithburgh.

In August, the RMS difference between forecast wind direction and that observed by the buoy had increased only marginally, but for wind speed it had increased substantially - to more than 6 knots. This was slightly greater than the comparison between forecasts and the other three anemometers. The number of occasions when observed winds were within the 5 knot forecast range had also decreased to 33%. The magnitude of the bias (the "over-forecast" component) had increased to 4 knots, and the correlation in wind speed decreased to 0.73.

With respect to the comparison of forecasts with buoy wind speed data, this trend continued in September. The RMS difference for wind speed increased to almost 8 knots, the bias in wind speed forecasts increased to more than 5 knots, and the percentage of "accurate" wind speed forecasts fell to 22%.

A "downward" trend in forecast performance was noted from the comparison with Port Stanvac data, but it was not nearly as dramatic. Reasons are not clear. One possible explanation is (as indicated previously), that due to its exposure over time to the elements, the buoy impellor is not responding fully to the wind, and is under-reading wind speed. However, a recent on site inspection of the buoy indicated that all components, including the impellor were in very good condition. Re-calibration of the instrument should provide the full answer to this.

Another explanation may lie in the lack of forecaster understanding of the behaviour of wind over the Gulf during the warmer months of the year. The phenomenon of stable stratification of the lower atmosphere over the sea which leads to "decoupling" of the wind flow from the sea surface has been acknowledged for years through visual observations, and reports from marine users. The onset and development of this phenomenon is however not well understood, and this makes the task of accurately forecasting marine winds more difficult than in colder months.

Summary

The deployment of the FGGE buoy in St Vincent Gulf South Australia has provided meteorologists at the South Australian Regional Office with marine environment data not previously available. For the first time ever, forecasters are able to monitor in near real time, wind speed and direction, air pressure and temperature, and sea surface temperature from a point in St Vincent Gulf which is representative of the southern part of the Adelaide metropolitan waters zone. This continuous feedback has already impacted positively on the confidence and quality of coastal waters wind forecasts.

Buoy Wind data has been compared to that from a standard anemometer at Port Stanvac Oil Refinery, 16 kilometres to the northeast of the buoy location. Wind data recorded from the buoy and Port Stanvac during June, August and September 1999 showed a correlation of better than 0.84. The RMS difference in wind speed was less than 1.5 knots, and for wind direction was less than 25^0. These results provide confidence that the buoy wind data are a close representation of wind conditions near the sea surface.

The buoy data have also provided the opportunity to objectively assess the accuracy of wind forecasts for the southern part of St Vincent Gulf. Comparisons indicated RMS errors between forecasts and observations of 4 to 5 knots in June, increasing to 6 to 8 knots in September. There was a systematic positive bias, indicating a tendency to "over-forecast". These results have been fed back to forecasters, and will continue as the part of a new coastal waters verification scheme.

Verification information such as this has never previously been available to forecasters in South Australia. It can only serve as being useful feedback information. Feedback like this, available soon after the fact, on a routine basis, and over an extended period, is a valuable part of the forecast process. It provides the forecaster with the necessary information to assess the quality of the forecast. This should be one of the vehicles by which forecasters acquire a better understanding of the interaction of the atmosphere with the marine boundary layer. The process hopefully will progressively lead to improved forecasts for the marine area.

The impact of drifting buoy data

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Operational forecasters and numeric modellers are well aware of the impact that a single observation can have on a synoptic analysis, and the effect that such observations can have on computer generated models. This paper reviews several investigations to assess the operational impact of drifting buoy data and answer the age old question of why deploy drifting buoys.

Introduction

Most operational forecasters or synoptic analysts can speak from experience and describe situations where a single observation has been sufficient to force a change in the way a synoptic situation was analysed. From my own experience I can recall one event where a single late ship observation was sufficient to force a substantial re-analyse over a vast area to the south of Australia to reflect a rapidly developing low pressure system.

Just as I relied on that single observation over fifteen years ago, forecasters today still depend on a relatively small number of marine observations in conjunction with satellite imagery to accurately analyse and describe the synoptic situation over the large ocean areas of the globe.

This paper reviews the impact of buoy data on operational meteorology within the Australian Bureau of Meteorology. It begins by summarising the results of the FGGE buoy data evaluation and then describes several recent investigations to further consider the impact of drifting buoy data.

Early buoy data evaluation

One of the earliest evaluations of the impact of drifting buoy data was by *Guymer and Le Marshall* and was based on two years of data from the First GARP Global Experiment (FGGE).

Their paper found the main impact of buoy data on operational use was that MSL analyses differed markedly from pre-FGGE analyses. There was both an increase in the number of intense low pressure systems below 960 hPa and an increase in the number of sub-tropical high pressure systems above 1030hPa. Mean monthly MSL pressure charts showed the average depth of the circumpolar trough increased by 14hPa and the sub-tropical ridge was more intense producing much stronger north-south gradients. There was also a greater amplitude in the mean monthly trough-ridge pattern.

The paper concluded that as a result of the analysis changes, there was a corresponding performance improvement in the numerical models.

Western Australian investigation

An investigation (unpublished) was conducted in 1997 by meteorologists in the Western Australian Regional Forecasting Centre as a practical attempt to illustrate the usefulness of drifting buoy data.

Western Australia is the largest state of Australia and bordered to the north and west by the Indian Ocean, and to the south by the Southern Ocean. Surface marine observations are considered crucial in supplementing satellite imagery of mid and high latitude systems approaching the coast, and even tropical cyclones at low latitudes. It was this reliance on marine observations, and in particular data from drifting buoys, that prompted their investigation.

The initial synoptic situation consisted of a deep low pressure system at high latitudes over central Indian Ocean longitudes with an associated cold front extending northwards to mid latitudes. A ridge of high pressure extended from southern Australia across the Indian Ocean. A high pressure system was located over the western Indian Ocean longitudes. Minor frontal systems were embedded in the westerly stream.

The investigation comprised five stages made up of three analysis phases and two assessment phases.

Stage 1 was reminiscent of the way that meteorologists and analysts operated before the advent of satellite imagery and drifting buoys. The meteorologist was required to analyse the Indian Ocean Mean Sea Level Pressure (MSLP) chart restricted to SYNOP and SHIP observations only. The previous analysis was available for guidance. The resultant analysis is shown in Fig 1.

Stage 2 introduced the latest satellite image, see Fig 2. The meteorologist was required to analyse the Indian Ocean MSLP chart, again restricted to SYNOP and SHIP observations only. The previous analysis and the latest satellite image were available for guidance. The resultant analysis is shown as Fig 3.

Stage 3 was an analysis of the Stage 2 - Stage 1 grid point differences. The results are shown in Fig 4. The major differences occur about in the vicinity of the Indian Ocean low pressure system with an area of +10hPa due to the re-positioning of the centre of the low pressure system based on the satellite image. The satellite image also infers less ridging over the western Indian Ocean which translates to an overestimate of 20 hPa (-20) in the Stage 1 analysis. The ridging to the south of Australia is also considered to be overestimated by 10hPa (-10).

Stage 4 introduced BUOY observations. The meteorologist was required to analyse the Indian Ocean MSLP chart with no restriction on surface observations. The previous analysis and the latest satellite image were available for guidance. The resultant analysis is shown in Fig 5.

Stage 5 was an analysis of the Stage 4 - Stage 1 grid point differences. The results are shown in Fig 6. The BUOY observations help to locate the central pressures of the systems over the Indian Ocean and show the extent of ridging on either side of the major Indian Ocean frontal system. The low is re-positioned to the southeast and results in a moderate difference of +4 hPa. The high pressure system over the western Indian Ocean is also re-positioned further to the southeast resulting in a difference of +6hPa. The BUOY observations confirm the ridging over the western Indian Ocean analysed in Stage 1 was overestimated by 20hPa (-20). The BUOY observations also confirm the ridging preceding the major Indian Ocean frontal system is overestimated by 12hPa (-12).

Although this investigation was fairly simple, and noting that every analysis is subjective, it has however demonstrated in a practical manner, the benefit of drifting buoy observations over data-sparse ocean areas as a supplement to SYNOP and SHIP observations as well as providing ground truth for satellite imagery.

The results can be summarised as follows:

- conventional surface based observations in the form of infrequent SHIP reports and isolated SYNOP from island stations are insufficient on which to base an accurate synoptic analysis.

- satellite imagery provides very good guidance in detecting pressure systems and low level flow, however it cannot be relied on in isolation to accurately locate the centres of pressure systems or estimate the central pressures of systems.

- drifting buoys improve the spatial (and temporal) density of surface based observations over otherwise data-sparse oceanic areas.

- the most complete and accurate analyses includes all three observing systems previously described; (1) SYNOP and SHIP, (2) satellite imagery and (3) BUOY.

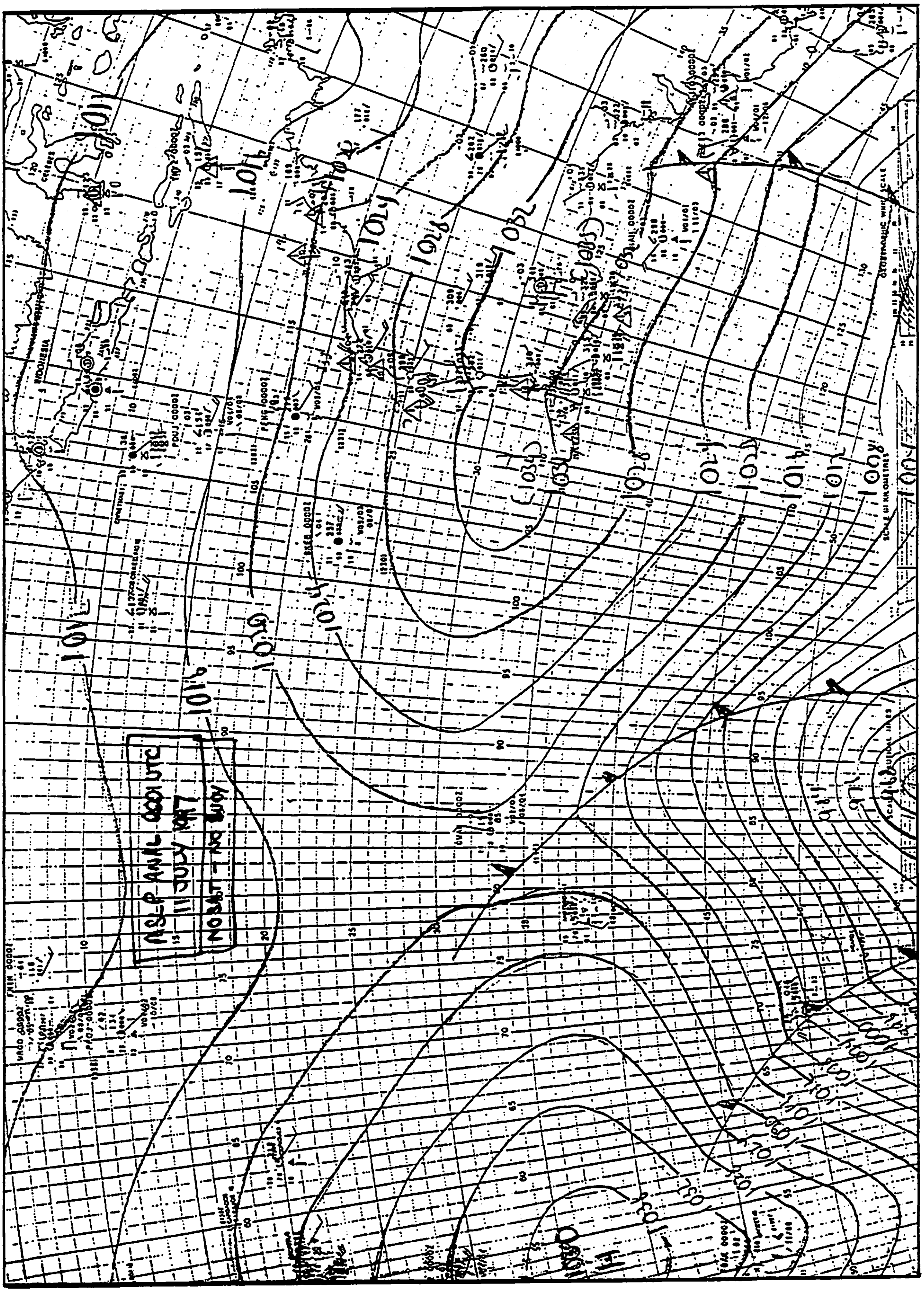

Figure 1. Stage 1, using SYNOP and SHIP and previous analysis only.

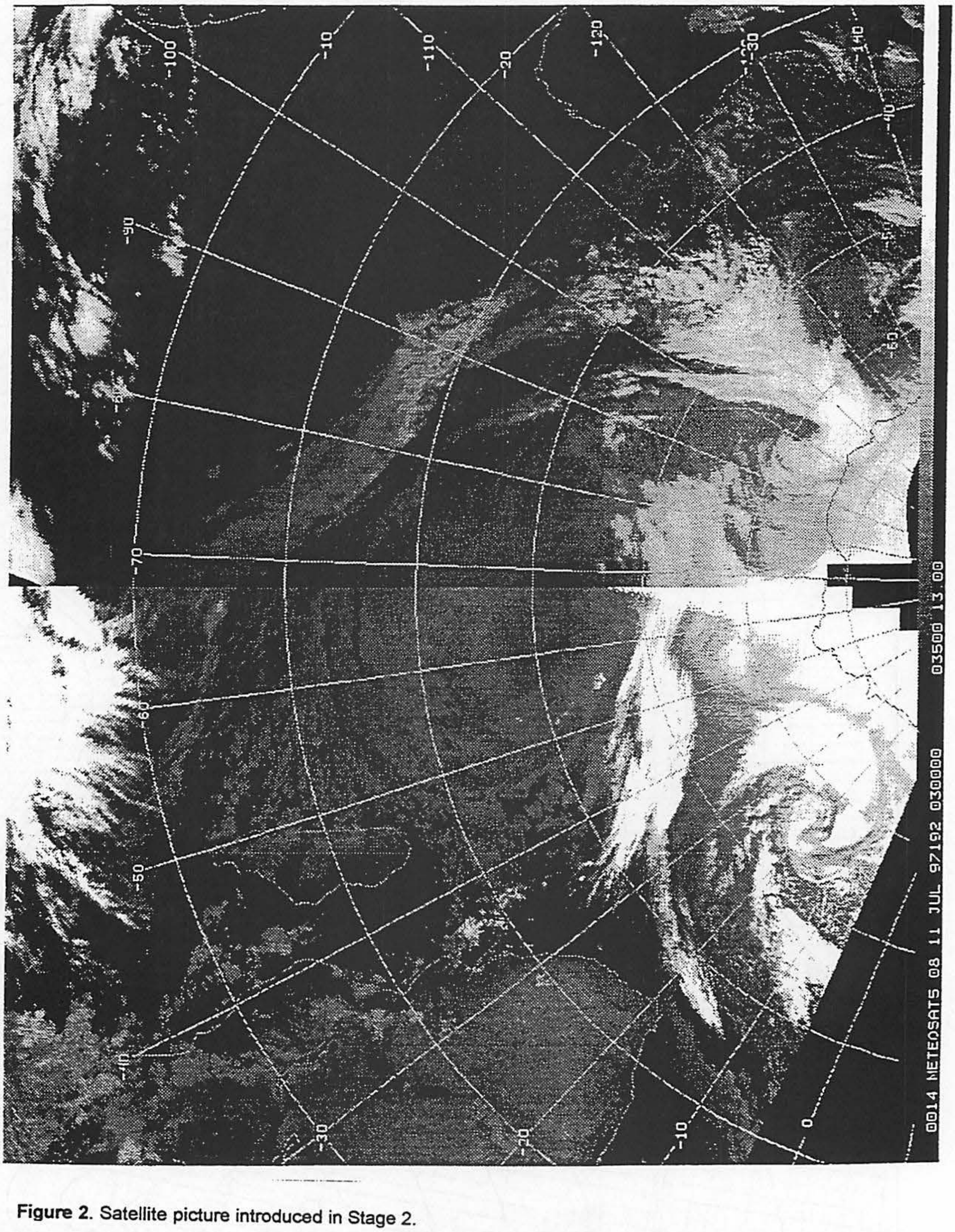

Figure 2. Satellite picture introduced in Stage 2.

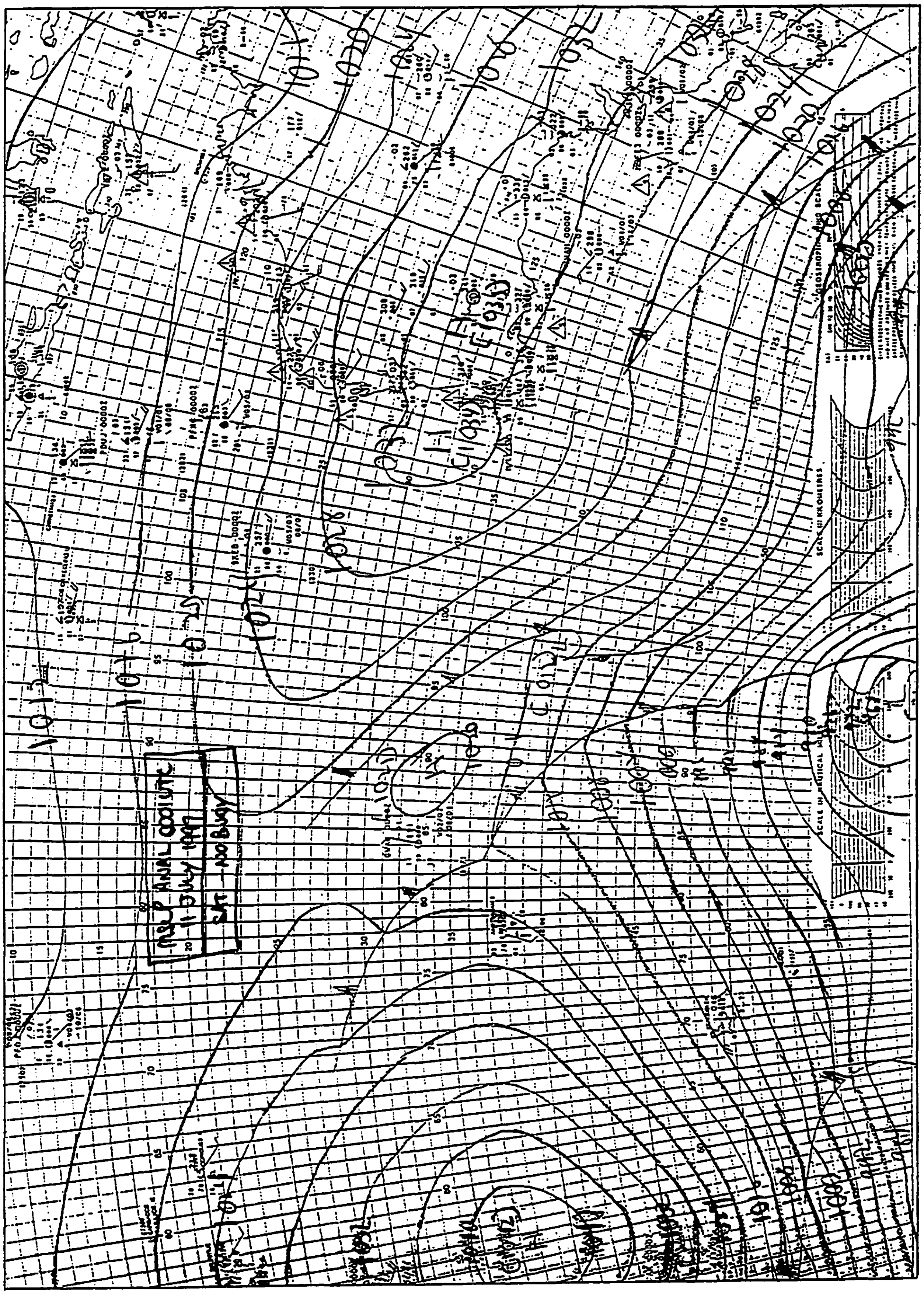

Figure 3. Stage 2, using SYNOP and SHIP, and satellite image and previous analysis.

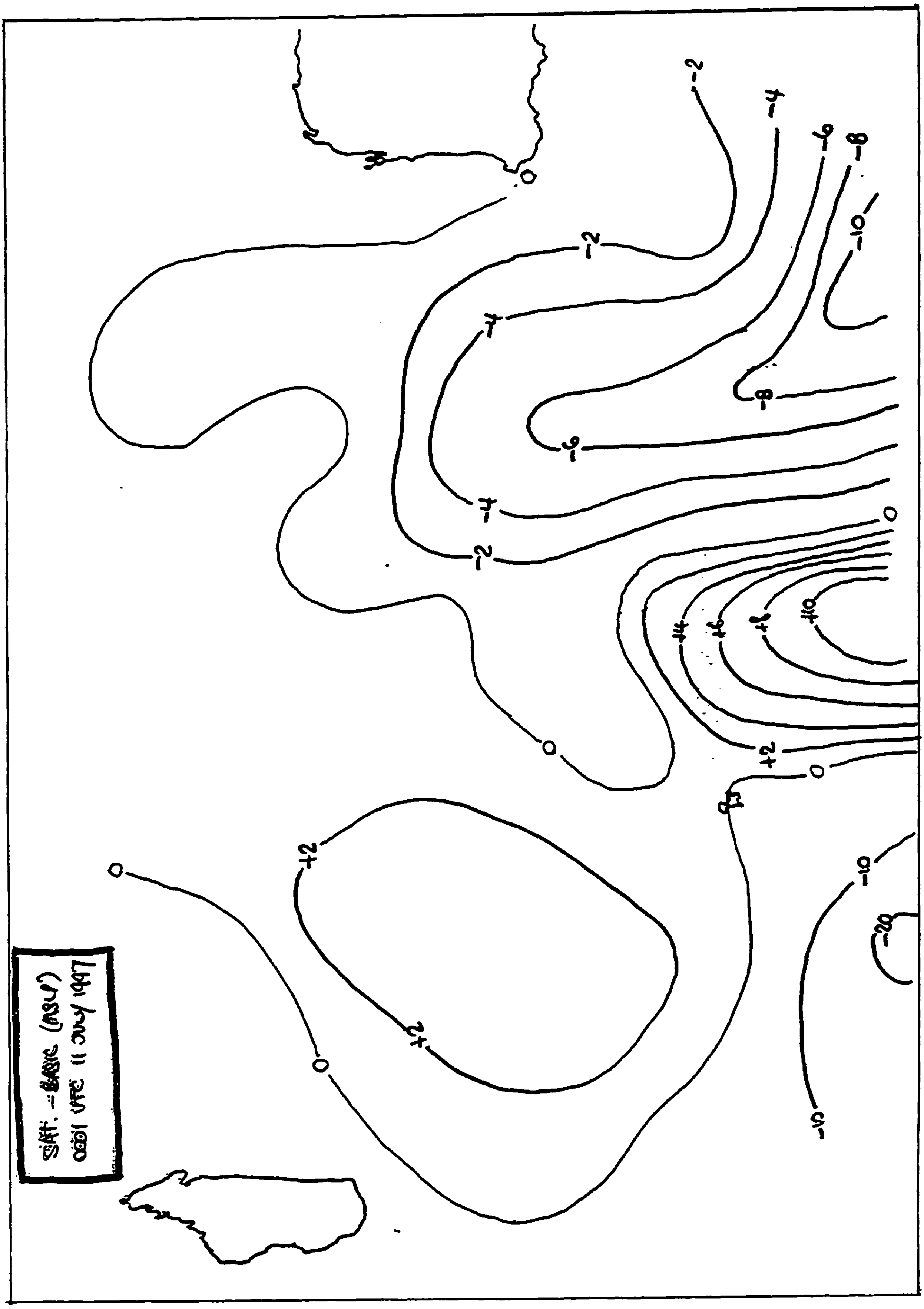

Figure 4. Stage 2 - Stage 1 MSLP grid point differences (hPA.), range - 20 to + 10

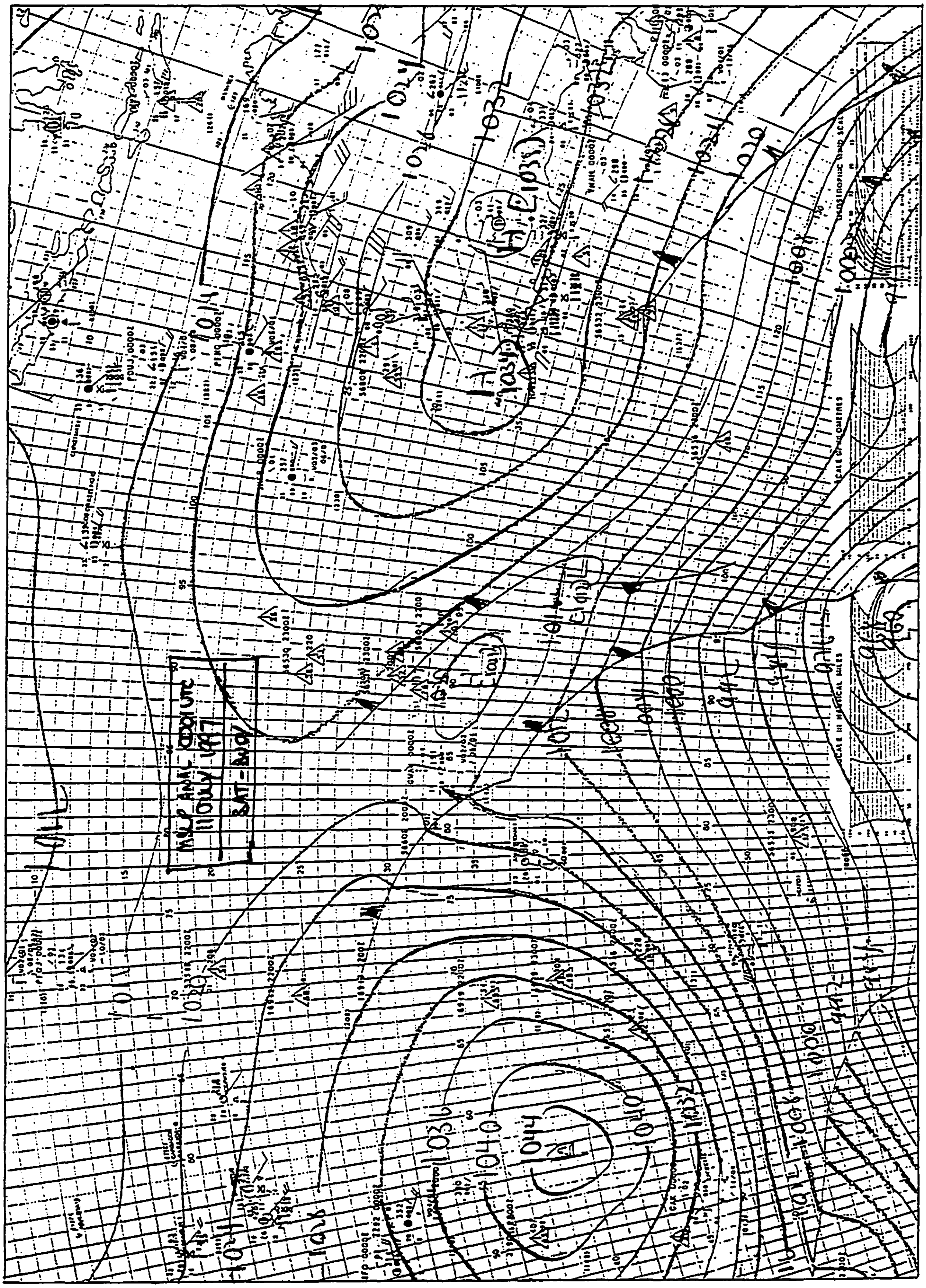

Figure 5. Stage 4. using SYNOP, SHIP and BUOY, satellite picture and previous analysis.

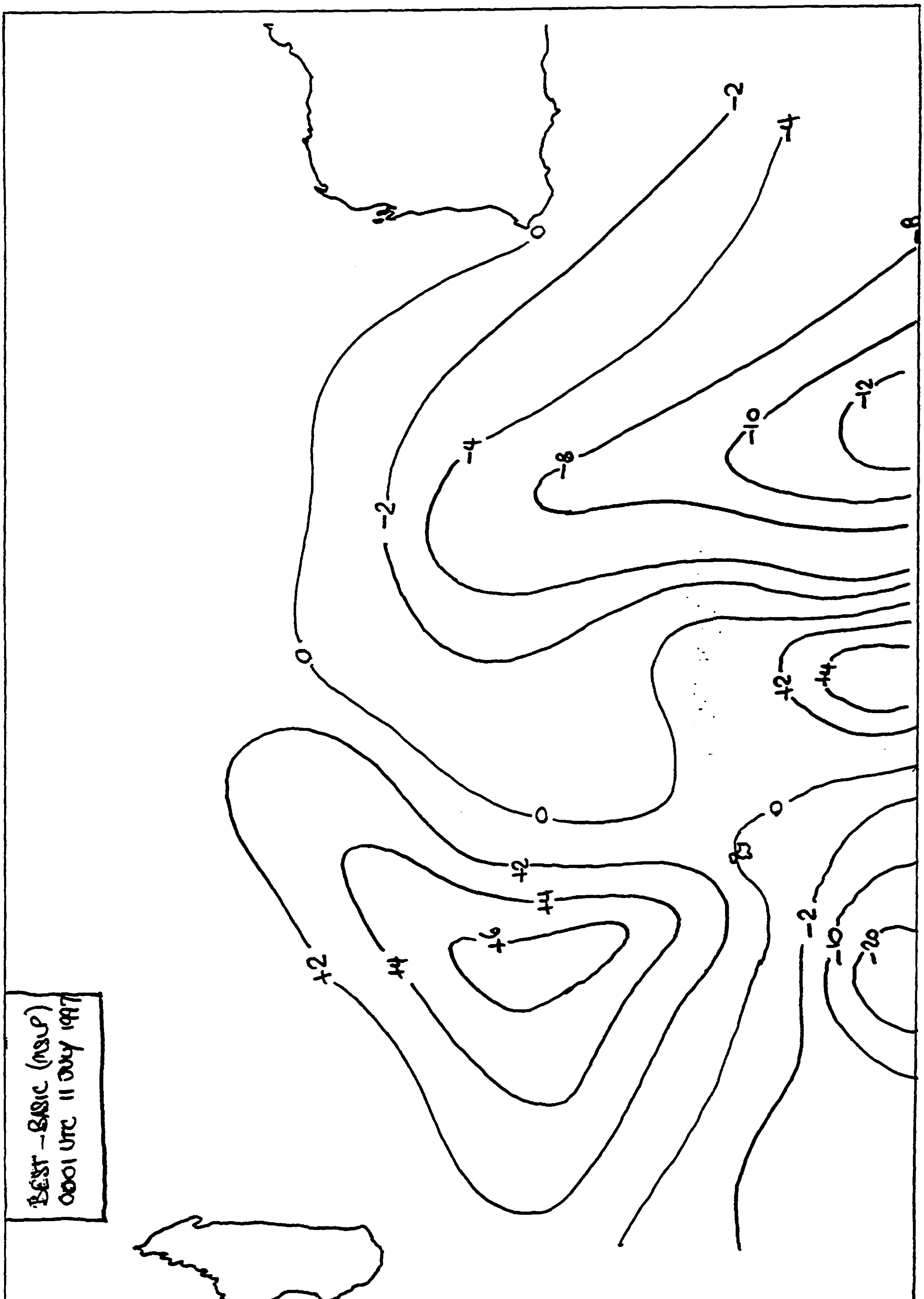

Figure 6. Stage 4 - Stage 1 MSLP grid point differences (hPA.), range - 20 to + 6

Seaman's investigation 1

The second investigation was conducted by Mr. R. S. Seaman from the Bureau of Meteorology's Research Centre in 1993, and showed the quantitative effect that drifting buoys have on analyses and data assimilation.

Seaman's paper introduced a concept termed 'analysis impact assessment', described as the difference between the (numerical) analysis using the observation and the (numerical) analysis not using the observation. It is beyond the scope of this paper to describe the methodologies and techniques used in the impact assessment.

Of interest however are some examples which demonstrate impact assessments implemented in the Bureau's global data assimilation system. At each synoptic analysis time, the impact assessment is calculated on every sea-level pressure value. The magnitudes of the impacts are sorted and those representing the ten largest Southern Hemisphere impacts listed. This indicates the ten data that individually were the most influential at the time. The listing for 1700 UTC, 22 June 1993 is shown in Table 1.

Station	Latitude	Longitude	Impact (hPa)
Buoy 33021	59.5	332.7	- 4.5
Young I.	66.3	162.3	4.3
Marion I.	46.9	37.9	- 3.7
Macquarie I.	54.5	158.9	3.4
Grytviken	54.3	323.5	- 2.9
Buoy 71552	61.0	48.7	- 2.4
Port Moresby	9.4	147.2	- 2.2
Buoy 33835	57.8	0.6	- 2.0
Buoy 71554	57.2	49.4	2.0
Amsterdam I.	37.8	77.5	2.0

Table 1. The top ten southern hemisphere sea-level pressure impacts at 1700 UTC, 22 June 1993.

In this particular case, most of the stations were in data-sparse areas. This is not always the case and depends on the whether the background field is in good agreement with the isolated observation. As a general rule though, impacts should be less in a data-dense area because of the data redundancy and background fields.

(Mr. Seaman confirmed at the time of preparation of this paper, that drifting buoys continue to occupy between 25% to 50% of stations in the top ten sea level pressure impacts.)

On the basis of the previous discussion, Seaman goes on to say that observing platforms deliberately deployed in data-sparse areas should figure prominently among the larger impacts. This is confirmed in an analysis of the impacts taken over a period of one month. Table 2 shows that drifting buoys appear in the June 1993 top-ten with a much higher frequency in proportion to their total numbers.

Synoptic observation	1100 UTC				2300 UTC			
Observation type	Synop	Ship	Buoy	PAOB	Synop	Ship	Buoy	PAOB
average number per synoptic time	857	93	78	224	959	100	88	224
average occurrences in top ten	4.17	0.34	2.58	2.90	3.52	0.38	3.07	3.03
relative likelihood of appearing in top ten	1.00	0.76	6.81	2.66	1.00	1.03	9.48	3.70

Table 2. Average numbers of southern hemisphere sea-level pressure data types at the major synoptic times and average occurrences in the top ten most influential sea level data, based on 29 days during June 1993. PAOBs are manual bogus data.

Figure 7 shows a typical 1100UTC plot of surface observations comprising SYNOP, SHIP and BUOY reports. Superimposed on this plot are the 20 platforms reporting sea-level pressure (out of a total of 1200 at the major synoptic times) that had the greatest RMS impacts on Southern Hemisphere sea-level pressure analyses during June 1993. Thirteen of the twenty stations are land based in data-sparse areas, the remaining seven are drifting buoys.

Seaman's investigation 2
As a separate exercise, Seaman provided computer generated Southern Hemispheric charts centred over Antarctica, showing the differences between the operational analyses run with and without buoy data.

This review was conducted from 19 May 1999 to 13 June 1999. Table 3 lists all occasions during this period when removing the buoy data impacted on the operational analyses by 10hPa or more.

Fig 8 shows the difference chart for 2300UTC, 11 June 1999. The impact of buoy data is clearly demonstrated in this 'worst case' example where the analysis differences ranged from -7 to +16 hPa.

In all cases during the period of review, the areas of extreme difference were located in close proximity to Antarctica. This clearly demonstrates both the inadequacy of the Antarctic synoptic network and the importance of drifting buoys for analysis and model initialisation.

Chart Date	operational minus no buoys (contour range)
May 24, 2300UTC	- 6 to 15
May 25, 2300UTC	- 5 to 16
May 26, 2300UTC	- 12 to 5
May 28, 2300UTC	- 11 to 3
May 29, 2300UTC	- 5 to 13
May 31, 1100UTC	- 4 to 16
May 31, 2300UTC	- 7 to 15
June 1, 2300UTC	- 10 to 4
June 11, 2300UTC	- 7 to 16

Table 3. Results of operational analysis minus no buoy data

Conclusion
In an age where the spending of public money comes under close scrutiny and questions are regularly asked about worth of drifting buoys, this report confirms the operational value of drifting buoys which was first recognised by the Bureau of Meteorology during FGGE.

The impact of drifting buoys can be assessed by comparing analyses with and without buoy observations, and holds true for both manual and numeric products. Three investigations were presented and the results are summarised as follows:

- Infrequent SHIP and isolated SYNOP reports are insufficient to completely and accurately analyse the synoptic situation.
- Synoptic features can be detected by satellite imagery but without surface based observations to provide ground truth, the position and intensity of the system may not be accurate.
- Drifting buoys continue to figure prominently in the day-to-day top ten sea level pressure impacts in the Bureau's global data assimilation scheme.
- The disproportionate frequency of buoys in the day-to-day top ten impacts is due in part to the deliberate deployment of buoys in data-sparse areas.

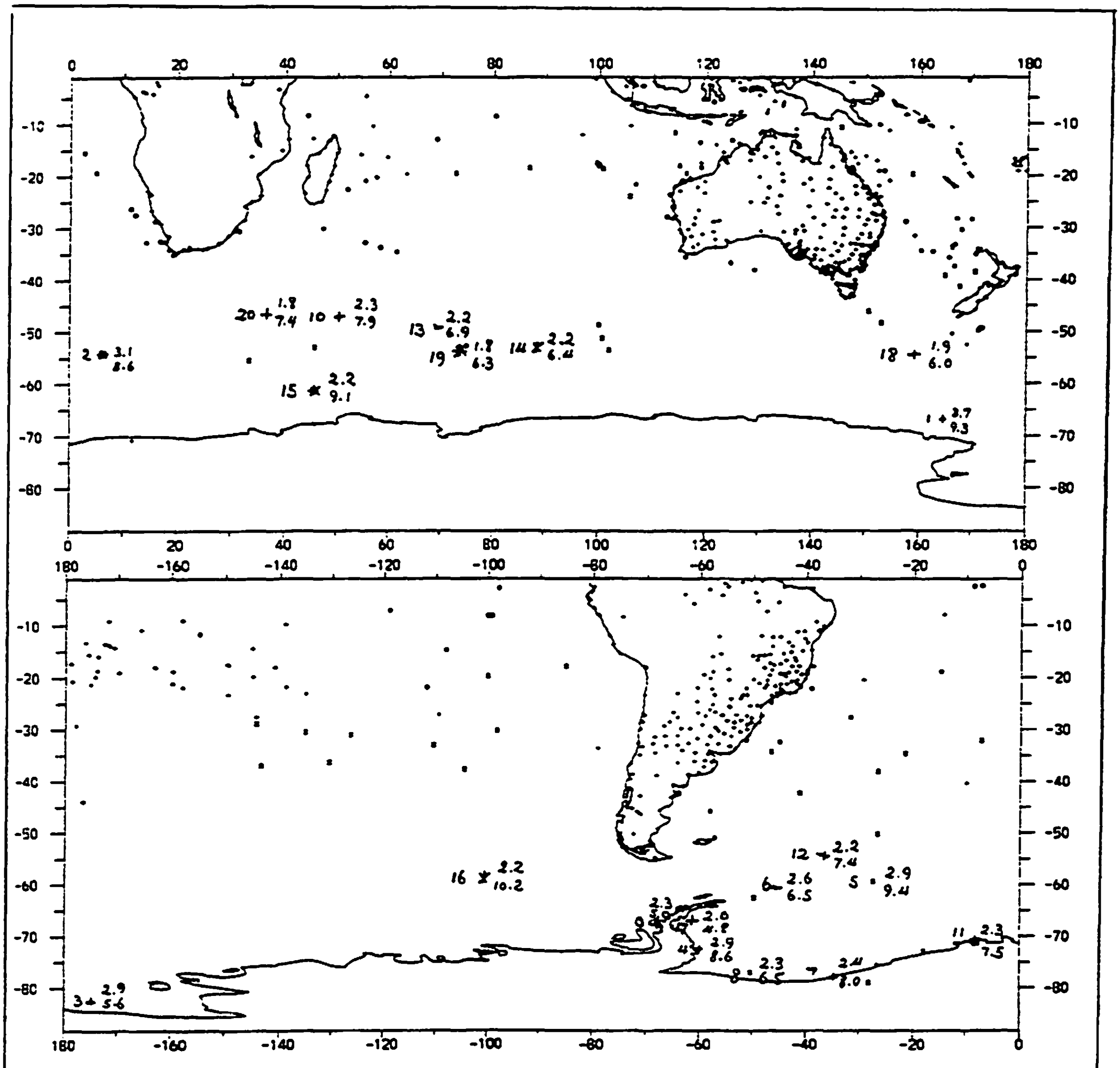

Figure 7. The largest 20 Southern Hemisphere rms sea-level pressure impacts during 1993, superimposed on a typical 1100UTC network of SYNOP, SHIP and BUOY reports. The number to the left of each location is the impact ranking, the upper number to the right is the rms impact (hPa) and the lower number to the right is the extreme impact. Key: + = SYNOP, * = BUOY and o = SHIP.

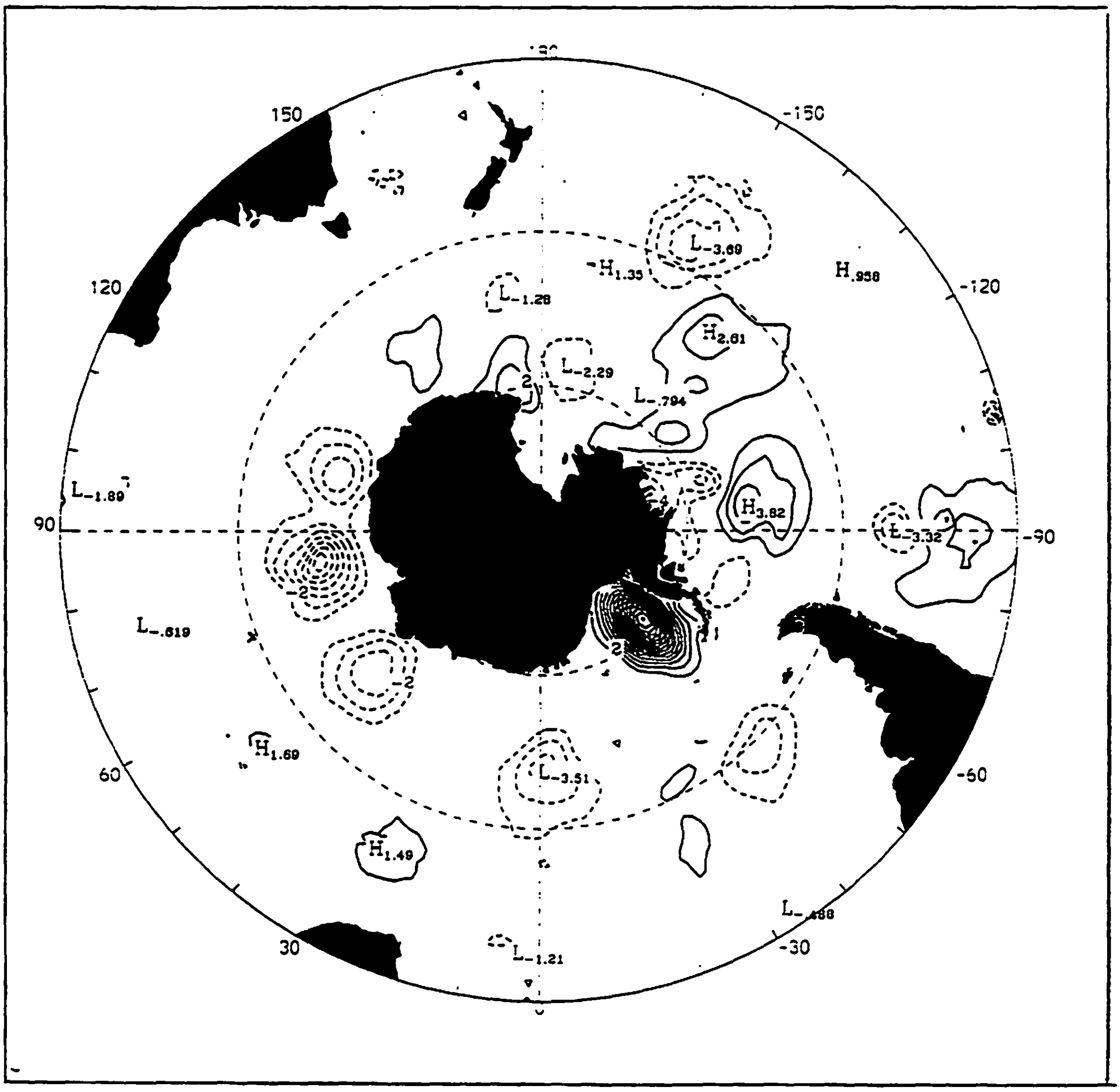

Figure 8. Sea-level pressure differences, operational minus no buoy data, for 2300 UTC 11 June 1999. Contours between -7 to + 16 (hPa) by 1.

Acknowledgement
The author acknowledges the work and cooperation of the Western Australian Regional Forecasting Centre and Mr. Seaman in the preparation of this paper. Thanks are also extended to Dr. R. Canterford and Mr. D. Evans for comments on earlier drafts of this paper.

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NEW PHASE OF DRIFTER EXPERIMENT IN THE BLACK SEA

by

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Introduction

The Black Sea is of interest to the European Community because of its crucial economic significance for six independent states of Eastern Europe and the Former Soviet Union, namely, Turkey, Bulgaria, Romania, Ukraine, Russia and Georgia. Among all the Mediterranean Sea basins, the Black Sea has the poorest ecological conditions, as a result of its limited water exchange with other basins, weak vertical mixing due to the strong density stratification and enhanced contamination by river discharge, city and tourist resort wastes, and oil and other discharges from shipping and oil terminals. Because most of the contamination is coming from coastal and shelf regions, processes of horizontal mixing and shelf – open sea exchange are of paramount importance. However, so far these processes have been poorly studied.

The generally accepted scheme of the large scale Black Sea circulation consists of a closed persistent cyclonic gyre, called Rim Current, that flows generally above the outer edge of the continental slope and separates the shelf region from the central open sea (Altman et al., 1990). According to this scheme, based on hydrological ship-borne data, very limited horizontal mixing occur. Satellite thermal and color images, however, have revealed the existence of substantial mesoscale eddy variability in the entire Black Sea, including the Rim Current itself which probably is one of the source of such variability. Satellite data show that the circulation in the surface layers of the Black Sea and the associated physical and biological processes are considerably more complicated than those described from geostrophic motions, based on traditional hydrological data sets (Fedorov and Ginzburg, 1988; Ginzburg, 1994, 1995). The concentration of various admixtures and supply of nutrients in the near-surface layer are determined by horizontal and vertical water eddy structures such as vortices, vortex dipoles and multi-poles, filaments and jets. These structures easily penetrate across the Rim Current zone and are responsible for the effective exchange between the shelf region and the open sea. So, it is possible to speculate that the Rim Current is actually not very persistent in space and time and that most of water parcels are not simply advected by the closed large scale cyclonic circulation but rather have complicated trajectories controlled by mesoscale variability.

One of the best modern tools to study the motion of water parcels in the upper mixed layer are satellite-tracked Lagrangian drifters (Global Drifting Buoy Observations, 1999). In September 1999 six such drifters were launched in the northeastern Black Sea in order to study the surface water dynamics with main focus on the mesoscale circulation features. The Black Sea 99 drifter experiment was organized as a part of a complex scientific study of the Black Sea ecosystem and of the shelf – deep basin interactions conducted by Russian oceanographers from P. P. Shirshov Institute of Oceanology, Russian Academy of Sciences (Moscow) on the R/V "Akvanavt" (length - 34 m, load displacement - 273 m^3, cruising speed - 7.5 kn, number of scientists on board – 10) in collaboration with specialists from other Russian Institutes and Universities and with Ukrainian scientists, particularly, from the Marine Hydrophysical Institute of National Academy of Sciences of Ukraine (MHI NASU, Sebastopol). The main strategy of the Black Sea 99 expedition was based on the joint application of satellite imagery, satellite-tracked drifters and hydrographic, chemical and biological surveys of selected mesoscale structures. This modern strategy has never been used in Black Sea studies.

The aim of this paper is to present some brief information on the strategy and preliminary results of the Black Sea 99 drifter experiment. In order to put these new observations in context, previous Lagrangian explorations of the Black Sea circulation are first summarized.

History of drifter investigations in the Black Sea

The first drifter experiment in the Black Sea was organized in 1987. A total of fourteen surface floats, called LOBAN, were used during a period of ten years from 1987 to 1997 (Motyzhev, 1996, 1998). The LOBAN buoy design had its wet center of mass about one meter beneath the water surface. This drifter had a drag area ratio of about 28, and thus it could be considered as a quasi-Lagrangian buoy. The lifetime of the LOBAN buoys did not exceed three months, while they had a theoretical lifetime of 150 days. The buoys stopped transmitting useful data prematurely mostly because they were washed on shore or were picked-up by seafarers. The buoy data were transmitted via the Cospas/Sarsat space communication system (in the test format of message) or the Russian system Course. These systems are similar the Argos tracking onboard the NOAA satellites.

The major goal of the experiments using the LOBAN drifters was to monitor, over a relatively long time period, the Rim Current all along the perimeter of the Black Sea. Such observations were obtained in concert with the monitoring of the sea surface temperature (SST) by means of satellite infra-red radiometers (AVHRR) on board the NOAA satellites. Joint analysis of drifter data and satellite thermal images of the sea surface have shown that the summer dynamics of the Black Sea differ significantly from the winter ones.

The summer drifter trajectories revealed very active mesoscale variability of the currents and the intermittent character of the Rim Current. Due to the small cloud activity numerous satellite SST images were obtained on a regular basis and it was possible to identify the influence of the "thermally visible" mesoscale structures on the drifter displacements. It was shown that most of the mesoscale structures disclosed in the satellite SST images were actually dynamical features associated with strong circulation features (cyclonic and anticyclonic eddies, jets, filaments etc.) revealed by the drifters. It became clear that a joint analysis of satellite SST images and Lagrangian drifter trajectories is a powerful tool for the investigation of the Black Sea mesoscale dynamics.

The winter observations of the drifter trajectories revealed the existence of a strong cyclonic Rim Current and rather weak mesoscale dynamics. The satellite thermal observations were limited because of the frequent cloud cover over the Black Sea.

The small depth of the LOBAN drifters only allowed to study the surface currents. However the surface currents are strongly affected by wind and waves. Sometimes they differ significantly from the subsurface or the upper layer currents that include most of the dynamic features at large and mesoscales. The investigation of deeper ocean currents with Lagrangian drifters became possible when more modern satellite-tracked drifters – the SVP drifters with a holey-sock drogue about 15 meter beneath the water surface - were developed about a decade ago (Sybrandy and Niiler, 1991). The SVP drifter design was used to study near-surface mixed layer currents in many parts of the World Ocean and in some marginal seas, but was never operated in the Black Sea. The possibility to use SVP-type drifters for the investigation of the Black Sea upper layer currents during the Black Sea 99 expedition was achieved due to the international scientific collaboration between Russian, Turkey, Ukrainian and American scientists. Among the 6 drifters deployed in September, 1999, three of them were manufactured by Marlin Company (MHI NASU), Sebastopol, Ukraine (referred hereafter as the "Ukrainean drifters") and the other three were kindly presented by Dr. Peter Niiler

(USA) to the P. P. Shirshov Institute of Oceanology (called "American drifters"). The satellite tracking of all these drifters during more than 3 months was made through the Argos Data Location and Collection System (DCLS) kindly supported by Dr. Pierre-Marie Poulain (USA). The main technical parameters of the drifters are presented in the table below.

№	Parameters	American drifters (a)	Ukrainian drifters (b)	Remarks
1	Buoy Description	Eight MetOcean SVP standard drifters were manufactured in 1990. In 1999 Dr. Peter Niiler (USA) kindly presented them to the P. P. Shirshov Institute of Oceanology. Three of these buoys were prepared for the Black Sea 99 experiment (replacement of batteries) in Moscow.	Three Marlin SVP drifters were constructed in August 1999. Their lifetime was limited by programming the transmitter (PTT) to shut off after about 90 days. At the request of Shirshov Institute the buoys were not equipped with any sensors and could only be used for the tracing.	
2	Argos ID	17483 17486 17491	17430 17431 17432	
3	Self-contained power supplies	2×10=20 Alkaline-Manganese Dioxide Batteries, MN1300, Size:D, which were directly connected to the buoy's electronics.	3×8=24 Alkaline-Manganese Dioxide Battery, MN1300, Size:D of DURACELL Inc., which were connected to the buoy's electronics via the High Efficiency Switching Regulator.	+20% power for buoys (b)
4	Lifetime	Limited by the power of batteries.	93 days, as programmed in the transmitter (PTT) software	
5	Power of transmitter	1.9±0.2 W	1.2 ±0.1 W	
6	Antenna	Narrow-band short antenna with an inductive insert and additional condenser.	Rod antenna close to a quarter wave vibrator with an inductive transformer coupling and capacitive load.	
7	Antenna base	Metallic iron circle finding approximately on the level of water in a spacehold.	Plastic disc with copper cover disposed above the level of water in a spacehold.	

Preliminary results of the Black Sea 99 drifter experiment

The modern strategy and methods of observations that were used during the Black Sea 99 expedition made it possible to obtain innovative results on the mesoscale dynamics and on its role in the eco-system functioning and pollution transport in the northeastern Black Sea. Previously it was considered that the mesoscale variability mainly exists in the near-shore and Rim Current zone and that it is absent in the central part of the sea where the circulation is rather stable and mainly cyclonic. Particularly two cyclonic sub-gyres were thought to be quasi-permanent features of the central part of the Black Sea: The Eastern gyre (to the east of Crimea peninsula) and the Western gyre (to the west of it). The analysis of satellite SST images in August-September 1999 revealed the existence of an unusual anticyclonic circulation feature in the center of the eastern part of the sea. This anticyclonic eddy formed a large vortex pair (about 150 km in the cross section) with a cyclonic eddy located to the north of it and closer to the Rim Current (Fig. 1). It was decided to focus the investigation efforts of the Black Sea 99 expedition on this vortex pair or dipole. During the first phase of the expedition (25 – 30 September) the hydrological (physical, chemical and biological) survey of this dipole structure and adjacent areas was carried out. During the survey 6 SVP drifters were deployed into and near the dipole structure: two in the anticyclone, two in the cyclone and last two drifters just in front of the structure. During the first four days after deployment, all six drifters were successfully tracked by the Argos satellite system. The deployment locations and the 4-day long trajectories are shown in Fig.1, superimposed on the AVHRR channel 4 image of 29 September. The regions of anticyclonic and cyclonic rotation are clearly distinguished in the satellite image. According to the drifters the typical orbital velocities in the anticyclone are 15 – 20 cm/s, and in the cyclone 25 – 30 cm/s (at the outer edge near the Rim Current). The currents just in front of the dipole structure were two or three times weaker. Approximately the same velocity magnitudes in the dipole eddy structure were calculated using the geostrophic approach (Fig 2).

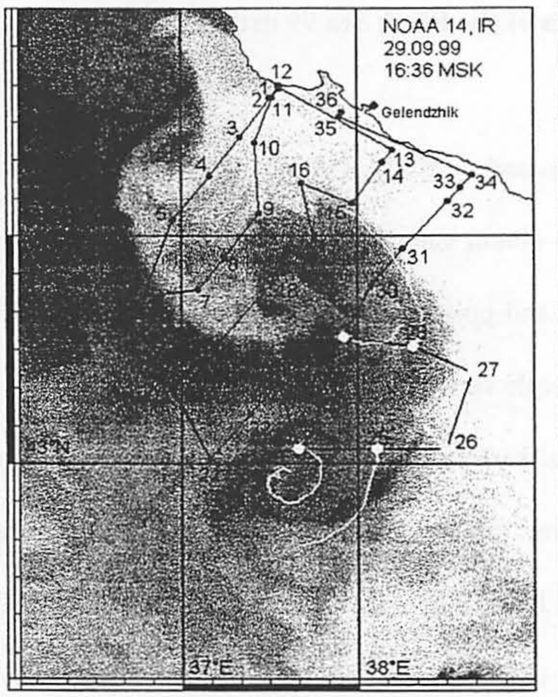

Fig. 1. AVHRR Ch4 image of the northeastern Black Sea on 29 September. Dark (bright) gray shades indicate cooler (warmer) temperatures. Ship track and stations are depicted with black lines. Drifter deployment locations and 4-day long tracks are shown with white dots and lines, respectively.

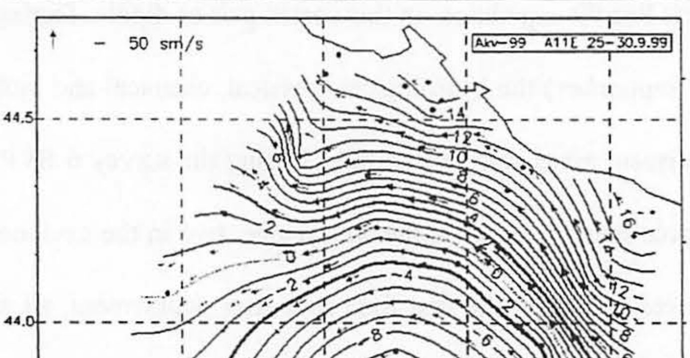

Fig. 2. Surface dynamic height (solid contours) relative to 500 db and geostrophic velocities (arrows) in the northeastern part of the Black Sea (R/V "Akvanavt", 25 – 30.1999).

After 4 days from the deployment date, two of the "American" drifters (PTT numbers 17483 and 17486) failed to transmit for some unknown reason. The remaining four drifters (3 Ukrainian and 1 American) were tracked by Argos until the end of the year 1999. They revealed very complicated trajectories of long term upper layer water displacement (Fig 3). As we can see in Fig. 3, one of the drifters that was deployed near the center of the anticyclonic part of the dipole structure was trapped by the eddy for more than 2 months (trajectory 1). The two drifters that were deployed into the cyclonic part of the structure left it very soon and were entrained into the Rim Current (trajectories 2 and 3). They moved westward, one following the other by about one week, and followed approximately the same path as far west as the tip of the Crimean Peninsula. Then they reached a region of high mesoscale activity. The first of them (trajectory 2) turned to the north moving from the deep open sea towards the coast. It crossed the shelf break but soon after that returned to the deep sea via a cyclonic loop. Subsequently, it moved straight to the south and in ten days reached the center of the western part of the sea. The second of them (trajectory 3) was trapped by the so-called "Sevastopol Anticyclonic Eddy" during one and a half period of rotation. After it left the eddy and, through a cyclonic reversal, moved to the south approximately along the same path as the previous drifter and eventually reached the center of the western part of the sea. The last long-lived drifter (trajectory 4) that was deployed just in front of the dipole structure moved very slowly (less than 8 cm/s) for about 40 days (first to the south and than to the east) until reaching the Rim Current. After that it accelerated and moved very fast (50 – 60 cm/s) in the northwest direction, crossing the shelf-break near Novorossiysk. It was within one mile of the coast for about one day. Fortunately, it was not trapped by the shore and left the narrow (width of a few miles) Novorossiysk shelf zone to move into the much wider Kerch shelf zone. The latter is sometimes considered as the site of strong anticyclonic mesoscale activity (Ginzburg, 2000). The complicated drifter trajectory basically supported this fact. After several reversals followed by the crossing of the shelf-break in both directions, the drifter left the near-shore area and moved to the southwest from the Crimean Peninsula towards the center of the western part of the sea (it reached it in the middle of December 1999). It is remarkable that the three drifter trajectories converged and intersected in that area. Also, it is remarkable that the central western Black Sea, like in the central eastern region, is a area of high mesoscale activity with predominance of anticyclonic circulation features. Such results are very unusual and surprising. Finally all drifters except the last one (trajectory 4) left both centers of the eastern and western basins. This fact may be regarded as the signature of reorganization of the large and mesoscale circulation features from the summer type to the winter type. Unfortunately the three Ukrainean drifters were automatically switched of at the end of the year 1999, so it is not possible to substantiate the last assumption with additional drifter observations.

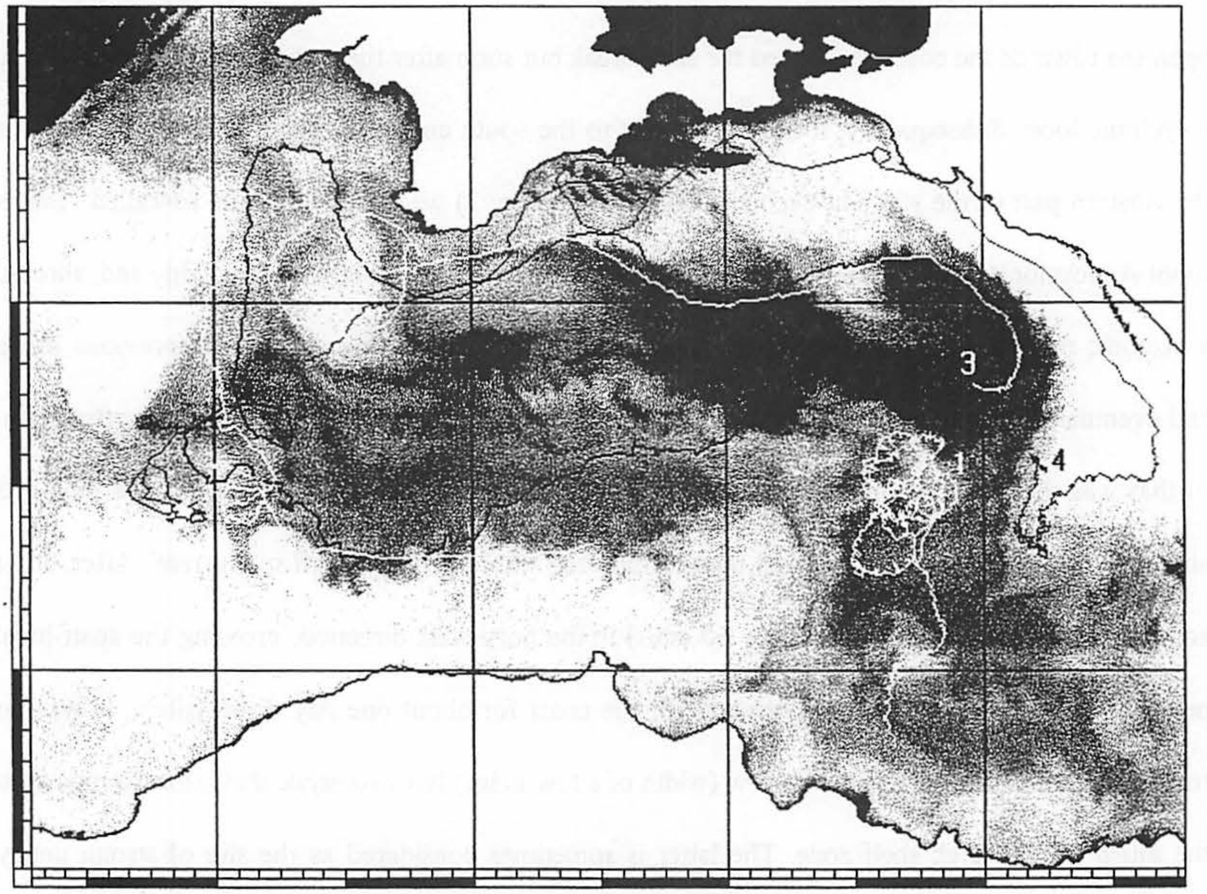

Fig.3 AVHRR Ch4 image for December 2 with drifter trajectories for time period 29 Sep. –31 Dec. 1999. Relative cooler (warmer) temperatures are represented with darker (brighter) gray shades.

The drifter data obtained allowed to estimate the typical temporal periods of the dynamical processes. Fig. 4 shows the high frequency portion of the power spectrum for the zonal velocity of drifter 17430 (first 1000 hours). The inertial (~17 hours) and diurnal tidal (24 hours) bands are well detected.

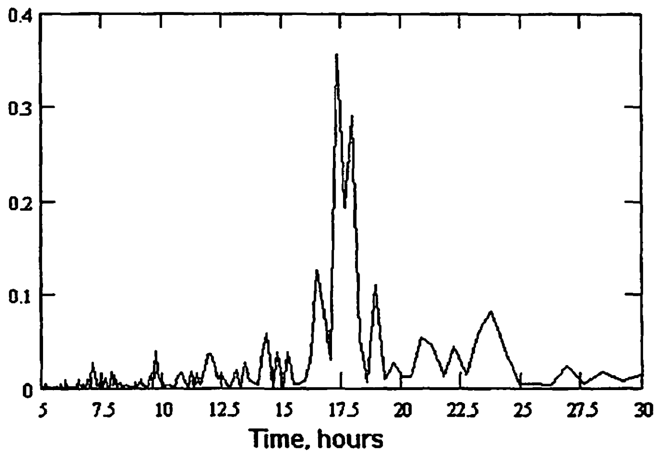

Fig.4 Power spectrum for zonal velocity of drifter 17430.

Conclusions and recommendations

1. The joint application of satellite imagery, satellite-tracked drifters and hydrographic surveys is a powerful strategy for the investigation of selected complex mesoscale dynamical structures. This modern strategy has been used successfully used for the first time in September 1999 to study the mesoscale variability and associated cross-shelf transports in the northeastern Black Sea.

2. In summer and autumn the mesoscale dynamics are prevailing, not only in near-shore and Rim Current regions, but also in the central parts of the Black Sea. It contains long-lived coherent structures (like the pair of vortices with an anticyclone in the central eastern Black Sea and a cyclone

north of it), so the mesoscale field may be not chaotic, but is rather well organized and thus, interact effectively with the large scale dynamics.

3. Drifter trajectories demonstrate that the large scale currents in the Black Sea are not smooth and do not necessary follow the isobaths as was usually stated before. Evidently, the western gyre did was not strong in fall 1999, so that the drifters were able to cross the western part of the sea in its central part.

4. The potential vorticity gradient induced by steep topography is not a barrier for shelf-deep basin interactions and water/pollutants exchange or transports. The mesoscale eddy dynamics appear to be a major factor for the shelf-deep basin interactions in the Black Sea

5. Based on the success of the Black Sea 99 drifter experiment, it is recommended that a large scale drifter experiment be organised in the near future as a part of the Black Sea GOOS. We have estimated that at least a total of 40 surface drifters should be deployed throughout the Black Sea basin over a period of 1.5 year in order to assess the seasonal cycle in the surface circulation. All of these drifters should be of the SVP type and should be equipped with sensors to measure oceanographic (SST and salinity) and atmospheric (pressure, wind speed and direction) parameters. The major goals of this experiment will be: (a) to provide meteorological and weather monitoring over the entire area of the Black Sea; (b) to study the large and mesoscale structure of the upper layer currents, their seasonal variability and their dependence on atmospheric forcing.

Acknowledgements

The authors are very thankful to Prof. Peter Niiler for making 8 SVP drifters available for the Black Sea circulation study. This work was supported by the Ministry of Science and Technologies of Russia, Russian Foundation of Basic Research , and by the European Community under the INCO-Copernicus program (contract N IC15 CT96-0111).

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An Error in the Initialisation of the NCEP ENSO Predictions

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and
Hugo Bezdek

NOAA/AOML

It is commonly thought that the seasonal to annual lag predictability ENSO resides in the thermal structure of the tropical Pacific Ocean. Accordingly, great care is taken to initialise the thermal str5ucutre of the ocean component of the coupled model used at NCEP for ENSO predictions. The wind forcing and/or model ocean response to wind forcing are not adequate for the task, so temperature measurements from XBTs, the TAO array, surface drifting buoys and AVHRR are assimilated to arrive at "optimal" ocean initial conditions. Over time, the sequence of these initialisations provides a time series of "optimal" ocean conditions. Operational weekly initial conditions are available from July 1996. Furthermore, a reanalysis (ra6) using the same algorithms is available monthly from January 1980. The question of verification of this ocean analysis naturally arises. In this paper we depict the structure of large differences between the model states and surface current observations in the tropical Pacific since 1988.

Three points are worth emphasising. First, there are differences between the weekly product and ra6, but they are not important for this study, so we use ra6 to extend the comparison to the effective beginning of the observations. Second, drifter currents are not assimilated in the model, so this is a true verification test. Finally, SVP-type drifters measure currents at 15m depth, which corresponds to the second level of the model output.

The analysis is very simple. The model output is interpolated in space and time to produce values for zonal currents that match the time and place of weekly-averaged zonal currents from SVP-type drifting buoys with intact drogues. We then discuss all model observation pairs that do not meet both of two conditions:
(1) sign(u_m) not equal sign(u_o)
(2) abs($u_o - u_m$) > 50 cm/s
We emphasise that these are large differences.

Figures 1 and 2 show the temporal and spatial distribution of the model/observation pairs that meet both criteria. There are three main features that emerge from these figures. First, there is a consistent tendency for large differences in the western tropical Pacific, usually between about 150E and 180E (Figure 1). Second, there is a strong tendency for the large differences to centre on the equator (Figure2). Finally, it is interesting to note that these differences propagate eastward from about 150E in mid 1996 to 160W in mid 1998 and to about 110W by early 1998. Recall that mid 1996 precedes the development of the 1997 ENSO while mid 1997 corresponds to the time during which the event developed into one of the largest events of the century.

We hypothesise that these large differences result from times when westerly wind bursts cause the ocean to respond in a way that the model system cannot capture. During strong westerly wind bursts, drifters converge toward the equator and accelerate eastward along the equator, where rotational forces are small. It appears that either the wind forcing used in the model does not well represent westerly wind bursts or the model ocean does not adequately respond to westerly wind bursts (or both). We will further investigate this hypothesis by correlating the occurrence of westerly wind bursts with the development of these strong model/observation differences.

Ultimately, we hope to assess the impact of this error on the ENSO predictions.

Figure 1. Longitude vs. time for model/observation difference pairs with large differences. Left: All locations. Middle: 3 x 3 matrix smoothing of all locations. Right: Second application of 3 x 3 matrix smoothing of all locations. 3 x 3 smoother produces 1 or 0 according to whether a majority of bins in 3 x 3 array centred on location are filled.

Figure 2. Longitude vs. latitude by year for model/observation pairs with large differences.

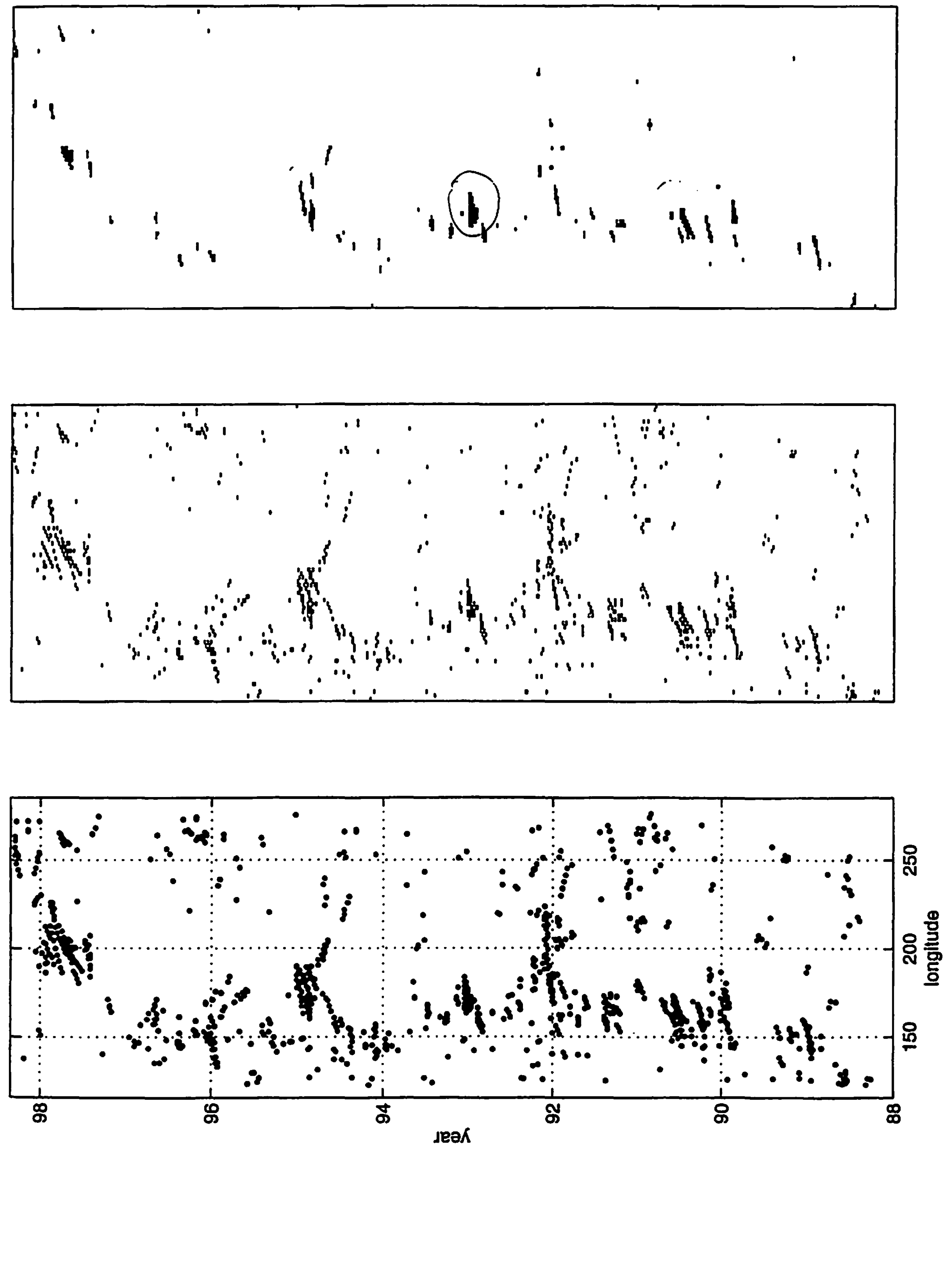


Figure 1.

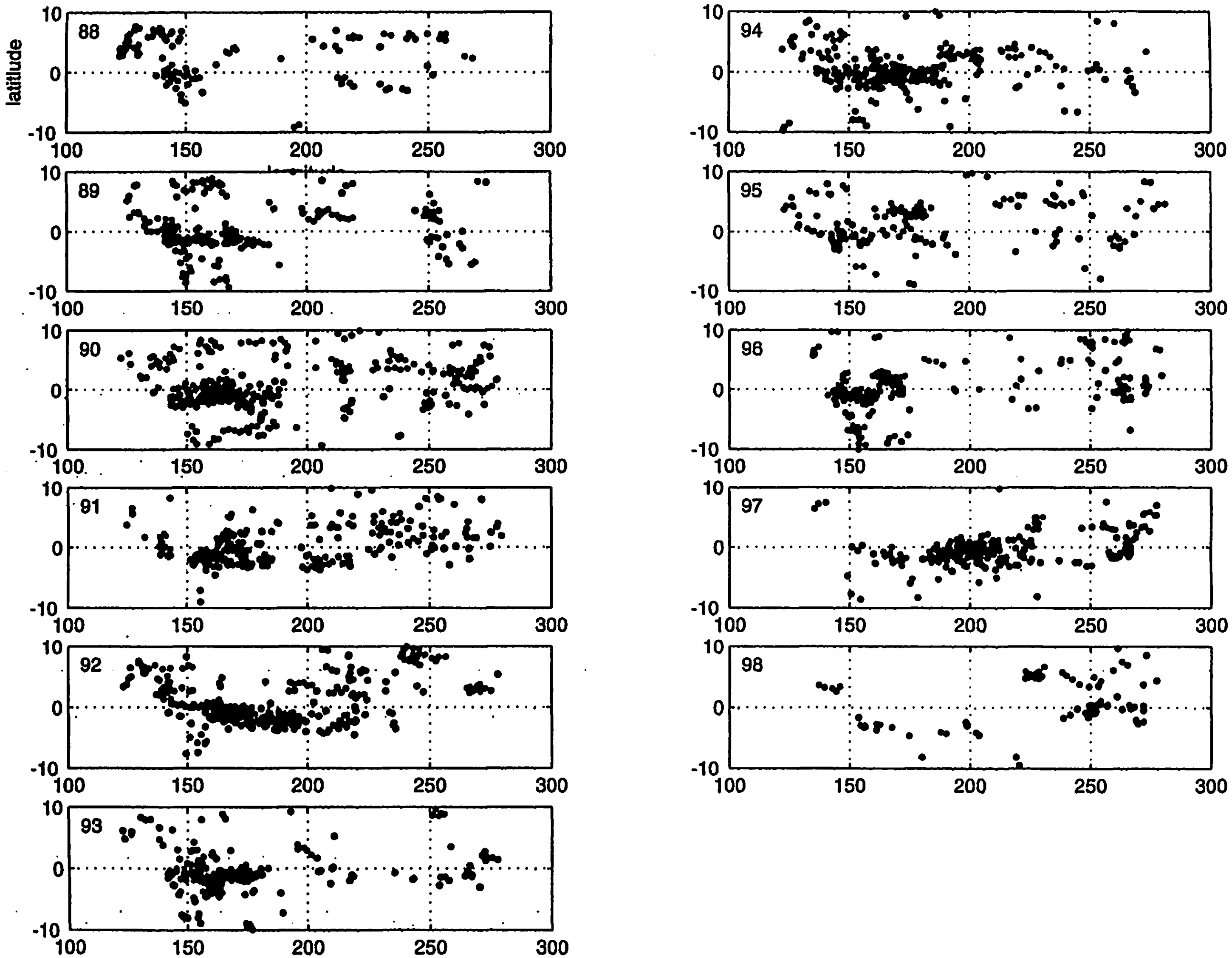

latitude
88
89
90
91
92
93
94
95
96
97
98
10
0
-10
100
150
200
250
300

Figure 2.

An Assessment of the Uncertainty in Drifting Buoy and Moored Buoy observations

D.W. Jones, H.M. Tanner & P. Blouch

1. Abstract

An earlier paper presented at DBCP XIV produced estimates of the uncertainties in pressure readings from drifting buoys in the North Atlantic, and in the Background fields used universally in the buoy QC process. The paper also presented results from two closely located buoys, one moored, the other a drifter; the drifting buoy appeared to have much higher variability than the moored buoy, when both were compared to the BGF. However, further analysis of these data, with a filter applied to the drifting buoy data to exclude those observations which are not close in time to the model run time, reveal much lower variability. The results of this re-analysis will be presented. The analysis will also be extended to other periods where drifters are in close proximity to a moored buoy, and include comparisons of wind speed and direction for both FGGE (TOGA) and SVP-B (WOCE) drifting buoys.

2. Background

A paper was presented at the DBCP Technical Workshop in Florida in October 1998 entitled 'An Assessment of the Uncertainty in NWP Background Field Data Based on Duplicate Observations from Moored Buoys' by D.W. Jones and H.M.Tanner (DBCP Technical Document No. 15). The paper assessed the uncertainty of the Background Field (BGF) data, based on comparisons with the duplicated sensors deployed on the UK Open Ocean Buoys. The data from both sensors usually agree much more closely with each other than they do with the BGF, and an analysis of the uncertainties of the respective differences provided estimates of the uncertainty in the individual sensor values and of the BGF. This analysis was extended to provide estimates of the uncertainty in drifting buoy data computed using the estimates of the BGF uncertainties derived from the moored buoys.

The 1998 Paper focused solely on observations of MSL Pressure. This paper will extend the analysis to assess the uncertainty of observations for other environmental variables, specifically wind speed and direction. This paper will also address the issue of the quality of observations reported from different types of marine platforms.

3. Comparison of Closely Located Moored Buoys and Drifting Buoys - Extension of 1998 Paper

3.1 Brief Description of the Findings of the 1998 DBCP paper

In the 1998 Paper, a comparison was made of the observations of a UK Met Office SVP-B Drifting Buoy (44771) and the UK Met Office Moored Buoy K3, which were in close proximity during June 1998 (Figure 1). The close proximity of these two types of meteorological buoy provided an opportunity to compare pressure observations from two types of marine platform closely located in space and time.

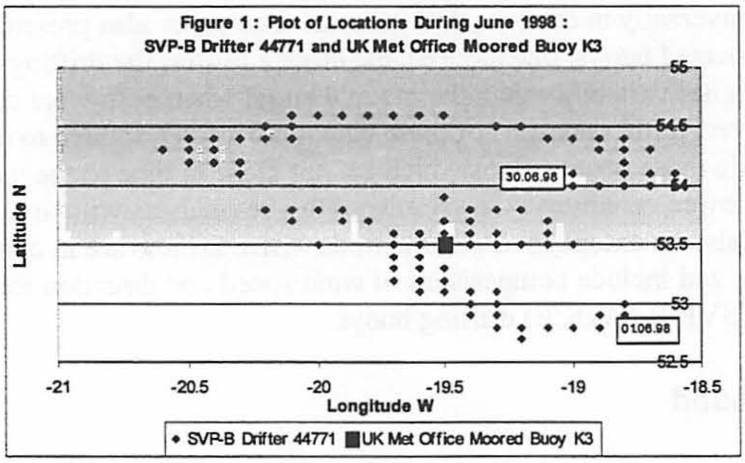
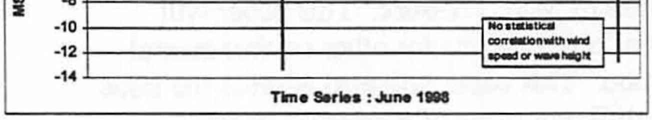
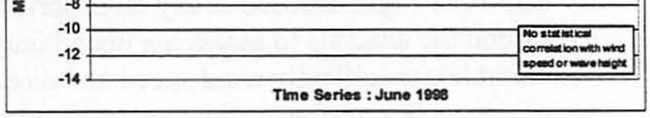


Figure 2 shows the differences between the Drifting Buoy observations and the BGF and Figure 3 shows the differences between the Moored Buoy observations and the BGF.

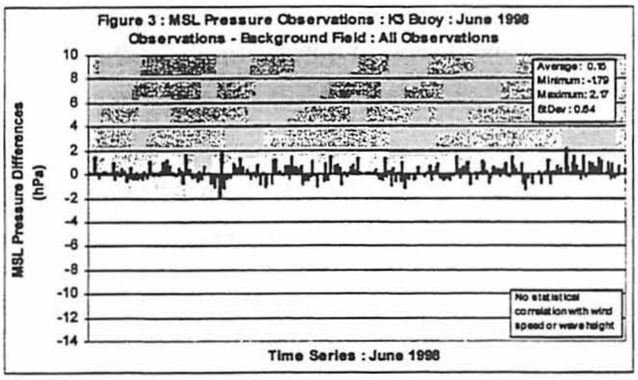


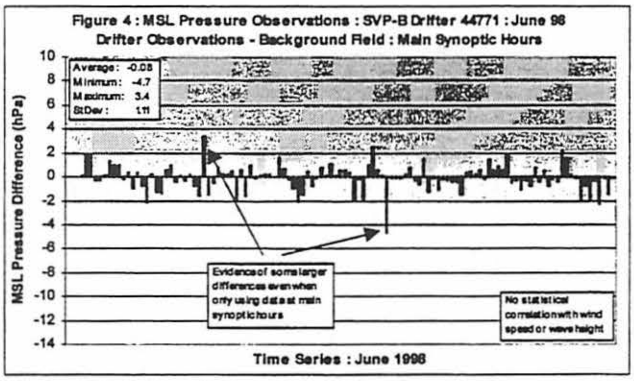


Figures 2 and 3 appear to demonstrate that improved pressure observations are available from the Moored Buoy compared with those from the Drifting Buoy. However, further investigation showed that the observed trends were significantly different if only observations at main synoptic hours were analysed rather than all observations. The conclusion made in the 1998 Paper that Moored Buoy observations have significantly lower variances than Drifting Buoy observations was in fact, incorrect.

3.2 Impact of only using observations at main synoptic hours

Figure 4 shows the difference in MSL Pressure for the Drifting Buoy observations and the BGF where only observations within 20 minutes of main synoptic hours are included.

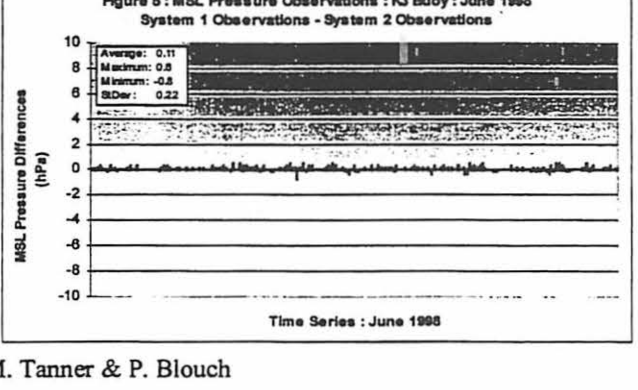




The trends shown in Figures 3 and 4 clearly display that the differences between the Drifting Buoy observations and the BGF when only observations at main synoptic hours are included, are similar to the differences between the Moored Buoy observations and the BGF. BGF estimates are only produced at main synoptic hours and comparing the Drifter observations in-between these main synoptic hours can be misleading, particularly for rapidly moving synoptic scale features, as the data may not be well matched in time. However, this conflicts with current operational practice, where all observations are compared with the BGF and observations are only excluded if they are duplicated, or within a short period of other observations or if they show a gross error.

However, even when we only use data at main synoptic hours, the scatter of the differences between the Drifter observations and the BGF are still slightly higher than the differences between the Moored Buoy observations and the BGF. The 1998 Paper recognised that Moored Buoys and Drifting Buoys differ in the way that they can be matched to the BGF data. Moored Buoys report hourly observations and have a well-defined location. They will therefore be well matched with the BGF in space and time. Drifting Buoys, however, do not report at fixed times and it is possible for the BGF and the observation to be offset in time. Drifting Buoys also vary in location and therefore the model and the observation may also be offset in space.

It should be noted that the differences between the two pressure sensors on the Moored Buoy are significantly smaller than the differences between either sensor and the BGF (Figure 5). This indicates that much of the uncertainty lies within the BGF rather than the observation. Indeed, this was one of the conclusions of the 1998 Paper, which also computed estimates of the BGF uncertainty.



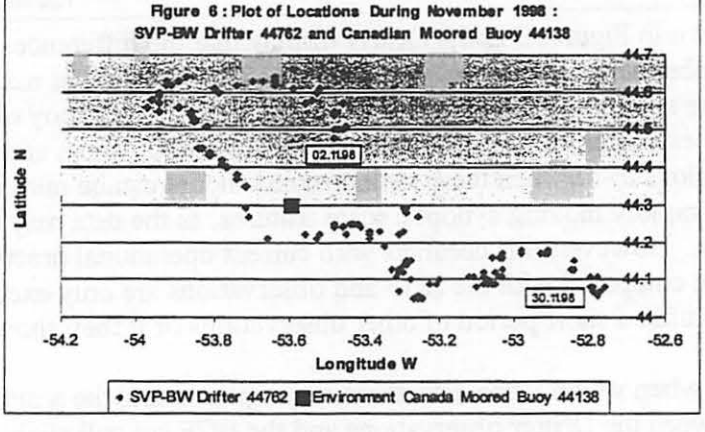
For the rest of this paper, we will only analyse observations made within 20 minutes of main synoptic hours for Drifting Buoy comparisons with the BGF.

4. Comparison of Closely Located Moored Buoys and Drifting Buoys - Further Analysis

This section will assess pressure, wind speed and wind direction observations for the following examples of closely located Drifting Buoys and Moored Buoys :

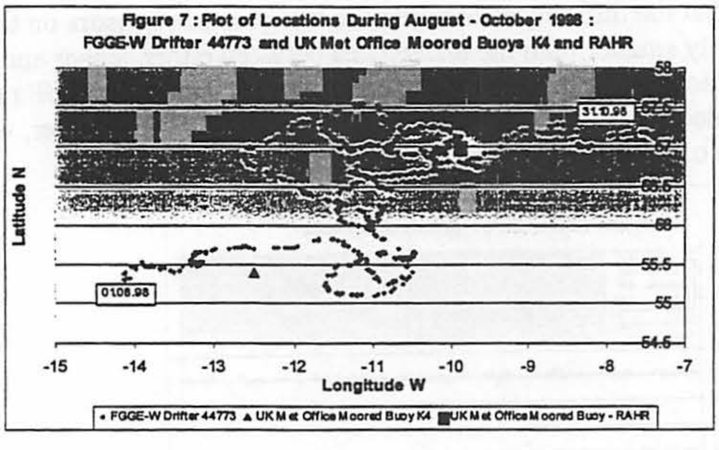
- **The Canadian Comparison**

During November 1998, Environment Canada deployed a UK Met Office SVP-BW Drifting Buoy (44762) in close proximity to one of their Moored Buoys (44138) – Figure 6. The buoys were located at approximately 53.6°N 44.3°W for approximately one month.



- **The North Atlantic Comparison**

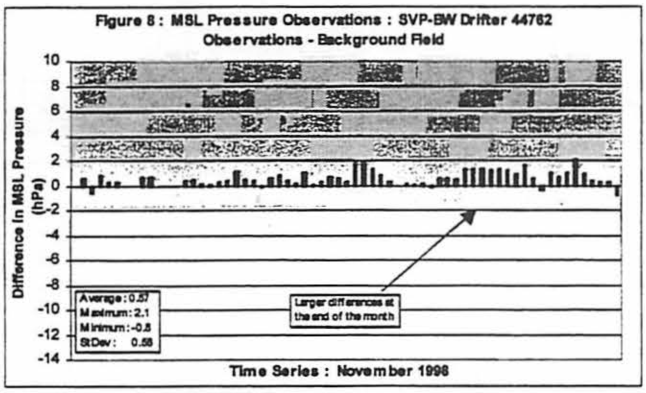
During August - October 1998, a FGGE-WSD Drifting Buoy (44773) was in close proximity to two UK Met Office Moored Buoys – K4 (62105) and RAHR (62106) – Figure 7. The buoys were located at approximately 56°N 11°W for a period of three months.

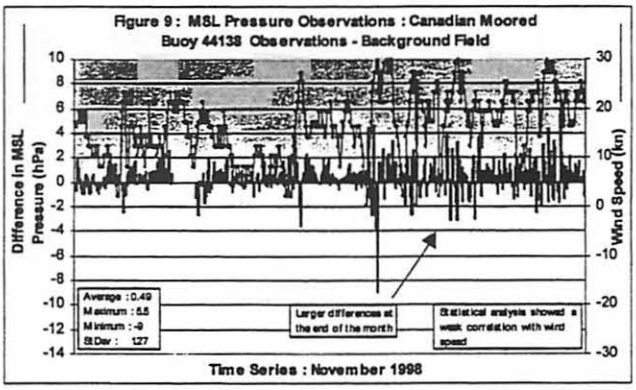


4.1 Pressure Observations

4.1.1 Canadian Moored Buoy 44138 and SVP-BW Drifting Buoy 44762 : November 1998

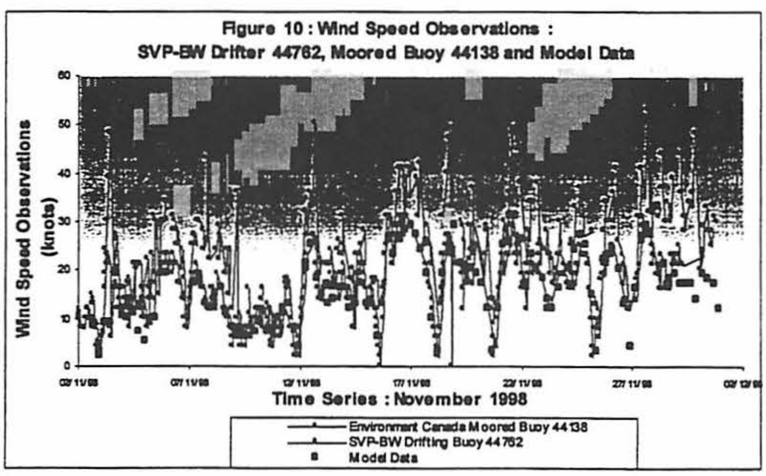
Figure 8 shows the differences between the observations and the BGF for the Drifting Buoy and Figure 9 shows the differences between the observations and the BGF for the Moored Buoy. Also shown are the wind speeds as recorded by the moored buoy.





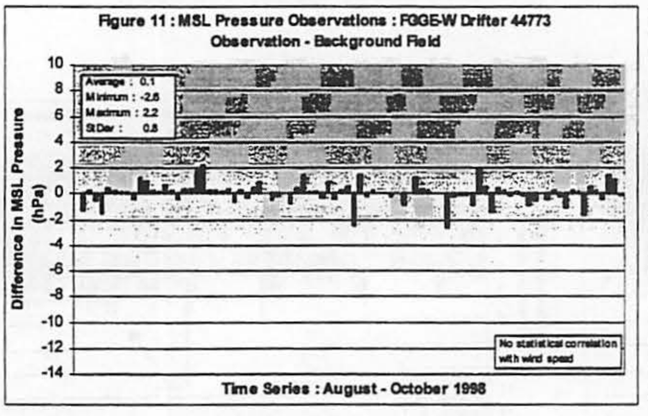
The range of differences and the standard deviation of the differences between the Moored Buoy and Drifting Buoy observations with the BGF are of a similar magnitude for both types of buoy platform.

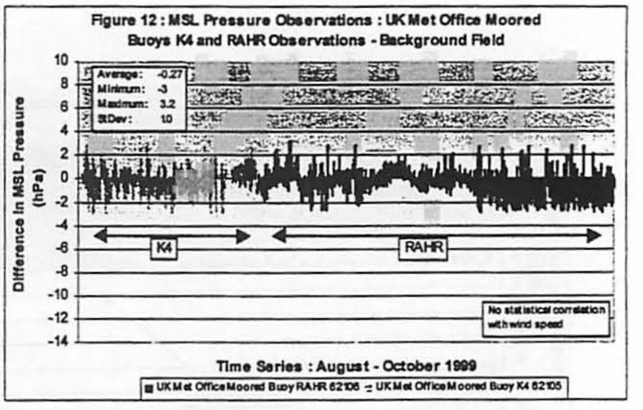
Both buoys show evidence of better correlation with the BGF at the start of the month than at the end of the month. Regression plots showed evidence of a weak correlation between the differences with the BGF and periods of higher wind speed at the end of the time period shown in Figure 10. Higher wind speeds will affect the sea conditions and therefore the percentage of time that the drifter is below the surface and hence the quality and quantity of the data used in the pressure computation.



4.1.2 Open Ocean Buoys K4 and RAHR and FGGE-WSD Drifting Buoy 44773 : August – October 1998

Figure 11 shows the differences between the observations and the BGF for the Drifting Buoy. Figure 12 shows the differences between the observations and the BGF for Moored Buoy K4 and Moored Buoy RAHR.





The range of differences and the standard deviation of the differences between the Moored Buoy and Drifting Buoy observations with the BGF are of similar magnitudes for both types of buoy platform.

Towards the end of August 1998, Moored Buoy K4 showed evidence of a sensor fault and similarly, Moored Buoy RAHR experienced similar sensor problems towards the end of October 1998. The spurious data reported during these times of sensor failure has been removed from this analysis.

4.2 Wind Speed Observations

4.2.1 Canadian Moored Buoy 44138 and SVP-BW Drifting Buoy 44762 : November 1998

Figure 13 shows the differences between the observations and the BGF for the Drifting Buoy and Figure 14 shows the differences between the observations and the BGF for the Moored Buoy.

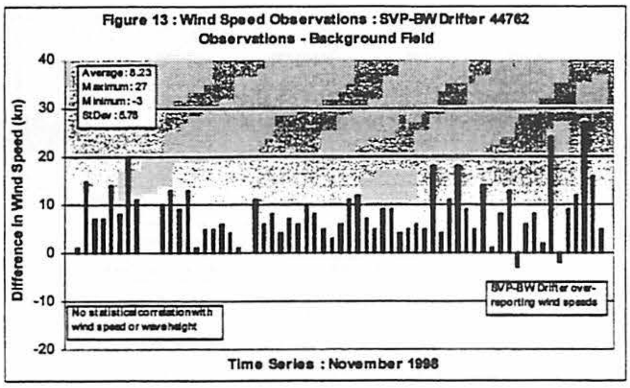


Figure 13 : Wind Speed Observations : SVP-BW Drifter 44762
Observations - Background Field

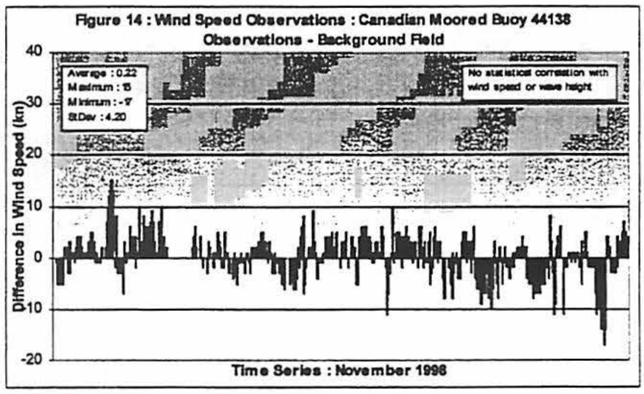


Figure 14 : Wind Speed Observations : Canadian Moored Buoy 44138
Observations - Background Field

The range of differences and the standard deviation of the differences between the Drifting Buoy observations and the BGF were higher than for the differences between the Moored Buoy observations and the BGF. The Drifting Buoy wind speed observations appear to show a positive bias and read approximately 9 knots higher than the wind speed observations made by the Moored Buoy and the BGF.

Figure 15 shows a very weak correlation between the differences between the observations and the BGF, and the reported wind speed. However, from the time series plot (Figure 10), it can be observed that the SVP-BW Drifter tends to respond to synoptic scale features albeit over-reading in varying wind conditions. The SVP-BW Drifting Buoy measures wind speed using a subsurface acoustic sensor. The reason for the over-reading of the wind speed could be that the acoustic signal varies in character according to how long the particular sea state has persisted and the amount of noise corruption from precipitation.

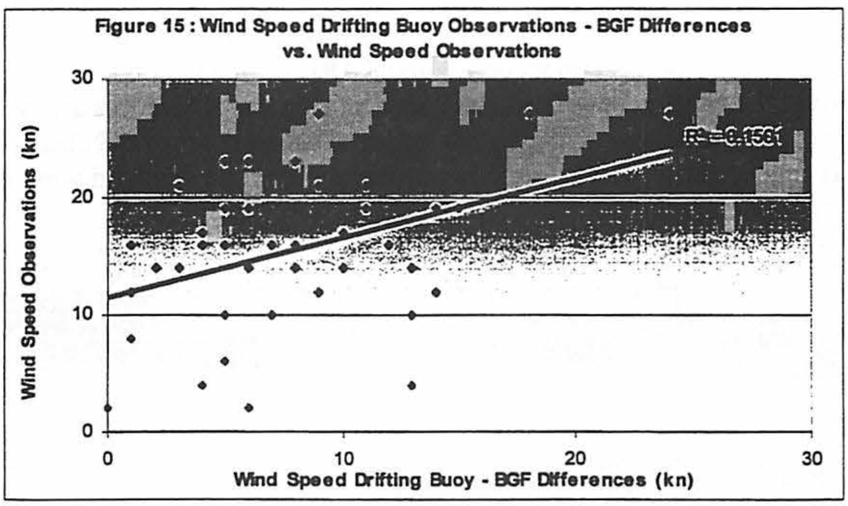


Figure 15 : Wind Speed Drifting Buoy Observations - BGF Differences
vs. Wind Speed Observations

4.2.2 Open Ocean Buoys K4 and RAHR and FGGE-WSD Drifting Buoy 44773 : August – October 1998

Figure 16 shows the differences between the observations and the BGF for the Drifting Buoy. Figure 17 shows the differences between the observations and the BGF for Moored Buoy K4 and Moored Buoy RAHR.

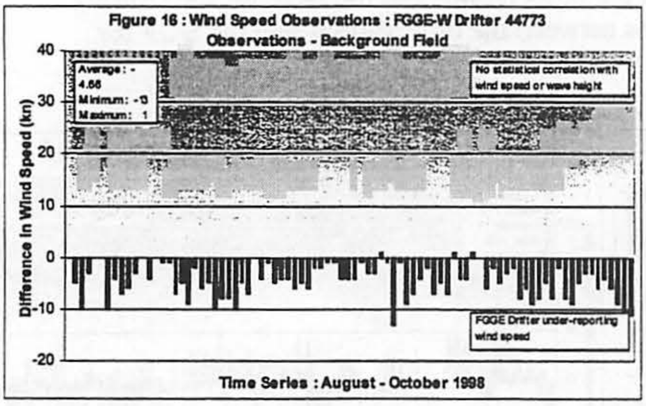


Figure 16 : Wind Speed Observations : FGGE-W Drifter 44773 Observations - Background Field

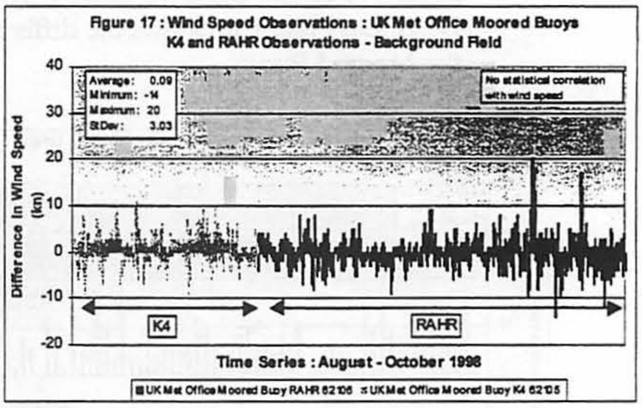


Figure 17 : Wind Speed Observations : UK Met Office Moored Buoys K4 and RAHR Observations - Background Field

The range of differences and the standard deviation for the differences between the Moored Buoy and Drifting Buoy observations with the BGF are similar for both types of buoy platforms. However, the Drifting Buoy wind speed observations appear to show a negative bias and read approximately 6 – 8 knots lower than the wind speed observations made by the Moored Buoy and the BGF.

The fact that the FGGE-WSD Drifter is observed to under-read wind speed is likely to be due to the location of the anemometer on the FGGE-WSD Drifter, which will affect the degree of exposure. The anemometer is located approximately 1m above sea level, which means that the anemometer may be sheltered from the winds in developed sea conditions. The wind speeds reported from the anemometer are being compared with the model wind speeds estimated for a height of 10m above sea level. If we include an additional 30% correction factor onto the Drifter wind speeds, the differences with the BGF are altered considerably (Figure 18). The differences do not now show a negative bias and are comparable with the differences between the Moored Buoy observations and the BGF. It should be noted that the Moored Buoy anemometer is situated at 4m above sea-level and no correction factor is used.

Figure 19 shows the differences between the wind speeds as recorded by the two anemometers on a moored buoy. The example used is from K3 for June 1998, as only one anemometer was functional on K4 and RARH for the period under consideration in this paper. However, the authors can confirm that these differences are typical of those experienced by all buoys in the UKMO moored buoy network, and clearly demonstrate that, as with pressure, there is greater uncertainty in the background wind field than in the actual observation.

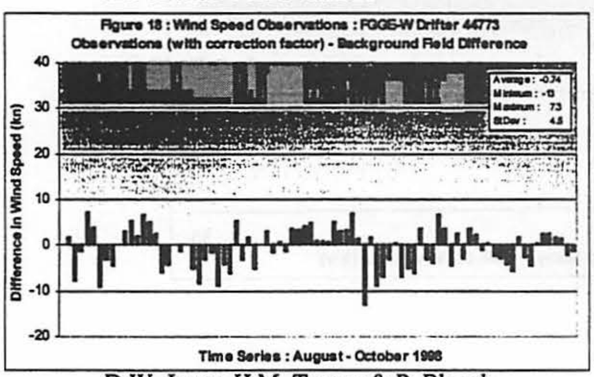


Figure 18 : Wind Speed Observations : FGGE-W Drifter 44773 Observations (with correction factor) - Background Field Difference

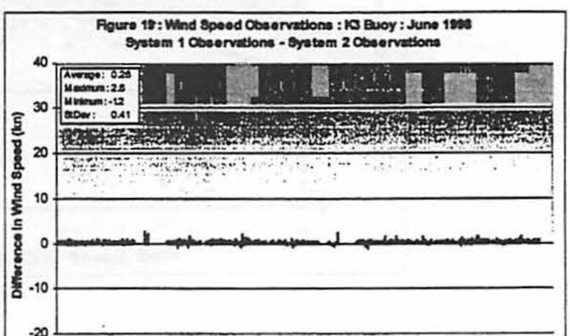
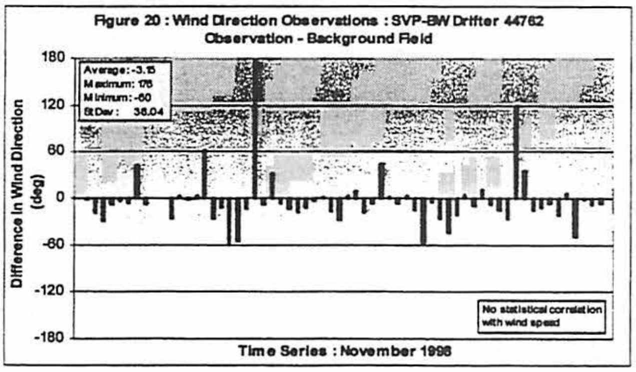


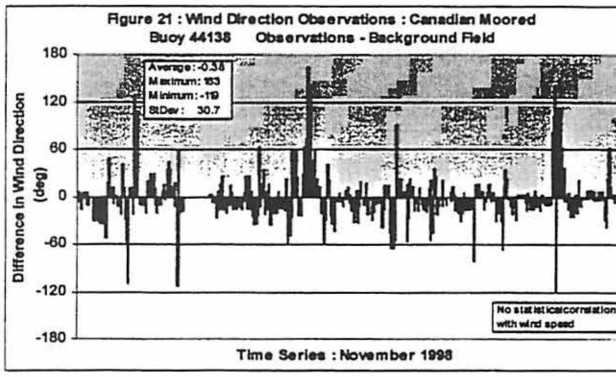
Figure 19 : Wind Speed Observations : K3 Buoy : June 1998 System 1 Observations - System 2 Observations

4.3 Wind Direction Observations

4.3.1 Canadian Moored Buoy 44138 and SVP-BW Drifting Buoy 44762 : November 1998

Figure 20 shows the differences between the observations and the BGF for the Drifting Buoy and Figure 21 shows the differences between the observations and the BGF for the Moored Buoy.



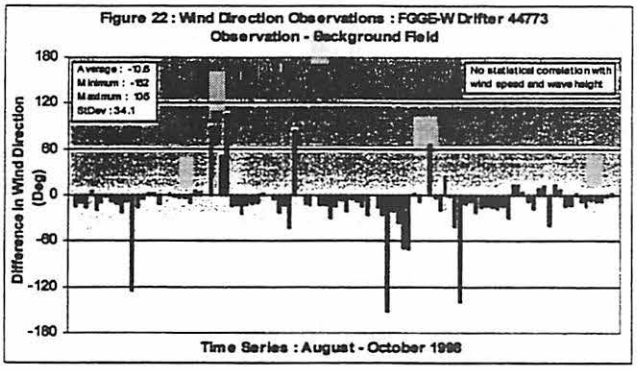


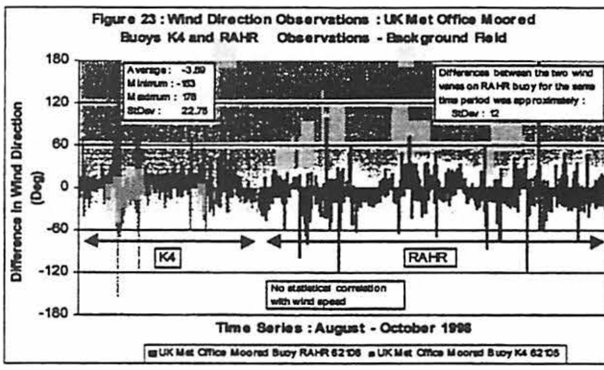
The range of differences and the standard deviation for the differences between the Moored Buoy and Drifting Buoy observations with the BGF are of similar magnitudes for both types of buoy platform.

Regression plots showed no evidence of a correlation between the differences with the BGF and wind speed observations shown in Figure 10.

4.3.2 Open Ocean Buoys K4 and RAHR and FGGE-WSD Drifting Buoy 44773 : August – October 1998

Figure 22 shows the differences between the observations and the BGF for the Drifting Buoy. Figure 23 shows the differences between the observations and the BGF for Moored Buoy K4 and Moored Buoy RAHR.





The range of differences and the standard deviation for the differences between the Moored Buoy and Drifting Buoy observations with the BGF are of similar magnitudes for both types of buoy platform.

Regression plots showed no evidence of a correlation between the differences with the BGF and wind speed observations.

It should be noted that the differences between the wind direction observations from the two wind vanes on the Moored Buoys are considerably smaller than the differences between either observation and the BGF for the same time series.

5. Summary

- This paper has described the comparison of the differences between the Moored Buoy observations and the BGF with the differences between Drifting Buoy observations and the BGF.

- The differences between Drifting Buoy observations and the BGF are considerably smaller when only observations at main synoptic hours are used. This is when the observations and the BGF are well-matched in time. It is recommended that this issue requires further empirical investigation before recommendations are made.

- Three case studies of closely located Drifting Buoys and Moored Buoys were made in the North Atlantic and Western Canada, to assess observations of pressure, wind speed and wind direction. The following observations were made :

    - There appears to be no significant difference for pressure and wind direction observations between the Moored Buoys and Drifting Buoys and the BGF.

    - It was observed that the differences between the Drifting Buoy wind speed observations and the BGF were significantly larger and more biased than the differences between the Moored Buoy wind speed observations and the BGF.

    - The SVP-BW Drifter was observed to respond to synoptic scale events but generally over-read wind speed. It is suggested that this is due to the influence of differing winds in developed sea states and the additional influence of noise from precipitation on the acoustic signal. It is recommended that this issue requires further empirical investigation leading to a refinement of the processing technique.

    - The FGGE-WSD Drifter was observed to generally under-read wind speed. However, the addition of a correction factor to produce a 10m wind speed, made the differences between Drifting Buoy observations and the BGF comparable with the Moored Buoys. It is recommended that this issue requires further empirical investigation to assess whether a simple correction factor should be used for all FGGE-WSD Drifter observations.

- It is anticipated that further work to extend the data analysis could incorporate a comparison of alternative types of Drifting Buoys and an assessment of more examples of closely located Drifting Buoys and Moored Buoys.

VAISALA

Melbourne October 25, 1999

Vaisala barometers for data buoy applications

Robert Caplikas

Vaisala Pty Ltd. Melbourne. Australia

The PMB100 for OEM applications is a new circuit board mountable barometric pressure transducer that is designed to interface with an AD converter and a microprocessor.

The PMB100 module is characterized over 800 to 1100 hPa (mbar) pressure range and over –5 to +45C temperature range. It ouputs pressure dependant voltage within 0 and 2.5 VDC along with a reference voltage of 2.5 VDC. All pressure and temperature related coefficients are given in a module specific certificate and also stored in an incorporated eeprom, which uses the I²C interface. All the user needs to do is to measure the temperature of the module and the two voltage outputs and then calculate the compensated pressure reading using the coefficients. A final offset correction against a high-class pressure standard is recommended as a final touch.

The PMB100 barometer modules use the BAROCAP® silicon capacitive absolute pressure sensor. The BAROCAP® sensor has excellent hysteresis and repeatability characteristics, low temperature dependence and a very good long-term stability. The ruggedness of the BAROCAP® sensor is outstanding and the sensor is resistant to mechanical and thermal shocks.

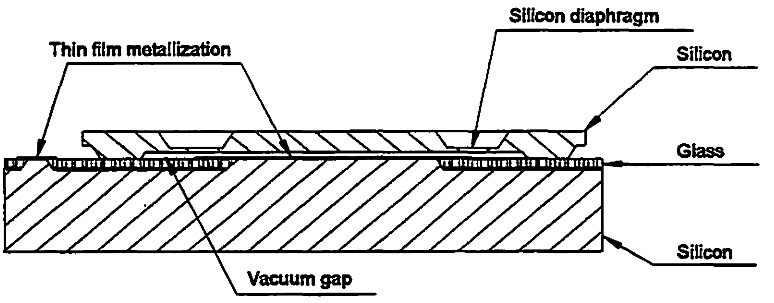


Figure 1 The BAROCAP® pressure sensor

The BAROCAP® pressure sensor consists of two layers of single crystal silicon having a layer of glass between them. The thinner silicon layer is etched on both sides to create an integrated vacuum reference chamber for the absolute pressure sensor and to form a pressure sensitive silicon diaphragm. The thicker silicon layer is the rigid base plate of the sensor and it is clad with a glass dielectric. The thinner piece of silicon is electrostatically bonded to the glass surface to form a strong and hermetic bond. Thin film metallization has been deposited to form a capacitor electrode inside the vacuum reference chamber; the other electrode is the pressure sensitive silicon diaphragm.

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VAISALA

Melbourne October 25, 1999

The coefficients of thermal expansion of silicon and glass materials used in the BAROCAP® pressure sensor are carefully matched together in order to minimize the temperature dependence and to maximize the long-term stability.

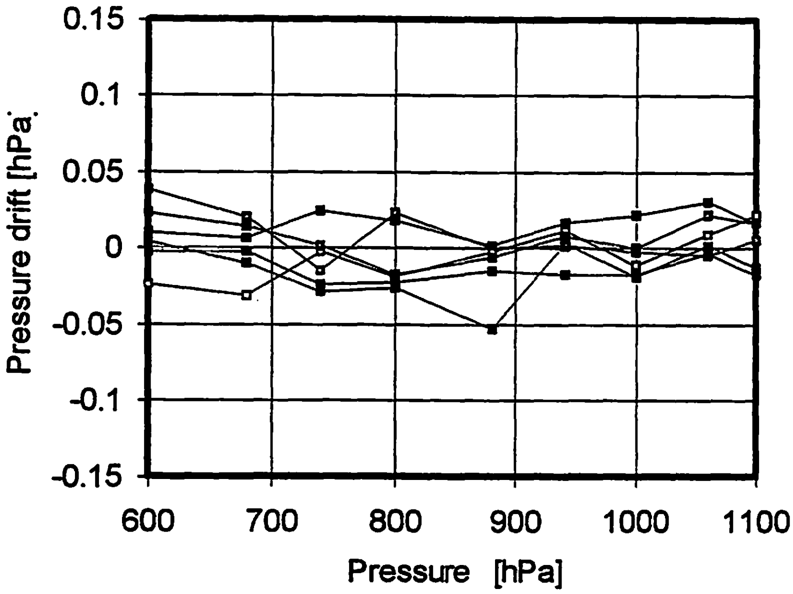

Figure 2 6 month drift test results- BAROCAP® capacitive pressure sensor

The BAROCAP® pressure sensor is designed to achieve zero temperature dependence at 1000 hPa and its long-term stability has been maximized by thermal ageing at an elevated temperature.

The BAROCAP® capacitive pressure sensor features a wide dynamic range and no self-heating effect. The excellent hysteresis and repeatability characteristics are based on the ideal spring characteristics of single crystal silicon. In the BAROCAP® pressure sensor, the silicon material is exerted to only a few percent of its whole elastic range.

To complement the barometer range for data buoy applications, a new digital barometer designated PTB 210 will shortly be introduced to the market. The PTB 210 uses the same BAROCAP® pressure sensor but offers a number of alternative packaging options including a choice of either TTL/RS232C or non-isolated RS485 digital outputs. Analogue output signals are also available.

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New Generation SVP-B Buoy Evaluation

S. Motyzhev, V. Yachmenev

The main directions of SVP-B drifter evolution were defined after three experimental MARLIN buoys testing in the South Atlantic in 1998-99. The reasons of buoy failures of other manufacturers, what were accessible from papers published by DBCP, were also taken into consideration. The jobs for the evolution were begun after receiving the Specification for WOCE Surface Velocity Barometer Drifter from Naval Oceanographic Office (USA) and executed in a period since September 1998 till April 1999. The purposes of these jobs consisted in increase of reliability of the electronics engineering and mechanics of buoys, increase of lifetime and decrease of drifter's cost.

The main directions of buoy's electronics engineering evolution were:

- Up-dating of the drifter's electronics for realization of its check for the all stages: manufacturing, certification, checking after transportation, testing before and after deployment;
- Creation of the barometric pressure system with accuracy ±1 hPa after affecting through a temperature range of minus 25 to +50°C in the time before deployment, and also of long-lived operation after deployment in a marine environment through a temperature range of minus 2 to + 42°C;
- Creation of the new self-contained power supply which should provide sufficient power to maintain an operational for minimum one year deployment.

The main directions of buoy's mechanics evolution were:

- Up-dating of the barometric port for the exception of molecular membrane rotation in an assembly time of a port;
- Creation of a new brackets of batteries and electronics engineering for exception of failure after air deployment of buoy;
- Development of the compact packing buoy for the decreasing of the transportation cost and volume of warehouse for the storage of buoys, and also for simplification of manufacturing of the SVP-B drifters.

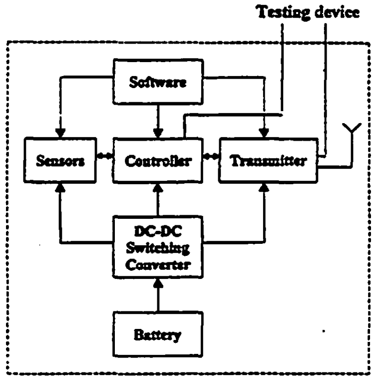

Fig.1. Electronic engineering of Marlin SVP-B drifter

Marlin strategy of buoy creation was that the low cost and good reliability of drifter could be when buoy was built as completed device, all parts of which was created by one hands. Ten buoys, which were built for Navoceano, became the results of this ideology of SVP-B drifter creation.

Electronics engineering of buoy is schematically presented on Fig.1. It was configured for full checking on the all phases of buoy manufacturing. The signal from drifter's electronics could be sent onto checking device via antenna, antenna nozzle or interface RS-232. New oscillator, new duplexes and new software were developed for PTT.

The major efforts were made for creation of the new air pressure (AP) sensor. The Navoceano Specification request about operation of AP electronics system from a temperature of minus 25°C has designated a problem of new AP channel development. The low cost, on-chip compensated and calibrated sensor MPX2100A (by Motorola production) has showed the good time stability and it was chosen for AP channel creation. But it has the hysteresis phenomena after affecting through a temperature range of minus 5 to minus 25°C. Hysteresis curves of offset errors for different outside temperatures are presented on Fig.2.

Different conditions of the heat affecting onto sensor MPX2100A were being investigated for the understanding the hysteresis problem. It is necessary to take into consideration that SVP-B drifter is similar to passive thermostat, when it is in the water. The temperature inside the surface float should be through a range of minus 5 to plus 40°C during the full lifetime of buoy after deployment. This condition was taken into account before creation of the Automatic Preparation system for the AP sensor.

The essence of this system is that sensor is being heated before and after of buoy deployment. First heating is being made when the power on, and second one is being made after the buoy impact of

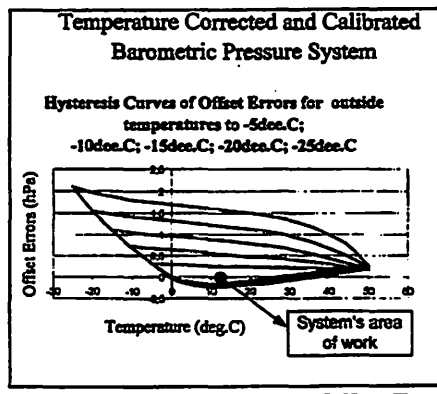

Fig.2. Hysteresis Curves of Offset Errors of MPX2100A Air Pressure sensor

water. First heating is necessary for the removal of possible additional error of AP data after influence of negative temperatures during storage or transportation. This cycle is being made before burn-in test of buoy in laboratory or before deployment. Second cycle of heating is necessary because buoy can be subjected to influence of low temperatures after the first cycle of heating. For example, this fact can take place when buoy was activated on the deck of ship, and continue to stay during long time before deployment under influence of negative outside temperatures.

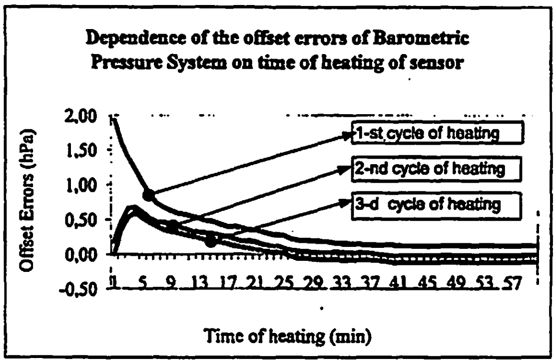

Fig.3. Shifts of AP curve after heating. First curve is presenting the AP data after influence of negative temperatures

The additional lack of this sensor is that there is a shear of AP curve after each cycle of heating as it is exhibited on Fig.3. It was taken into consideration when no more three-five cycles of heating were recommended before buoy deployment. Of course, this recommendation is inconvenient for users, but it is the payment for the low cost of AP sensor and buoy entirely (price of MPX2100A sensor in Ukraine is approximately 10 USD). Furthermore, three times testing of buoy should be enough for users because usually the first testing should be made after transportation, second one – after storage, and third – before deployment. Unconditionally, this engineering solution of AP sensor will be significant, if its reliable service will be demonstrated. The answer to this problem will be received after realization of buoys testing in ocean.

Creation of the self-contained power supply should be provided the sufficient power to maintain an operational for minimum one-year deployment. The following reasons for the power supply computation were taken into consideration:

1. Full time duty cycle
2. Electrical characteristics of hardware
3. Total power energy (8 blocks × 8 Alkaline-Manganese Dioxide Batteries. Thus, the total number of batteries is 64)
4. Period of observations
5. Length of the message Argos
6. Medium temperature of water
   < +10°C - polar areas
   from +10 to +20°C - medium latitudes
   > +20°C - equator areas
7. Probability of the batteries failure (12,5%), what is possible when only 7 blocks continue the work.

The results of computations are presented on the family of curves on Fig.4. As it is following from Fig.4 the theoretical lifetime of buoys should be more then one-year for the any outside temperatures. The certainty of these accounts should be also confirmed after realization of buoys testing in ocean.

Mark Bushnell from GDC NOAA/AOML indicated on the Fourteenth Session of DBCP (Maraton, Fl., USA, 12-16 October 1998) the problem of the barometer port membrane rotation. He has proposed the variant of barometer port updating. His proposal was taken into account when the new modification of Marlin port was being created. New filter retainer and fixing of filter by the three brass screws were used for removal of membrane rotation.

New generation of Marlin SVP-B drifters was created for the air deployment especially. The analysis of SVP-B buoy construction was made with the purpose of detection of mechanically weak places, which one could reduce the buoy failure after the air deployment. It was supposed that fixing of the electronics engineering and batteries inside the surface float by means of

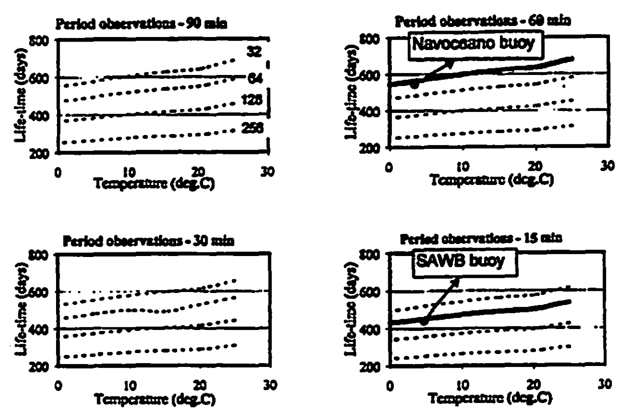

Fig.4. Theoretical lifetime of buoy for the different conditions of applications

building foam only does not ensure the indispensable mechanical durability. When the buoy is impacted of water the shift of the electronics engineering block concerning batteries with a simultaneous breaking of wires is possible. This fact could explain the large percent of buoy failures after the air deployments.

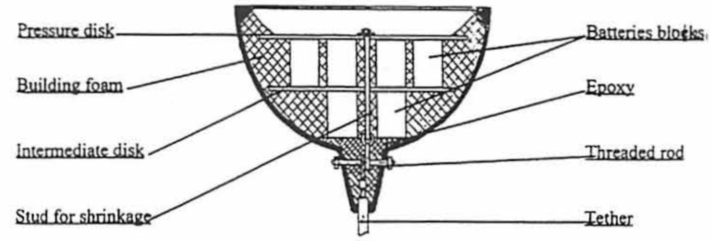

Fig.5. Method of battery blocks fixing inside the surface float

For elimination of this lack the new scheme of fixing of the buoy's electronics engineering and batteries inside of the surface float was designed. The separate fixation of electronics engineering and batteries was offered. The method of battery blocks fixing with usage of stud and two disks is presented on the Fig.5. The fixing of carrier disk with electronics between the upper and lower hemispheres is presented on the Fig.6.

New configuration of drifter, which was named the buoy of compact packing, was especially developed for the decreasing of shipping charge, and volume of warehouse, and simplification of buoy's manufacturing procedures. The essence of this configuration is that buoy is divided onto two parts. One part is the floats with tether line, another one is Holey-Sock. New drogue attachment scheme includes the new radial hub and lower end of tether. Connection of tether and radial hub is very simple and no more then five minutes are necessary for the buoy preparation before deployment.

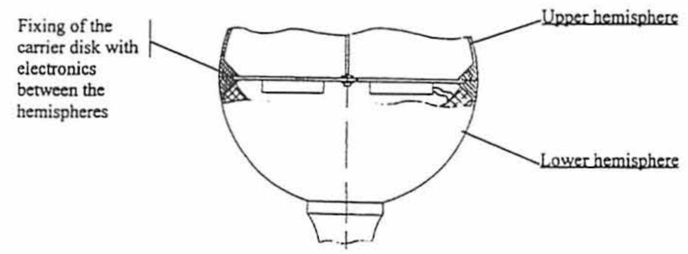

Fig.6. Method of electronics fixing inside the surface float

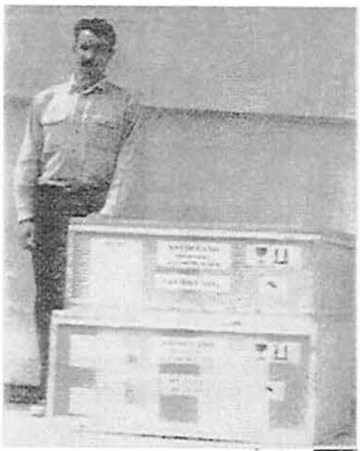

Fig.7. Two crates with two SVP-B drifters

The compact packing buoy has the incontestable adventures. The total volume of two crates for two packaged buoys (Fig.7) is 0,95 m^3, while the old crate with one buoy had the volume 1,03 m^3. The shipping expenses for ten buoys of old package from Sevastopol (Ukraine) to Rota (Spain) could be 3378 USD, while the real cost of shipping was 2248 USD. Thus, the economy was 33,5%. Dividing of buoy onto two parts gave the simplification of buoy's manufacturing procedures. While drogues are being stored at the warehouse, buoys are being tested in laboratory.

The main characteristics of new Marlin SVP-B drifter is presented in the table below.

Construction	**According to DBCP Technical Document No.4**		
Lifetime (full duty cycle)	**Up to a period of twelve (12) months**		
System of communication	**Argos**		
Sensors	**Atmospheric Pressure: 850 to 1054,6 hPa** **Battery Voltage: 5 to 17,6 V** **Sea Surface Temperature: minus 2 to +41,35°C** **Submergence: 0 to 100%**		
Data format	**Any**		
Operation temperature	**Minus 5 to +40°C**		
Storage Temperature	**Minus 25 to +50°C**		
Deployment	**Free fall deployment from cargo ship from 10m height above the ocean** **Air deployment**		
Compact packing variant for the air, rail, or truck transportation.		**Weight (kg)**	**Size (cm)**
	Crate for tethers and floats	**69**	**108×101×50**
	Crate for two Holey-Sock	**59**	**108×102×39**

Experiment for Marlin SVP-B drifter testing in Northern Atlantic and Indian ocean was started in November 1999 and will be prolonged in 2000. Marlin team are very grateful to Navoceano and Technical Coordinator DBCP for the assistance in data transfer. The results of evaluation of Marlin drifters operation will be presented on the following DBCP session in 2000.

SIO Minimet Drifter Progress Report

Andrew Lowy Sybrandy

Pacific Gyre Inc.

Abstract

Scripps Institution of Oceanography, with the help of Pacific Gyre, Clearwater Instrumentation, and Technocean Associates, continues to develop the Minimet drifter, (Figure 2). This drifter in addition to measuring ocean currents, sea surface temperature, and barometric pressure, also measures acoustic ambient noise, and wind direction. Using the acoustic ambient noise data, one can determine wind speed, and precipitation. These drifters have been developed over the past four years, deployed as prototypes in the Labrador Sea, the Adriatic Sea, the coast of California, and most recently in the East, or Japan Sea.

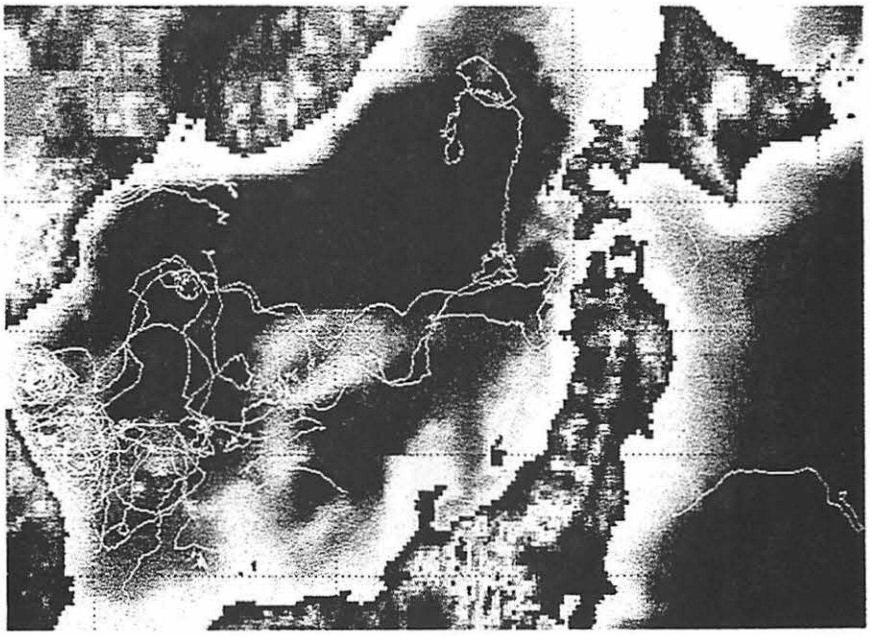

Figure 1

The East Sea drifters, (Drifter tracks on Figure 1), include the latest improvements. These drifters are part of the QuikScat calibration project and show improved performance in measurements of ambient noise and wind direction. Most notably the individual sensors are now absolutely calibrated before deployment. The East Sea deployments themselves have led to further design improvements. Scripps plans to complete the East Sea experiment, and begin deploying along the coast of California and further south before the summer of 2000. Additionally, Scripps will perform at least one additional at sea calibration off the coast of San Diego to gather more wind speed calibration data.

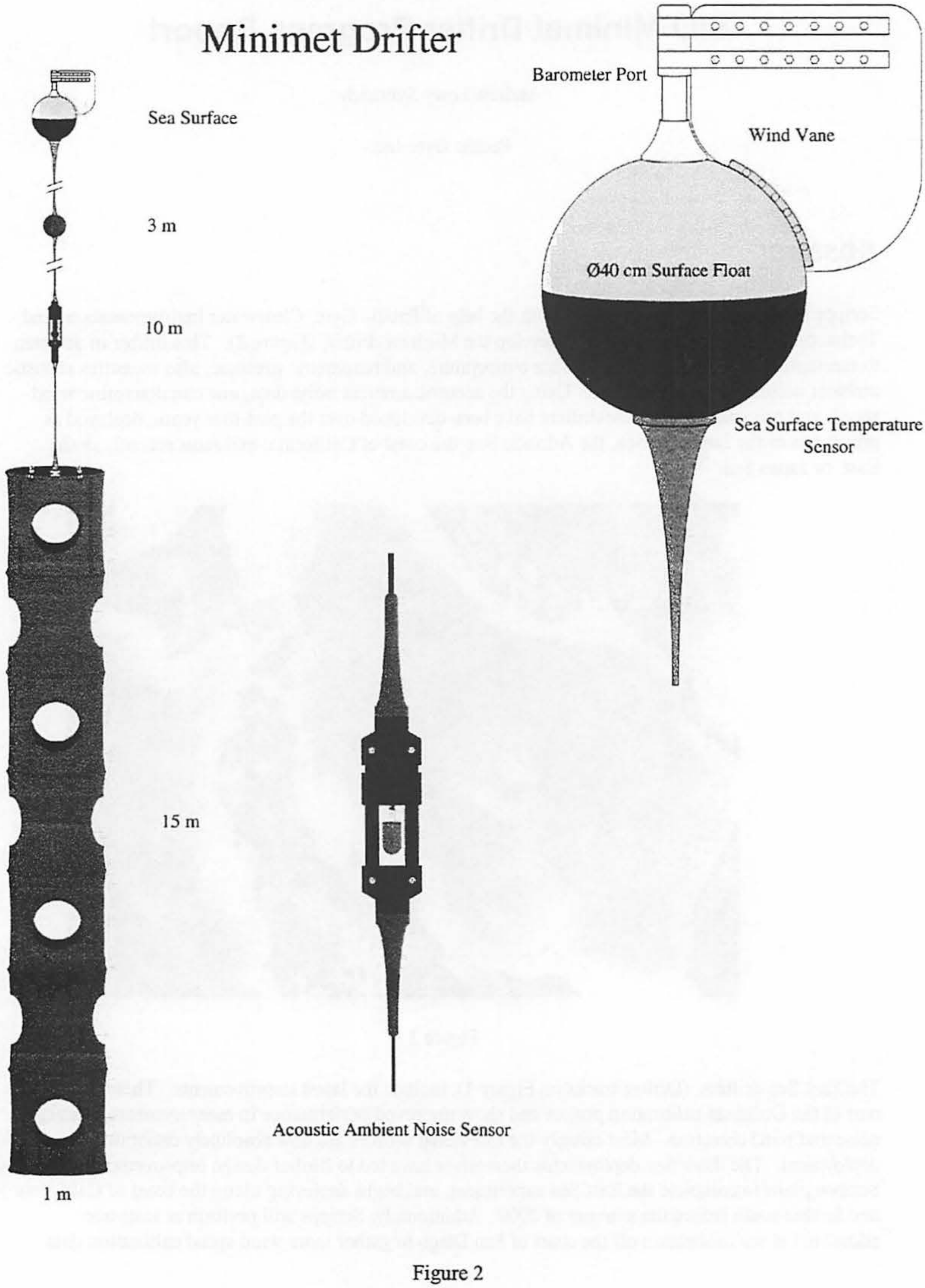
Minimet Drifter
Sea Surface
3 m
10 m
15 m
1 m
Acoustic Ambient Noise Sensor
Barometer Port
Wind Vane
Ø40 cm Surface Float
Sea Surface Temperature
Sensor

Figure 2

Previous Deployments

Minimet drifters were previously deployed in the Labrador Sea, the Adriatic Sea, and the coast of California. The Labrador Sea deployments occurred during the winter of 1996-1997. The Adriatic Deployments in 1997, and the California coast deployments in 1998. All of these drifters used the original Scripps Institution of Oceanography design. Much was learned during these deployments, which contributed to technical improvements and design changes.

Leaky Labrador Sea Drifter Acoustics

A new silicone potting material used to seal the hydrophone assembly caused leaks, which destroyed the electronics near the hydrophone. This was the result of the potting material shrinking while curing. Almost half the drifters lost their acoustic data stream soon after deployment.

Large Compass Offsets

Analysis of all the data from these early deployments show disturbingly large offsets in the flux gate compass data. These offsets were as large as 75 degrees. This was the result of poorly degaussed battery packs. While the battery packs were degaussed, the degaussing tool was simply not powerful enough for the larger battery packs used in these drifters. Each drifter was individually calibrated in order to eliminate these large offsets, and even with these calibrations, the offsets seemed to change when the drifter was actually placed in water.

Lithium Batteries Too Expensive

Lithium batteries are an attractive option when powering autonomous floating oceanographic instrumentation. They have almost three times the power density of alkaline batteries. The first three sets of Minimet deployments all used drifters with lithium batteries installed. This was necessary because the acoustic subsystem consumed much energy. Lithium batteries are seven to ten times more expensive than alkaline batteries. Battery packs for these first Minimet drifters cost over US$500 each.

Hydrophone Too Expensive

The hydrophone used in these original units was a spherical, omni-directional crystal. While these units had good sensitivity, they, like the lithium batteries, were just too expensive. For the purposes of measuring ambient acoustic noise, one could just as well use a vertically mounted cylindrical hydrophone.

Improvements

Having deployed almost 40 Minimet drifters, Scripps, with the help of Pacific Gyre, Clearwater Instrumentation, and Technocean Associates, set out to make some changes in the drifter design. Changes were made in the controller, transmitter, digital signal processor, hydrophone, battery packs, flux gate compass, mechanical mounting of the electronics, and pressure sensor. Changes in procedures such as, battery degaussing, acoustic component calibrations, drifter checkout also occurred. The only components not changed were the drogue, tether, and barometer port. This was an ambitious redesign.

New Sensors

Many new sensors were used in the redesigned drifters. These include the Honeywell HPB pressure sensor, the Precision Navigation TCM-2-20-VR compass, and the T.A.P. Consulting cylindrical hydrophone. All of these sensors were used to lower cost, while maintaining or increasing accuracy. Most were also simply plug in replacements for previously used sensors.

New Custom Electronics

Most of the custom electronics used in the original Minimet drifter needed to be refined to be used in production ready drifters. Scripps asked Pacific Gyre to design a new set of production ready electronics. Pacific Gyre, using the newly chosen set of sensors, designed a new system. The individual components include a hydrophone preamplifier and amplifier, designed with the help of Winfield Hill of the Rowland Institute of Sciences, in Cambridge Massachusetts, a redesigned DSP board, and a new main controller board. Pacific Gyre also redesigned the electronics mounting plates to accommodate the new electronics.

New Mechanical Components

The wind vane used on the original drifter was also not ready to be included in a production type drifter. Most drifter manufacturers now use ABS plastic surface floats with good results, and Scripps used this type of float as provided by both Clearwater instrumentation, and Technocean Associates. Technocean Associates helped redesign the wind vane. The new wind vanes now consist of only two cleverly molded pieces of ABS plastic. This reduced the time required to manufacture and assemble the wind vanes.

New Transmitter and Antenna

Scripps now uses Seimac transmitters in all their drifters. They mate nicely with PCB ground plane antennas from Clearwater Instrumentation. The PCB antennas are less expensive, and easier to mount.

East Sea Data

Through February 2000, Scripps has deployed 28 Minimet drifters in the East Sea. These drifters are much improved, lower cost drifters. Data from these drifters can be seen on the following web site, http://lutetia.ucsd.edu/drifters/EastSea/. The site includes data plots for each drifter, updated daily. The data from each drifter is compared to data from the National Center for Environmental Prediction (NCEP). Figure 3 shows data from one of the drifters. One can see the data compares well with NCEP. Many of the drifters in this experiment, were placed in the water close to shore, and washed up shortly after deployment. Others that did not wash ashore, show higher than usual low frequency sound signal levels. This is due to large amounts of ship traffic in these areas. It was observed that shifting of the battery packs during high impact deployments also caused some early failures. Subsequent deployments from research ships where drifters were placed more carefully into the water eliminated these early failures.

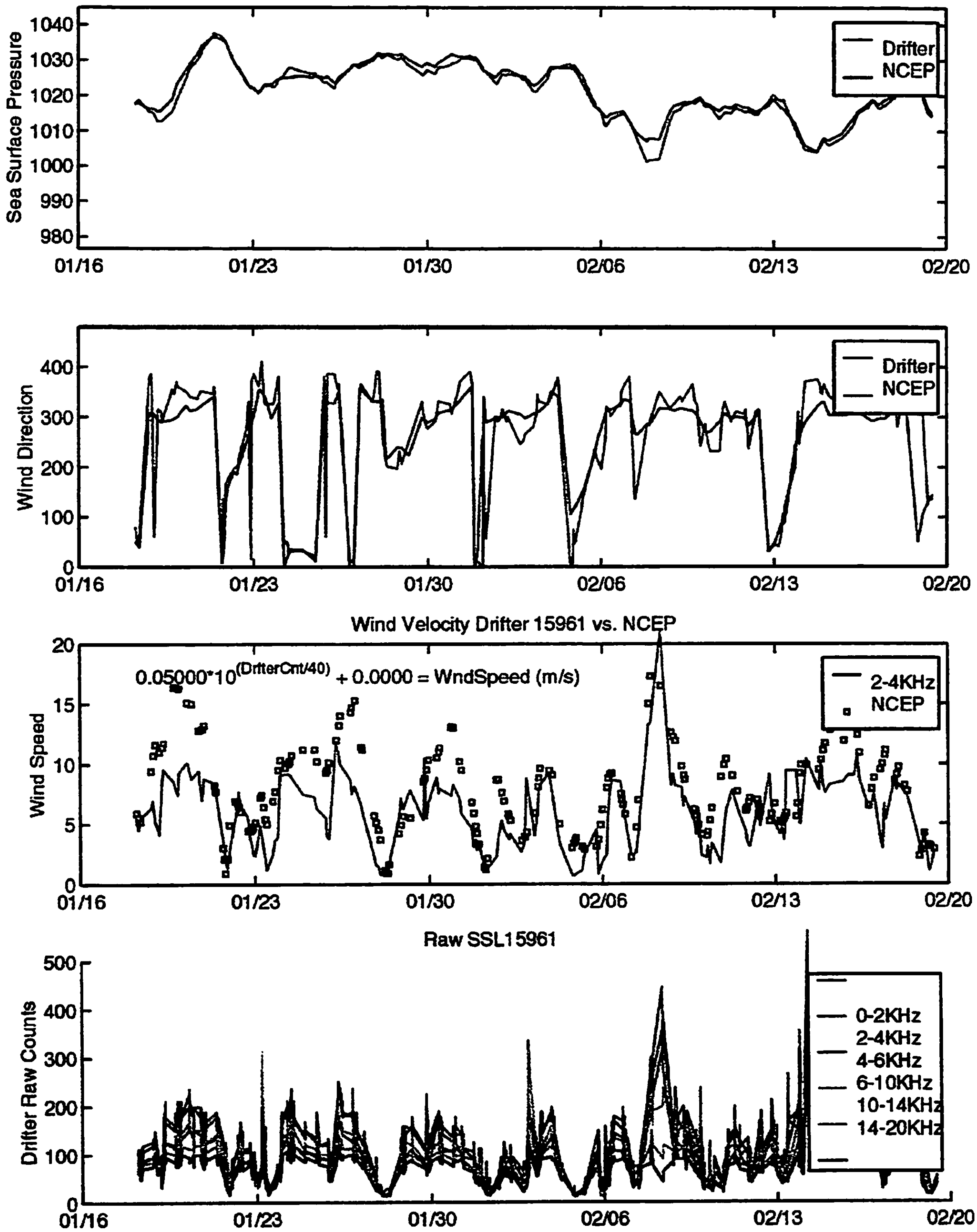
Sea Surface Pressure
Drifter
NCEP
Wind Direction
Drifter
NCEP
Wind Velocity Drifter 15961 vs. NCEP
0.05000*10^(DrifterCnt/40) + 0.0000 = WndSpeed (m/s)
2-4KHz
NCEP
Wind Speed
Raw SSL15961
Drifter Raw Counts
0-2KHz
2-4KHz
4-6KHz
6-10KHz
10-14KHz
14-20KHz
01/16
01/23
01/30
02/06
02/13
02/20

Figure 3

Next Steps

Scripps continues to develop the Minimet drifter. The current instrument eliminates past problems with large compass offsets, and is now absolutely calibrated. Future plans include: 1. Beginning to shift production from the Scripps Institution of Oceanography to outside manufacturers. 2. Further work will be done to improve wind speed calculations, based on the current East Sea deployment, and future calibration cruises. 3. Deployments in the East Sea will be completed, and begun along the coast of California and further south.

Air-Deployment of SVP Drifters

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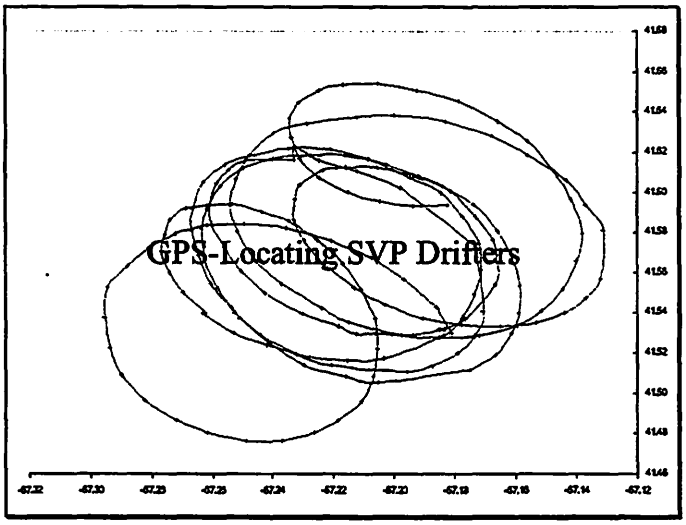
SVP drifters have been successfully deployed from a variety of fixed-wing aircraft with systems consisting of special packaging for the drifter and a parachute to control the descent of the drifter into the sea. In these cases, the development of air deployment systems and deployment procedures have been preceded by a systematic design program. The steps of the program include specification of the drop parameters; solution of the significant problems in air deployment; and testing of the proposed solutions. The conditions of an air deployment are described by the type of aircraft, flight conditions, and payload specification The significant problems which must be addressed during the design phase are safe exit from the aircraft; protection of the drifter upon sudden deceleration when the parachute opens after leaving the aircraft; safe entry of the drifter into the water, separating the parachute and its shrouds from the drifter, and releasing the drifter from packaging. This presentation will discuss results of air deployment systems for smaller, short-range aircraft flying at 70 kias (knots indicated air speed) and from the C-130 at 140 kias.



GPS-Locating SVP Drifters

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1 Introduction.

From its beginning, the Argos system has provided users accurate locations for drifting buoys using it to obtain data from their equipment located throughout the world's oceans. The more recent advent of equipment location through the US-government operated Global Positioning System (GPS) has made available to users a new means of locating drifting buoys that can augment Argos positioning, or add new capabilities to these instruments. GPS allows the user to have very accurate locations, even with a purposely-degraded signal, exactly when the user wants it. At first, GPS engines - the electronic systems that received signals from GPS satellite and calculated positions – were power hungry. This limited the early use of GPS to drifting buoy applications with very short deployments. Examples of these would be the Self-Locating Datum Marker Buoy developed by the US Coast Guard to aid in search and rescue operations which last only a few days, and studies of freshwater from river discharges mixing over the continental shelf where the equipment was picked up after short deployments. Advances in circuit design and software have improved the performance of GPS engines considerably so that today's GPS engines typically track 12 satellites and are very power efficient. The result is that the power expended to determine a GPS location has been greatly reduced. GPS can now be considered as a viable means of locating a drifting buoy in those applications it would benefit. It is the purpose of this paper to suggest what those other uses might be.

1.1 What is GPS.

GPS depends upon a constellation of satellites orbiting about 1000 miles above the earth and transmitting accurately timed signals and other information related to satellite location. Most popular handheld GPS equipment receives the signal broadcast at 1.2 gHz. A GPS engine decodes these transmissions and determines the location of the antenna receiving the signal and the exact time of the location. Although there may be as many as twelve satellites visible at one time, only three well-positioned satellites are needed to determine a twodimensional location; four satellites allow the altitude to be determined, as well. When more satellites are available, the GPS engine software can apply stratagems for efficiently switching the constellation should a satellite in use become occluded, or otherwise unavailable. These algorithms are written for scenarios involved in maintaining active positioning in an urban environment where the signals can be blocked by buildings or blocked by foliage (the 1.2 gHz radio signal is absorbed by water, including that present in leaves). However, these tracking algorithms are useful in drifting buoys because the signal can be blocked when a drifter is swamped by a wave.

GPS locations have an accuracy of +/- 100 meters when Selective Availability (SA) is turned on, which is most of the time. The US Air Force, which operates the GPS system, degrades the signal for civilian use as a security measure. The degradation imposes a pseudo random error that limits GPS accuracy; without SA GPS accuracy would be about +/- 10 meters. The US government has stated that it will remove SA in the future, but a firm date hasn't been set for this. GPS time is very accurate. GPS positions can be acquired as rapidly as 1/second.

2 ClearSat-15 GPS Self Locating Drifter.

The ClearSat-15 GPS is an SVP drifter into which has been integrated a Rockwell Jupiter GPS engine (Figure 1). The drifter's ClearSat-2.0 controller turns on the Jupiter at the appropriate intervals, monitors the GPS data until an acceptable GPS solution has been found, updates the position table with the new data, and places the GPS data into the Argos format which is transmitted every 90 seconds. The surface float also holds a GPS antenna and additional battery power to supply the increased power demand resulting from operation of the GPS engine and the transmitting 256-bit Argos messages.

2.1 ClearSat-GPS Format.

Several factors were considered in determining the format for the ClearSat-15 Argos GPS message: desired GPS location frequency, message content, and the length of the most probable Argos pass gap. We first determined that data would be reported to the following precision:

Universal time: year, month, data, time ± 1 second

Latitude: ± 90.0000 ± 0.0001 deg.

Longitude: ± 180.0000 ± 0.0001 deg.

This accuracy will permit our equipment to report the full accuracy of GPS positions when use of SA is ended. We selected GPS location rate of 1/30 minute as the basis for designing the Argos format. This sampling rate ensures adequate sampling for tides, inertial motions, and approaches a reasonable level of detail for wind driven currents.

2.1.1 Argos Satellite Pass Distribution

We settled on a satellite gap of eight hours for designing the Argos format because this is the largest we have seen in the past few years. Figure 2 shows data representative of intervals between sequential Argos positions from a ClearSat-15 GPS drifters. These data show a longer gaps than intervals computed from satellite pass prediction; there are times when the satellite cannot receiver the drifter because of rough seas. Almost 80% of the locations are less than two hours apart. Six percent occur at three hours. This probably represents the gap that occurs when the satellite passes almost directly overhead and Argos is not able to compute an accurate solution for the position. Slightly more than 10% of the gaps center around six hours, which is due to satellite orbit configuration. In the past this number has been as high as eight hours, so this seemed a reasonable value to select as the maximum information that needed to be stored and reported in the Argos messages.

2.1.2 GPS Message Format

The ClearSat-15 GPS format consists of four 256-bit Argos messages, or data "pages." Each page contains the most recent GPS time (year, month, day, time) and position. (In all following further discussions, when GPS positions are mentioned, it will be understood that what is implied is the position in latitude and longitude along with the full time information, needed to reconstitute date and time to +/- 1 second.) The first page also holds three GPS differential positions and drifter status information including sea surface temperature. The other three pages contain four differential times and positions besides the latest position information. So the four pages contain a total of sixteen GPS positions, fifteen of which are in differential form. The standard GPS sampling configuration for a ClearSat-15 is once every 30 minutes; so four data pages cover almost eight hours.

Each Argos GPS data page has internal four-bit checksums for quality control on the Argos transmission. Our experience with 256-bit Argos messages is that data loss increases towards the end of the message. On the average about 25% of the last several bytes of the message are corrupted. Additional checksums within the message allow most of the message to be saved if the later portions are corrupted. Each Argos page also has an 8-bit total checksum in the last byte for the previous 31 bytes.

3 Current GPS Applications

GPS location has been used in oceanographic instrumentation for several years. Among current applications are the observation of highly variable surface currents, and use as a location tool in managing active field programs requiring coordination of drifting instrumentation deployed over an area of several square miles.

ClearSat GPS format promotes ready access to the most recent GPS position, which is useful in knowing the recent location of equipment. When the Argos message bytes are evaluated as hexadecimals the concatenation of bytes two and three (counting the first byte as byte zero) are universal time in seconds divided by two. Latitude and longitude are contained in the next six bytes which are concatenated into groups of three bytes each with the most significant bit reserved as a sign bit, then evaluated as decimals and divided by 10,000. This application is greatly facilitated by using an Argos uplink receiver to acquire directly the drifter broadcast. The information could be obtained through Service Argos, but it will be between one and two hours old. If direct contact with the drifter is lost, an Argos or GPS position obtained from Argos as a last resort can bring the searcher close enough to the equipment to re-establish direct radio contact.

3.1 Locating Autonomous Drifting Equipment

A recent NASA field demonstration of remote surface salinity sensing used GPS positions from ClearSat-15 GPS drifters equipped with conductivity-temperature sensors mounted on their surface floats to direct over flights by aircraft carrying a test sensor. Clearwater has used GPS to locate and recover drifting instruments deployed for periods of several hours in foggy conditions with very poor visibility.

3.2 Studies of Energetic Currents

GPS position information can provide detailed information in highly variable current regimes. Dick Limeburner (Woods Hole Oceanographic Institution) has released several ClearSat-15 GPS drifters in the vicinity of Georges Bank located east of Cape Cod. Georges Bank is a shallow oblong area aligned northeast to southwest approximately 50 miles wide and 70 miles long (Figure 3). The circulation over the banks is characterized by strong tides. Drifters with drogue centers at 10 meters were set to capture GPS positions approximately once every 30 minutes; this rate should sample tidal currents approximately twenty-four times in one period. The tidal ellipses are very well defined (Figure 4).

4 New Uses of GPS Location Information

A self-locating drifter offers the possibility of operating more efficiently to increase the life of drifters by saving power now allocated to transmitting, and to optimize data collection by minimizing the number of transmissions. However, developing new applications requires an understanding how well GPS positioning works in drifters the ways in which GPS operation affects a drifter, particularly in the area of power budget.

4.1 Performance of a GPS Drifter

GPS performance can be understood in terms of how rapidly a GPS position is acquired, and the reliability of GPS positioning. The speed of location acquisition is important to the power budget for GPS. GPS reliability must be assured, particularly if GPS is to be the only means of location.

4.1.1 Time to Navigation

In Figure 5 we see the distribution of GPS location intervals for a three-month period for an instrument where the GPS repetition rate was set at 30 minutes. In this instance the GPS engine was started every thirty minutes regardless of the time taken to obtain the previous location. The engine was allowed to run until it obtained a valid location. (It is shut down after 20 minutes if the navigation is not acquired.) An interval between locations of less than 30 minutes means that the time to navigation of the previous GPS location probably was greater than the average time of approximately two minutes. Eighty percent of the intervals are found between 29 and 32 minutes. This means that the GPS engine usually is able to navigate and render an acceptable value in less than two minutes. The next 15 percent of instances require and additional two minutes. However, the record does indicate that five percent of the time conditions related to sea state or satellite configuration are such that more time is required to obtain an acceptable position. Figure 5a shows that in ideal conditions (on a roof top) navigation is attained is a little more than one minute.

4.1.2 GPS Accuracy and Reliability

GPS stated accuracy is +/-100 meters with selective availability turned on. Figure 6 compares the locations obtained by Argos, accurate to between 100 and 1000 m, positioning to GPS positions. While Argos positions are accurate, they do not resolve the fine scale tidal motions and do not provide the smoothness displayed by GPS.

4.2 Potential for Power Savings

While it is clear that GPS is well suited to elucidating high frequency surface current structure and providing more accurate positions, it is useful to explore other possible applications for GPS which might reduce the amount of data processed, lower satellite transmission costs, or prolong drifter life by reducing power consumption. Could GPS be used to supplement, or replace, Argos positioning for open ocean conditions where surface currents typically exhibit much lower frequency scales, or in situations where information is not needed synoptically? Indeed, much of the surface information for the WOCE SVP program used position information from drifters operating on the schedule of on for 24 hours and off for 48 hours that was processed months later and mathematically fitted to provide positions at six-hour intervals. To investigate the possibility of obtaining more accurate position information using GPS we ran SVP-GPS drifter electronics configured to obtain GPS locations every four hours placed on the roof of our facility. The positions reconstituted from Argos messages are presented in Figure 7 and show that the longer interval did not significantly affect the time needed by the GPS engine to navigate. The interval probably could be stretched out to 6 hours without any change in operating parameters for GPS.

4.2.1 GPS and Transmitter Power Budgets

If it is desirable to acquire synoptically accurate positions every four hours, or six hours, power requirements need not be considered, other than to have an estimate of how GPS operation affects battery life and life of the equipment. If the goal is power savings to increase the length of equipment operation, or reduction of satellite data transmission, and GPS is used to fill in the position gaps, then the power budget becomes an important consideration. The daily power budget for Argos transmission is approximately 170 mAh. This is reduced to one-third if a one-third duty cycle is employed; for example, one day on followed by 2 days off. So the combined requirements of Argos transmission and GPS operation must fall below approximately 60 mAh per day to compete with the power savings afforded by a one-third duty cycle. If positions every six hours are sufficient and the average time to navigate is taken to be two minutes, then GPS operation requires 24 mAh per day. The breakeven point in the power budget is Argos transmissions at the duty cycle of one day of transmission every five days, at the least; once every eight days would allows more of a cushion. This transmission cycle would require more data pages for GPS data and other data; however, multiple pages could be sent several times during 24 hours with the expectation of a high rate of accurate data transmittal.

4.2.2 Potential for Additional Power Savings

We anticipate that power budgets will be affected by two factors: Argos satellite receiver sensitivity and improved GPS hardware and firmware, and improved drifter controllers. CLS is increasing sensitivity of satellite receivers so that one should be able to reduce Argos PTT power to 0.5 watt, without sacrificing data throughput. Since most drifter transmitters operate at 1 watt, the transmitter power budget should be reduced by one-half. At this time only one satellite has the improved receivers. Transmitting equipment relying on more sensitive satellite receivers cannot be implemented at this time without risking loss of data when the less sensitive satellite passes overhead.

There have been continuous improvements in GPS engine performance resulting in ever, lower power requirements and increasingly improved algorithm giving more efficient performance. Taken together, the power required to obtain a GPS fix has dropped dramatically over the past several years. The huge consumer market for equipment utilizing GPS has stimulated these improvements. We expect this trend to continue; for example, we soon will incorporate a GPS engine operating on 3 VDC, rather than five volts, which will help further reduce GPS engine power consumption. Transmitters and controllers operating on 3 VDC will soon be available and this will also reduce power requirements.

4.3 Power savings through satellite pass prediction.

A second approach to extending drifter life by lowering power consumption and saving batteries is to employ pass prediction to dictate the time for transmitting to the Argos satellites. If a drifter knows its location and the time, it has the information necessary to estimate when a satellite will be overhead and can transmit only at those times.

4.3.1 Accurate Pass prediction

It is possible to reduce transmission power needs by 90% with accurate pass prediction. It is imperative that the transmitting equipment be aware of the status of Tyros satellites. However, if Tyros satellites handling Argos data are changed because of failure, or replacement, or satellite ephemeris degrade and the drifter is not aware of these changes, pass prediction will cease to work or work less effectively. The problem is compounded when the time between equipment manufacture and deployment is long. These problems will be solved when Argos offers two-way communication in the next generation of satellites. In fact, updating of satellite information will be automatic with Argos III for PTT's with two-way communication.

4.3.2 Approximate Pass Prediction

Perhaps a more limited approach can be applied to affect power savings, since Argos III will not be operational for at least two years. A GPS drifter that knows its position and the time can use it to predict approximately the presence of Tyros satellites. The rationale behind the proposed method is demonstrated in Figure 8 that illustrates how passes are concentrated in two intervals, one of which is between 1800h to 0000h. Complete daily Argos records were sorted to select only the transmission occurring in that interval. In Figure 9 the red markers represent Argos transmissions received bewteen 1800h to 0000h. The blue "plusses" are the archived times of GPS positions determined from this time-restricted data set. In this experiment the GPS drifter determined locations once every half hour and reported its data in Argos messages, which contained 15 previous positions, or 7.5 hours, of GPS data. If the experiment had been designed to sample only every hour, close to the entire record could have been relayed. By employing this crude pass prediction techniques, it seems possible to expect a 75% reduction in power required for transmissions.

5 Conclusion

Use of GPS in drifters is a mature technology. It can be used in SVP drifters to observe energetic surface currents in the surface mixed layer and in CODE drifters in the upper meter. It is now time to look at other applications of GPS information to enhance drifter performance in areas where synoptic information is not needed: power conservation and reduced data transmission. These applications will be based on prediction of satellite orbits, as well as storage of drifter location information. The absence today of a way to refresh information of satellites in service and orbital characteristics limits capabilities of pass prediction at this time, but the situation surely will evolve in the next few years.

Figures

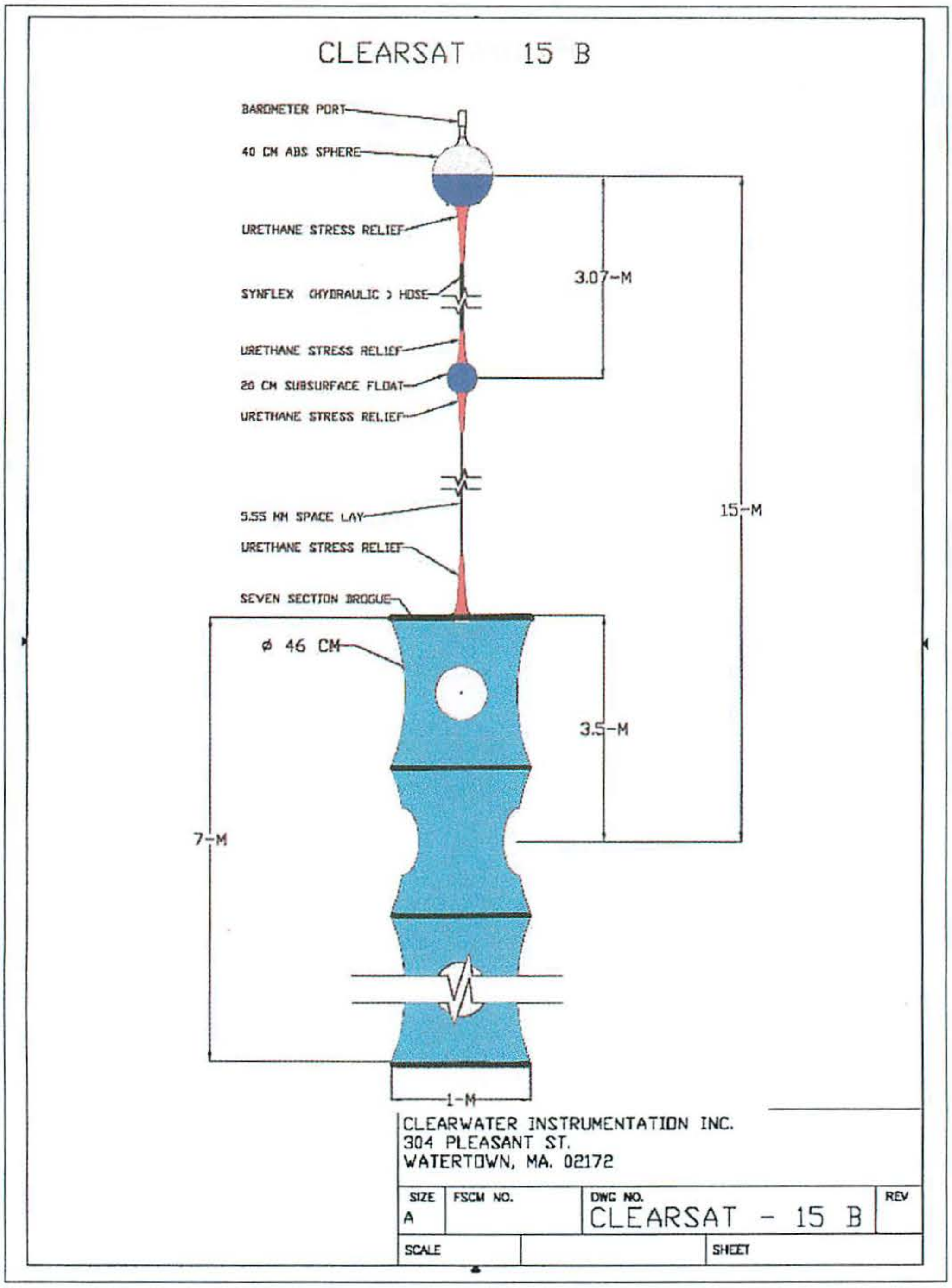

Figure 1. ClearSat-15 GPS with barometer port.

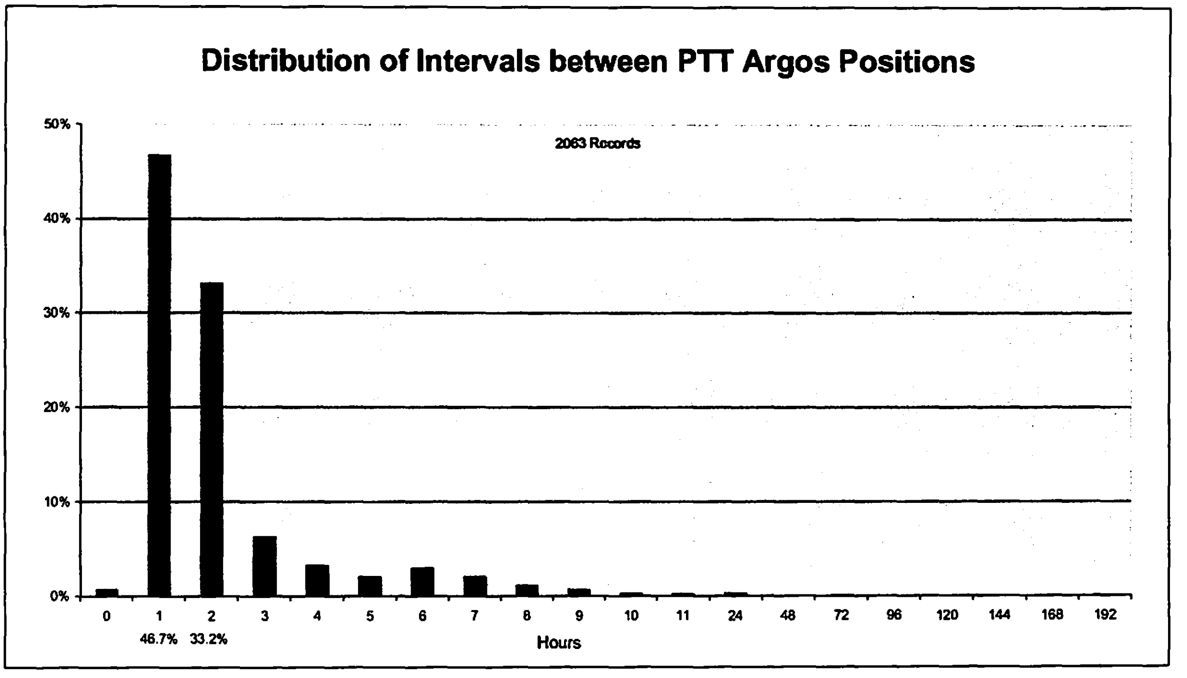

Figure 2. Distributions of intervals between Argos positions.

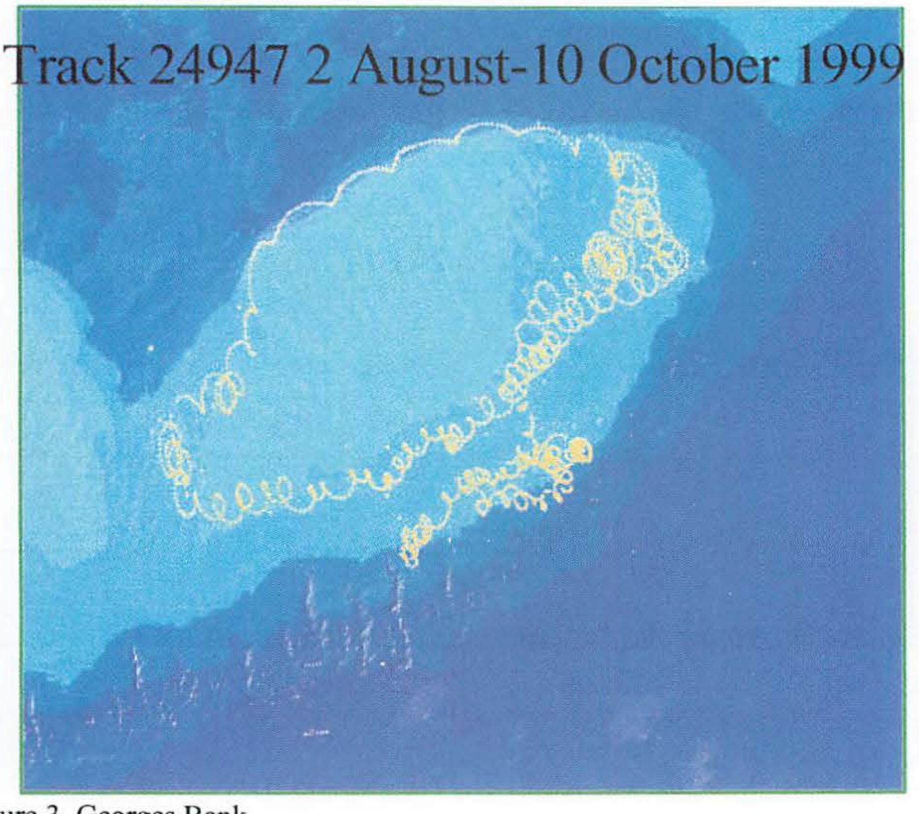

Figure 3. Georges Bank.

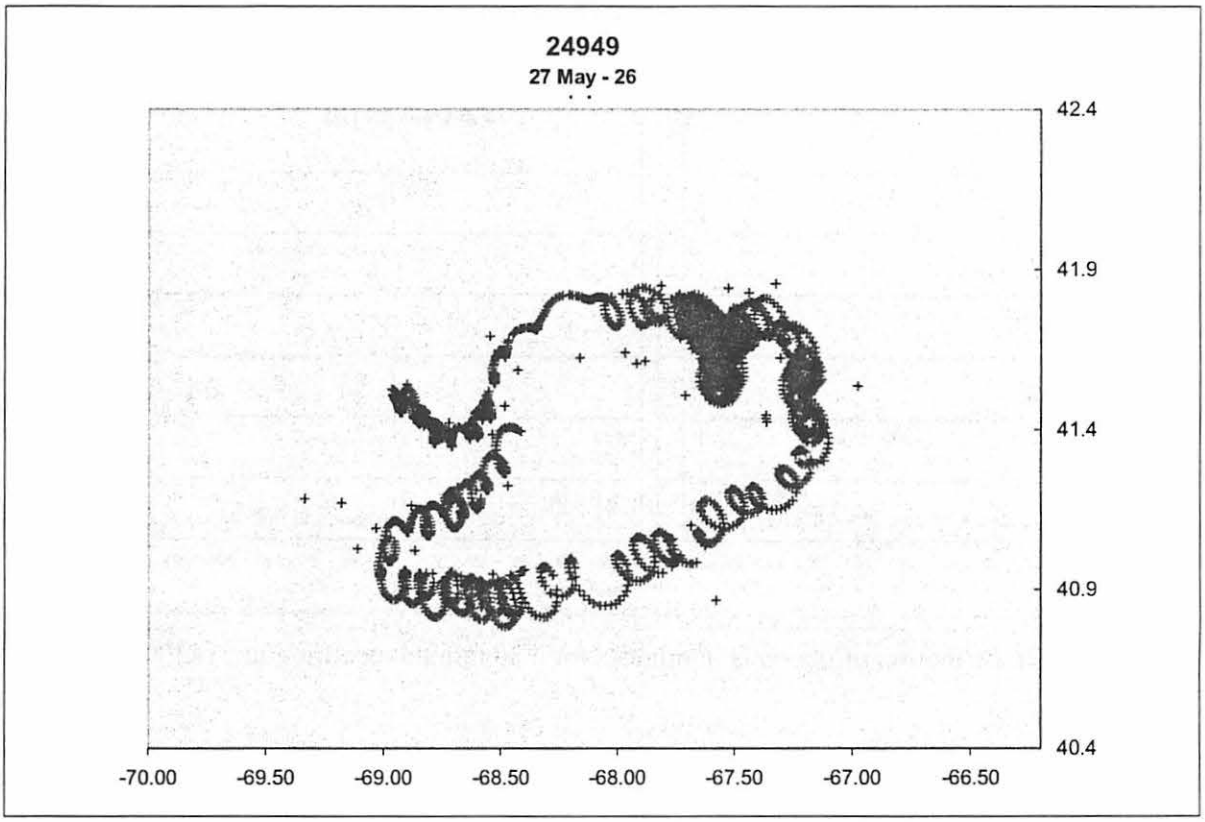

Figure 4. Drifter 24949 27 May to 26 July 1999.

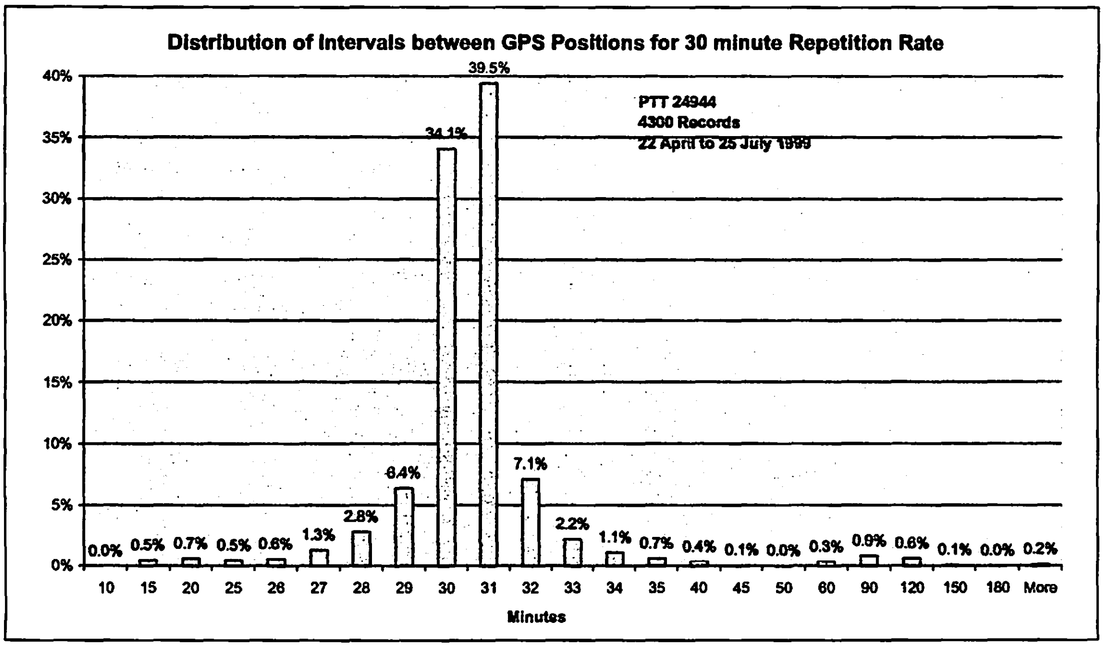

Figure 5.Distribution of intervals in minutes for a 30 minute repetition rate (4300 records).

Figure. Time to Acquire Position

GPS ON	GPS OFF	Acquire
8:00:35	8:01:37	0:01:02
12:00:37	12:01:48	0:01:11
16:00:37	16:01:45	0:01:08
20:00:37	20:01:42	0:01:05
0:00:37	0:01:47	0:01:10
4:00:37	4:01:45	0:01:08
8:00:37	8:01:47	0:01:10
12:00:37	12:01:41	0:01:04
16:00:37	16:02:17	0:01:40
20:00:37	20:01:36	0:00:59
0:00:37	0:01:46	0:01:09
4:00:37	4:01:40	0:01:03
8:00:36	8:01:46	0:01:10
12:00:35	12:01:46	0:01:11
16:00:34	16:01:34	0:01:00
	Average	0:01:09

Figure 5a. Time to acquire GPS position under ideal conditions.

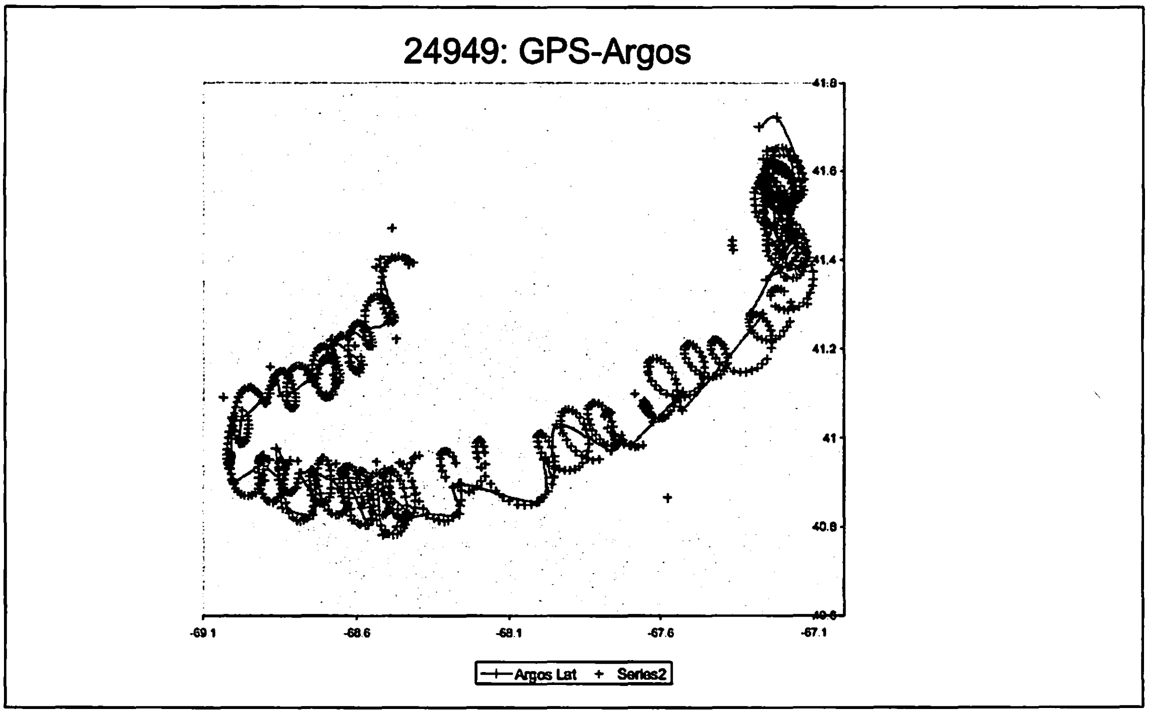

Figure 6 Argos positions superimposed on GPS positions obtained at 30 minute intervals.

PTT ID	Argos UT		Page	P	GPS UT	Year	Year Frac	Latitude	Longitude
25374	10/20/1999	12:40:25	Page0	0	10/20/99 11:49:24	1999	0.804089422	42.3672	-71.1989
25374	10/20/1999	12:40:25	Page0	1	10/20/99 07:49:28	1999	0.803632927	42.3676	-71.1992
25374	10/20/1999	12:40:25	Page0	2	10/20/99 03:49:24	1999	0.80317618	42.3676	-71.1993
25374	10/20/1999	12:40:25	Page0	3	10/19/99 23:49:16	1999	0.802719305	42.3675	-71.1996
25374	10/20/1999	12:41:50	Page1	0	10/20/99 11:49:24	1999	0.804089422	42.3672	-71.1989
25374	10/20/1999	12:41:50	Page1	1	10/19/99 19:49:16	1999	0.802262684	42.3678	-71.1988
25374	10/20/1999	12:41:50	Page1	2	10/19/99 15:49:16	1999	0.801806063	42.3679	-71.1994
25374	10/20/1999	12:41:50	Page1	3	10/19/99 11:49:12	1999	0.801349315	42.3675	-71.1991
25374	10/20/1999	12:41:50	Page1	4	10/19/99 07:49:12	1999	0.800892694	42.3676	-71.1989
25374	10/20/1999	12:43:15	Page1	0	10/20/99 11:49:24	1999	0.804089422	42.3672	-71.1989
25374	10/20/1999	12:43:15	Page2	1	10/19/99 03:49:20	1999	0.800436327	42.3679	-71.1991
25374	10/20/1999	12:43:15	Page2	2	10/18/99 23:49:16	1999	0.799979579	42.3676	-71.1992
25374	10/20/1999	12:43:15	Page2	3	10/18/99 19:49:36	1999	0.799523592	42.3672	-71.1994
25374	10/20/1999	12:43:15	Page2	4	10/18/99 15:49:40	1999	0.799067098	42.3673	-71.1988
25374	10/20/1999	12:44:40	Page1	0	10/20/99 11:49:24	1999	0.804089422	42.3672	-71.1989
25374	10/20/1999	12:44:40	Page3	1	10/18/99 11:49:44	1999	0.798610604	42.3673	-71.1991
25374	10/20/1999	12:44:40	Page3	2	10/18/99 07:49:36	1999	0.798153729	42.3669	-71.1995
25374	10/20/1999	12:44:40	Page3	3	10/18/99 03:49:44	1999	0.797697362	42.3677	-71.1993
25374	10/20/1999	12:44:40	Page3	4	10/17/99 23:49:48	1999	0.797240868	42.3678	-71.1987
						Standard Deviation		**0.00028**	**0.000261**
							Max	**42.3679**	**-71.1987**
							Min	**42.3669**	**-71.1996**
							Range	**0.0010**	**0.0009**
							Range, m	**111**	

Figure 7. GPS positions from equipment set to obtain a position once every four hours.

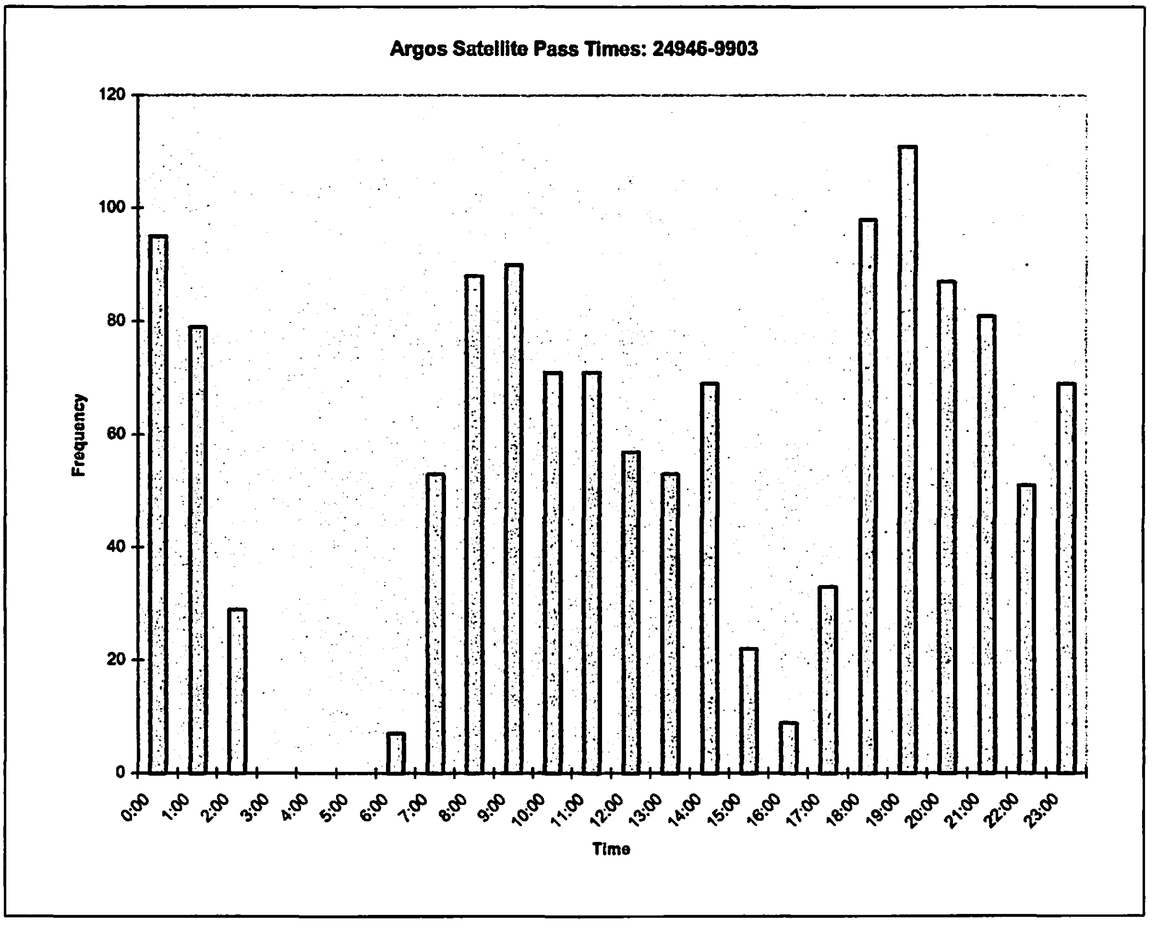

Figure 8. Distribution of satellite pass times for PTT ID 24946 during the month of March 1999.

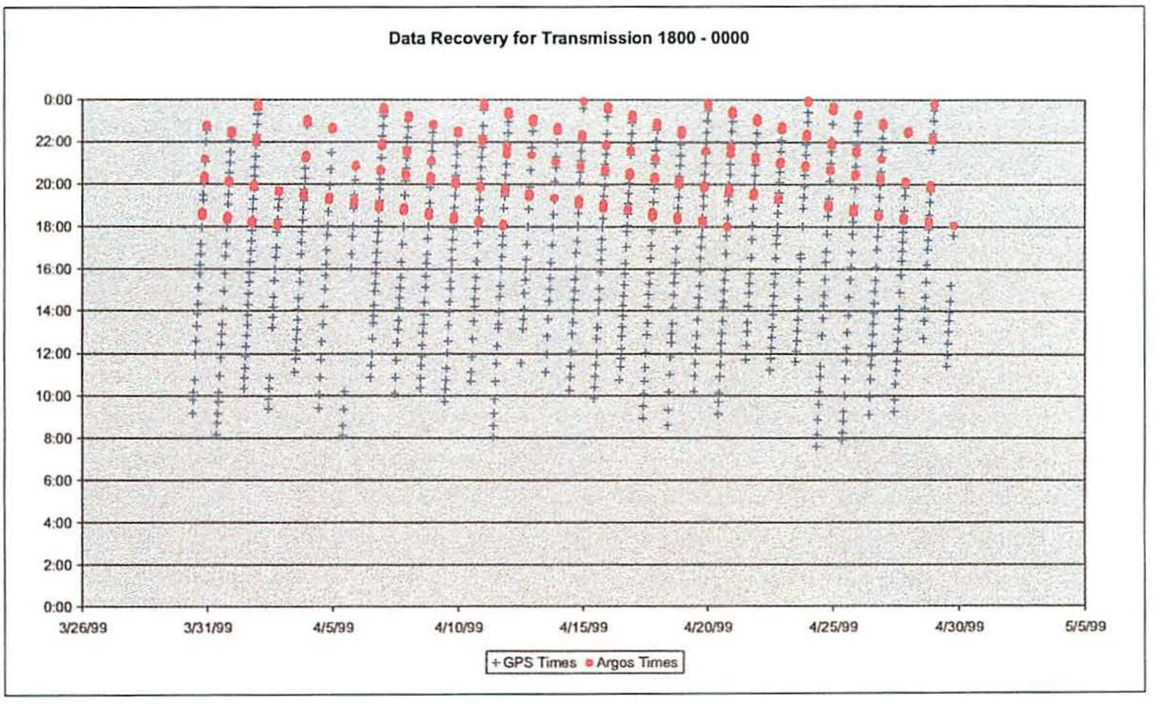

Figure 9. Data recovery for Argos transmission adjusted to 1800-000 from observed pass occurrences.

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