INTERGOVERNMENTAL OCEANOGRAPHIC
COMMISSION (OF UNESCO)

WORLD METEOROLOGICAL
ORGANIZATION

DATA BUOY COOPERATION PANEL

# DEVELOPMENTS IN BUOY AND COMMUNICATIONS TECHNOLOGIES

TECHNICAL PRESENTATIONS
MADE AT THE TWELFTH SESSION OF THE DBCP

(Henley-on-Thames, October 1996)

DBCP Technical Document No. 10

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## NOTES



*Editorial note*: This publication is for the greater part an offset reproduction of material submitted by the authors and has not been subjected to additional editorial revision.

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# FOREWORD

At the eleventh session of the Data Buoy Co-operation Panel in Pretoria, a whole day was devoted to a series of technical presentations on developments in buoy technology and enabling methods. The significant success of this technical workshop prompted the Panel to take immediate steps to ensure that the event would be repeated at its next session as a practical means of promoting a useful dialogue and co-operation between all sections of the buoy community, the buoy manufacturers and the communications service providers.

As a result, an extended technical workshop, lasting for one and a half days, was convened at the twelfth session of the Panel in Henley-on-Thames. Speakers, drawn from a wide variety of technical backgrounds, presented a total of 23 papers, all of significant help in advancing the capabilities of buoy programmes and the interpretation of buoy data. A particular theme highlighted in the workshop was the emergence of new technologies and systems for communicating with data buoys, and the Panel was especially gratified by the participation of representatives of many of the new satellite communications service operators.

The majority of papers are printed in full in the pages that follow. A few papers, for which the complete text has not been received, are given as abstracts. Abstracts are also given on behalf of speakers who were ultimately unable to read their papers at the session. In all cases, the papers are printed as received, without additional editorial intervention.

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Michel Taillade, CLS Argos, France
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Christine Caruso, NOAA-NCEP, USA (presented by Eric Meindl, NOAA-NDBC)
'QUIPS' - THE NCEP QUALITY IMPROVEMENT PERFORMANCE SYSTEM

Richard Graham, Meteorological Office, UK
IMPACT OF DRIFTING BUOY OBSERVATIONS ON AN NWP FORECAST - THE CASE OF 29 SEPTEMBER 1995

Andrew Donald, University of Leicester, UK
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Liam Fernand, Ministry of Agriculture, Fisheries and Food, UK
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**Buoy and sensor technology**

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Mark Bushnell, NOAA-AOML, USA
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# PRESENTATIONS

Keynote Address
Peter Niiler, Scripps Institution of Oceanography, USA

## Status of the Global Drifter Programme- Past, Present and Future

Since the latter part of the nineteenth century, oceanographers have released drifters in the open sea to determine ocean currents. First, they tracked drifter floats by ship and in the latter part of the 20th century, radio transmissions from the floats have been used to locate drifters world-wide. The Global Drifter Programme is a project of the DBCP. It is an outgrowth of the WCRP sponsored WOCE and TOGA plans to monitor the surface circulation, SST and Pa of the global ocean with drifting buoys. It began with the "Pan Pacific Surface Current Program" of TOGA in 1987 with about 160 drifters in the tropical Pacific and today there over 800 drifters distributed around the globe. Since its inception 45 scientific projects from 20 countries have contributed data and resources to its operation. Over 90 scientific papers and reports have been published

Many different designs of drifters have been used throughout history. Today, most of the drifters have a small float on the surface and the large drogue 10-15 m. below the surface. The ratio of the area of the surface float and the tether line to the area of the drogue governs how well drifters follow water. Experimentally, it has been determined that the drogue size had to be increased five times over what had been used historically. The modern drifters can return data from SST, Pa, wind speed, wind direction, upwelling and downwelling irradiances and they can carry small data chains to 50 m depth. They are light weight, deployable by one able bodied seaman from VOS and they are rugged, lasting on the average 300-400 days in the open sea. Seventeen companies and laboratories have learned to build low-cost Lagrangian drifters with very similar hydrodynamic and data retrieval characteristics for use in the Global Drifter Progamme.

Currently, the data is retrieved via the Argos satellite systems. Service Argos decodes the data and places it of GTS. The scientific data and drifter deployments are managed at the Global Drifter Center at AOML/NOAA and, with a six month delay, at MEDS, Canada. The atmospheric pressure data is used in real time for severe weather analysis and prediction and NOAA/NCEP uses the drifter SST data, together with satellite and ship reports, to make weekly global SST maps for medium and long range weather prediction. Surface current maps have been made for the Pacific Ocean (FIG 1.), with the North Atlantic, Indian Ocean and Southern Ocean maps to be completed by the turn of the century.

At the beginning of the programme in 1987, the drifter technology was the limiting factor in maintaining a global array of sensors in the ocean. In ten years, the ocean engineering and manufacturing communities have produced many innovative solutions to the problems of longevity, sensor stability, deployment methods from ships and aircraft and scientific data processing. Globally, there are about equal resources between oceanographers and meteorologist for the maintenance of global arrays of drifters. For the efficient use of the drifter resources to maintain and increase the arrays in the future (the tropical and south Atlantic Oceans have no drifters), the following problem require the attention of the DBCP members:

i) The full purchase price of an SVP-B drifter is about $3500 (US) and its operating cost with Service Argos is about $4000 (US) per year. The cost of FGGE-type drifters deployed by several meteorological sub-programs of DBCP is reported to be about five times of the modern drifters, or $37,000 per year. It is therefore possible that the number of drifters deployed by these meteorological programs can increase by a substantial numbers if SVP-Bs were adopted more uniformly over the next several years.

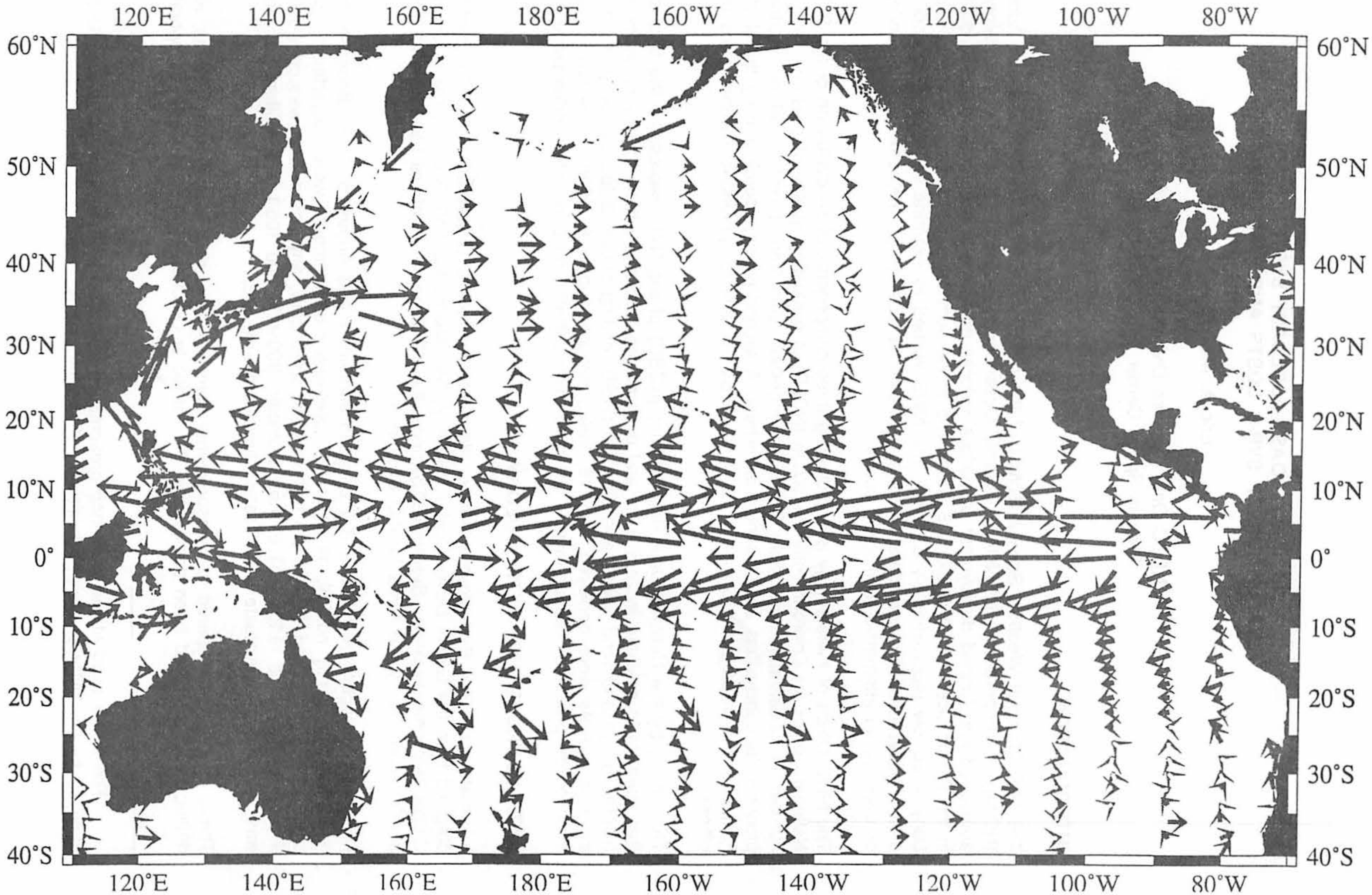
ii) Short term climate and long range weather prediction required use of a global model and input of a global data set. Operational agencies which have to date focused on obtaining data only from the regions of the ocean closest to their own coasts for marine will be required to take a more global view. The Global Drifter Program can offer platforms on which to mount meteorological sensors globally. For example, a barometer addition in 1996 cost $2000 (US).

iii) The most sever restriction to the growth and maintenance of the Global Drifter Program is the cost of data retrieval from the Argos system satellites. The current Tariff agreement with Service Argos, which is based on a "platform year" does not reflect the true costs of retrieving data from a large number of uniform platforms, globally distributed. The large number platform user presently subsidizes the programs very small platform user. A new method of accounting must be developed with Service Argos for utilization of their management, customer services and computer time in order for equitable allocation of costs be done between programs of very different scope and needs.

In summary, in the past ten years, the Global Drifter Program has grown to be a mature observing system in the global ocean. During this period it was largely supported by research funds, but recently an increasing portion of resources each year have come from operational agencies. DBCP, therefore, has become its home. Its future largely lies in the farsighted interests of its members.

# AVERAGE VELOCITY at 15m Depth

30 cm/sec 2° Lat x 8° Long Average 1 Jan 1979 - 31 July 1996



# NWS WEST COAST FORECAST SYSTEM (CFS) EVALUATION OF SVP-B COSTS AND PERFORMANCE

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## INTRODUCTION

The U.S. National Weather Service (NWS) of the National Oceanic and Atmospheric Administration (NOAA), in cooperation with NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML), authorized and funded deployment of surface velocity profiler with barometer (SVP-B) drifting buoys in the Pacific Ocean west of the U.S., beginning in the summer of 1995. Because the cost per SVP-B buoy is so low (approximately \$3.8 K[1]), the NWS wished to examine whether a network of SVP-B drifting buoys deserves consideration as a supplemental operational meteorological observing system, or even as an alternative to moored buoys.

The NWS Office of Meteorology is coordinating three components of an evaluation of the SVP-Bs. The National Center for Environmental Prediction (NCEP) is evaluating quality of pressure measurements, number of observations available for model ingestion, and impact on centralized marine forecast products. Its conclusions are presented elsewhere. A second phase, coordinated by the NWS Western Region, is still in progress to assess the value of SVP-B data to operational marine forecasters at field offices.

This study, by the National Data Buoy Center (NDBC) of the NWS represents the third component that attempts to evaluate system costs and performance, and relate them to existing systems such as moored buoys and wind speed and direction (WSD) drifting buoys. It focuses on performance since the first SVP-Bs were deployed, July 18, 1995, through August 6, 1996. Since NWS interest is in atmospheric pressure measurements, this report concentrates on barometer performance.

## DATA SOURCES AND METHODOLOGY

Information on SVP-B deployments and World Meteorological Organization (WMO) identifiers were obtained from the Global Drifter Center (GDC), AOML, Miami, FL. SVP-B data were received over the Global Telecommunications System (GTS) under the WMO communications header SSVX18KARS, the header assigned by the NWS for this experiment.

Data were collected 24 hours a day between January 1 and August 6, 1996. Because there is no real-time data quality control, all barometric pressure measurements were subjected to gross error checks to eliminate bad data before this analysis; specifically, any observation was considered "good" if it fell between the range limit of the barometer, 900 hPa and 1053 hPa. Within that range, there was no attempt to evaluate bias, scatter, time continuity, etc.

These data were compared to measurements from two other data observation systems: eight WSD drifting buoys that had been deployed in the Pacific in October 1994 (and were still operating); and

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[1]The figure used at the workshop presentation was \$3.0 K. The corrected value, \$3.8 K, was provided by Dr. Niiler of Scripps Institution of Oceanography.

fifteen 3-m moored discus buoys deployed along the west coast of the U.S. that are a part of the NDBC moored buoy network. Data from the WSD drifting buoys were received from January 1 to August 31, 1996. The 3-m moored buoy data were estimated from performance statistics routinely generated every quarter by NDBC for the 9 months from October 1995 through June 1996. The data from the WSDs and moored buoys had undergone full quality checking (e.g., range checks and time continuity) prior to release to the GTS. A comparison was also made to First Global Atmospheric Research Program (GARP) Global Experiment (FGGE)/Tropical Ocean and Global Atmosphere (TOGA) type drifting buoys (hereafter referred to as TOGA). Although no TOGA drifting buoys were deployed at the time, it is possible to compare and normalize costs in a similar manner to that for WSD drifting buoys. This is possible because they are identical to WSD drifting buoys (except for wind measuring equipment), and there is an established performance record for 339 of these systems that were deployed during TOGA (mean-time-to-failure (MTTF) of 477 days). The TOGA drifting buoy is most similar to the SVP-B in terms of meteorological data provided.

Using the data, the following were evaluated:

- MTTF, including mean operating time of barometer systems still operating
- infant mortality (i.e., apparent failure at or soon after deployment)
- normalized unit costs per year for each system
- estimated direct network costs to NWS of the SVP-B network, WSD network, and 3-m networks since the first SVP-B deployments
- cost per observation for messages from each system

The types of data provided by each buoy type are shown in Table 1.

**RESULTS**

Table 2 summarizes the data gathered. For the SVP-Bs, it was noted that 26 percent (11 of 43) apparently failed at deployment (i.e., data were never received). For the SVP-Bs, MTTF calculations were based on pressure measurements of 24 of the 43 buoys deployed. The MTTF was determined from those buoys that were deployed, operated, and failed between initial deployments and August 6, 1996 (14 buoys for an MTTF of 124.7 days); and buoys that were deployed and still operating, as long as operating time exceeded 124 days (10 buoys for an average operating time of 269.5 days). The weighted MTTF/mean operating time of these 24 buoys was 185.0 days. Finally, the average number of "good" observations per day per SVP-B buoy was 4.2; they usually were received as multiple (i.e., 2 or 3) hourly observations in a single message. The average of 10.3 messages from the WSDs and 21.3 from the 3-m moored buoys represent individual observations. Comparing the number of SVP-B observations directly with the other systems is difficult because the SVP-B drifting buoys were programmed to report on ⅓-duty cycle (versus a full duty cycle for the WSDs). The effect

**Table 1. Types of data provided by (or may be derived from) each system**

**SVP-B EVALUATION**
**NDBC PHASE**
**TYPES OF DATA PROVIDED**

| ITEM | SVP-B | TOGA | WSD | 3-M MOORED BUOY |
|---|---|---|---|---|
| BAROMETRIC PRESSURE | ✔ | ✔ | ✔ | ✔ |
| SEA SURFACE TEMPERATURE | ✔ | ✔ | ✔ | ✔ |
| SURFACE OCEAN CURRENTS | ✔ | | | |
| AIR TEMPERATURE | | ✔ | ✔ | ✔ |
| WIND DIRECTION | | | ✔ | ✔ |
| WIND SPEED | | | ✔ | ✔ |
| WAVE HEIGHT | | | | ✔ |
| WAVE PERIOD | | | | ✔ |

**Table 2. Summary of performance of the SVP-B, WSD, and the 3-m moored buoys. Data were received during the periods indicated in footnotes. MTTF/mean operating time was calculated since initial deployments for SVP-Bs and WSDs.**

# SVP-B EVALUATION
## NDBC PHASE
### SUMMARY

| | SVP-B | WSD | 3-M MOORED* |
|---|---|---|---|
| NO. DEPLOYED | 43 | 8 | 15 |
| DEPLOYMENT FAILURES | 11 | 0 | 0 |
| NO. OPERATING | 32 | 8 | 15 |
| TOTAL OBSERVATIONS | 32,047** | 20,149*** | 87,100 (EST) |
| "GOOD" OBSERVATIONS | 23,395 | 20,149 | 87,100 (EST) |
| AVERAGE OBSERVATIONS/BUOY | 731.1 | 2,518.6 | 5,807 (EST) |
| AVERAGE MTTF | 185.0 (24) | 655.5 | 365 (EST)**** |
| "GOOD" OBSERVATIONS/MTTF BUOYS | 917.3 | | |
| AVERAGE "GOOD" OBSERVATIONS/BUOY/DAY | 3.3 (32)<br>4.2 (24) | 10.3 | 21.2 (EST) |

*ESTIMATE OR TALLY FOR 10/1/95 THROUGH 6/30/96 (274 DAYS)
**TALLY FOR 1/1/96 THROUGH 8/6/96 (219 DAYS)
***TALLY FOR 1/1/96 THROUGH 8/31/96 (244 DAYS)
****REPRESENTS MEAN TIME BETWEEN SERVICE VISITS FOR ANY REASON; AVERAGE MTTF FOR BAROMETER IS ESTIMATED TO BE GREATER THAN 450 DAYS.

of this difference cannot be quantified with the existing data set. The SVP-Bs would have to be programmed to report on full cycle to be compared to the other Argos-reporting systems.

Because the moored buoys are visited approximately yearly for service, and hulls are not normally exchanged more often than every 2 years, mean operating time was estimated at 365 days. Service specifically to restore atmospheric pressure may or may not have been necessary.

To compare hardware costs required to satisfy a data requirement, unit costs must be normalized. For example, if there is a data requirement for a period of 1 full year, then the cost per unit must be adjusted upward if it operates less than 1 year because it must be replaced to continue delivering data. Conversely, it should be adjusted downward if it operates for more than 1 year since replacement is not necessary to continue receiving data for longer than 1 year. Thus, a normalized annual cost, $C_n$, may be determined by:

$$C_n = C_u(T) + C_u(M) \quad ,$$

where $C_u$ = unit cost
$T = 366/MTTF$ (units/year)
$M = N_{(Failed\ at\ Deployment)} / N_{(Deployed)}$ (infant mortality)

Table 3 shows the results of this analysis. It indicates the normalized annual cost of the SVP-B increases from \$3.8 to \$8.5 K per year for a data point, which is substantially lower than the TOGA, WSD, and 3-m moored buoys.

Next, the direct cost of the networks to the NWS from the start of the SVP-B experiment until August 6, 1996, was estimated for the three system types (Table 4). The cost for the SVP-B network

**Table 3. Annualized unit cost, adjusted for MTTF and failure at deployment, to receive atmospheric pressure measurements**

## SVP-B EVALUATION
### NDBC PHASE
### NORMALIZED COST/YEAR ($ K)
### (MTTF AND INFANT MORTALITY ONLY)

| COST COMPONENT | SVP-B | TOGA | WSD | 3-M MOORED |
|---|---|---|---|---|
| UNIT* | 3.8 | 14.0 | 20.0 | 60.0** |
| UNITS/YEAR | 7.5 | 10.8 | 11.2 | 60.0 |
| INFANT MORTALITY | 1.0 | 0.4 | 0.0 | 0.0 |
| NORMALIZED COST | 8.5 | 11.2 | 11.2 | 60.0 |

*DOES NOT INCLUDE THE COST OF THE DEPLOYMENT PACKAGE FOR SVP-B, TOGA, AND WSD DRIFTING BUOYS.

**FIGURE PRESENTED AT WORKSHOP WAS $41.5 K, WHICH IS A 1-YEAR OPERATION AND MAINTENANCE COST ONLY. THE REVISED FIGURE MUST BE USED TO SUSTAIN 3-M OPERATIONS FOR A LONGER TIME.

**Table 4. Estimated direct costs, excluding deployment packages, of the SVP-B, WSD, and 3-m moored buoy networks since start of SVP-B experiment**

## SVP-B EVALUATION
### NDBC PHASE
### ESTIMATED DIRECT NETWORK COST (TO 8/6/96)

| | SVP-B | WSD | 3-M MOORED |
|---|---|---|---|
| HARDWARE | 43($3.8 K) = $163.4 K | 8($20.0 K) = $160.0 K | 15($60.0 K) = $900.0 |
| COMMUNI-CATIONS | 32(158.6/366) = 13.9 YR<br>13.9 YR($1.3 K/YR) = $18.1 K | 8($3.8 K) = $30.4 K | |
| TOTAL | $181.5 K | $190.4 K | $900.0 K |
| # OBS* | 39,100 (EST) | 30,223 (EST) | 123,215 (EST) |
| COST/OBS | $4.64 | $6.30 | $7.30 |

*NUMBER OF OBSERVATIONS ESTIMATED FROM DATA TALLIED DURING PERIODS INDICATED IN TABLE 1, THEN ADJUSTED FOR 166 MORE DAYS (FROM 7/18/95 TO 12/31/95).

is lower than the WSDs and 3-m discus buoys. Since the product used by marine forecasters is data (not buoys), an attempt was made to relate the network cost to the number of observations. The bottom line of Table 4 shows that cost per data message is lowest for the SVP-B, followed by WSD drifting buoys and moored buoys, in that order.

To sustain such networks for more than a year, annual adjusted network costs were estimated (Tables 5 through 7). These calculations indicated the lowest cost per observation, in order, comes from the TOGA, WSD, and SVP-B drifting buoys and the 3-m moored buoy. In other words, as a result of significant differences in MTTF and number of observations delivered, the large unit cost advantage of the SVP-B is negated when compared to the WSD and TOGA drifting buoys over the long term. The cost per message from the SVP-B remains lower than the moored buoy, however.

**DISCUSSION**

A number of very important factors were not considered in this analysis because, in general, they are related to preferences among user groups (e.g., operational marine forecasters in the field, modelers, climatologists). First, no attempt was made to quantify the amount of data received, data content in each message, or relative importance of each data type (see Table 1). For example, how much more valuable are 21 hourly observations per day (from a moored buoy station) when compared to

Table 5. Comparison of SVP-B and TOGA drifting buoys for estimated annualized cost per message to receive barometric pressure data

# SVP-B EVALUATION
## NDBC PHASE
### ADJUSTED COST (ANNUALIZED)

| | SVP-B (W/O DEPLOYMENT PACKAGE) | TOGA (W/O DEPLOYMENT PACKAGE) |
|---|---|---|
| HARDWARE | $3.8 K/BUOY | $14.0 K/BUOY |
| ADJUSTMENT (YR/MTTF) | 366/185 = 1.9 | 366/477 = 0.77 |
| ADJUSTED COST | $7.2 K | $10.8 K |
| COMMUNICATIONS | $1.3 K | $3.8 K |
| TOTAL | $8.5 K/PTT/YR | $14.6 K/PTT/YR |
| AVERAGE # "GOOD" MESSAGES | 917.3 (219 DAYS) | 2,518.6 (244) |
| ADJUSTED # "GOOD" MESSAGES/YR | 1,533 | 3,777 |
| ANNUALIZED COST/MESSAGE | $5.54 | $3.86 |

Table 6. Comparison of SVP-B and WSD drifting buoys for estimated annualized cost per message to receive barometric pressure data

# SVP-B EVALUATION
## NDBC PHASE
### ADJUSTED COST (ANNUALIZED)

| | SVP-B (W/O DEPLOYMENT PACKAGE) | WSD (W/O DEPLOYMENT PACKAGE) |
|---|---|---|
| HARDWARE | $3.8 K/BUOY | $20.0 K/BUOY |
| ADJUSTMENT (YR/MTTF) | 366/185 = 1.9 | 366/655.5 = 0.56 |
| ADJUSTED COST | $7.2 K | $11.2 K |
| COMMUNICATIONS | $1.3 K | 3.8 K |
| TOTAL | $8.5 K/PTT/YR | $15.0 K/PTT/YR |
| AVERAGE # "GOOD" MESSAGES | 917.3 (219 DAYS) | 2,518.6 (244) |
| ADJUSTED # "GOOD" MESSAGES/YR | 1,533 | 3,777 |
| ANNUALIZED COST/MESSAGES | $5.54 | $3.97 |

Table 7. Comparison of SVP-B and 3-m discus buoy for estimated annualized cost per message to receive barometric pressure data

# SVP-B EVALUATION
## NDBC PHASE
### ADJUSTED COST (ANNUALIZED)

| | SVP-B (W/O DEPLOYMENT PACKAGE) | 3-M MOORED BUOY |
|---|---|---|
| HARDWARE | $3.8 K/BUOY | $60.0 K/BUOY |
| ADJUSTMENT (YR/MTTF) | 366/185 = 1.9 | 1 |
| ADJUSTED COST | $7.2 K | $60.0 K |
| COMMUNICATIONS | $1.3 K | -0- |
| TOTAL | $8.5 K/PTT/YR | $60.0 K |
| AVERAGE # "GOOD" MESSAGES | 917.3 (219) | 7,756 MESSAGES/YR (@ 88.3%) |
| ADJUSTED # "GOOD" MESSAGES/YR | 1,533 | N/A |
| ANNUALIZED COST/MESSAGE | $5.54 | $7.74 |

4 observations from the SVP-B? How much more valuable are pressure, wind, and/or sea state compared to pressure only? What is the value of wave measurements?

Second, factors that could impact forecasting services were not quantified. For example, are services improved if data come from a stationary platform compared to a drifting platform? Are scheduled, hourly reports from moored buoys more useful than unscheduled reports from drifting buoys? How soon must data reach the user before it is too old to be useful? Do hourly observations add value to the climatological record when compared to daily averages?

Third, how should ruggedness or survivability in bad weather be quantified? For example, what are the consequences of system data loss or failure when a severe storm passes? It was noted that in this group of SVP-Bs, failures tended to occur during severe storms; subsequently, the survivability of SVP-Bs deployed in August in the tropical Atlantic has been excellent when tropical storms passed.

Finally, it must be emphasized that this analysis looked only at direct, identifiable costs. Many other costs, such as data quality control, program management and administration, communications, engineering, and others, should be considered to understand the true picture.

## CONCLUSIONS

This study examined direct unit cost and performance of SVP-B drifting buoys deployed on behalf of the NWS in the Pacific Ocean west of the U.S. from July 18, 1995, to August 6, 1996. Comparisons were made to other buoy systems based on availability of barometric pressure measurements. It did not address indirect costs and numerous questions that relate to value of data type, quantity, and quality that was delivered. The MTTF/mean operating time of the SVP-B was 185.0 days, compared to 477 days for the TOGA drifting buoys and 655 days for WSD drifting buoys. When unit costs are normalized to account for MTTF and infant mortality, the SVP-B cost is 32 percent lower than both the TOGA and the WSD drifting buoys. The total direct cost of the SVP-B network through August 6, 1996, was 5 percent lower than the WSD network and 396 percent lower than the 3-m moored buoy network. When costs are annualized and estimated in the context of cost per message, the SVP-B cost is $5.54, 44 percent higher than TOGA drifting buoys ($3.86); 40 percent higher than WSD drifting buoys ($3.97); and 40 percent lower than 3-m moored buoys ($7.74). Since the requirements vary with various user groups, quantifying factors such as type, timeliness, and quantity of data were not attempted. Based on known deployments and data actually seen on the GTS, the SVP-B had a high apparent rate of infant mortality (approximately 26 percent).

## WEST COAST SEA LEVEL PRESSURE OBSERVATIONS FROM DRIFTERS

By Richard W. Reynolds, NOAA National Center for Environmental Prediction

The purpose of this study is to examine the accuracy of Sea Level Pressure (SLP) Observations from drifting buoys off the West Coast of North America. The methodology adopted was to plot buoy distributions and to compare sea level pressure observations with operational analyses. The Climate Modelling Branch evaluated the SIO/AOML drifting buoy along with the other drifting and moored buoys within the defined area. This is a summary of the study results.

Figure 1 shows the moored buoy distribution with SLP observations for August 1996. The positions are indicated by a circle. Buoys are labelled with a 1 to 2 digit number which is related to the WMO Identification number in the table on the right side of the figure. Observations in dotted circle pass quality control; observations in plain circle do not. Buoys in plain (25, 28, 30) are rejected by the NCEP forecast model because they are too near the coast to be resolved by the model.

Figure 2 shows drifting buoy distribution with SLP observations for July 1996. The last position of the buoy is indicated by a circle. Bad observations (plain) are shown for buoys 18 and 25. Buoy 18 (46912) is rejected because it is too near the coast.

Figure 3 shows drifting buoy distribution with SLP observations for August 1996. Note how the change in the distribution as buoys are added, advected (southward and eastward in this case) and deleted. In addition to the coastal problem with buoy 46912 (labelled 22 in this plot), note the suspicious track of buoy 30 (46927) located near 60N and 150W. The data for buoy 30 were not rejected.

Figure 4 shows bias (top panel) and standard deviation (middle panel) of the differences between the buoy and the model first guess sea level pressure. The model was available at six hour intervals. The SLP buoy data within +/- 3 hours of the model time intervals were averaged for each buoy. This results in time series of up to 124 points (31 days times 4). The model was interpolated to the 6-hour average position of the buoy. The lower panel shows the number of 6-hour periods with data. The abscissa (x-axis) is the buoy index which corresponds to the WMO Identification number in the table on the left hand side. The red curve shows the drifter to model difference, the green curve the moored to model difference. Note that although the biases are similar, the drifting buoy standard deviation tends to a little larger than the moored buoys. Also the moored buoys usually have at least one observation per 6-hour period while the drifters miss some 6-hour periods because of the on/off duty cycling with Argos.

Figure 5 shows the same as figure 4, except the buoys are compared to the analysis rather than the first guess. Note that the average standard deviations have been reduced from roughly 1.5 hPa to roughly 0.5 hPa. This reduction occurs because the model has been adjusted to the data and thus fits it better (lower standard deviation). In other words, the data is having impact on the model.

The following conclusions were reached:

1. Drifting buoys usually have similar error statistics (biases and standard deviations) to those of moored buoys. The standard deviation tends to be slightly higher for drifters than for moored buoys. The standard deviation from both drifters and moored buoys is lower than for ships.

2. Quality control of 'bad buoy' observations, limits the impact of these observations on the forecast. These observations should be removed before they reach the GTS.

3. Drifting buoys can improve marine forecasts. However, the observations tend to arrive too late. The on/off duty cycle makes the buoy SLP observations less useful to forecasters because the entire buoy array is not available during the same synoptic period.

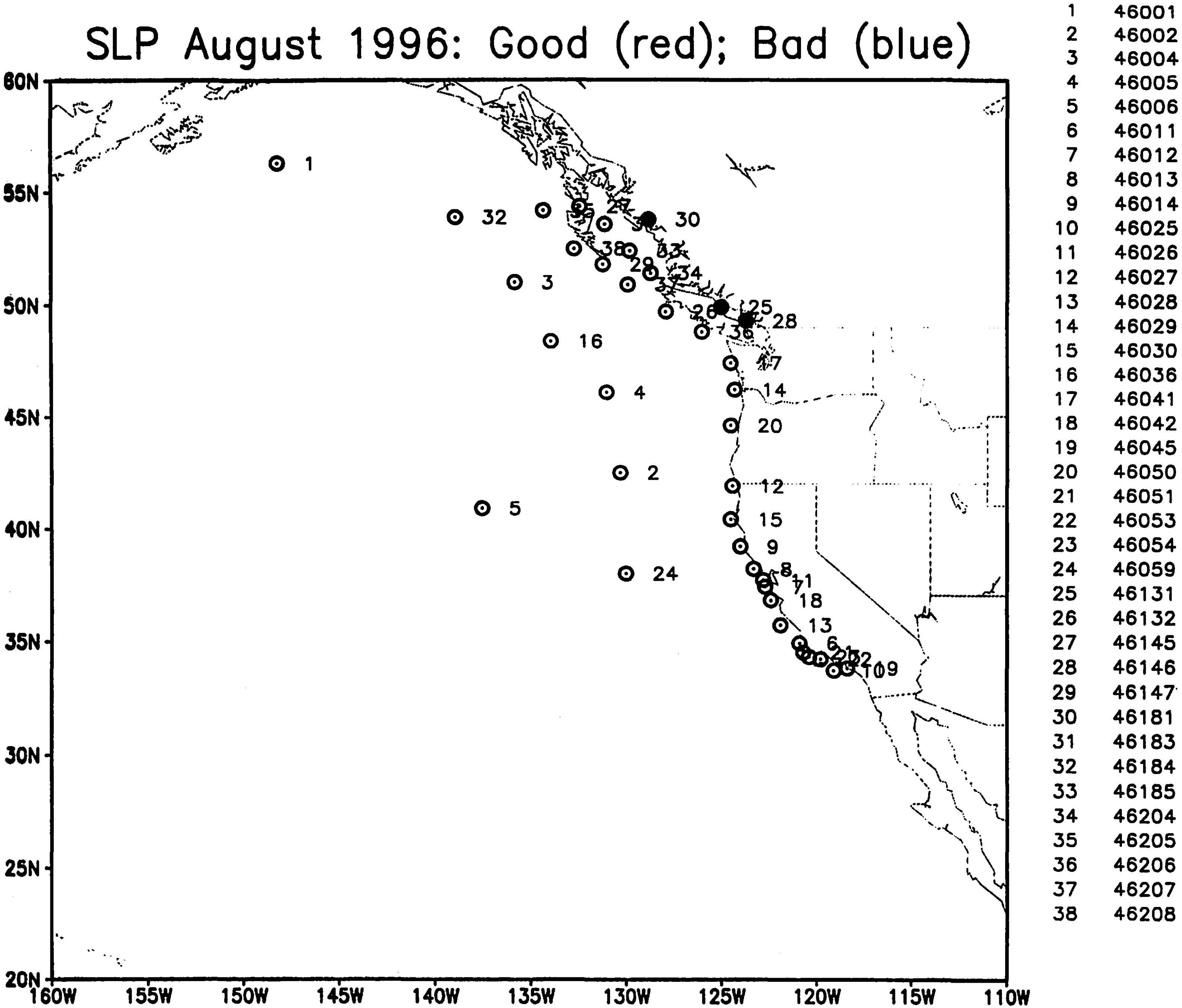
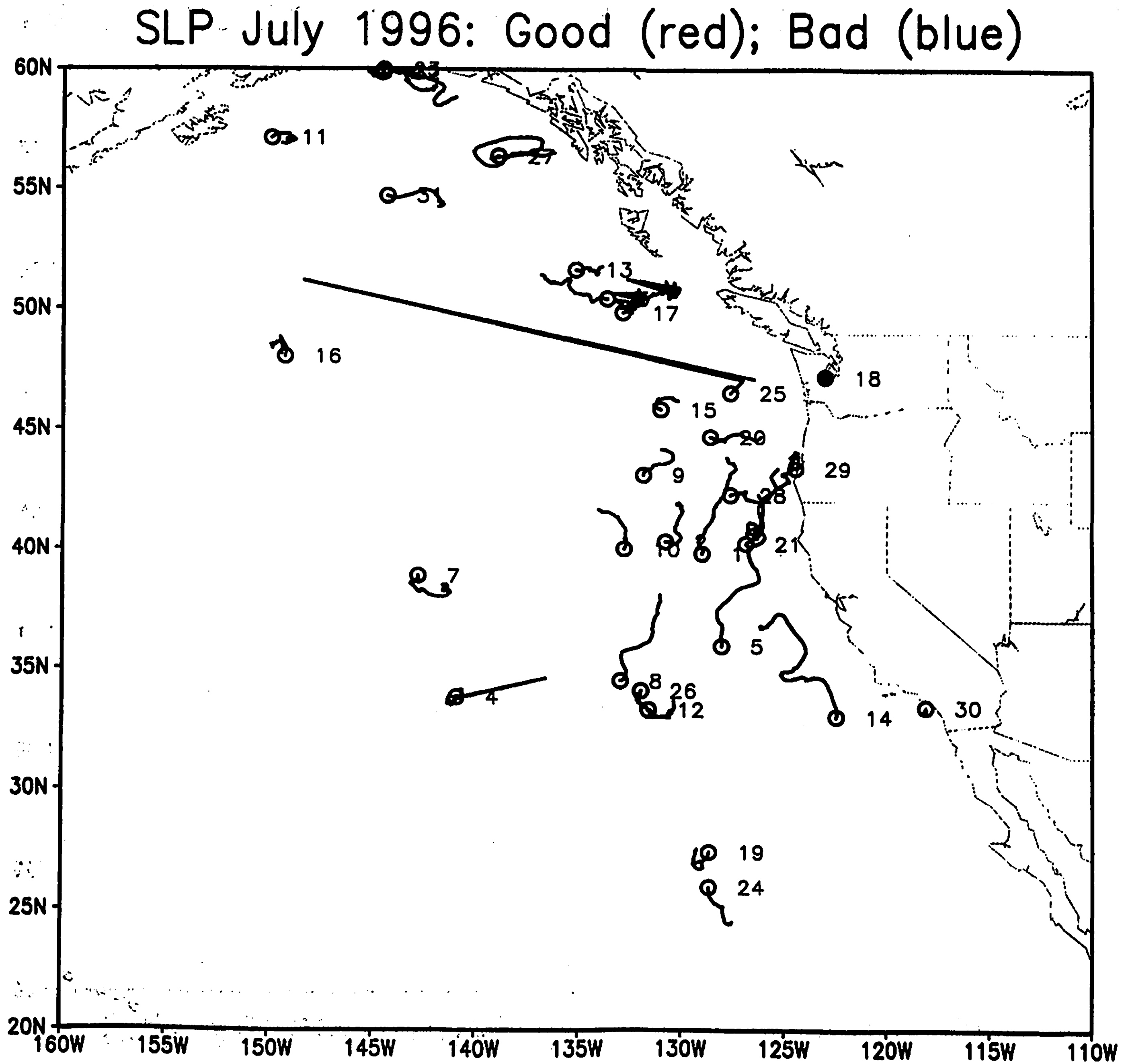
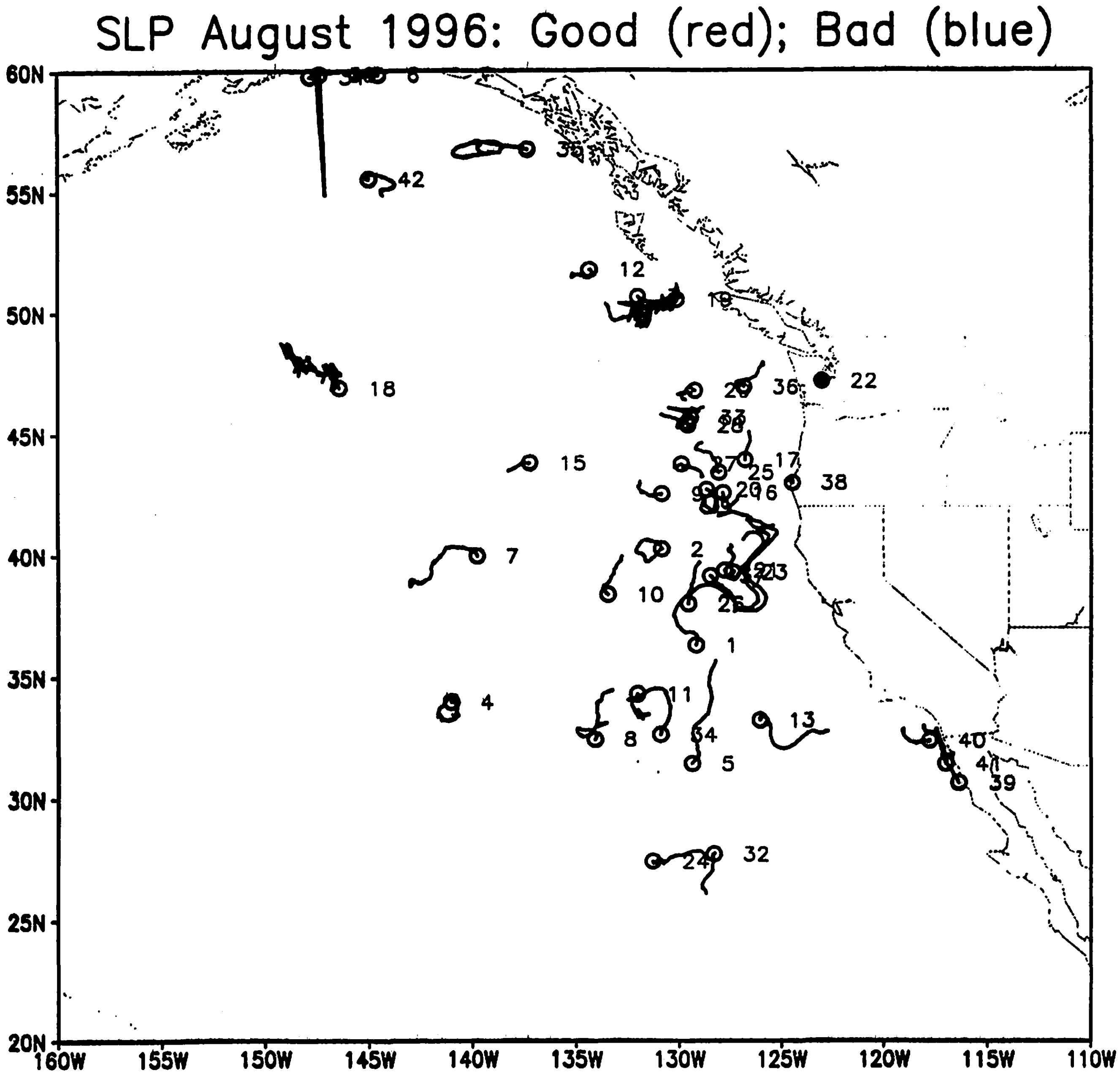



Figure 1: Moored buoy distribution with SLP for August 1996




| | |
|---|---|
| 1 | 46551 |
| 2 | 46552 |
| 3 | 46553 |
| 4 | 46554 |
| 5 | 46555 |
| 6 | 46556 |
| 7 | 46557 |
| 8 | 46558 |
| 9 | 46559 |
| 10 | 46561 |
| 11 | 46564 |
| 12 | 46565 |
| 13 | 46580 |
| 14 | 46584 |
| 15 | 46588 |
| 16 | 46632 |
| 17 | 46692 |
| 18 | 46912 |
| 19 | 46914 |
| 20 | 46915 |
| 21 | 46916 |
| 22 | 46927 |
| 23 | 46929 |
| 24 | 46952 |
| 25 | 46953 |
| 26 | 46956 |
| 27 | 46958 |
| 28 | 46961 |
| 29 | 46964 |
| 30 | 51542 |
| 31 | 51652 |

Figure 2: Drifting buoy distribution with SLP for July 1996




| | |
|---|---|
| 1 | 46551 |
| 2 | 46552 |
| 3 | 46553 |
| 4 | 46554 |
| 5 | 46555 |
| 6 | 46556 |
| 7 | 46557 |
| 8 | 46558 |
| 9 | 46559 |
| 10 | 46561 |
| 11 | 46565 |
| 12 | 46580 |
| 13 | 46584 |
| 14 | 46588 |
| 15 | 46605 |
| 16 | 46606 |
| 17 | 46607 |
| 18 | 46632 |
| 19 | 46692 |
| 20 | 46907 |
| 21 | 46910 |
| 22 | 46912 |
| 23 | 46913 |
| 24 | 46914 |
| 25 | 46915 |
| 26 | 46916 |
| 27 | 46920 |
| 28 | 46924 |
| 29 | 46925 |
| 30 | 46927 |
| 31 | 46929 |
| 32 | 46952 |
| 33 | 46954 |
| 34 | 46956 |
| 35 | 46958 |
| 36 | 46960 |
| 37 | 46961 |
| 38 | 46964 |
| 39 | 51544 |
| 40 | 51545 |
| 41 | 51546 |
| 42 | 51652 |

Figure 3: Drifting buoy distribution with SLP for August 1996

| | MOORED | DRIFT |
|---|---|---|
| 1 | 46001 | 46551 |
| 2 | 46002 | 46552 |
| 3 | 46004 | 46553 |
| 4 | 46005 | 46554 |
| 5 | 46006 | 46555 |
| 6 | 46011 | 46556 |
| 7 | 46012 | 46557 |
| 8 | 46013 | 46558 |
| 9 | 46014 | 46559 |
| 10 | 46025 | 46561 |
| 11 | 46026 | 46565 |
| 12 | 46027 | 46580 |
| 13 | 46028 | 46584 |
| 14 | 46029 | 46588 |
| 15 | 46030 | 46605 |
| 16 | 46036 | 46606 |
| 17 | 46041 | 46607 |
| 18 | 46042 | 46632 |
| 19 | 46045 | 46692 |
| 20 | 46050 | 46907 |
| 21 | 46051 | 46910 |
| 22 | 46053 | 46912 |
| 23 | 46054 | 46913 |
| 24 | 46059 | 46914 |
| 25 | 46131 | 46915 |
| 26 | 46132 | 46916 |
| 27 | 46145 | 46920 |
| 28 | 46146 | 46924 |
| 29 | 46147 | 46925 |
| 30 | 46181 | 46927 |
| 31 | 46183 | 46929 |
| 32 | 46184 | 46952 |
| 33 | 46185 | 46954 |
| 34 | 46204 | 46956 |
| 35 | 46205 | 46958 |
| 36 | 46206 | 46960 |
| 37 | 46207 | 46961 |
| 38 | 46208 | 46964 |
| 39 | | 51544 |
| 40 | | 51545 |
| 41 | | 51546 |
| 42 | | 51652 |

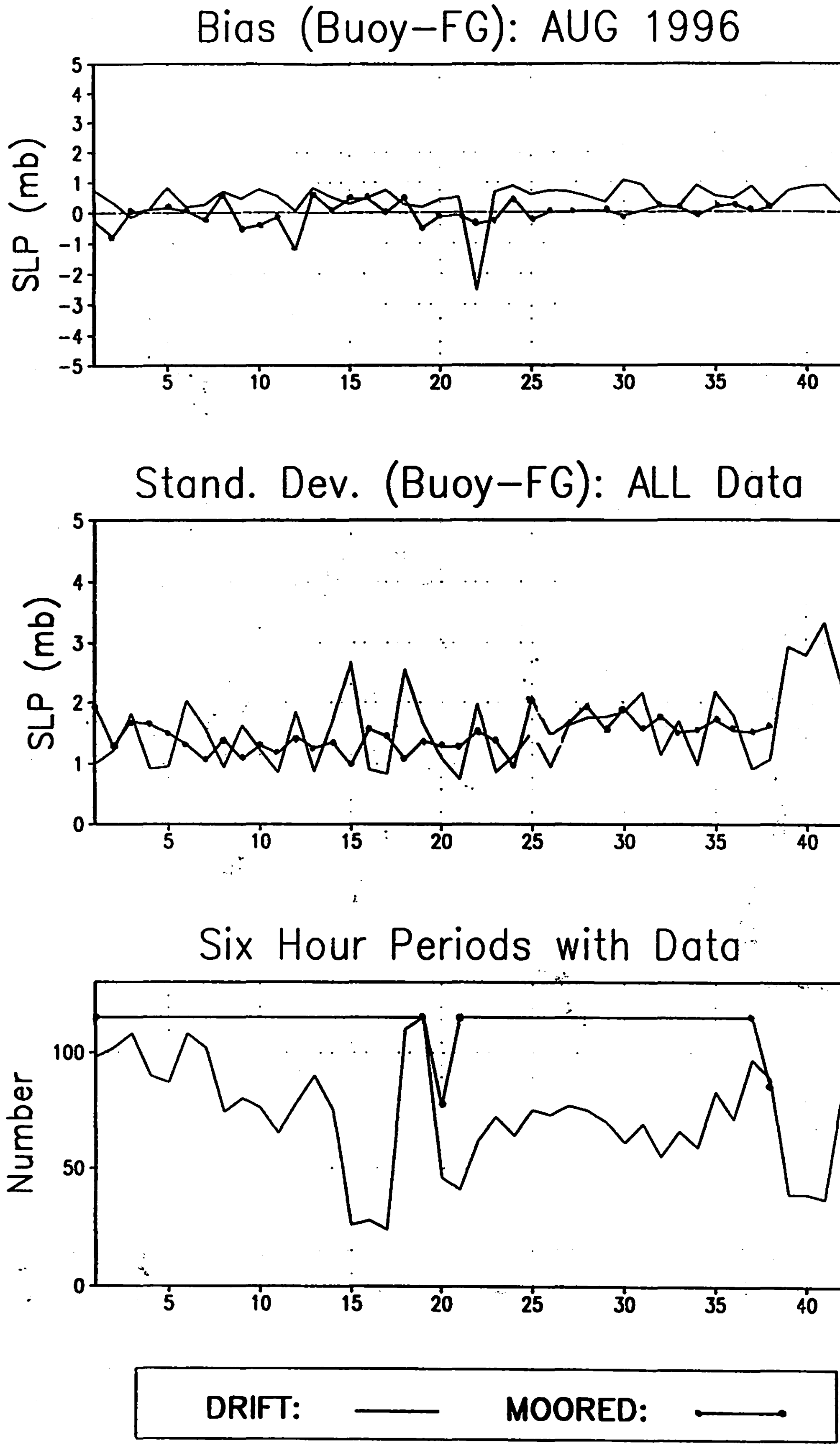



Figure 4: Comparison with model first guess: bias, standard deviation, and number of 6-hour periods with data

| | MOORED | DRIFT |
|---|---|---|
| 1 | 46001 | 46551 |
| 2 | 46002 | 46552 |
| 3 | 46004 | 46553 |
| 4 | 46005 | 46554 |
| 5 | 46006 | 46555 |
| 6 | 46011 | 46556 |
| 7 | 46012 | 46557 |
| 8 | 46013 | 46558 |
| 9 | 46014 | 46559 |
| 10 | 46025 | 46561 |
| 11 | 46026 | 46565 |
| 12 | 46027 | 46580 |
| 13 | 46028 | 46584 |
| 14 | 46029 | 46588 |
| 15 | 46030 | 46605 |
| 16 | 46036 | 46606 |
| 17 | 46041 | 46607 |
| 18 | 46042 | 46632 |
| 19 | 46045 | 46692 |
| 20 | 46050 | 46907 |
| 21 | 46051 | 46910 |
| 22 | 46053 | 46912 |
| 23 | 46054 | 46913 |
| 24 | 46059 | 46914 |
| 25 | 46131 | 46915 |
| 26 | 46132 | 46916 |
| 27 | 46145 | 46920 |
| 28 | 46146 | 46924 |
| 29 | 46147 | 46925 |
| 30 | 46181 | 46927 |
| 31 | 46183 | 46929 |
| 32 | 46184 | 46952 |
| 33 | 46185 | 46954 |
| 34 | 46204 | 46956 |
| 35 | 46205 | 46958 |
| 36 | 46206 | 46960 |
| 37 | 46207 | 46961 |
| 38 | 46208 | 46964 |
| 39 | | 51544 |
| 40 | | 51545 |
| 41 | | 51546 |
| 42 | | 51652 |

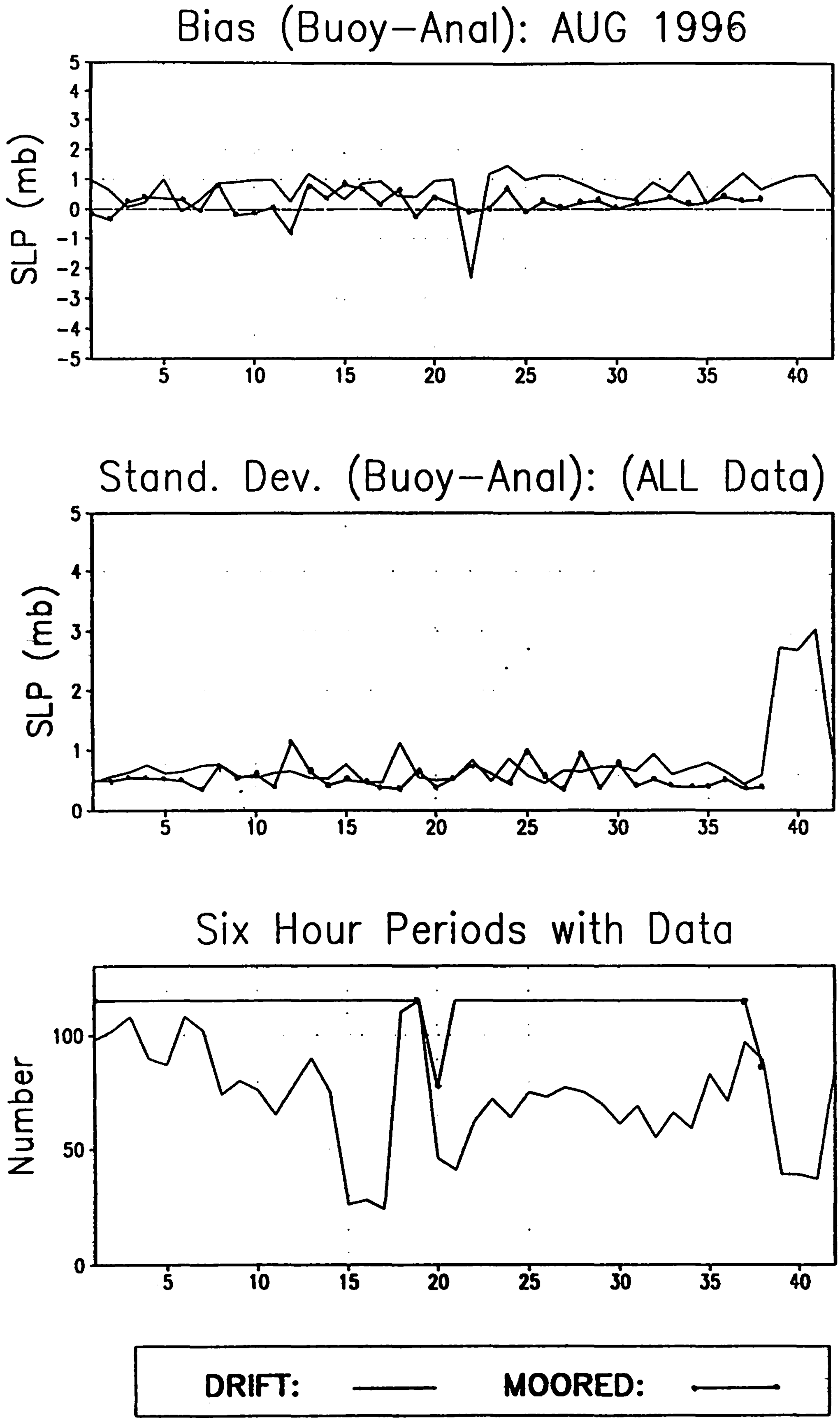



Figure 5: Comparison with model analysis: bias, standard deviation, and number of 6-hour periods with data

## THE SVP-B DRIFTER - A PERFORMANCE ASSESSMENT

**Mark Swenson**, NOAA-AOML, USA

### ABSTRACT

Although over 300 SVP-B drifters have been acquiring and distributing sea-level pressure data over the GTS during the last several years, no one has assessed the performance of the drifters from a broad perspective. As a first step, we look at the performance of SVP-B drifters deployed since 1 January 1995. Buoys that were taken off of the GTS while still transmitting data are singled out for a detailed look at the statistics of the time series both before and after removal from the GTS. Comparisons are made with buoys that remained on the GTS to see if patterns can be identified that will help assess SVP-B performance and suggest improvements in SVP-B design.

# The quality control of buoy data transmitted on the GTS and its use in evaluating the SVP-B drifter

Pierre Blouch
Centre de Météorologie Marine
Météo-France

**Abstract**

*Within the frame of the Data Buoy Co-operation Panel, Météo-France controls with other Meteorological institutes the quality of buoy data transmitted on the GTS. One part of this control consists in carrying out monthly statistics of differences between observations and first guess values. At present four centres - the Centre de Météorologie Marine of Météo-France (CMM), ECMWF, NMC and UKMO - are providing such statistics. CMM brings them together and makes them available on the Internet through a user-friendly interface.*

*More than 300 SVP-Barometer drifters have been deployed over the world's oceans. These cheap lagrangian buoys (unit cost less than $4000) are now able to provide more than 600 days of reliable Air Pressure data each, even though they are often submerged by the waves. The monthly statistics provided by ECMWF for Air Pressure data were used here to compute the lifetime of this measurement. Updated results on Air Pressure lifetime for these drifters are detailed.*

## Quality control of buoy data

The dramatic increase in the number of buoys reporting their data on the GTS (Global Telecommunication System of WMO) during the past years was mainly due to scientific programs such as TOGA (Tropical Ocean and Global Atmosphere) and WOCE (World Ocean Climate Experiment). Even though the quality control of data could be done after the program is finished when they are not used in real time, the GTS transmission of such data requires they are permanently controlled. It is actually necessary to stop as soon as possible the transmission of bad data on the system to not pollute weather forecasting models. Scientists - mainly oceanographers - are not yet very concerned by real time data use. In addition, their priority parameters may be different from those of «operational people» i.e. meteorologists. If they agree the data provided by their buoys be transmitted on the GTS, they haven't the possibility to monitor them so efficiently than meteorological centres. However they are the only ones entitled to ask modifications to transmission centres (service Argos principally).

In 1991, the Data Buoy Co-operation Panel (DBCP) decided to implement Quality Control (QC) Guidelines for buoy data. The scheme is now based on an Internet distribution list (*buoy-qc@vedur.is*) on which a feedback from the data users can be assessed to the data providers. Two kinds of feedback exist: QC messages reporting a specific problem for a particular buoy for instance and monthly QC statistics.

## QC statistics

The statistics are carried out on differences between observations and first guess values (i.e. forecast values at the location of the buoys interpolated from model outputs). At present they are provided by four centres:

- Centre de Météorologie Marine of Météo-France (CMM) ;
- European Centre for Medium Range Weather Forecasts (ECMWF) ;
- National Center for Environmental Prediction (NOAA/NWS/NCEP) ;
- UK Meteorological Office (UKMO).

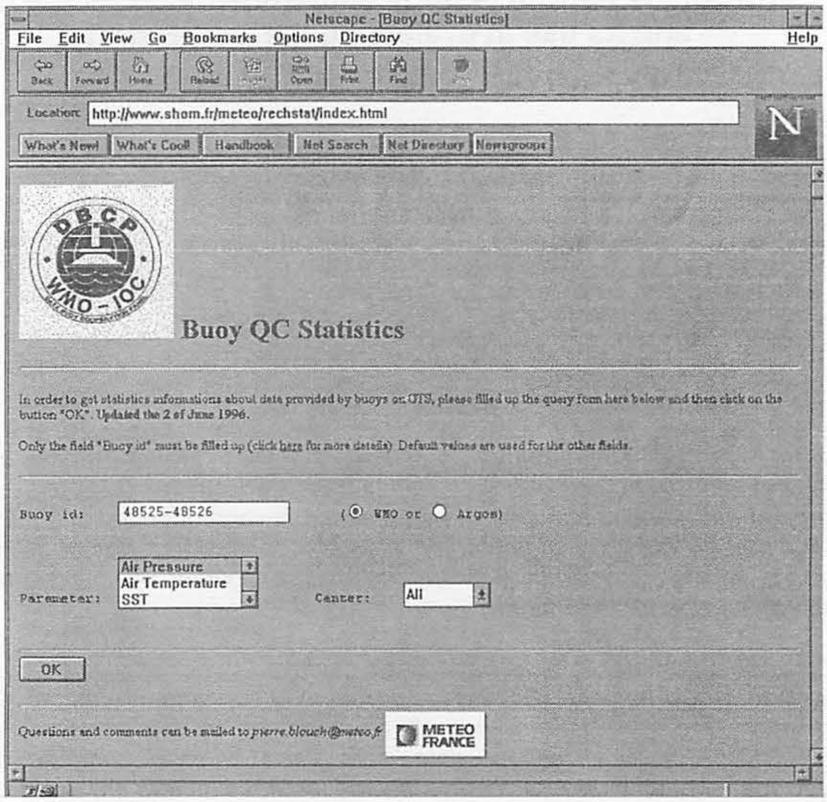



*Figure 1* - Monthly statistics query form on the Internet Web

**QC Statistics - Wind Direction**
**Buoy WMO 44613 / Argos 3324 - Owner: UKMO**

| Date | Origin | Code | Centre | Lat | Lon | Nobs | GE | Bias | sd | rms |
|---|---|---|---|---|---|---|---|---|---|---|
| 960131 | BGSF | B | CMM | 47.4 | -15.2 | 175 | 1 | -8. | 20. | 22. |
| 960131 | ENMI | B | CMM | 47.5 | -15.2 | 290 | 3 | -11. | 22. | 24. |
| **960131** | **LFPW** | **B** | **CMM** | **47.5** | **-15.2** | **478** | **5** | **7.** | **25.** | **26.** |
| 960229 | BGSF | B | CMM | 45.3 | -12.8 | 160 | 0 | -4. | 21. | 21. |
| 960229 | ENMI | B | CMM | 45.3 | -12.9 | 279 | 1 | -7. | 20. | 21. |
| **960229** | **LFPW** | **B** | **CMM** | **45.3** | **-12.8** | **423** | **1** | **9.** | **19.** | **21.** |
| 960331 | BGSF | B | CMM | 45.3 | -11.6 | 117 | 3 | -8. | 21. | 23. |
| 960331 | ENMI | B | CMM | 45.3 | -11.5 | 267 | 10 | -11. | 21. | 24. |
| **960331** | **LFPW** | **B** | **CMM** | **45.3** | **-11.5** | **393** | **14** | **9.** | **23.** | **25.** |
| 960430 | BGSF | B | CMM | 44.8 | -11.4 | 160 | 11 | -11. | 23. | 25. |
| 960430 | ENMI | B | CMM | 44.8 | -11.7 | 264 | 19 | -10. | 22. | 24. |
| **960430** | **LFPW** | **B** | **CMM** | **44.8** | **-11.8** | **450** | **50** | **7.** | **22.** | **23.** |
| 960519 | BGSF | B | CMM | 44.0 | -12.7 | 91 | 0 | -10. | 18. | 20. |
| 960519 | ENMI | B | CMM | 44.1 | -12.4 | 158 | 1 | -12. | 13. | 18. |
| **960519** | **LFPW** | **B** | **CMM** | **44.1** | **-12.4** | **297** | **6** | **7.** | **18.** | **19.** |

*Table 1* - Example of monthly statistics
Wind direction comparisons with model outputs (in degrees)

The results consist in average differences and standard deviations for each parameter of each buoy as well as the number of «gross errors» (differences which exceed a given limit) over the period. Some parameters may have also a specific process. For instance, mean wind speed ratios are provided in addition to the mean differences because the wind speed corrections are rather slopes than biases.

At CMM, the computation of the mean wind direction differences (and the related standard deviation) takes in account the fact that the bias can be close to 180 degrees. In that case, the differences vary from -180° to 180° with a strong concentration near -180° and +180°. Without any special processing, the mean difference can be close to 0° and the standard deviation high although it should be close to -180° or +180° with a lower standard deviation.

CMM also shares all the statistics according to the origin of the reports on GTS. This enables to point out specific problems due to a particular data dissemination centre when several are used.

Each month, CMM brings the statistics together and makes them available on the Internet Web through a user-friendly interface at *http://www.shom.fr/meteo/rechstat/* (figure 1). The results obtained by the 4 centres, for a specific parameter measured by a specific buoy, can be compared (table 1). The files are also available through anonymous FTP at *ftp.shom.fr* in directory *pub/meteo/qc-stats*.

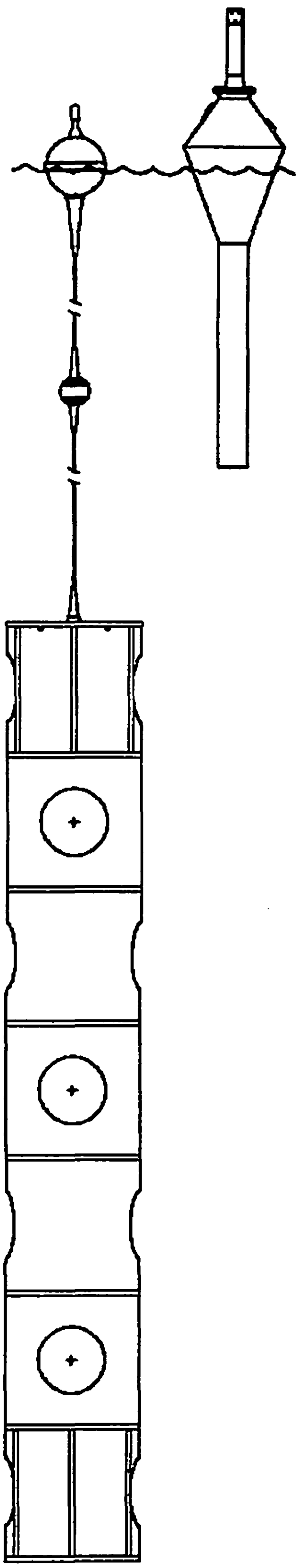


*Figure 2* - SVP-B drifter and FGGE buoy

**SVP-Barometer drifter**

The appearance of the SVP-B drifter in drifting buoy technology has probably been constituting one of the main technological step since the First Global GARP Experiment (FGGE). The characteristics of the FGGE buoy (figure 2), sometimes improperly called TOGA buoy, are typically 100 kg in weight, 70-80 cm in diameter (max.) and 2.70 m long. It is generally not considered as a lagrangian drifter - even equipped with a drogue, because the drag area ratio is not high enough - although some studies were carried out thanks to the location data. It measures air pressure and sea surface temperature. Later, wind-FGGE buoys were derived from the original FGGE buoy by fixing a profiled mast (1.5 m high) at the top of the buoy to rotate it under the wind influence. The wind direction is then measured thanks to a compass located inside the hull and the wind speed is obtained thanks to an anemometer located at the top of the mast. Some FGGE buoys were also fitted with thermistor strings and/or air temperature sensors.

The SVP-B drifter (figure 2) takes up again the measurements of the standard FGGE buoy but, because it is smaller (sphere of 40 cm in diameter, 30 kg in weight), it is considered as lagrangian drifter when fitted with a holey sock drogue. The drag area ratio is then greater than 30. In fact, it meets the needs of meteorologists interested in air pressure measurements and oceanographers who need surface current measurements. In addition, the SVP-B drifter is cheaper than the standard FGGE buoy (less than $4000). It is actually derived from the standard SVP (Surface Velocity programme of TOGA and WOCE). Both drifters were designed at the Scripps Institution of Oceanography. They are mainly operated by the Global Drifter Center (GDC) of NOAA in Miami, but several meteorological agencies such as the South African Weather Bureau (SAWB), Meteo-France, the UK Meteorological Office (UKMO) and the Australian Bureau of Meteorology (BOM) have been interested in the SVP-B drifter and use it now.

**Evaluation method**

Since the beginning of the WOCE programme, more than 300 SVP-Barometer drifters from 4 different manufacturers have been deployed over the world's oceans (figure 3). To evaluate their performances (air pressure lifetime), the monthly statistics provided by ECMWF were used exclusively. The criteria for air pressure measurement failures were: gross errors greater than 5% or bias greater than 5 hPa or standard deviation greater than 3 hPa. Table 2 shows the statistics obtained for one buoy which failed in January 1996. The first day of the month was kept as day of failure. Figure 4 shows the air pressure differences between measurements and model outputs for another buoy. It failed at the end of January 1996 too.

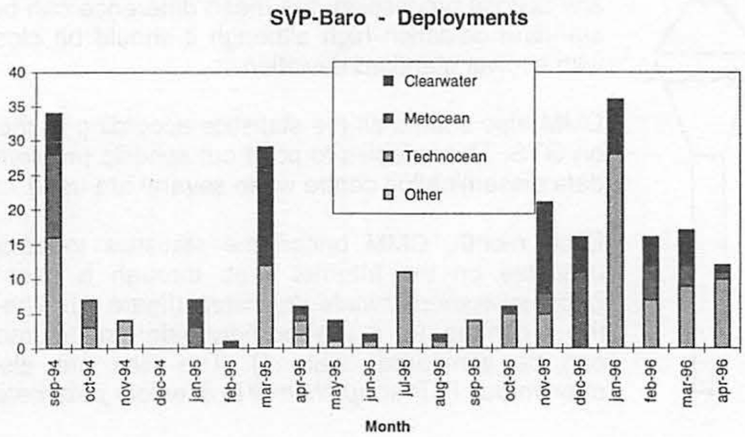



*Figure 3* - SVP-Baro deployments from September 94 to April 96

**QC Statistics - Air Pressure**
**Buoy WMO 17613 / Argos 22581 - Owner: SAWB**

| Date | Origin | Code | Centre | Lat | Lon | Nobs | GE | Bias | sd | rms |
|---|---|---|---|---|---|---|---|---|---|---|
| 950531 | ALL | B | ECMWF | -52.1 | 22.8 | 880 | 0 | 0.8 | 1.5 | 1.7 |
| 950630 | ALL | B | ECMWF | -52.2 | 25.5 | 827 | 0 | 1.3 | 1.9 | 2.3 |
| 950731 | ALL | B | ECMWF | -54.0 | 26.8 | 885 | 0 | 1.0 | 2.6 | 2.8 |
| 950831 | ALL | B | ECMWF | -57.1 | 28.8 | 1099 | 2 | 0.8 | 2.7 | 2.8 |
| 950930 | ALL | B | ECMWF | -57.5 | 33.4 | 1042 | 0 | 0.4 | 2.2 | 2.3 |
| 951031 | ALL | B | ECMWF | -55.7 | 39.4 | 972 | 0 | 0.7 | 2.1 | 2.2 |
| 951130 | ALL | B | ECMWF | -54.7 | 44.2 | 869 | 0 | 1.3 | 2.0 | 2.4 |
| 951231 | ALL | B | ECMWF | -54.4 | 47.8 | 850 | 0 | 0.9 | 2.0 | 2.2 |
| 960131 | ALL | B | ECMWF | -55.7 | 50.1 | 985 | ***156*** | 0.5 | ***6.9*** | 6.9 |
| 960229 | ALL | B | ECMWF | -57.1 | 52.8 | 957 | ***173*** | -1.6 | ***6.6*** | 6.8 |
| 960331 | ALL | B | ECMWF | -56.8 | 56.7 | 147 | 0 | 2.5 | ***5.1*** | 5.6 |

*Table 2* - Monthly statistics for one SVP-Baro (air pressure)

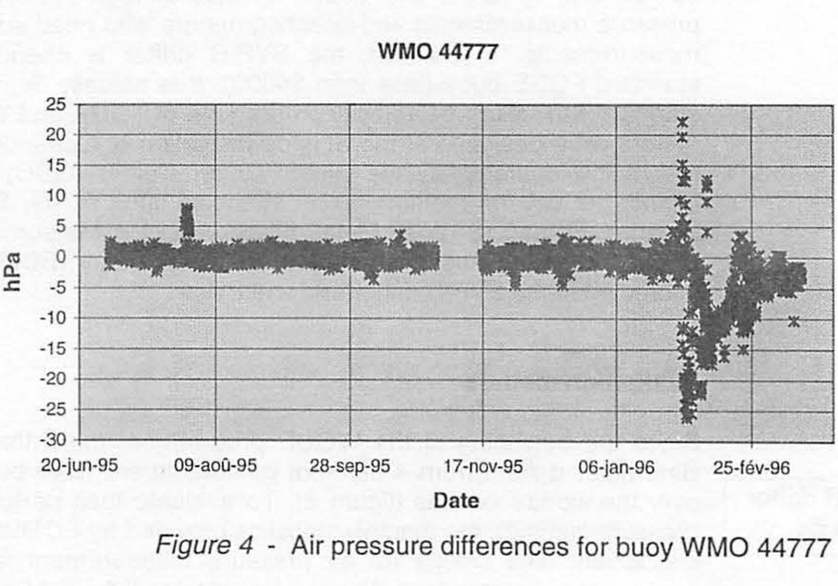



*Figure 4* - Air pressure differences for buoy WMO 44777

**Air pressure lifetime**

Figure 5 shows the AP lifetimes for the 165 drifters deployed before May 1st, 1996 (sorted by decreasing lifetime) and which failed before October 1st, 1996. The mean lifetime is 168 days.

Figures 6 and 7 show the AP lifetimes for the 231 drifters deployed before May 1st, 1996 including those still operating on October 1st, 1996. **The mean lifetime is 196 days** that is more than the value obtained with buoys which failed although the present computation takes in account numerous buoys deployed a few weeks before the 1st of May. This is due to some buoys deployed a long time ago which were still alive the 1st of October. **Some buoys have been working for more than 700 days !!**

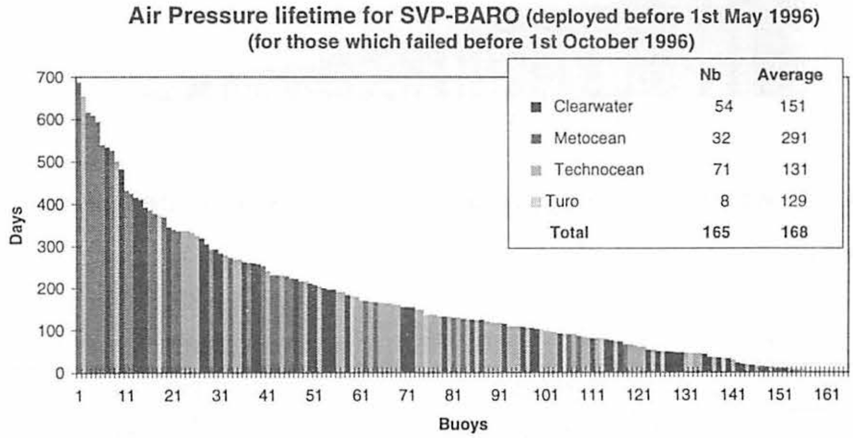



*Figure 5* - Air pressure lifetime for buoys which ceased to work before Oct. 96

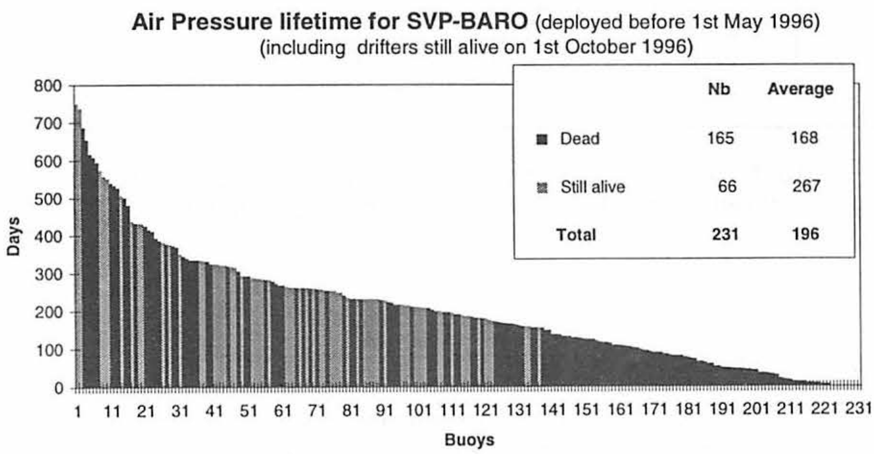



*Figure 6* - Air pressure lifetime according to their status in Oct. 96

**Failures**

Although the mean lifetime for air pressure measurements is not too bad - and seems on the increase - it appears however that many buoys fail at their launch time or a few days later. Perhaps some buoys were also deployed although they didn't work properly. Table 3 shows the percentage of loss after less than 20 days of operation. For all kind of deployments, about 1/6 th of the buoys fails and it seems this number is increasing. By air, the failures are more frequent than by ship and reach 1/4 th of the buoys. It is obvious there are some problems here which reduce dramatically the lifetime of air pressure measurements. The increasing of the percentage of failures should be carefully watched.

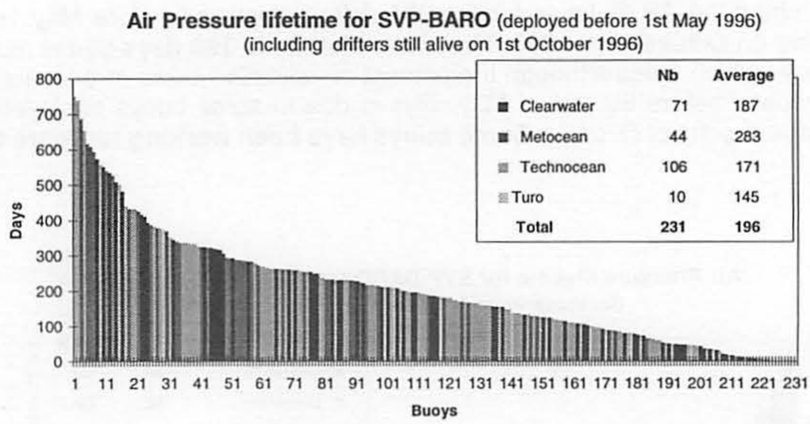



*Figure 7* - Air pressure lifetime assuming buoys still alive will die tomorrow

| | All buoys | | | Deployed by Air | | |
|---|---|---|---|---|---|---|
| | Deployed | < 20 days | Percentage | Deployed | <20 days | Percentage |
| Sep 94 - Jan 95 | 52 | 7 | 13 % | 19 | 4 | 21 % |
| Feb 95 - Jun 95 | 41 | 4 | 10 % | 19 | 2 | 11 % |
| Jul 95 - Nov 95 | 44 | 3 | 7% | | | |
| Dec 95 - Apr 96 | 99 | 16 | 16% | 23 | 8 | 35 % |
| May 96 - Sep 96 | 76 | 21 | 28 % | 29 | 8 | 28 % |
| Total | 312 | 51 | 16 % | 90 | 22 | 24 % |

*Table 3* - Percentage of drifters for which AP measurements failed quickly (less than 20 days after deployment)

**Conclusion**

Considering the low cost of these drifters and the acceptable lifetime of Air pressure measurements - which should increase in the next months - Météo-France relies on them. It uses them now instead of standard FGGE buoys and also funds barometers to equip standard SVP drifters owned by oceanographers such as GDC. However, the important loss at the time of deployment must be carefully analysed. The problems encountered must be identified and corrected. Some appropriate actions must be studied, then applied to improve the reliability of the drifters.

# PRELIMINARY RESULTS FROM GLOBAL LAGRANGIAN DRIFTERS USING GPS RECEIVERS

Mark Bushnell, NOAA/AOML-Global Drifter Center

Four standard Global Lagrangian Drifters (GLD), constructed as described by Sybrandy et al (1991), have been manufactured with GPS receivers aboard. The drifters were manufactured by Clearwater Instrumentation, who selected the Rockwell NavCore MicroTracker LP GPS receiver with a patch antenna on the inside of the surface float. Since there is no external antenna mount, the drifters resemble a standard drifter in every way. The drifters logged hourly GPS fixes and stored them, transmitting 16 hourly positions in four interleaved data "pages". The drifters also made use of the Argos Limited Use 1/3 duty cycle, transmitting for three hours and off for six hours.

One of the drifters was tested at AOML prior to deployment. Drifter 11894 was activated on 02 April 1995. It was held stationary and active for a week, and the resulting Argos and GPS positions are seen in Figure 1. Nineteen satellite passes yielded 10 Argos positions, with standard deviations of 343 meters in latitude and 350 meters in longitude. During the same time a total of 115 GPS positions were obtained (from a possible 134 hourly positions). After discarding 3 outliers, the standard deviations of the GPS positions was 53 meters in latitude and 34 meters in longitude.

The drifters were deployed in the North Brazil Current retroflection region by the merchant vessel SEA FOX, whose assistance is gratefully acknowledged. By placing them in this energetic eddy field, it was hoped that the value of the improved positioning technique would be apparent. They were deployed on July 04, and Figure 2 shows the data from the four drifters for the month of July. Deployments occurred as the ship crossed latitudes 4°N, 3°N, 2°N, and 1°N. The data shown have not been quality controlled in any way, with the exception of a data transmission checksum.

Several features of interest are apparent in Figure 2. In addition to the obvious anticyclonic eddy, it can be seen that the two drifters heading northeast at the end of the month (deployed at 4°N and 2°N) both executed a quick anticyclonic turn to exit the eddy. The remaining two drifter trajectories show small wavelike features, presumed to be tidal interaction with the continental shelf break at that location. Gaps in the trajectories very nearly coincide in time with each other, and the cause is unknown.

It is interesting to compare the resulting GPS trajectory to that derived from the Argos positions. Most standard drifters operate on a one-day-on, two-day-off 1/3 duty cycle rather than the 3 hours on, 6 hours off cycle used for the GPS drifters. To create a data set that would more closely resemble that of a standard drifter, Argos positions were discarded for two out of every three days. This subset was then overlaid on the GPS series, and the results are seen in Figure 3. While the individual positions compare well, it is clear that many of the smaller scale features are missed by the 1/3 duty Argos positioning.

REFERENCES

Sybrandy, A. L. and P. Niiler, 1991. WOCE/TOGA Lagrangian Drifter Construction Manual. WOCE Report No. 63; SIO Report No. 91/6. Scripps Institution of Oceanography, La Jolla, CA

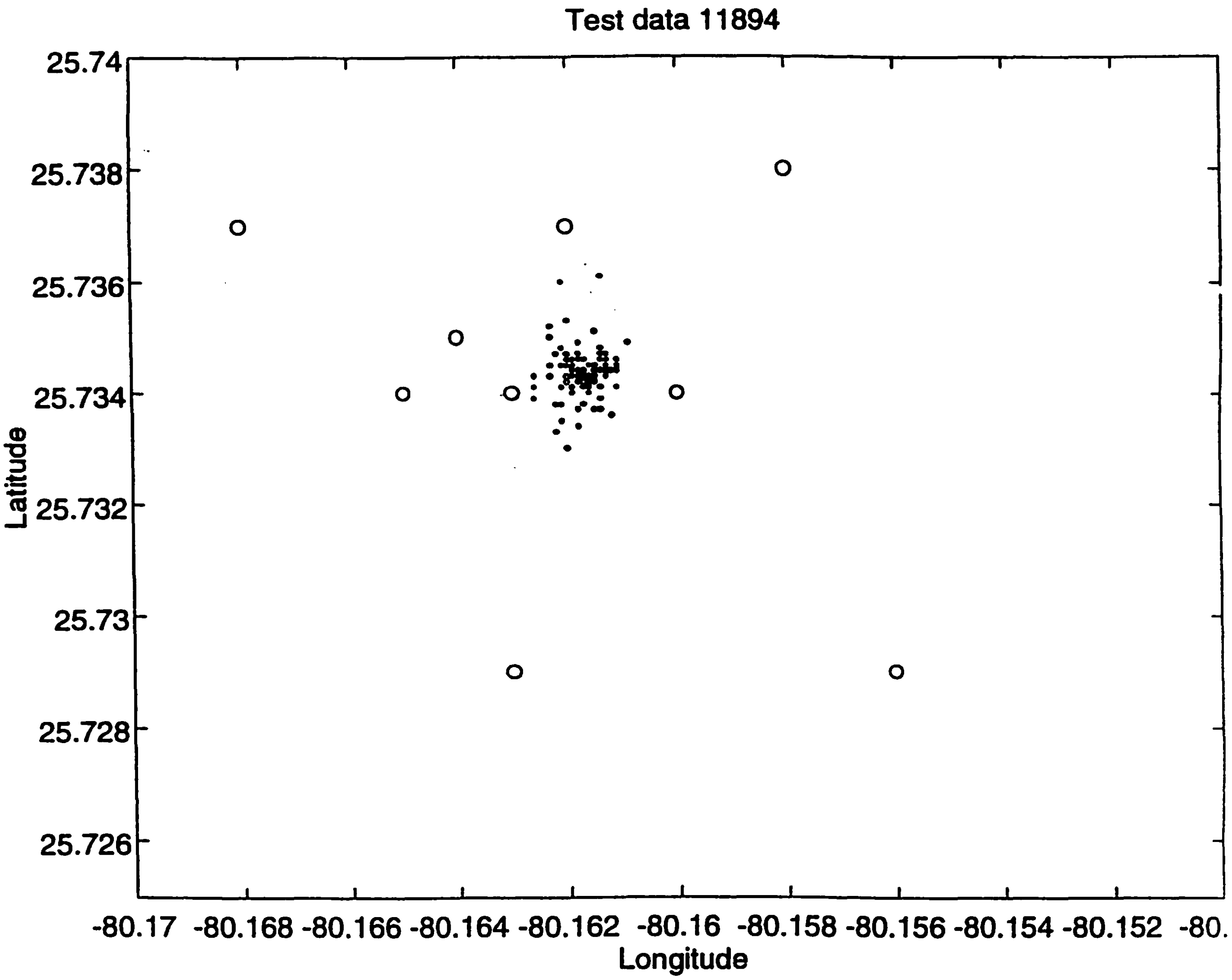
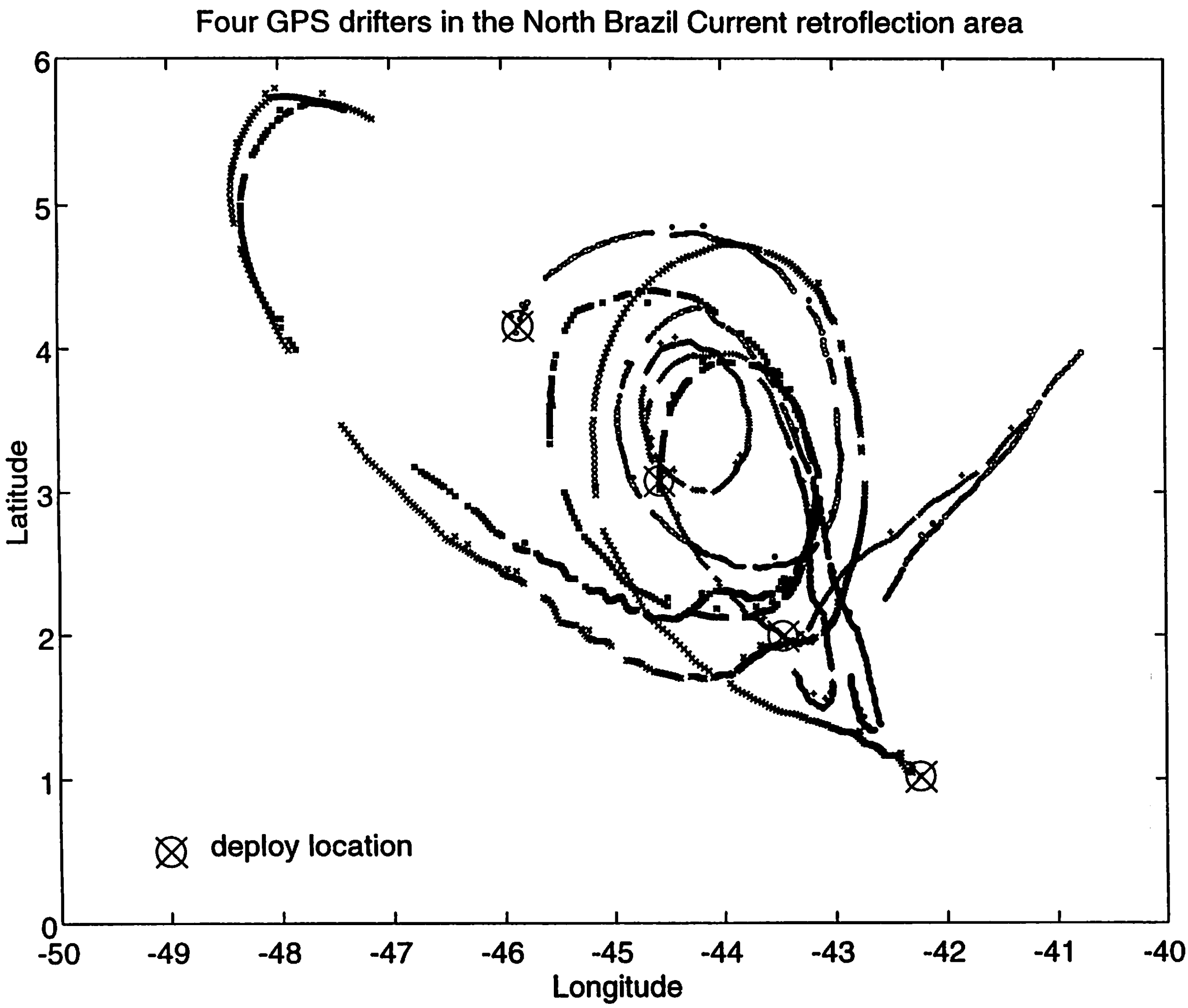



Figure 1. Drifter 11894 test data prior to deployment. The drifter was on and stationary for seven days. Large open circles are Argos positions, dots are GPS positions.


Four GPS drifters in the North Brazil Current retroflection area
Latitude
Longitude
deploy location
0
1
2
3
4
5
6
-50
-49
-48
-47
-46
-45
-44
-43
-42
-41
-40

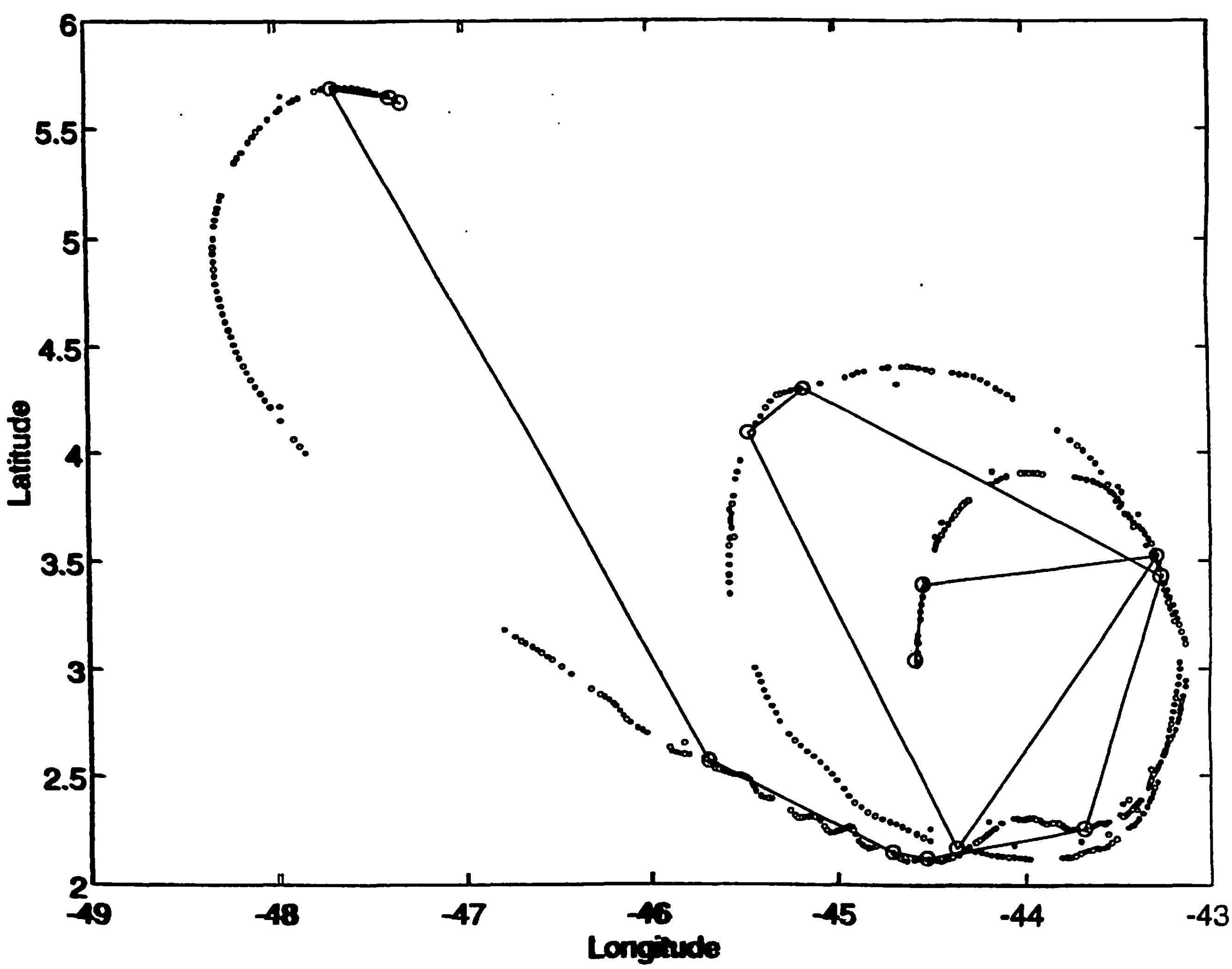



Figure 3. Overlaid drifter 11891 trajectories from GPS (small dots) and Argos positioning (open circles and straight line segments). The Argos position time series has been sub-sampled to emulate that of a standard drifter cycling one day on, two days off.

## THE GLOBAL DRIFTER PROGRAMME MINIMET DRIFTER - TECHNOLOGY UPDATE

**Andy Sybrandy**, Scripps Institution of Oceanography, USA

ABSTRACT

The Global Drifter Programme Minimet Drifter is an SVP-B drifter with the ability to measure wind speed and direction. The drifters will determine wind speed by measuring acoustic ambient noise and sense wind direction from the orientation of the surface float. The first test deployments of three prototype units occurred off the coast of Southern California. The data was processed after the deployments to determine the algorithms needed to extract wind direction from the compass readings and wind speed from the acoustic data. The results show the drifter is capable of measuring wind direction to an accuracy of better than +/- 10 degrees. The test deployments also supplied the first few points necessary to calibrate the relationship between ambient acoustic noise and wind speed of this configuration. In mid October, 1996, 18 drifters will be deployed in the Labrador sea to further calibrate the wind speed: in the spring of 1997 another 23 will be deployed.

# USE OF LOW EARTH ORBIT SATELLITE COMMUNICATIONS SERVICES IN OCEANOGRAPHIC MONITORING

**Bob Kelly**, ORBCOMM, USA

## ABSTRACT

On April 3, 1995, Orbital Communications Corporation (ORBCOMM) of Dulles, VA, USA, successfully launched the first two of a constellation of 26 satellites into low earth orbit (LEO). ORBCOMM is building a worldwide, low cost, messaging and data communications system with inherent position determination capability. ORBCOMM is the world's first US-licensed LEO mobile satellite service and is a joint venture of Orbital Sciences Corporation and Teleglobe, Inc. of Canada.

The three main components of the ORBCOMM System are the space segment, ground segment, and SCs (subscriber communicators). For coverage of the US, there are four unmanned Gateway Earth Stations (GES) in the four corners of the US, one Network Control Centre (NCC) and a constellation of 26 small satellites. Other countries around the world will have their own NCC and GES (the number of GES being dependent on the size of the country). Companies in twenty two countries have signed candidate license agreements with ORBCOMM to procure ground segments and provide service. ORBCOMM expects to provide service in 36 international markets by 1998.

The space segment is comprised of 26 small communication satellites in orbit 425 miles (785 km) above the earth. The satellites relay messages between ORBCOMM SCs and the ground segment. Some LEO satellite systems advantages are:

- Lower launch costs than geostationary or geosynchronous satellites.
- Less power required to communicate with a LEO versus GEO satellite.
- Availability of Doppler shift in the signal for integrated position determination.
- Use of proven, inexpensive VHF electronics, and omnidirectional VHF antennas.
- Excellent overall link availability independent of local terrain features.

The ground segment is comprised of the unmanned GES and the NCC. The GES and the satellites provide transparent access from SCs to the NCC. The NCC routes messages to the addressee of the message.

Subscriber communicators will be available in a number of different configurations. Some will be compact, lightweight devices with long life batteries, 5-watt transmitter, antenna, keypad and LCD screens. Most will have RS-232 data ports and some will be simple black boxes which can be integrated with GPS receivers, sensors of all types including oceanographic, computers and other systems.

The system's basic characteristics enable the use of small, low cost, power-frugal communicators with inherent position determination capability. The potential uses of the ORBCOMM system for oceanographic applications are extensive. The author's paper will discuss the technology and practical issues attendant on using the ORBCOMM system for oceanographic data collection, transmission and control.

# AN OVERVIEW OF THE STARSYS LEO SATELLITE SYSTEM

Marc Leminh, Starsys Europe, Toulouse

**STARSYS Global Positioning, Inc.**

## SERVICE DESCRIPTION

The following Service Description is based on plans for the development of the STARSYS System as of the date hereof. STARSYS may amend this Service Description from time to time as its plans for the STARSYS System change. The Service Description is qualified by the STARSYS User Segment Applications Center ("USAC") agreement, which is incorporated by reference and the terms of which shall take precedence.

The implementation of the STARSYS System is subject to the negotiation of a number of definitives, legal documents, to applicable licensing procedures, and to a number of uncertainties and other factors relating to the construction, launch and operation of the System. STARSYS makes no representation and warranties in this Service Description or in the USAC agreement with respect to the foregoing. STARSYS disclaims any liability to any Person who relies on any information contained in this Service Description for any purpose.

### Applications

STARSYS is a low-Earth-orbiting mobile satellite service system ("Little LEO"). STARSYS provides low cost, non-time-sensitive, low speed burst data messaging and geo-positioning services on a worldwide basis; initially the services will be available in North America and Europe. STARSYS functions as a network service provider, offering system capacity to re-sellers who in turn provide support directly to end-users.

### Anticipated Service Areas

STARSYS will be initially available in the following regions:

- Contiguous U.S., Southern Canada, Mexico, and the Caribbean
- Western and Central Europe (extending to Moscow)
- off-shore regions of the above areas

Later, STARSYS will provide coverage in other regions around the world, as licensing permits.

### Specific Services Proposed

• *Inbound Services* (Remote Terminal(s) to Central Site)

◊ **Data Collection**
User-defined data can be sent from the remote terminal(s) to a central site. This data can contain any user-specified information of a routine or critical nature, and can be transmitted periodically (*i.e.*, once per day, week, month), upon request (see "Polling" below), or may be event driven (*i.e.*, when pre-set limits are exceeded).

◊ **Geo-Positioning**
The STARSYS system can calculate the geographic position of a remote or mobile terminal on a predetermined schedule, or upon request (see "Polling" below). This position can be accurate to within 1000 meters. Alternatively, a GPS card may be used to calculate a GPS-derived location, accurate to within 100 meters, which can then be relayed to the central site via the STARSYS system. User-defined data (see above) may also be collected and transmitted in conjunction with position determination.

• *Outbound Services* (Central Site to Remote Terminal(s))

◊ **Data Transmission**
Data from a central site can be sent either to an individual remote or mobile terminal, or to a group of terminals (*i.e.*, a broadcast message). This data can be informational in nature (*e.g.*, text), used to command the users equipment (*e.g.*, control signals), or to "re-program" or otherwise control the terminal itself. Acknowledgements are an integral part of the system, confirming to the user that the data has been delivered.

◊ **Polling**
The STARSYS terminals themselves may be controlled by means of a polling request issued from a central site. This polling request may be used for a number of purposes, including requesting a position location, initiating a pre-programmed control function, requesting a data transmission, *et cetera*, and may be used to poll an individual terminal, or in broadcast mode.

## Estimated System Operating Parameters

• *Message Parameters*

| | |
|---|---|
| average user message length | 64 bits (8 bytes) |
| maximum user message length | 256 bits (32 bytes) |
| bit rates — inbound | 600 bps |
| outbound | 2,400 bps |
| number of messages per day | determined by user |
| message burst duration | 450 ms (maximum) |

• *System Margins*

| | |
|---|---|
| inbound | 2.3 dB to $1 \times 10^{-4}$ BER (at 5° elevation) |
| outbound | 3.3 dB to $5 \times 10^{-4}$ BER (at 5° elevation) |

• *Mean Time of Satellite Visibility* (North America and Europe)

| 2 satellites | 6 satellites | 12 satellites | 24 satellites |
|---|---|---|---|
| 13% | 40% | 77% | 98% |

STARSYS

### • *Latency*

average/not exceeded for 90% of the time, stated in minutes

| 2 satellites | 6 satellites | 12 satellites | 24 satellites |
|---|---|---|---|
| 125/500 | 15/45 | 4/15 | 1/2 |

### • *System Capacity*

total number of *inbound* messages which can be processed per day in the U.S. (*i.e.*, with 2 Command & Data Acquisition stations (CDAs))

| 2 satellites | 6 satellites | 12 satellites | 24 satellites |
|---|---|---|---|
| 185,000 | 550,000 | 1.1M | 1.5M |

total number of *outbound* messages which can be processed per day in the U.S. (*i.e.*, with 2 CDAs)

| 2 satellites | 6 satellites | 12 satellites | 24 satellites |
|---|---|---|---|
| 55,000 | 170,000 | 335,000 | 425,000 |

There will be up to 500 groups of terminals supported, which can be used to send common polling or broadcast data messages. Up to 5,000 terminals may be in any one group.

### • *Expected Frequency Bands/Channel Bandwidth*

| | |
|---|---|
| inbound uplink | 148.4525 MHz/905 Khz |
| inbound downlink | 137.500 MHz/905 KHz |
| outbound uplink | 150.025 MHz/50 KHz |
| outbound downlink | 400.620 MHz/50 KHz |

### • *Proposed User Terminal Characteristics*

| | | |
|---|---|---|
| terminal size (without batteries) | | 5 cm x 7.5 cm x 15 cm (2" x 3" x 6") |
| antenna size — | terminal | 25 cm (10") whip or a flat plate |
| | GPS option | 2.5 cm x 2.5 cm patch or egg-shell |
| transmitter output power | | 2 W |
| interface with sensor or control port | | serial or parallel EIA RS-232C or I2C ports |
| power — | external | 12 v DC |
| | internal | varies with application requirements; further dependent upon use/non-use of GPS |
| | back-up | each terminal will contain a back-up battery, which will be capable of alerting the user of a power outage condition; the back-up battery will have a minimum lifetime of 48 hours |
| design life | | +/- 10 years |
| antenna polarization | | linear vertical |
| interference immunity | | STARSYS uses spread spectrum modulation technique to provide interference rejection of VHF radios in the same frequency band. The satellite also has a unique adaptive notch filter to reject strong terrestrial interferences. |

STARSYS

GLOBAL POSITIONING, INC.

## Plans Concerning User Segment Application Centers (Value-Added Re-sellers)

STARSYS provides service to end-users through User Segment Application Centers, which are value-added re-sellers. USACs receive collected data from user terminals registered to them, and also initiate any polling and data transmission actions. USACs connect to the STARSYS system through regional Processing Analysis & Control Centers around the world, and can communicate with the PACCs via telephone lines, VSAT, Internet, and other public access networks. Current plans call for PACCs to be located on the U.S. East Coast, and in Toulouse, France; additional PACCs may be located elsewhere to meet market demands. USACs may negotiate a "capacity reservation" with STARSYS on a non-exclusive basis, to support a wide variety of end-user applications.

## Planned Service Schedule

STARSYS plans to offer service within a few weeks of launching its first two satellites. Service capacity and time-responsiveness will improve with the launch of each additional grouping of satellites, ranging from the first two through the maximum constellation size of 24 satellites. To reach its "Initial Operating Capability" of six satellites, STARSYS plans:

| | |
|---|---|
| 2 satellites in orbit | early-1999 |
| 6 satellites in orbit | by 2000 |

# MARINE APPLICATIONS OF THE ICO MOBILE SATELLITE SYSTEM

**Qiaogen Shan**, ICO/Inmarsat, UK

ABSTRACT

The presentation will describe ICO's system configuration and capabilities and provide a perspective on the current and future requirements of the maritime market for global mobile satellite communications services. This will include factors which influence the development of the maritime market and segment-specific products as well as the role of Inmarsat as a distributor.

**IRIS : Intercontinental Retrieval of Information via Satellite**

Victor LAROCK,
Assistant Space & Defense Manager, SAIT Systems
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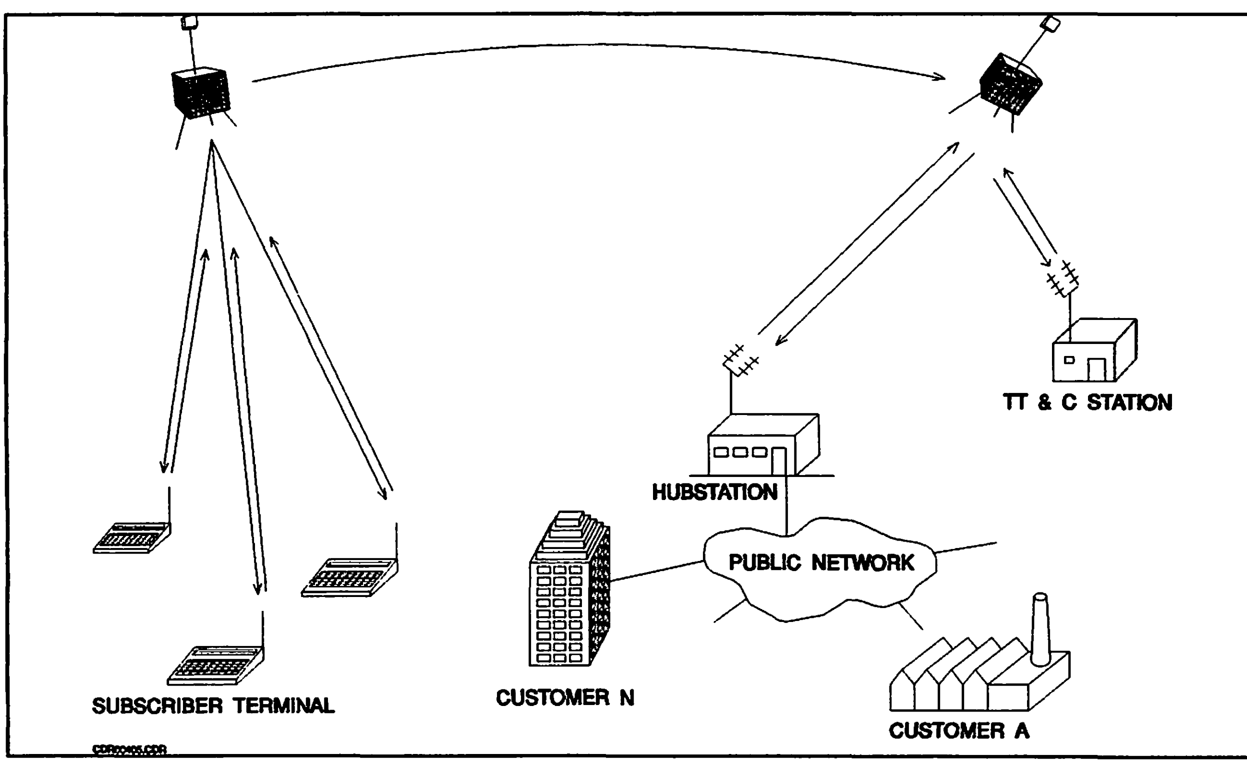
## 1 INTRODUCTION

IRIS is a 'Little-Leo' store-and-forward messaging system planning to offer a low-cost, world-wide mail-like service. It is the result of the technical developments in the LLMS (Little-Leo Messaging System) project supported by the European Space Agency.

This presentation descrines the general features of IRIS, the goes on to explain their relevance to the field of data buoys.

## 2 OPERATING PRINCIPLE



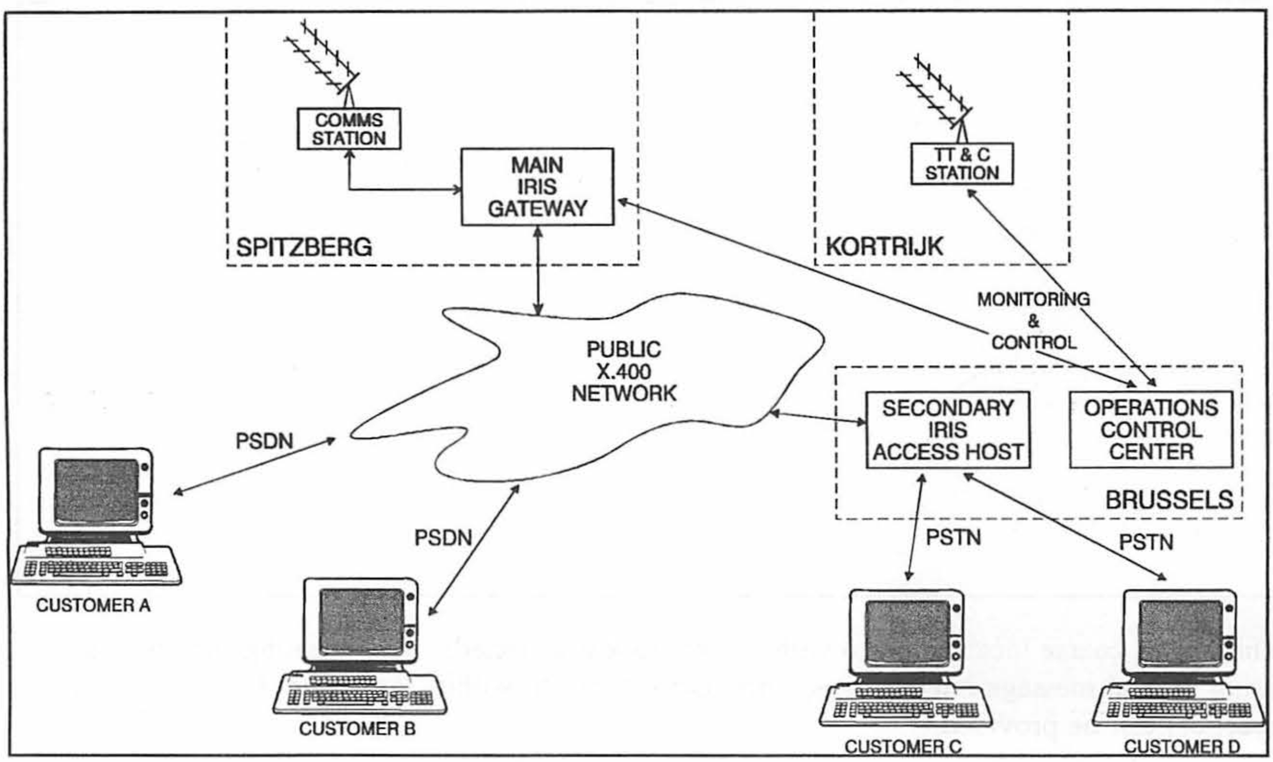

The system targets customers with headquarters in regions well served by landline networks, but agents or assets in far-off areas with little conventional means of communicating.

It uses a baseline of two (for redundancy and capacity reasons) satellites in near-polar orbit. Due to the rotation of the Earth, each satellite will see any point on Earth at least twice daily, regions at higher latitudes seeing the spacecraft more often.

and acknowledges their storage on-board the satellite. When it comes in view of the communications hubstation, it beams them down for distribution to the 'fixed user' via E-mail. The hubstation sees all 14 daily orbits, being situated at a high Northern latitude (Spitzbergen - 78°N). Outbound messages to the terminals are handled in a similar fashion.

## 3 SERVICE FEATURES

The system offers fixed users landline access using X.400 or Internet E-mail, or alternatively direct PSTN/PSDN connection to the IRIS service center access host. In practice, the fixed user will have a Personal Computer on his premises allowing him to compose and receive messages as well as display the position of his terminals on a map.




IRIS is a system for closed user groups. Thanks to this feature, and to a light infrastructure, it can offer low service charges.

The standard short message is 150 Bytes in length, but nothing precludes IRIS from handling messages in the kByte range in both directions.

Once an inbound message is embarked on-board the satellite, its delivery to the fixed user occurs within one orbit, or less than two hours. (if using the Internet, allowance must be made for the Web's delays). Satellite waiting times can reach 12 hours at most.

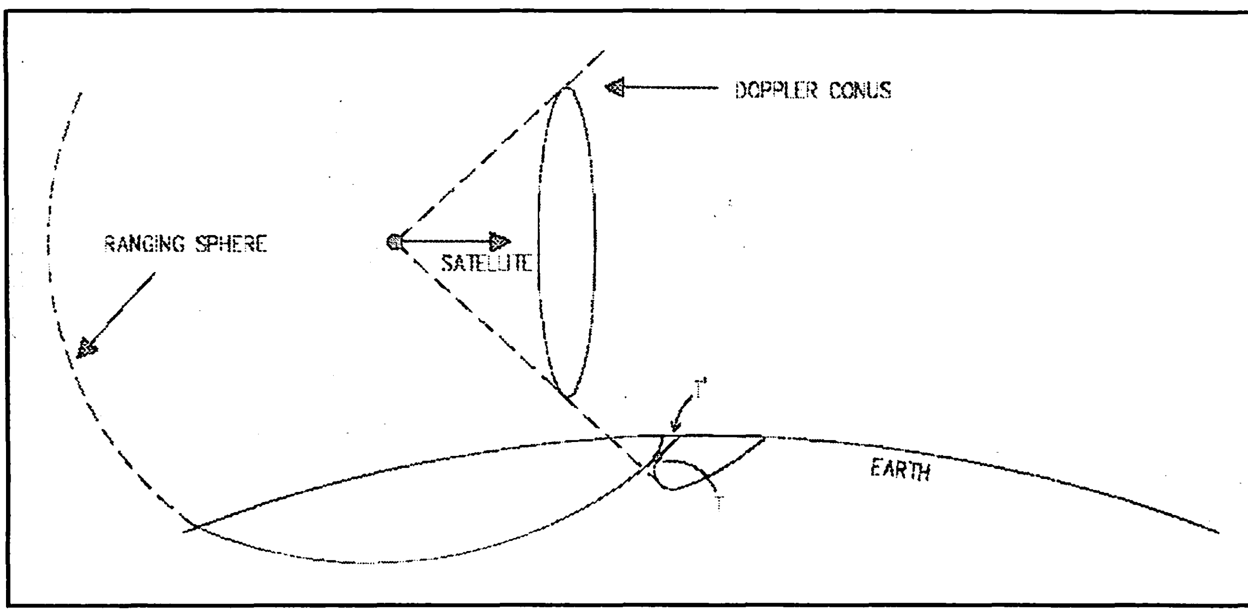
The two-satellite IRIS system is capable of ferrying 10,000 1kByte pages in the inbound direction, and 17,000 in the outbound direction. Its main efficiency lies, however, in the performance of its random access scheme to the spacecraft. The peak user density a satellite can handle is approximately 3 users per second with short messages. This is a consequence of the spread-spectrum techniques used in the communications links.

Spread-spectrum also yields built-in position location capability, necessary to the system's operation and offered as an added-value service to users.

## 4 LOCALIZATION

IRIS will provide position location based on a single short message exchange between user terminal and satellite.

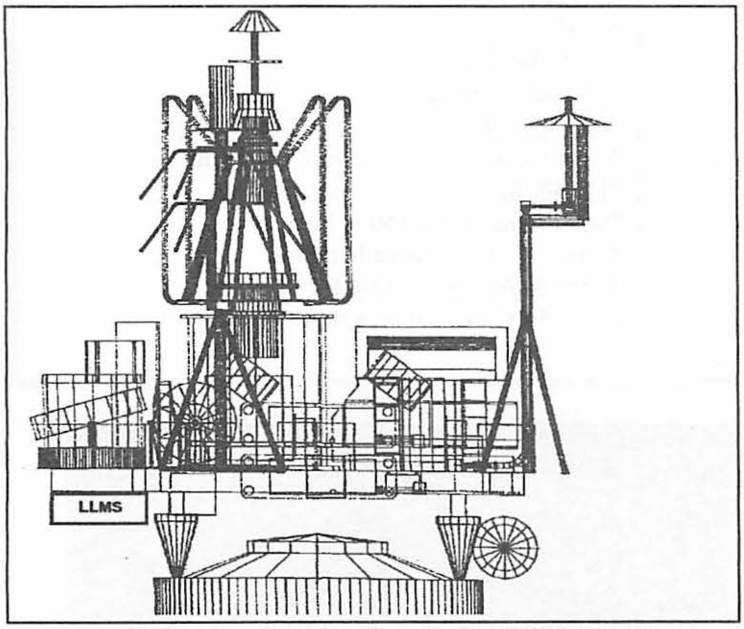
This is achieved by a combination of spread-spectrum ranging and Doppler measurement at the terminal. The intersection on the Earth's surface of the ranging sphere and iso-Doppler conus yields determines the terminal's position, after ambiguity removal.




This yields coarse localization to within 5 km (3 km expected). By repeating the process using several message interchanges, finer localization (to within 1km, with 350m expected in practice) can be provided.

## 5 THE SPACE SEGMENT

The first LLMS/IRIS spacecraft will be an 'Attached Payload' on board a Russian Earth observation satellite.



LLMS Attached Payload on RESOURCE

This spacecraft, RESOURCE-O1 N4, is due for launch from September 1997. This will enable early-entry triallists to inaugurate the service in the first quarter of 1998.

At this time the second spacecraft, nominally a free-flying microsatellite, should be launched.

This enables the start of commercial operations by 1 July 1998.

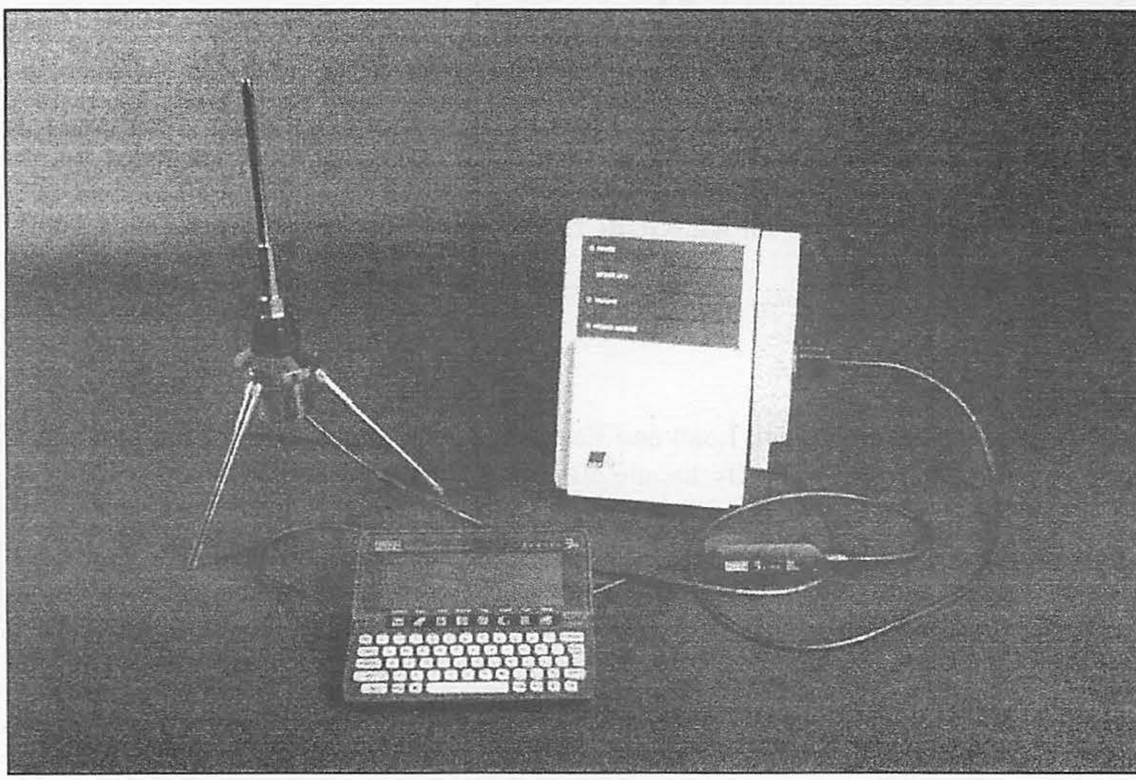
Thereafter, by adding more Free-Flyers, the constellation can be maintained and upgraded to track demand.

## 6 THE USER TERMINAL

The user terminal is an intelligent 'Load and Forget' modem, meaning that once the message is loaded into it, it will automatically handle all transactions with the satellite once it flies by.

The terminal has power down modes to extend autonomy, a script language for user-customization, and an interchangeable interface module to accommodate various kinds of external sensors. SAIT Systems is fully open to other forms of optimization (application software writing, re-packaging) for a given field of use. Hereafter the terminal's main features, and a view of the terminal, with antenna, connected to a Personal Organizer.

| | |
|---|---|
| TRANSMISSION<br>1200 bits/s user data rate<br>Tx Power typ. 1W @ 388 MHz (BPN - BW =1.5 MHz )<br>RECEPTION<br>4800 bits/s user data rate<br>400.6 MHz (OQPN - BW =790 kHz)<br>STANDARD INTERFACES<br>1 standard RS-232 +1 RS-232 opto-isolated/NMEA 183<br>General-Purpose I/O<br>4 indicator LEDs<br>DC Adapter<br>Antenna connector (BNC) | ANTENNA<br>Quarter-Wave Groundplane<br>Quadrifilar helix, etc..<br>BATTERIES<br>6 x UM-3<br>NiCd, Alcaline, NiMH<br>External charging only<br>AUTONOMY<br>5 hours continuous receive / 100 hours standby<br>PHYSICAL<br>Dimensions 200 x 150 x 50 mm<br>Weight < 1kg without batteries<br>TEMPERATURE RANGE<br>0 to 50°C or -20 to +70°C |



## 7 AN OPERATIONAL SCENARIO

To quantify the details of using IRIS in a data buoy operation, let us make the following assumptions. Data collection consists in retrieving 8-Byte buoy messages giving position etc... We use IRIS 150-Byte short messages and fill these optimally with data points, sampled by the terminal programmed to 'wake up' periodiocally and interrogate the buoy's sensors or associated GPS receiver. Even on the Equator where there are only two passages per day, more than one measurement per hour can thus be collected and stored between passes, and transmitted using a single short message. These figures are in no way limitative. Other locations will have more passes per day and we can use more than one message per pass.

Let us first examine the energy consumption budget. This is, per satellite pass interval :

| | | | |
|---|---|---|---|
| 20 x 15s | to sample the data (microcontroller switch-on) | @ 100mA | =8.33mAh |
| 120s | of TCXO preheat | @ 20 mA | =0.7 mAh |
| 30s | in Receive mode to lock on satellite | @ 600mA | =5 mAh |
| 3 x 1s | three transmit attempts to upload message | @ 1250mA | =1 mAh |

(successful upload is acknowledged; three attempts is worse case for fully loaded system)
Hence an average of 15mAh per pass or **30-60mAh/day** (for 2 to 4 passes)

A cost simulation for such a service case would look like this (per year) :

| | | |
|---|---|---|
| Fixed fee | 30 $/month x 12 | =360$ |
| Service charge | 0.1$/msg x 2-4x 365 | =110$ |
| Terminal amortizing | 900$/3yrs | =300$ |
| For a total of less than | | **800 $/year** |

The reader, based on, the above figures, can draw up his own examples.

## 8 CONCLUSIONS

IRIS is a two-way global store-and-forward system capable of handling messages in the kByte range. Its two-spacecraft baseline system provides a minimum of two satellite pases per day, and delivery of data within one orbit (under two hours) once embarked on the satellite. The system provides e-mail access to the 'fixed user' waiting for the data from the buoy.

The usage of advanced spread-spectrum technology guarantees an efficient satellite access scheme, and also assists in position location. Localization of user terminals is a system function. It can be enhanced by coupling a GPS receiver to the user terminal's NMEA 18X interface.

The user terminal is an intelligent 'satellite modem' with data storage. It can be optimized for the data buoy field through application software writing, customizing of its interface module, and repackaging.

Flexibility in customizing and low usage cost are features of the IRIS service, which targets niche markets, of which data buoys are a good example.

# SAFIR: Satellite For Information Relay

J. W. Wylie
A1Marketing

## Background information

(fig. 1)

OHB-Teledata is the Satellite operator and service provider for theglobal data communication SAFIR a bi-directional satellite communication system manufactured by its sister company OHB System GmbH, Bremen, Germany.

(Fig. 2)

In 1991 OHB System GmbH started to develop its own communication satellite series, called SAFIR (Satellite For Information Relay), and related ground stations. Ground equipment was also developed for other satellite systems such as INMARSAT. Trial tests for the tracking of mobile objects on land and sea have been completed successfully. The SAFIR Satellite Control Station started its operation with the launch of the first test payload, SAFIR 1, in November 1994. SAFIR-1 was launched into a polar orbit at an altitude of approximately 700Km (440 mls.). SAFIR's technology is based on the "store and forward" method. SAFIR's polar orbit makes it possible for mobile subscribers to communicate with one another directly and worldwide; this is a major improvement from geostationary satellite systems that still require central ground stations to establish connections between customers.

OHB-Teledata is the first European telecommunication company to operate a privately owned low earth-orbit satellite system like SAFIR-1. With this project the company established itself as a provider of value added wireless communication services.

OHB-Tetedata offers its clients small, lightweight, multi mode mobile ground terminals at a low cost. These terminals, called MACRODATA, use the same software for all stations to transmit and receive all services. They can be equipped with GPS (Global Positioning System) receivers to locate mobile customers and outstations around the world. A Rockwell GPS receiver is used.

Specifically OHB-Teledata offers the following services:

* Worldwide communication and data transmission services via satellite and/or terrestrial connections.
* Customised fleet management solutions for transportation services, i.e. Cargo Tracking Systems (CATS).
* Individualised solutions for the short message services. Transmission of positional and digital status data for worldwide container tracking.
* Monitoring and transmission services for operational and positional data of oceanographic buoys.

In the continuous effort to improve and optimise its systems, OHB-Teledata is presently concluding test runs with selected clients such as cargo logistic centres, harbour terminals, freight forwarders, shipping companies, waterway authorities and Deutsche Bahn AG.

## Satellite Communication Capabilities

OHB-Teledata offer, and is preparing to offer, the following satellite communication services:

* SAFIR
* INMARSAT D/D+ (in preparation)
* ORBCOMM (in preparation)

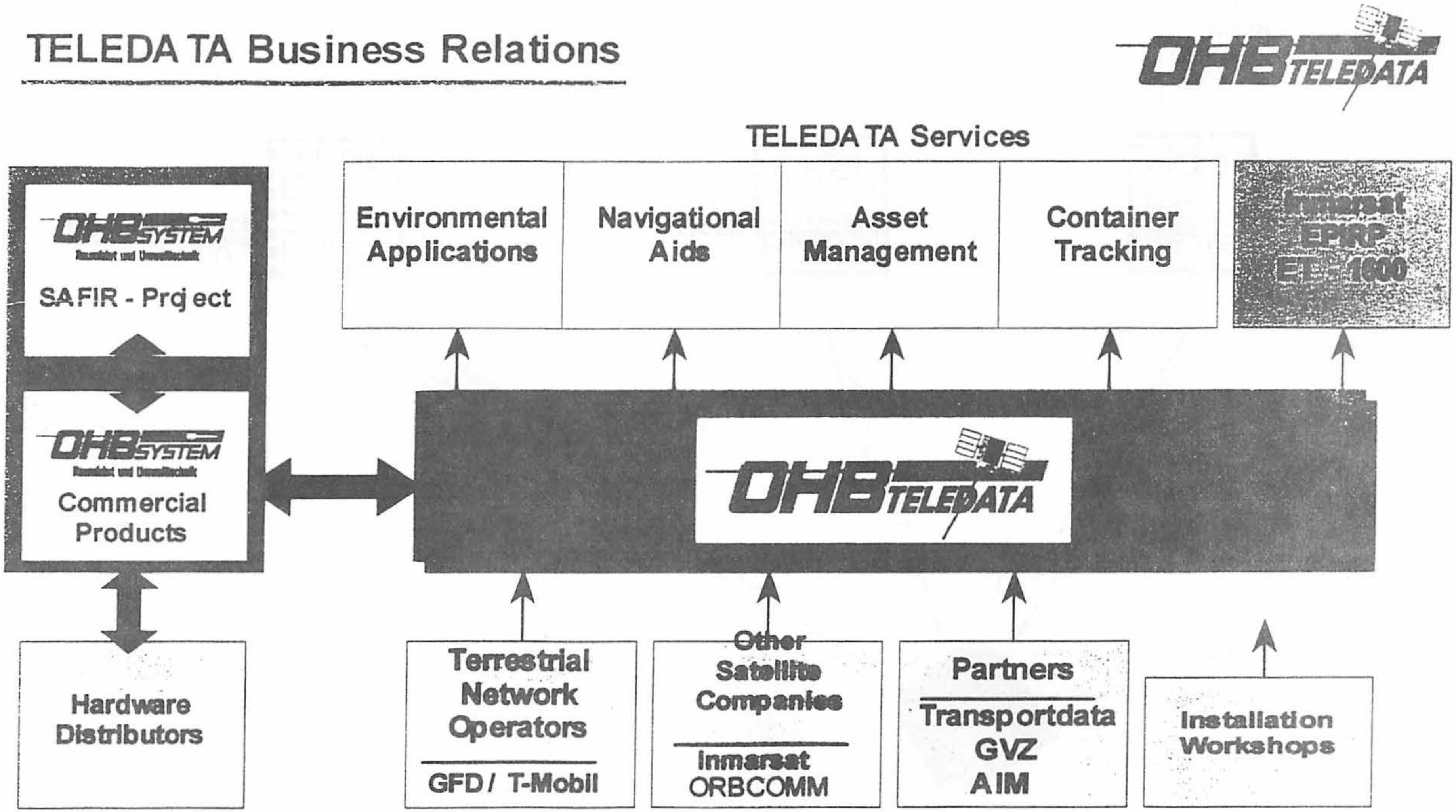

TELEDATA Business Relations
OHB TELEDATA
TELEDATA Services
Environmental Applications
Navigational Aids
Asset Management
Container Tracking
OHB SYSTEM
SAFIR - Project
OHB SYSTEM
Commercial Products
OHB TELEDATA
Hardware Distributors
Terrestrial Network Operators
GFD / T-Mobil
Other Satellite Companies
Inmarsat
ORBCOMM
Partners
Transportdata
GVZ
AIM
Installation Workshops

FIG. 1

# SAFIR USER OPERATIONS

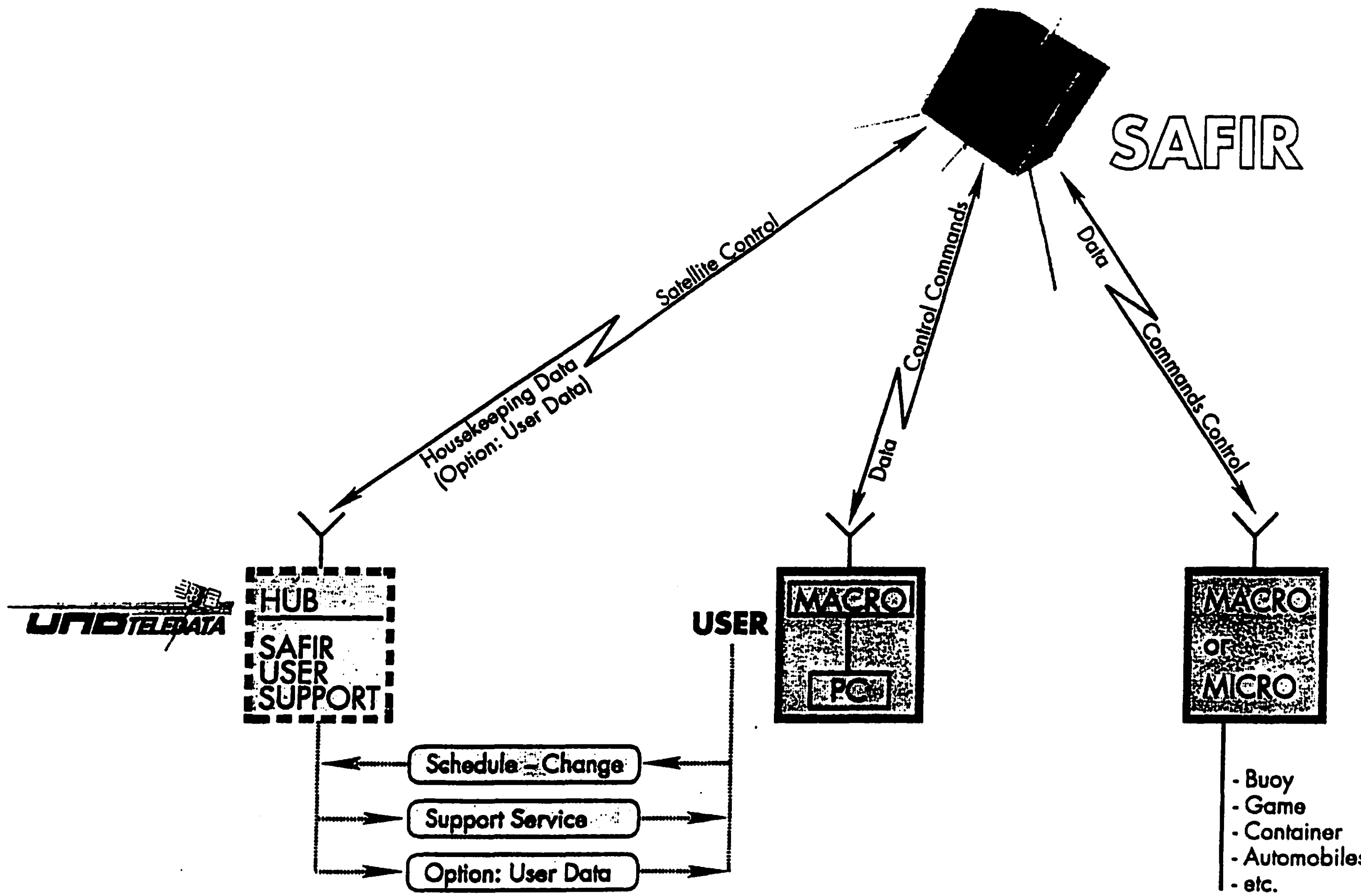



Fig. 2.

The collaboration with INMARSAT and ORBCOMM is as a service provider for Germany only, at this time.

__SAFIR__
(Fig. 3)

SAFIR stands for Satellite For Information Relay. SAFIR-1 is the first operational satellite of OHB-Teledata and is one of the most powerful small satellites for international data communications
which allows users access to worldwide distribution of information.

The components of the SAFIR system are basic; small portable ground stations (MACRODATA) and SAFIR satellites which circle the earth every 98 minutes. The system allows the transfer of any kind of digitised information from any ground station anywhere in the world via the SAFIR satellite to the desired target stations anywhere else. The operational architecture of the SAFIR systems guarantees absolute link and data integrity, using advanced access code mechanisms and information verification.

The SAFIR satellite can make contact with a particular ground station once per orbit. i.e. every 1 1/2 hours for ground stations above 70 degrees of latitude (North or South), while central Europe is served about 4 - 6 times a day by one satellite.

**Typical SAFIR features are:**

* Direct data communication between the ground stations of the user; not via a Central Ground Receiving Station.
  i.e. the user communicates directly with his outstation from his office or lab based PC or laptop computer.
* SAFIR addresses the ground station based upon a programmed contact schedule.
* Setting and changing the contact schedule is via a separate link of the OHB-Teledata HUB station based in Bremen.
* Data transmission between ground stations of the user is controlled by SAFIR.
* Store and Forward capability for communication between user terminals.
* There is 10 MB memory storage onboard SAFIR. Data is transfered to ground stations when they are in the SAFIR antenna footprint.
* Stored data in the ground stations will be acquired by SAFIR.
* Standard message length is 8 Byte (for positioning data), for data files there is no limitation.
* Data rate is SAFIR-1: 300 bps, SAFIR-2: 2400 bps uplink and 4800 bps downlink.
* The HF-Unit, in the ground station, provides the interface to the SAFIR satellite with 400mhz uplink and downlink frequency. Data are transfered in half duplex mode. Transmitter power is 5W.

(Fig. 4)

The first test satellite SAFIR-1 was launched in November 1994 and is still in operation. The next launch of an OHB-System satellite, SAFIR-2, is in the third quarter of 1997. The launch contract has already been signed. SAFIR-3 and SAFIR-4 are in planning. Their launch is scheduled for 1999.

__INMARSAT D/D+__

INMARSAT is an organisation for the operation of communication satellites, with its headquarters in London, supported by about 70 shareholders, mainly Telecom authorities. The nearly global coverage of the INMARSAT satellites enables communication services nearly all over the world.

The newly established INMARSAT D is a worldwide low Data Rate Service, which helps to perform in principle the following three global applications:


Partly funded by BMFT - DARA
Bi-directional Satellite
Communication System
with global coverage
OHB SYSTEM
The Manufacturer of small Satellites in Germany
OHB TELEDATA
The Service Provider for global Data Communication
ORBITAL - UND HYDROTECHNOLOGIE BREMEN SYSTEM GMBH
UNIVERSITÄTSALLEE 27 · 28359 BREMEN · F.R.G.
TELEFON 0421 - 22098 - 0 · TELEFAX 0421 - 2209810 · TELEX 245316 ohb

OHB TELEDATA

# STATUS SATELLITE COMMUNICATION CAPABILITIES

## SAFIR

- SAFIR 1: Pilot Tests with MAN (Trucks), Swedish National Maritime Administration (Navigation aids, buoys), German Railway (Trains) GVZ Bremen (Cargo, Logistics)
- SAFIR 2: Under construction, launch during second half of 1997
- SAFIR 3 and SAFIR 4: Project start in September 1996, these satellites will be equipped with new, advanced communication technology.
- Final Configuration: 6 Satellites

Fig. 4.

* paging of travellers and mobiles (cars, trucks, trains, ships and aeroplanes)
* transfer of messages
* remote switching on/off of devices or electronic systems

The advanced service INMARSAT D+ allows the bi-directional short message communication with a data package length of 8 Byte transmitted from the remote unit. This 8 Byte message can be status information or position data acquired by a GPS receiver.

**ORBCOMM**

ORBCOMM service capability was launched in 1995, with two operational satellites. Up to 34 additional satellites are scheduled for deployment during 1997, to provide nearv real-time communication availability. ORBCOMM is backed by an alliance between Orbital Sciences Corporation and Teleglobe Inc. of Canada. ORBCOMM is a two-way wireless communication system. ORBCOMM provides low cost, high value communication solutions through a low-earth orbit satellite network and VHF subscriber communicators.

OHB-Teledata have been a member of the European Partnership since July 1996. The negotiations between ORBCOMM and OHB about the co-existence of ORBCOMM and SAFIR sateliites were finalised in October 1996. Prior to start-up of the operation, a series of test and compatibility measurements have been performed successfully by OHB-Teledata, ORBCOMM specialists and German PTT.

The licence, and allowance, for test operations are now being requested. The next trial phase will start with 10 communicators used for container tracking.

**Services and Applications**
(Fig. 5)

OHB-Teledata provides two-way satellite communication between the customer's office, or laboratory, and a remotely located, unmanned monitoring station gathering data from sensors, actuators etc. in the field of:

* Environmental monitoring
* Navigation aids monitoring
* Asset management (private and industrial equipment)
* Container tracking

OHB-Teledata also provides two-way communication between mobile, personnel-operated, terminals in the field of:

* Personnel and business communication
* Cargo logistic centres
* Harbour terminals
* Freight forwarders
* Shipping companies
* Railway companies

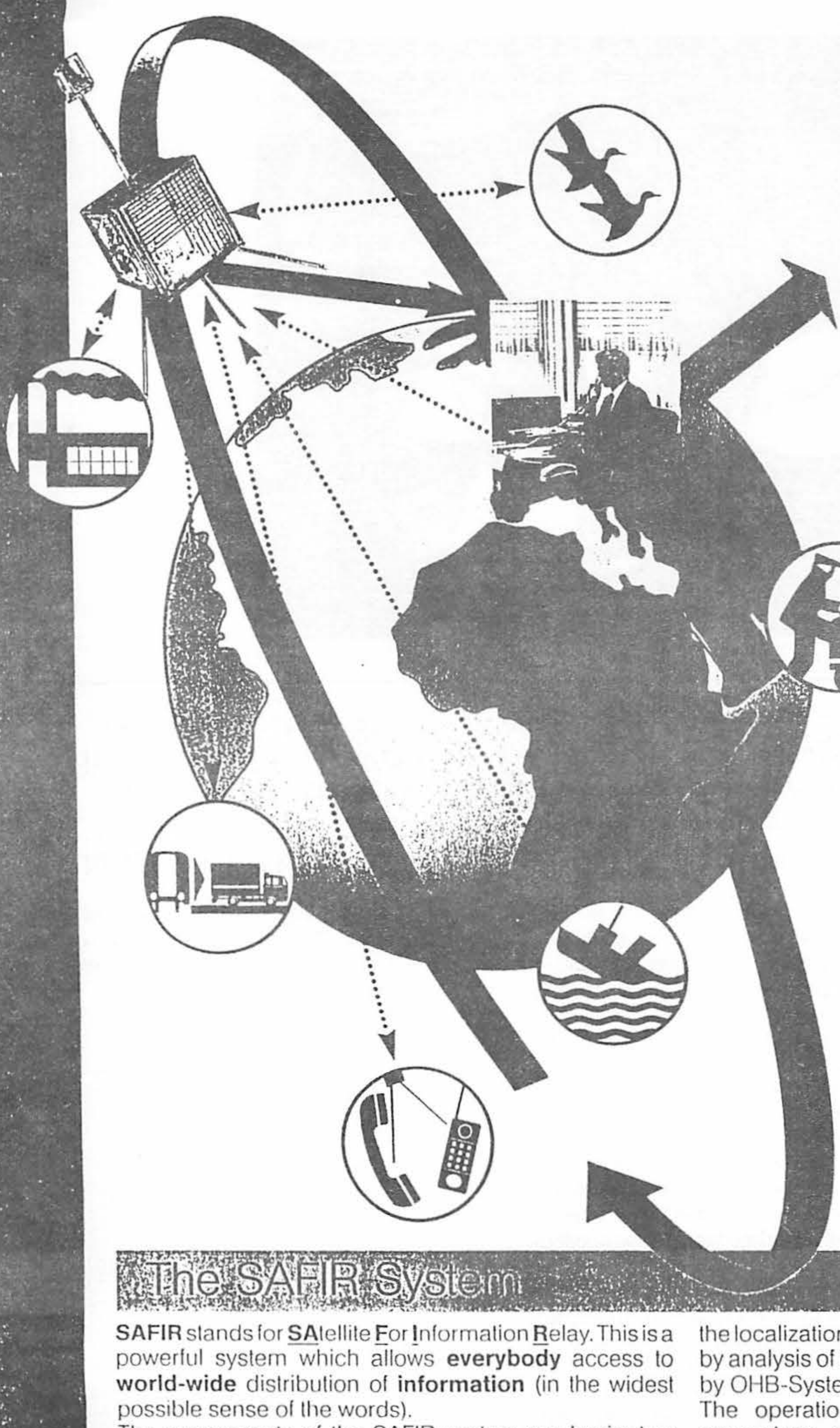
Typical applications for remote sensing oceanographic platforms which require global bi-directional communication services are the DOMSA and MARINUS buoys.

**DOMSA (Datatransmission of Oceanographic Measurements with SAFIR)**
(Fig. 6)

In the last few years of ocean research there has been an increase in the application of drifting measuring systems and fixed devices operating on the bottom of the sea for better understanding drift, the carbon dioxide circle and marine polution. In addition to the further development of the sonds and anchoring technology, an increasing requirement exists for the direct transfer of larger amounts of data of remotely controlling the data acquisition as well as

# SAFIR

SATELLITE PROGRAMME FOR GLOBAL LOW-COST
BI-DIRECTIONAL COMMUNICATION SERVICES



## Potential Users!

- Scientific research institutes and universities
- Car insurance companies, car manufacturers, and owners
- Cargo transport companies and shipping organizations
- International organizations with personnel in remote areas
- Organizers of trekking and adventure holidays
- Mountain rescue, coast guard rescue etc.
- and YOU!...

  for sending your people a message anywhere in the world
  checking your house or precious possessions while away
  as a back-up for emergency cases, when "going out" (into the mountains, sailing, tracing the pharaoh's,...)

## Applications

- Transfer of environmental data from remote measuring stations (including active control of the measurement station operation)
- Emergency messaging for global search and rescue
- Animal tracking and wildlife studies
- Global messaging, paging
- Localization of stolen automobiles
- Cargo tracking
- World-wide distribution of information/data etc.

## The SAFIR System

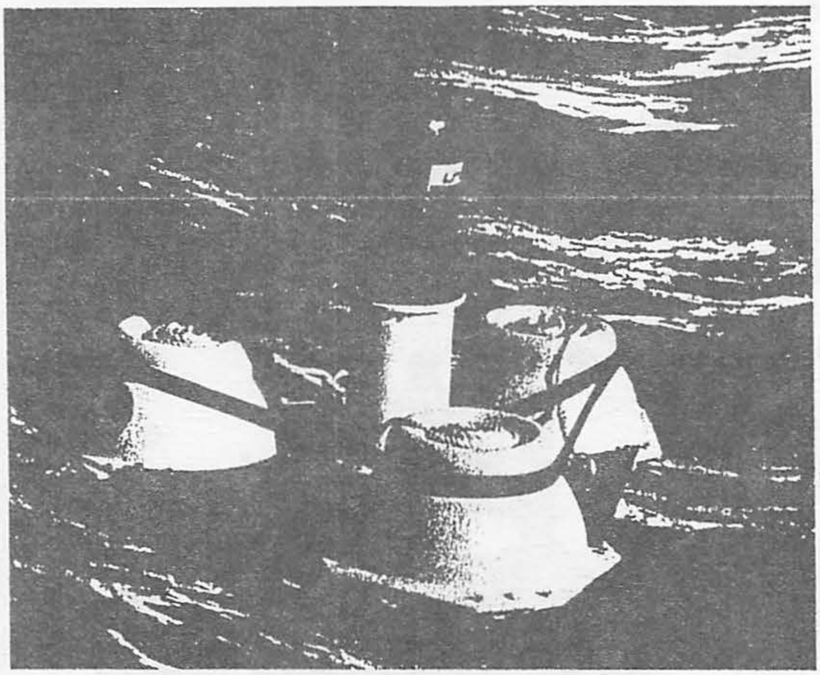
Partly funded by DARA

**SAFIR** stands for **SA**tellite **F**or **I**nformation **R**elay. This is a powerful system which allows **everybody** access to **world-wide** distribution of **information** (in the widest possible sense of the words).
The components of the SAFIR system are basic: two types of small portable **ground stations** and a number of SAFIR **satellites** which circle the earth every 98 minutes. The system allows you to transfer *any* kind of (digitized) information from *any* of your ground stations *anywhere* in the world via one of the SAFIR satellites to the desired target stations of your network *anywhere* else. In addition, the localization of mobile ground stations can be effected by analysis of Doppler shift measurement data provided by OHB-System, Bremen.
The operational architecture of the SAFIR system guarantees absolute link and data integrity, using advanced access code mechanisms and information verification. This is to make sure that you can access your ground stations *every time* it is scheduled and safely transfer of your data, but that no one else can make use of your facilities or your information at *any* time.

Fig. 5.

# DOMSA-BUOY. DATATRANSFER OF OCEANOGRAPHIC MEASUREMENTS WITH SAFIR

SAFIR



## A CO-OPERATIVE DEVELOPMENT OF OHB-SYSTEM GMBH AND THE GEOLOGICAL DEPARTMENT OF THE UNIVERSITY OF BREMEN, PROF. WEFER, WITH THE SUPPORT OF THE SENATOR FOR ENVIRONMENTAL PROTECTION AND URBAN DEVELOPMENT, BREMEN

In the last few years of ocean research, there has been an increase in the application of drifting measuring systems and fixed devices operating on the bottom of the sea for better understanding drift, the carbon dioxid circle and marine pollution. In addition to the further development of the sonds- and anchoring-technology, an increasing requirement exists for the direct transfer of larger amounts of data, of remotely controlling the data acquisition as well as an accurate location method for finding these expensive systems. To accomplish these high demands, it is essential to have a Two-Way-Communication with a satellite, including the equivalent interfaces on the oceanographic measuring systems.

The DOMSA-Buoy represents together with the small satellite SAFIR such a system. The buoy, as a part of the measuring chain, is able to store the data and after emerging to relay the data to the satellite. If the measuring chain must unintentionally rise to the surface, the intergrated GPS-receiver will locate the exact position and with the help of SAFIR it is possible to send it to every station on earth. Therefore, the possibility exists to find and save loose measuring chains which would normally be irretrievably lost. A corresponding sensory analysis recognizes, if the buoy is in submerged or floating condition. When the buoy is in the submerged or diving phase there is no data transfer possible. In this state, the buoy can be switched, with the sensory analysis, to a sleeping mode. The current consumption is then very low, and this guarantees a long operating life.

OHB SYSTEM
Raumfahrt und Umwelt-Technik
Mr. Dr. K. Kretzschmar
Universitätsallee 27 · D-2800 Bremen 33 · F.R.G.
Tel. 0421/22098-0 · Fax 0421/2209810 · Telex 245316 ohb

Fig. 6.

an accurate location method for finding these expensive systems. To accomplish these high demands it is essential to have two-way communication with a satellite, including the equivalent interfaces on the oceanographic measuring systems.

The DOMAS Buoy represents, together with the small satellite SAFIR, such a system. The buoy, as part of the measuring chain, is able to store the data and, after surfacing, to relay the data to the satellite. If the measuring chain surfaces unintentionally, the integrated GPS receiver will locate the exact postion and with the help of SAFIR it is possible to send the buoy positional data to every station on earth. Therefor, the possibility exists to find and save loose measuring chains which would normally be irretrievably lost. A corresponding sensory analysis recognises if the buoy is submerged or floating. When the buoy is in the submerged or diving phase no data transfer is possible. In this state the buoy can be switched to a sleep mode which guarantees, with low power consumption, a long operating life.

**MARINUS** (Drifter and Profiler Buoy)
(Fig. 7)

The development of the MARINUS Buoy is a co-operation of the companies VEERS safety electronics, Kiel University and OHB-Teledata, Bremen. The project will be realised in three steps:

| | |
|---|---|
| MARINUS I | surface drifter buoy |
| MARINUS II | profiler for depth betwee 0-400 m |
| MARINUS III | profiler for depth down to 1500 m |

The depth profiler will be programmable via SAFIR satellite.

The internal buoy equipment consists mainly of:

* buoyancy device (pister, spindle, motor)
* sensor package (GPS, temperature, pressure, conductivity)
* data acquisition and storage unit
* satellite communication unit (SAFIR-MACRODATA)
* battery package

Presently there is a MACRODATA terminal onboard the German polar research vessel FS POLARSTERN. This station should support data communications in areas not covered by INMARSAT (Polar regions over 70 degrees latitude).

Finally let me recap on the main point of the various satellite systems:

INMARSAT is ideal for tracking objects with its message length of 8 bytes.

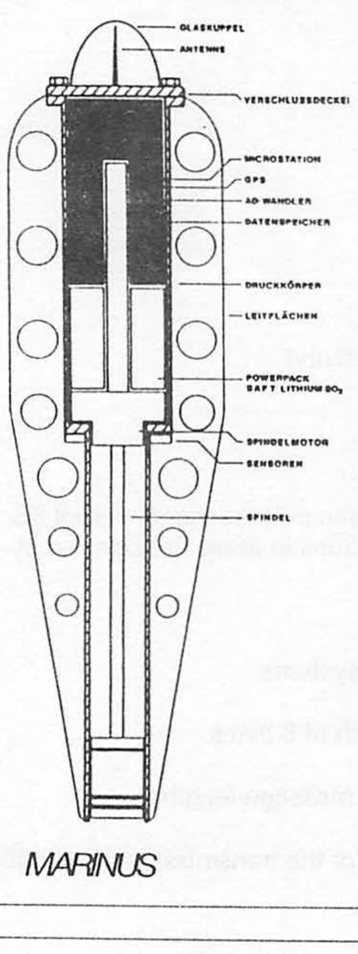
ORBCOMM is ideal for short messages as it uses a 200 Byte message length.

SAFIR, due to its unlimited message length, is ideally suited for the transmission of scientific data from oceanographic buoys and other outstations.

Sicherheitselektronik für Sport- u. Berufsschiffahrt

# MARINUS

## Strömungsabhängige Bojen mit satellitengestützter 2-Weg-Datenübermittlung



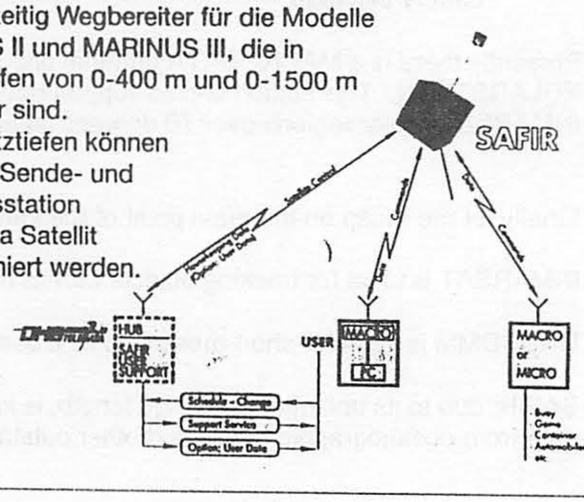

Die Bojen des Projekts MARINUS sollen einen Weg zu kostengünstiger Datenerfassung von

**Position**
**Temperatur**
**Druck**
**Leitwert**

mittels 2-Weg-Datenübertragung im Bereich Meeres- und Klimaforschung ermöglichen.

Als Datenübermittler wird das System SAFIR der OHB TELEDATA Bremen eingesetzt.

Begonnen wird das Projekt MARINUS mit dem Oberflächendrifter MARINUS I. Dieses Modell ist gleichzeitig Wegbereiter für die Modelle MARINUS II und MARINUS III, die in Wassertiefen von 0-400 m und 0-1500 m einsetzbar sind.
Die Einsatztiefen können von einer Sende- und Empfangsstation (Macro) via Satellit programmiert werden.




VEERS Sicherheitselektronik für Sport- und Berufsschiffahrt
Geibelallee 6 · 24116 Kiel · Tel. 0431-18400 · Fax 0431-129017

Fig. 7.

# OCEAN NET - A 21ST CENTURY OCEAN COMMUNICATIONS SYSTEM

Andy Clark, Harbor Branch Oceanographic Institution, USA

## Introduction

Creation of a global oceanographic observing system (GOOS) was established as an international priority at the United Nations Conference on Environment and Development (1992 Earth Summit in Rio de Janeiro). Two obstacles which have hindered the more rapid realization of this objective have been 1) the lack of technology enabling continuous gathering and transmission of large amounts of data from any point in the ocean, and 2) the lack of participation from private sector partners with the financial and engineering resources to drive this technology development . A partnership between one of the United States' leading developers of satellite communication systems and one of the nation's leading oceanographic research institutions has been formed to overcome those obstacles. The private-sector funded effort to establish a network of moored, high bandwidth telemetry buoys was announced at the Oceans '96 conference in Ft. Lauderdale, Florida. The trade name secured for this venture is *Ocean Net*, and the first of these telemetry buoys is currently under construction. The communications technology necessary to make this concept a reality was first proven on a number of government funded programs. Leveraging this prior technology investment will provide the civilian community with a heretofore unavailable service capable of providing high data rate communications from remote ocean locations at a cost within the reach of even modestly supported oceanographic research programs.

## Ocean Net Concept

Real-time data access, increased data throughput, and a lower cost per bit transferred are required to support 21st century ocean observatories and will provide the capability "for systematic observations adequate for forecasting climate variability and change; for assessing the health or state of the marine environment and its resources, including the coastal zone; and for supporting an improved decision-making and management process, which takes into account potential natural and man-made changes in the environment and their effect on human health and resources" (IOC, 1993). *Ocean Net* will enable high rate (up to 1 Mbps) data communications from a highly dynamic moored platform, operating in conditions as poor as sea state 6. The capability to receive data from seafloor sensors at full ocean depth is a key element of the *Ocean Net* concept. Fiber-optic moorings with power conductors will link the buoys to seafloor junction boxes enabling ROV attachment of experimental packages. Each moored system can be readily deployed and maintained from standard oceanographic vessels. Data forwarding costs are minimized by "cooperative sharing" of the available satellite bandwidth. The net result is a communication system with a throughput capacity an order of magnitude greater than currently available systems and a cost per bit of data transferred that is an order of magnitude less than current systems.

## Existing Systems

The data collection capability of current buoy-based telemetry systems is limited by satellite throughput, the cost of data transport, and the size and power requirements of existing satellite communication terminals. Most of today's telemetry buoys utilize either the ARGOS or GOES satellite systems. While the communication terminals for these satellites are relatively small and can be battery powered, data throughput amounts to only a few bits per second and there is no real-time data delivery capability. INMARSAT can provide can provide higher data rates, up to 64,000 bps, but at a much higher cost per bit. A number of low Earth orbit (LEO) and medium Earth orbit (MEO) personal communication satellite systems are planned for the coming decades. However, while these will provide real-time access by virtue of their large satellite constellations, they are designed either for low rate data packet or switched voice applications, rather than high data throughput. Higher data rates are available today from a number of satellite systems in geosynchronous orbit, such as INTELSAT. These systems are capable of continuous real-time forwarding of very large volumes of data. However, closing a link to these high-flying satellites requires much greater radiated power to accommodate the greater distance, and large, directional antennas, typically 2 -3 meters in diameter, to preclude interference with adjacent satellites. A typical oceanographic buoy, with its dynamic motion and small physical size, cannot support these large antenna structures. In addition, unlike ARGOS, GOES and INMARSAT, the geosynchronous systems require users to lease bandwidth on a long- term basis rather than provide demand-access service.

## Enabling Technology

The technology breakthrough that enables *Ocean Net* to provide affordable high data rate communications from small dynamic platforms is a new Very Small Aperture Terminal (VSAT). The *Ocean Net* VSAT antenna is less than 75-cm in diameter and provides high data throughput via existing commercial satellite systems such as INTELSAT. The antenna consists of a number of spiral elements with a fixed-element phasing for beam forming purposes. The stabilization system employs a 3-axis positioner using digital signal processing algorithms to maintain accurate antenna pointing. The "hybrid" phased array and mechanical positioner system is superior to a fully electronically steerable array both in terms of cost and power. The system consumes 50% less power than an equivalent electronically steered array antenna at 25% the cost. A spread spectrum transmission waveform is utilized to meet the spatial radiated power requirements levied by the satellite system operators to minimize interference to adjacent satellites. While power consumption is significantly higher than conventional low rate systems, multi-month operation is possible with conventional battery chemistries or diesel powered solutions. The system is hosted on a tuned 5-m diameter buoy with sufficient space to house the VSAT and a variety of experimental packages. The addition of a subsea structure to the classic discus buoy shape helps reduce its sea-state induced motion. Each installation will be capable of unattended operation for extended periods of six months or more.

The data acquisition system provides an interface, based on data packet concepts, that will accept high rate data from seismic, acoustic, optical or other scientific packages, as well as low rate inputs from standard oceanographic and meteorological sensors. Battery, fuel cell, solar and wave-motion power sources were evaluated but rejected because of energy limitations or size, weight and power considerations. The buoys utilize redundant high-reliability diesel generators. Fuel for the generators is contained in a suite of fuel bladders located in the subsea structure beneath each buoy. Spent fuel is displaced with sea water to maintain buoy ballast and dynamics. Over 1 kW of continuous power will be provided to the user payloads. A prototype terminal has been extensively tested on a six degree of freedom hydraulic sea-state motion simulator, driven both by simulated storm conditions and actual sea-state data recorded during a number of sea trials. In the series of tests, antenna pointing accuracy was maintained in simulated conditions harsher than sea state 6.

## Prototype Installations

The *Ocean Net* partnership has been broadened during the prototype testing phase to benefit two important government oceanographic projects. The University of North Carolina at Wilmington operates the National Undersea Research Center (NURC) in Key Largo, Florida with funding from the National Oceanic and Atmospheric Administration. The centerpiece of NURC Key Largo is the United States' only manned undersea habitat, AQUARIUS. The AQUARIUS habitat is normally situated approximately 10 km offshore in about 22 m of water. The habitat is currently at Harbor Branch Oceanographic Institution, where it is undergoing a complete refurbishment. The most significant modification to the AQUARIUS will be the replacement of its manned life support barge with a moored, autonomous, life support buoy. The buoy is a coastal variant of the *Ocean Net* telemetry system, utilizing a line-of-sight microwave radio link to shore. While this line of sight link must transmit over only 10 km of sea surface, its 2 Mbps throughput will enable multiple simultaneous video channels to be transmitted from the habitat along with all the attendant command, control, communication and oceanographic data.

A more technically challenging line-of-sight telemetry buoy has been installed off Florida's east coast in a partnership formed between *Ocean Net* and the US Navy's Atlantic Undersea Test and Evaluation Center (AUTEC). In order to address national security needs, a number of AUTEC tracking transponders have been deployed in the shallow water (70-250 m) littoral area approximately 33 km off the coast of Ft. Pierce, Florida. This region is also of significant scientific interest. A nearby bank of *oculina* coral reef is a known spawning area for a number of soniferous (sound producing) fish including the gag grouper. Also, the endangered Northern Right Whale migrates through this region. In a classic example of dual use, the moored telemetry buoy used to provide transponder signals to shore from AUTEC's tracking site will also transmit data from an array of seafloor hydrophones specifically deployed to monitor biota. These hydrophones together with other seafloor and buoy-based oceanographic and meteorological sensors transform this shallow water acoustic tracking site into a "natural laboratory" enabling continuous monitoring of a host of phenomena including the Florida Current portion of the Gulf Stream. In an effort to protect the gag grouper spawning area, a 62-square kilometer region encompassing the *oculina* reef has been designated as a "no anchoring, no fishing" protected area by the South Atlantic Fisheries Management Council. Data from the seafloor hydrophone array will also be monitored and evaluated to determine whether or not similar systems may provide a means to monitor or enforce such restricted marine sanctuaries.

## Conclusion

Technology recently transitioned to the civilian sector now enables transmission of data from anywhere on the world's oceans at rates representing a full order of magnitude increase over previously available oceanographic telemetry systems. New signal processing techniques will enable the cost per bit of this service to be provided at an order of magnitude less than any currently available method. A private sector venture to provide this capability as a service, i.e., leased bandwidth, places this powerful new potential within the reach and realm of affordability of the scientific user community. This breakthrough came about as a direct result of a partnership between industry and the research community.

## References

The Approach to GOOS. Intergovernmental Oceanographic Commission (IOC), Doc IOC-XVII/8 Annex 2, 27 January 1993, p.(i).

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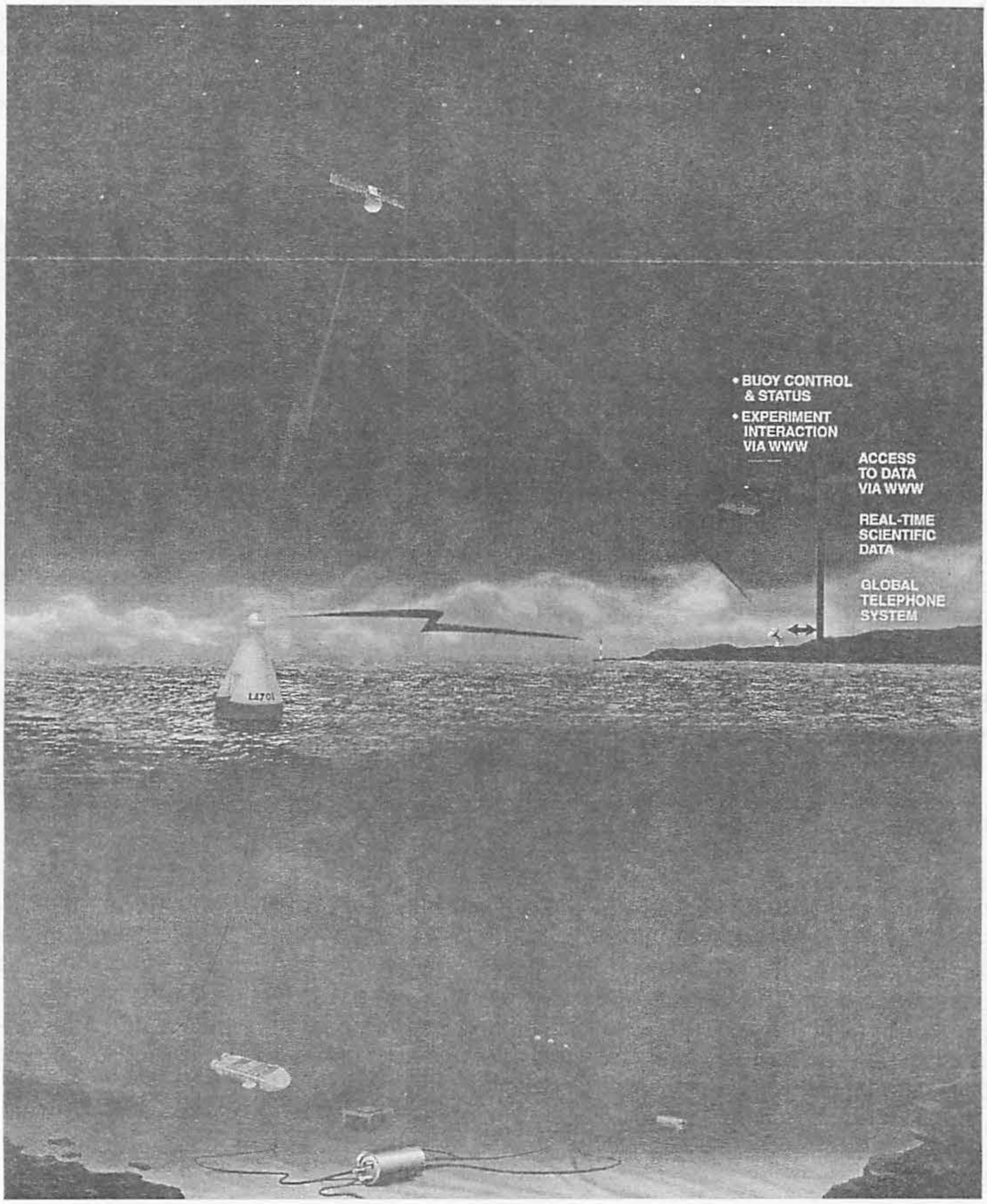



Depicted above, the *Ocean Net* system will provide affordable data telemetry from a network of coastal and open ocean moored buoys. The system will be capable of continuous, real-time data forwarding, at high data rates, and will accommodate a wide range of sensors mounted on the buoy, in the water column or on the seafloor.

# ARGOS SECOND AND THIRD GENERATIONS

**Keywords:** Argos, Satellite, Animal, tracking, location, data collection

## Abstract:

The Argos Data Collection and Location Satellite System is operated under a partnership agreement between NOAA (National Oceanographic and Atmospheric Administration - U.S.A.) and CNES (Centre National d'Etudes Spatiales - France) to provide a worldwide in-situ environmental data collection and Doppler-derived location service.
The most significant use of Argos involves the location and collection of data associated with worlwide scientific programs that study oceans (buoys and floats), animals (birds , marine and terrestrial animals), atmosphere and earth.
During late 1994, an independent survey of the major international users was conducted to obtain their perspective on Argos system capabilities. Further clarification of Argos system User requirements was obtained through responses to an extensive Argos questionnaire that was distributed in mid-1995.
The results of the survey indicated that certain Argos system Users' requirements could only be addressed through modification of the satellite instrument along with associated changes in ground system management.
The User requirements are summarized as follows:
- Improve Satellite Coverage
- Increase Data Volume transmission capability
- Improve Satellite Receiver Sensitivity to reduce platform power requirements or enhance transmission performance
- Allow to control platforms remotely by having a two-way communication capability with the satellite

The desirability of many of these improvements was anticipated by Argos, and this paper present plans for the second generation (Argos-2) beginning in 1997.
Enhancements for the third Argos generation (Argos 3) beginning in 2001 are under discussion and are presented.

# 1 - THE ARGOS SYSTEM

Argos, a worldwide satellite-based system, locates fixed and mobile platforms and collects the data they transmit. It was developed in cooperation between the French Space Agency (CNES) and the National Oceanic and Atmospheric Administration (NOAA, USA).
The Argos instrument is flown on board NOAA satellites. Three are simultaneously in service at most times, at 850 km altitude on circular, polar orbits. Together, they provide complete coverage of the Earth several times a day (figure 1).
User relations and worldwide system operations are handled by CLS (C*ollecte, Localisation, Satellites*) in Toulouse, France and Service Argos Inc in Largo, Maryland - U.S.A.
CLS is a subsidiary of CNES (the Space French Agency) and IFREMER (the French ocean agency).
CLS uses a worldwide network of representatives, regional offices, subsidiaries and processing centers to make users' platform locations and data available.

# 2 - ARGOS FOR THE EARTH ENVIRONMENT

Due to the regulations governing the radio frequency which Argos transmitters use, the Argos system is designed and reserved for the studying, monitoring and protection of the earth's environment. Traditional Argos applications include oceanography, meteorology, hydrology, fish stock management, monitoring vehicles carrying hazardous materials, and, of course, animal tracking.
In August 1996, Argos tracked 5494 active platforms:

| | |
|---|---|
| Drifting buoys | 1994 |
| Fixed stations | 549 |
| Moored buoys | 440 |
| Terrestrial animals | 418 |
| Alace floats | 404 |
| Birds | 385 |
| Subsurface floats | 330 |
| Marine animals | 264 |
| Fishing vessels | 236 |
| Containers | 154 |
| Miscellaneous | 110 |
| Manufacturers Tests | 88 |
| Terrestrial vehicules | 82 |
| Balloons | 27 |
| Orbitography platforms | 13 |

***Table 2: Active platforms in operation in August 1996***

These figures confirm the continued growth in the use of Argos for the studying, monitoring and protection of the earth's environment.
Design breakthroughs by manufacturers have fueled the demand, leading to ever-smaller, lighter transmitters for tracking more and more different types of measurement platforms.

# 3 - FEATURES OF THE ARGOS SYSTEM

## 3.1 - Global coverage

Argos is the only satellite-based system of its kind offering full global coverage.

**a) Polar orbits provide excellent visibility:**
- 28 (42*) passes a day over polar regions
- 12 (18*) passes a day over Europe
- 7 (11*) passes a day at the Equator
* with three satellites

**b) Tape recorders on board the satellites store data gathered along the whole orbital revolution**

## 3.2 - Excellent sensitivity

High sensitivity to transmitter messages, one of the main features of the Argos system, results from:
- low satellite altitude (800 km),
- very little interference on the 401.65-MHz band used,
- sophisticated onboard receiver technology.

These basic features, together with deliberate limiting of the data transmission rate (400 bits per second), mean that transmitters can:
- be miniaturized: 15 to 25 grams, including batteries,
- operate on low radiated power, achieving good results with just 250 mW,
- use very low power, so that unattended platforms can be tracked over long periods (several years).

## 3.3 - Doppler location + GPS

The Argos processing centers normally use the Doppler effect to locate transmitters. In regular operating conditions, this provides accuracy of 350 meters. Argos uses a dedicated network of orbitography beacons, and location involves fairly complex calculations at the processing centers. The advantages of Doppler location are:
- low transmitter power consumption,
- instant location opportunities throughout satellite passes, useful for intermittent transmitting platforms.

CLS has developed a dedicated processing system for low power transmitting platforms. This supplies significant results even when a transmitter is operating in a difficult environment for radio transmission.

Some users are also starting to use GPS receivers, which have come down considerably in size, weight and cost. The Argos processing system sees the GPS receiver as a sensor, and sends users their GPS positions as if they were sensor data. Low Argos transmitter power consumption and efficient transmission remain the main attractions.

The processing systems have been modified to make the GPS positions available in the same format as that used for the regular Doppler-derived locations. Users can choose whichever form of location best suits their needs, and have a "spare" system.

## 3.4 - Reliability, simplicity, efficiency, ease of use

The features Argos users most appreciate are:
- operational service which has never been interrupted (Figure 3),
- antenna and transmitter needing no adjustment,
- transmit frequency (401.65 MHz) and sensitive onboard receivers which permit reception from primitive transmitters and in difficult conditions,
- automatic startup of service as soon as a transmitter is switched on.

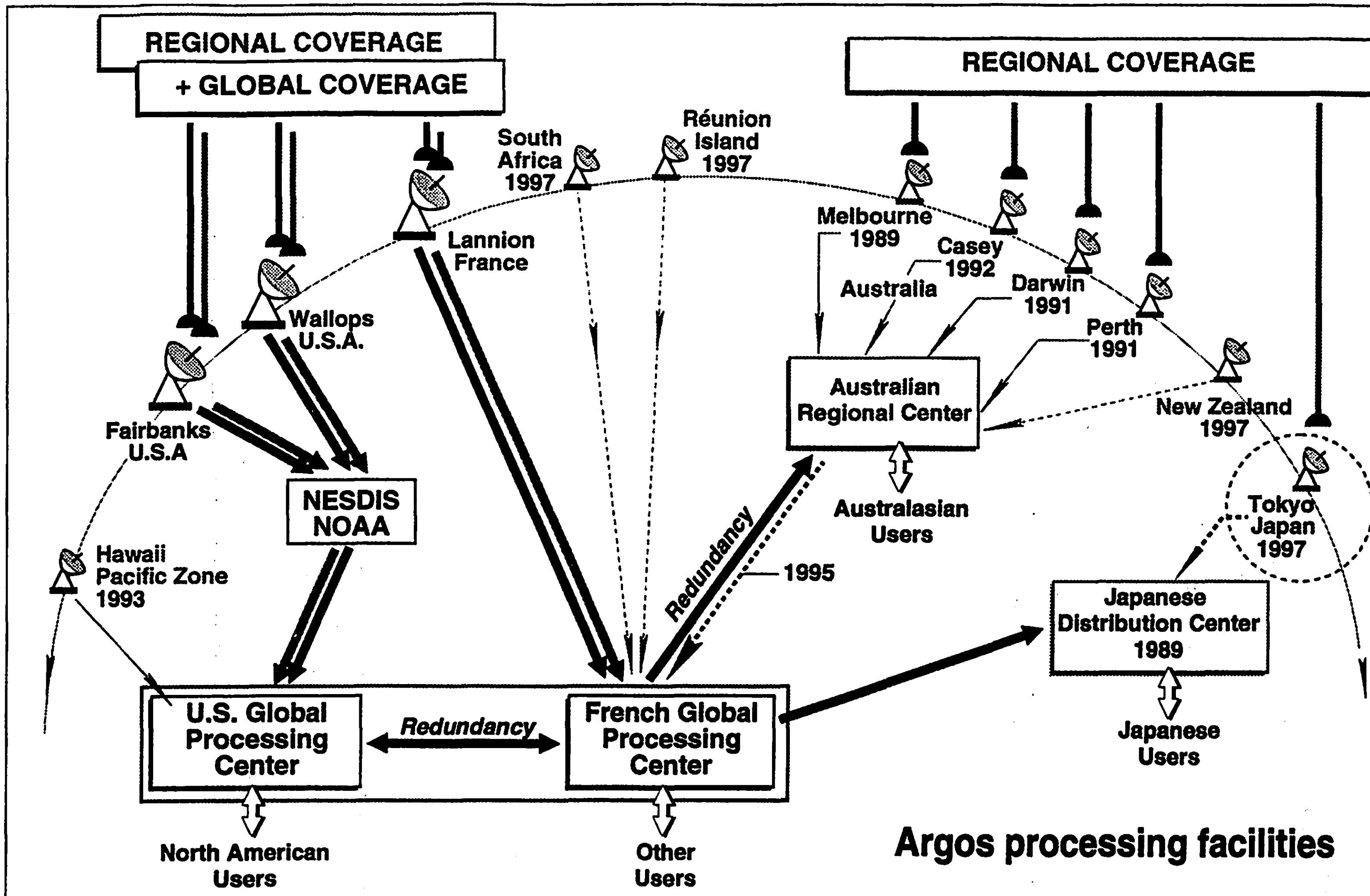



*Figure 3 - Argos Processing facilities*

# 4 - SYSTEM ENHANCEMENTS

## 4.1 - Users' evolving needs

The above features meet the needs of a broad range of users in scientific and applied fields. We at CLS and Service Argos Inc. are constantly in contact with them, either in person or through surveys, and record their feelings to make sure the Argos system keeps up with their requirements. The four main areas in which Argos evolves are:

- satellite coverage: increasing the number of satellites,
- data volume: increasing the amount of data sent on each satellite pass,
- improving the transmitter-to-satellite link: obtaining better data, reducing transmitter power consumption, and continuing to miniaturize transmitters,
- implementing a return link back to transmitters to make the system more flexible and to remotely control transmitters.

## 4.2 - Worldwide cooperation

People around the world are becoming increasingly concerned about the need to study and monitor the environment. Governments are responding by implementing worldwide satellite networks through international cooperation. To better meet these needs, and consolidate the role of our system for observing and protecting the environment, Argos is becoming more internationally based (Figure 4).

In 1996 the initial program between France and the United States was extended to bring in Japan. From 1999 the Argos instrument will be flown on the ADEOS II satellite, operated by the National Space Development Agency of Japan (NASDA). This will be the first satellite launch in what is expected to be a long-term cooperation program.

We are also in the final phase of signing an agreement to fly Argos, from 2002, on the METOP satellites operated by the European Meteorological Satellite Organization (EUMETSAT).

More cooperation agreements will doubtless follow. Gradually they will help to increase the number of satellites in orbit, and contribute to meeting worldwide needs for protecting the environment of our planet.

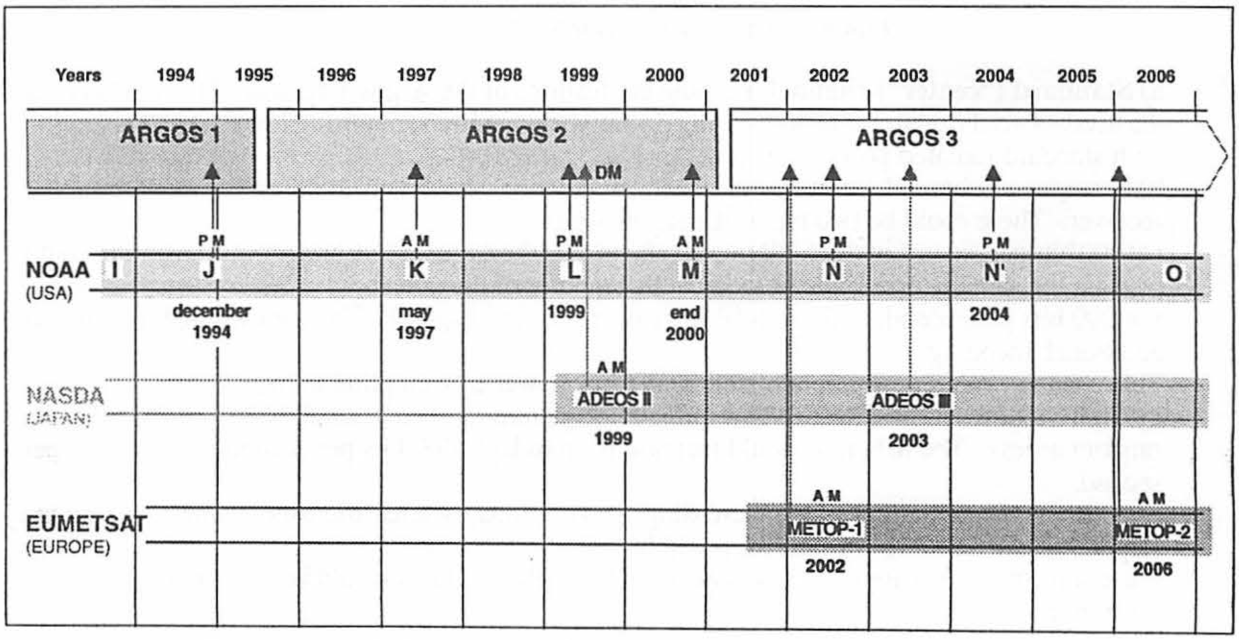



*Figure 4 - ABroader international Cooperation*

## 4.3 - Higher performance equipment on board the satellites

The second generation of Argos instruments will gradually go into service from 1997, starting with satellite K in the NOAA series. The main enhancements are as follows:
- receiver bandwidth up from 24 to 80 kHz,
- system capacity quadrupled,
- onboard receiver sensitivity increased by 2 dB.

The increase in receiver bandwidth means a new form of system management. To get the best out of the Argos system's high sensitivity, and reduce the risk of messages colliding, we plan to reserve a 24-kHz band (a width equivalent to that of the current Argos system) at the bottom end of the 80-kHz bandwidth for low-power transmitters. The remaining bandwidth will be for transmitters using normal power levels.

To take advantage of the quadrupling in system capacity with Argos2, transmitters will be able to send higher volumes of data.

These changes in the management of the Argos system from the second-generation, in 1997, is part of our continuing efforts to meet users' new needs while retaining compatibility with their existing equipment. This is opening the way for third-generation Argos; the design phase started in September 1996.

The latest needs analysis was done through questionnaires sent to all users in 1995, and is continuing through direct contact. We can already see that the data collection channel needs splitting into three separate portions (Figure 5) :

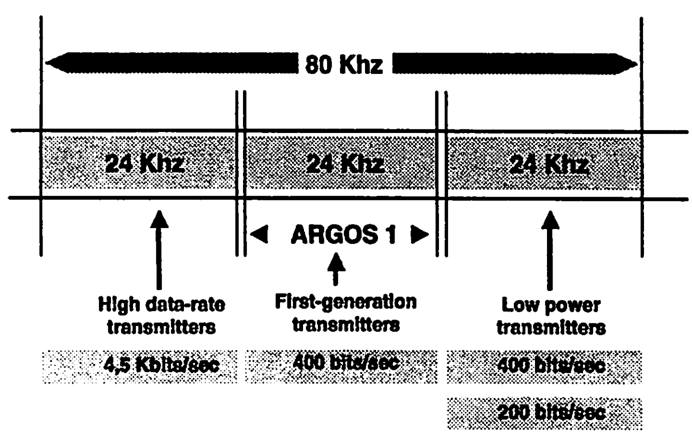



*Figure 5 - Argos system "chanelling"*

a) **Standard ("center") channel**, keeping the features of the Argos 1 system. This could cover the needs of traditional applications using primitive transmitters, requiring low cost and operating with standard radiated power.

b) **Low-power channel**, but still with today's modulation pattern and random access to the satellite receiver. There could be two types of transmissions:

• at 400 bits per second, with a 6-dB improvement over the Argos-1 link budget. A transmitter could provide the same performance as today with a quarter of the power.

• at 200 bits per second, with a 12-dB improvement over Argos 1. The data would have special additional encoding.

This channel would push miniaturization and low power consumption to their limits.

c) **High-volume channel**, with a new modulation pattern for data transmission, though still using random access. The data rate would increase from today's 400 bits per second to 5 kilo bits per second.

The new system would meet the increasing needs of today's scientific users while retaining the original features of Argos wherever possible.

Each of the three "separate" Argos systems on board the satellites would keep up with a particular set of needs.

From now to the phase B of Argos 3 in September 1997, we will continue our meetings and talks with users to refine the concepts outlined above and better understand the changes needed and their impacts on applications.

## 4.4 - Downlink messaging

Downlink messaging, i.e. two-way capability, will be implemented from when Argos flies on NASDA's ADEOS satellite.
The main need is to make transmitters more flexible to use. The capability to send messages to any transmitter anywhere on Earth from a low-earth-orbiting (LEO) satellite will doubtless be unique to Argos for a long time. Argos will be able to send messages to transmitters anywhere on Earth.
Users messages to transmitters will first be uploaded by a master platform network for storage on board the satellite (Figure 6)

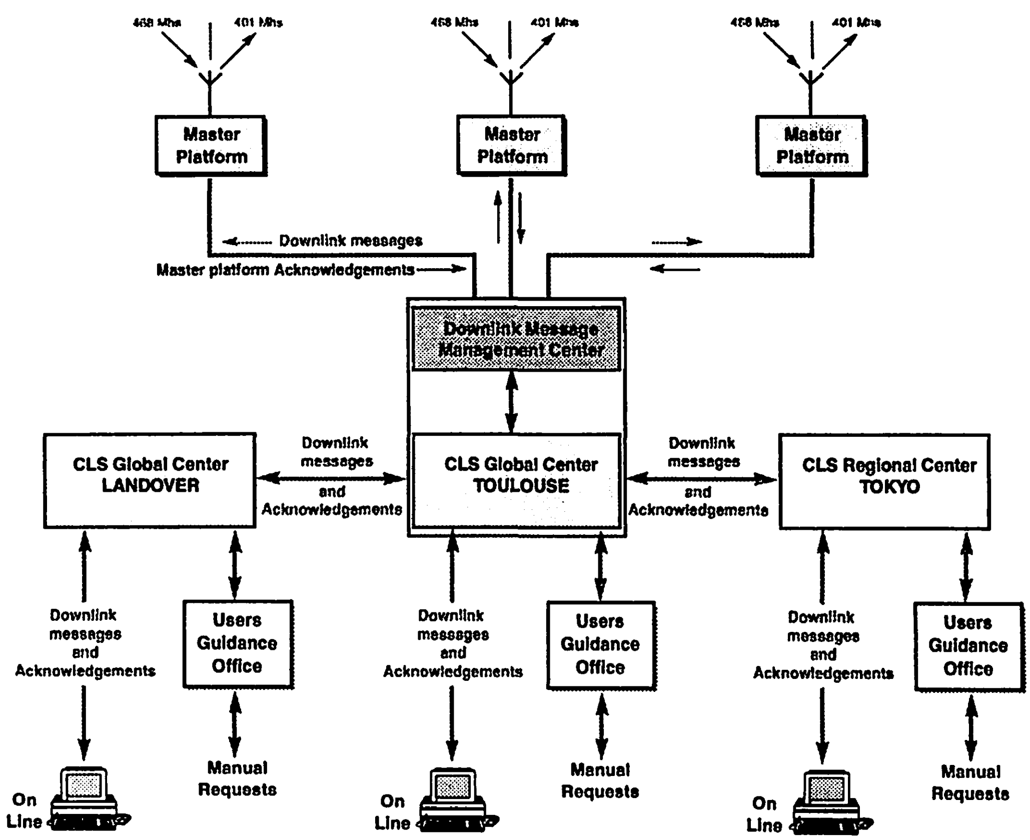



*Figure 6 - Downlink Messaging Diagram function*

They can then be sent to:
- **all transmitters "allcast" function.** This could be used to optimize transmissions by sending transmitters the times at which the satellites are to pass over them.
- **a set of transmitters: "multicast" function.** For example, a single group message could trigger an observation network into accelerated or routine observation mode.
- **a single transmitter: "monocast" function.** The many applications could include switching a transmitter on or off, changing the sampling rate, switching sensor configurations, sending numerical data, and so on.

Each message will have a useful length of 152 bits. This would be enough for the most complex applications.

As well as message transmission, the downlink could be used for:
• **detecting satellite passes**. A basic receiver will be able to detect a pass by picking up a special flag, repeated periodically in the data flow.
• **acknowledging reception of a transmitter message**. Once the satellite receives the message, error-free, it sends the Argos transmitter an acknowledgement over the downlink channel, so the transmitter can send the next message. This capability could be used to check on transmission quality and increase data volume.
To use the downlink function and still enjoy the advantages of today's Argos system, transmitters will need to be fitted with small, low-power receivers. Models without receivers will still be compatible with Argos, and will be able to operate in the same way as today.

# 5 - CONCLUSION

Argos users' changing needs, as evidenced by studies, questionnaires and personal contact, have led to the decision to develop a third-generation system for the early 2000s.
The main enhancements will be:
- more capacity to handle low-power, "sub-miniature" transmitters,
- a tenfold increase in the amount of data a transmitter will be able to send on each satellite pass,
- a worldwide downlink messaging function, operating worldwide and matched to the way the Argos system works.
The Argos system is also opening up to broader international cooperation, under agreements with the United States, Japan and soon Europe. Argos is consolidating its role as a worldwide system designed and dedicated for studying, observing and protecting the Earth's environment.

# Emerging LEOS Telemetry Options for Use in Scientific Data Buoys - A Marine Instrument Manufacturer's Perspective

**Jim Hanlon, Seimac Ltd, Dartmouth, Nova Scotia, Canada**

## 1.0 Seimac Corporate Background and Capability

Seimac Limited is a Canadian company that offers engineering services and specially designed products to customers in the marine science, transportation, energy and oil and gas sectors. All of these products and services are designed to collect, analyse and disseminate near real time data and information. In the course of this work, the company has developed a special expertise in the application of satellite telemetry to operational needs. For example, Seimac has been manufacturing the Smart Cat © terminal for use with the ARGOS satellite system since 1991. This product has been deployed in a wide variety of platforms including marine data buoys, weather stations, fishing vessels, shipping containers, rail cars and even in electric power meters.

The company has a well developed engineering, manufacturing, and quality control capability and is a registered ISO 9001 company.

Almost all of Seimac's satellite-related applications over the past 10 years have made use of the ARGOS satellite system, simply because that has been the only such system offering global, operational coverage. Within the past 2 years a number of other commercial satellite telemetry systems (and proposed upgrades to the ARGOS system ) have begun to offer the potential for increased capability and reduced operating costs. Because of its thorough understanding of satellite telemetry technology and of many of the applications for this technology, Seimac is well positioned to evaluate these various new competing systems and to make recommendations regarding their potential usefulness in particular applications.

Recognizing this strength, Seimac competed for, and won, a nationally competitive contract from the Canadian Space Agency to develop user terminal technology for one or more of the newly emerging low cost satellite systems. Work is currently underway on this contract.

There is a very significant financial investment being made in the field of low cost commercial satellite systems; some industry experts believe as much as $100 billion US will be spent over the next 5 years. Over 50 different systems have been publicly proposed in various levels of detail. This paper is intended to provide a basic framework for comparing these divergent systems based upon a requirements analysis, to provide a high level overview of the some of the most promising systems, and to evaluate the potential usefulness of some of these systems in marine buoy applications.

## 2.0 The Use of Satellite Telemetry in Marine Data Buoys.

The marine research community has been a long term user of satellite telemetry services. Ocean data buoys have been equipped with various satellite telemetry and positioning systems almost since such systems have been available. The community has been a early, eager adopter of this technology, primarily because it offers the only convenient, economical way to recover sensor data and buoy position data from the global oceans. The dominant satellite services provider for this market over the past 10 years has been ARGOS - the joint U.S & French data telemetry and positioning package - which is carried as a "piggyback" payload aboard the US NOAA series of polar orbiting weather satellites.

3.0 Generic Requirements for Marine Buoy Telemetry Terminals

All marine data buoy applications share a number of common requirements and constraints that can serve as criteria in the selection of satellite telemetry systems.

Marine data buoys can be subjected to severe shock and vibration environments during land transport prior to deployment, during deployment and recovery and also during normal operations under storm conditions. Any satellite telemetry equipment installed in buoys must be designed to tolerate such high shock and vibration environments. This requirement favours highly integrated products with relatively low component counts, with few connectors, and with sound mechanical packaging design.

Nearly all marine data buoys have limited electrical energy budgets, depending only on battery power to operate sensors, control computers, and data telemetry equipment. Large buoys may make some use of solar panels, although the limited size of most data buoys prevents the use of solar cells as the primary source of power for most applications. Only the very largest buoys are equipped with diesel engines for auxiliary power.

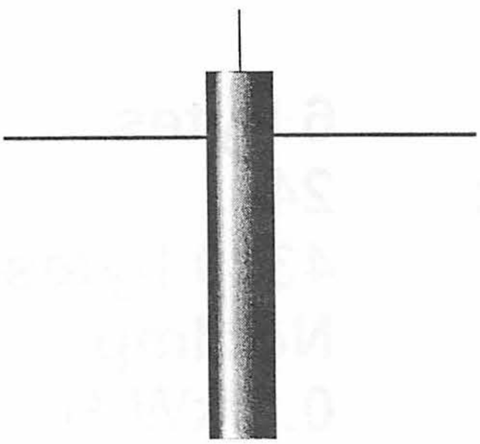
It would be advantageous to be able to make use of an antenna with directional gain on a marine data buoy because of the greater signal levels that can be sent to and received from the satellite. Unfortunately, by their nature, buoys are dynamic, making the use of mechanically pointed antennas with any significant directional gain impractical. While it is conceivable that a large buoy could be equipped with a mechanically steered antenna that would have a fast enough dynamic response to track a satellite, the energy budget required to operate such a tracking system would be prohibitive on a small autonomous buoy. Electronically steered antennas do offer significant potential for future use on buoys as the cost of such antennas becomes lower with time.

Marine data buoys generally act as data collection nodes; collecting and pre-processing buoy sensor data for telemetry to a central, land-based analysis centre. Buoys are obviously unmanned, and have limited computational power on board. This topology implies data traffic flow that is highly biased towards the in-bound direction (towards the land-based centre). Some data flow may be required in the outbound direction to enact changes in the sampling strategy, or to acknowledge receipt of transmitted data messages, however this is minimal. This data flow bias in the inbound direction is not optimal for many of the new commercial satellite systems, many of which assume that the remote terminal is "manned" with a resulting higher data rate in the outbound direction. (This is the data flow bias that is typically seen on the Internet - relatively small data requests inbound, followed by larger data sets outbound.)

4.0 Requirements of Specific Classes of Marine Buoys

While the above statements apply to marine data buoys in general, there is a wide variety of data telemetry and related needs in the marine data buoy community. In order to illustrate this diversity, a set of 4 classes of marine data buoys has been identified. Each of these is described below.

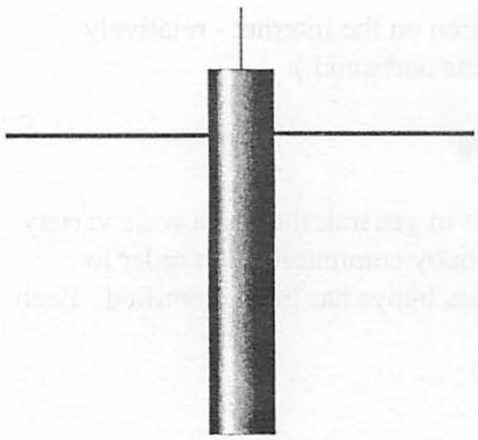
4.1 Simple Drifter



The largest single group of current marine ARGOS terminals are installed on free drifting Lagrangian surface drifters. These drifters provide simple position-only information, with some adding a simple sea surface temperature sensor. Such drifters provide valuable information about the global oceans' surface and shallow water current fields. The ARGOS satellite system has been used extensively in this application because of its built-in Doppler positioning capability and ease of data access for marine scientists throughout the world. Recently, GPS positioning has begun to replace Doppler positioning in a number of such applications. This change has been prompted by the commercial availability of small, low cost, low power GPS receiver boards. GPS equipped buoys offer better positional accuracies and more continuous position sampling than satellite Doppler systems at the cost of somewhat higher energy usage. Since the GPS positioning system calculates positions at the receiver (ie in the buoy), buoys equipped with GPS receivers have the added advantage of knowing their own position. This can be useful in optimizing satellite transmission plans to take advantage of known satellite pass times at certain positions on the earth. It is questionable, however, whether the energy saving gained through limiting satellite transmissions to known satellite overhead times is greater than the extra energy required to operate a GPS receiver. The rationale for including the GPS receiver in the drifter would probably be based more on the need for more precise and continuous position information than it would on possible energy savings. Table 1 summarizes the operating constraints and requirements of the generic simple drifter.

4.1.1 Size and Weight Constraints

Lagrangian drifters are used in relatively large quantities (up to 2000 deployed at any one time in the world) and so must be capable of being deployed at relatively low cost, often



# TABLE 1
# Simple Drifter

***Transmits GPS location only as a 6 byte message***

| | |
|---|---|
| **Data Per Sample:** | **6 bytes** |
| **Samples Per Day:** | **24** |
| **Data per Month:** | **4320 bytes** |
| **Latency:** | **Not Imp.** |
| **Energy Budget:** | **0.5 kW-H** |
| **Deployment:** | **2 years** |
| **Location:** | **Global** |

**Limited Interior Volume**

from ships of opportunity by crews with limited experience in doing at-sea buoy deployments. This lack of specialized crew and equipment necessitates that drifting buoys be quite small and light weight, ideally capable of being lifted and deployed by a single person. This size and weight constraint impacts directly on the choice of satellite terminal and on the battery payload the can be carried in the buoy.

### 4.1.2 Freeboard Constraints

Simple drifters are built to minimize the affect of wind on their drift velocity so that a pure measurement of water currents can be obtained. This requires minimizing the amount of buoy surface area exposed to the wind and thus implies a low freeboard design and minimal antenna cross section. This constraint challenges the satellite telemetry designer who would prefer a large antenna positioned well out of the water on a high freeboard buoy in order to maintain a reliable radio link to the satellite. Furthermore, many drifters are equipped with drogues in order to increase the cross-section of the buoy exposed to the ocean current and thus to more accurately track that current. The addition of a drogue generally reduces the ability of the surface buoy to stay on top of the water in substantial wave conditions, thus reducing the amount of time the satellite antenna is above water and able to communicate with the satellite. This limitation favours satellite systems that are tolerant of frequent gaps in the communications link with the buoy (ie those that use relatively short message structures with acknowledge protocols). This limitation also underlines the need for careful buoy drogue and antenna design to minimize the submergence problem while still providing accurate current tracking.

### 4.1.3 Data Requirements

A typical Lagrangian drifting buoy will generate one position data set every hour. Some drifting buoys make use of the Doppler positioning capability of the satellite telemetry system (ARGOS) while others rely on a built-in GPS receiver for positioning. It is reasonable to base a data volume estimation for such buoys on the GPS case since it is the more generic solution, and likely the preferred solution in the long term. It seems clear the that added cost of providing highly frequency stable transmitters in the drifting buoys in order to allow the over-flying satellite to Doppler position the buoy is, in the long term, less favoured than including an increasingly low cost and low power GPS receiver in the buoy.

Therefore, assuming the GPS case, each position data set would consist of a latitude and longitude value of the form:

LAT: ±xx.xxxx  LONG: ±xxx.xxxx

Where LAT can range from $-90^{o}$ to $+90^{o}$ with a required resolution of 100 meters or about 1/1000 of a degree at all latitudes and where LONG can range from $-180^{o}$ to $+180^{o}$ with a required resolution of 100 meters or about 1/1000 of a degree at the equator (The equator requires the highest resolution). The total binary "count" range to be represented is therefore:

| | | |
|---|---|---|
| LAT: | 1 part in 180,000 | or $2^{21}$ ie 21 bits |
| LONG: | 1 part in 360,000 | or $2^{22}$ ie 22 bits |

Thus a total of 43 bits of data can represent any position on the earth with a resolution of 100 meters. Allowing 5 bits of additional data per sample for error correction and possibly for a drogue sensor or simple sea surface temperature, this represents a total of 48 bits or 6 bytes per sample. More sophisticated data compression methods can be derived to further reduce the number of bits required to represent these positions, however such methods typically require assumptions about the actual position, or about drift velocities. For the generic case explored here, the above analysis is suitable. If these 6 byte messages are generated at a rate of 1 per hour, this represents a total data volume of about 4320 bytes per month.

While nearly all drifting buoys currently operate with the one-way ARGOS satellite system, there may be some requirement for a minimal data flow back to the buoy. This capability could be used to acknowledge transmitted messages and possibly to vary sampling rates under the control of a human operator. The outbound bandwidth requirement would be very low and intermittent.

4.1.4 Latency

Latency is defined as the total delay between actual measurement of data and arrival of that data at the shore-based analysis center. A number of factors can contribute to latency including delays between buoy data sampling time and next contact with an orbiting satellite, delays between data up-link to a satellite and data down-link to a ground station, processing time at the ground station and delays in the ground-based data dissemination network. Certain buoy applications, such as operational weather data collection, are less tolerant of long latencies than others. Long term research applications typically require long, continuous data sets to be collected before analysis can begin and are therefore more tolerant of latency.

Simple drifting buoys generally fall into the latter category. They are most often used by physical oceanographers who are measuring large and medium scale ocean circulation. Such measurements, by their nature, require the accumulation of drift data over a relatively long period of time prior to analysis. Thus latencies of hours to even days are not significant in the overall experimental plan. There are, however, other applications of simple drifters, such as in search and rescue and in marine pollution tracking, where users are much less tolerant of long latencies. In these cases, latencies of only several minutes may be desirable.

4.1.5 Deployment

Most marine scientists base their experimental plans on drifter deployments of between 1 and 2 years. Deployments can be made from almost any location in the world's oceans and position tracking and related data collection is required from all locations. Thus any satellite system used for collecting data from drifting buoys must have global coverage.

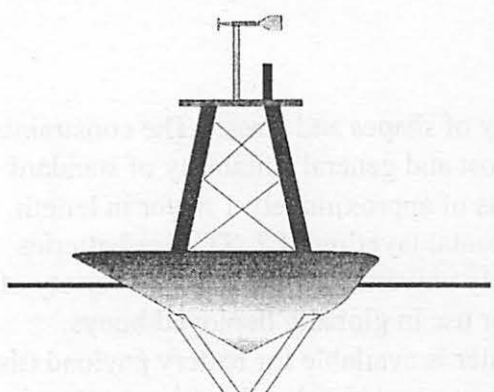
4.1.6 Energy Constraints

Simple drifting buoys are manufactured in a variety of shapes and sizes. The constraints described in sections 3.1.1 and 3.1.2 and the low cost and general suitability of standard PVC and ABS pipe tend to favour cylindrical forms of approximately 1 meter in length and 10 cm diameter. Such a diameter allows horizontal layering of 7 "D" size batteries in a near-optimal configuration. "D" cells are nearly universally available in a variety of battery chemistries and are therefore convenient for use in globally deployed buoys. Assuming that half of the interior length of the drifter is available for battery payload (the remainder being occupied by satellite terminal, antenna and simple wiring harness), this represents an interior volume of about 3900 $cm^3$ and allows for packaging of up to 7 layers of 7 "D" cells in the cylinder.

The two batteries chemistries that are potentially suitable for use in marine buoy applications are alkaline and lithium. Lithium offers higher energy densities, better high current performance, and better low temperature operation. Alkaline offers reasonable energy density, lower cost, ready availability and ease of transport (Lithium batteries may require specialized preparation and handling for shipment because of their potential for explosion and release of hazardous materials.) Given the possible requirement for handling by non-specialists and the need to transport drifting buoys by public transport carrier, most of these buoys are equipped with alkaline batteries.

An alkaline "D" cell provides a nominal open circuit voltage of 1.5 volts with a typical end-of-life voltage of about 1.2 volts. With appropriate de-rating for low temperature operation and for an end of life at 1.2 volts, a standard alkaline "D" will provide about 6 Ampere Hours of capacity. This represents an available energy of about 8.4 Watt Hours per cell. Thus the total available energy from 49 "D" cells would be about 411 Watt Hours. For the purposes of comparison this will be rounded to 0.5 KW-Hours of available energy in a simple drifter. This available energy could be increased by a factor of between 2 and 3 by using lithium instead of alkaline batteries, however the cost of such a battery pack could easily double the overall cost of the buoy and add substantially to the cost of shipping and handling the buoy and any replacement batteries. In general this is not a worthwhile trade-off.

4.2 Multi-Sensor Buoys



A second important class of buoy can be termed a multi-sensor buoy. This category would include a wide variety of specialized scientific and operational buoys all characterized by the fact that they are equipped with a relatively large number of environmental sensors. Often these sensors are monitored by a low power data acquisition computer that is also capable of simple calculations and decisions. This computer typically pre-formats sensor data and sends this data to an attached satellite terminal for communication to the satellite. The multi-sensor buoy is typified by the moored meteorological buoys deployed by many countries off of their coastlines. Such buoys obtain measurements of current weather conditions in marine areas. This data is both of direct importance to marine users in the area of the measurement and also of indirect importance to all weather data users since such offshore measurements are used to feed large scale weather forecasting models that predict both marine and land-based weather.

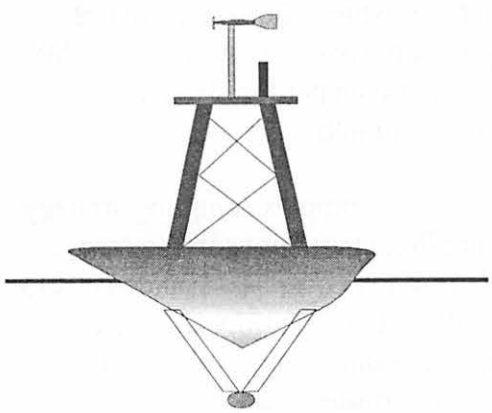
The Atmospheric Environment Service (AES) of Environment Canada operates several dozen large moored weather buoys off of both the East and West coast of Canada. These can be used as examples of multi-sensor buoys. Table 2 gives a summary of the characteristics and telemetry requirements of this class of buoy.

4.2.1 Size and Weight Constraints

The AES moored buoys are much larger and heavier than the free drifting buoys described earlier. The large size of these buoys allows much more substantial battery payloads to be carried. In fact, many of these buoys rely on battery payload as a significant part of their overall ballast. Also, because there is no direct constraint on windage, significant superstructures are added to these buoys to support both sensors and antennas well above the water surface. This greatly simplifies buoy to satellite communications.

4.2.2 Data Requirements

The AES moored buoys are equipped with sensors to measure wind speed and direction, air temperature, barometric pressure, sea surface temperature and vertical heave (one dimensional wave height). Because of historically high failure rates, the buoys are equipped with redundant wind speed and direction sensors. Position is monitored as a



# TABLE 2
# Multi-Sensor Moored Buoy

*Transmits WS(2), WD(2), BP. AT, SST & Heave Hourly; Position Backup*

| | |
|---|---|
| Data Per Sample: | 300 bytes |
| Samples Per Day: | 24 |
| Data per Month: | 216 KB |
| Latency: | Very Imp. |
| Energy Budget: | >100 kW-H |
| Deployment: | 2-5 years |
| Location: | Coastal |

precaution to ensure that the moored buoy has not broken free from its anchor and drifted position. These buoys are equipped with a simple computer which allows creation of secondary data derived from the primary sensors. (significant wave height, for example). In total, the AES moored buoys generate about 300 bytes of data per hourly sample. This represents a total data volume of about 216 Kbytes per month.

The relatively large number of sensors on these buoys and the complex sampling strategy could make it attractive to be able to download new sampling instructions in the case where a particular sensor has shifted calibration or failed. It may also be advantageous to be able to change sampling strategies based on measured weather conditions. These actions would require some amount of satellite to buoy communications, although the overall bandwidth required would be minimal, with only intermittent use required.

4.2.3 Latency

Weather buoy data is used by operational weather forecasters as one input into their forecasting models. The value of this data diminishes quite rapidly with time. Data from one hour ago is much more valuable than four hour old data. Data that is 12 hours old is probably useless from the perspective of operational weather forecasts. The need for low latency data and the fact that these buoys are permanently moored in fixed locations has led to the wide use of geostationary satellites for the collection of data from multi-sensor buoys. GOES, in particular, is widely used by both the US and Canadian governments for these applications. As larger constellations of non-geostationary, low earth orbit satellites become available, these may offer a viable alternative to such geostationary satellites.

4.2.4 Deployment

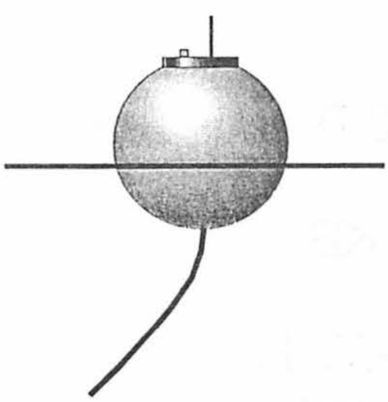
Weather buoys, and multi-sensor buoys in general, require a specialized ship for deployment, recovery and at-sea servicing. The cost of operating such ships is high and tends to increase the deployment intervals for these large buoys. A typical weather buoy would be inspected and serviced at sea yearly, batteries would be replaced every 3-5 years and the buoy would be recovered for refurbishing every 5-10 years.

Due to the limitations of very deep water moorings and because of the operational focus on weather monitoring within the EZ of the sponsoring countries, most large multi-sensor buoys are deployed within 300 km of the continental coastlines. (There are notable exceptions to this generalization, such as the TAO array of buoys that lie along the equator across the Pacific.) This focus on "near continent" deployments makes feasible the use of some of the satellite systems that do not provide "store and forward" on-satellite storage of data, but rely simply on "bent pipe" direct relay of data from the buoy through the satellite to a ground station. This obviously requires the satellite to be mutually in view of both the buoy and the ground station and thus puts hard limits on how far offshore a buoy can communicate through such a system.

4.2.5 Energy Constraints

As mentioned above, the much larger size of the multi-sensor buoys permits carrying significant battery payloads. For example, the NOMAD buoys deployed off of the Canadian East coast by AES are equipped with a bank of air depolarized lead acid gel cell batteries. The total battery capacity of each of these buoys is approximately 110 KW-hours. The total weight of the batteries is about 260 kg (650 lbs). The batteries have a life of about 3 years and cost over $5000 US to replace. The buoys are also equipped with 3 twenty watt solar panels. The solar panel output and the output from the primary lead acid battery are both connected to a secondary 17 AH battery in the main electronics unit with appropriate diode isolation to permit either the solar panels or the primary battery to supply power to the electronics. The primary battery pack will provide an average continuous power of over 4 watts. All of the low earth orbit satellites flying or planned will have terminals that will only require average powers of less that 0.5 watts. Thus, available energy should not act as a limiting factor in the selection of a satellite system for a large multi-sensor buoy.

4.3 High Data Volume Buoys

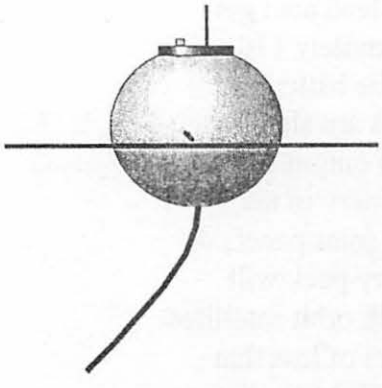


Another group of marine data buoys can be classed as high data volume buoys. A directional wave buoy or an acoustic Doppler current meter buoy would be typical of this group. Such buoys have traditionally not made use of satellite telemetry simply because the relatively high data rates generated by these buoys have not been supported at reasonable cost by the available satellite systems. Table 3 lists the characteristics of a typical wave buoy and ADCP buoy.

4.3.1 Size and Weight Constraints

Directional wave buoys are more or less size and weight constrained by their need to respond to the high frequency components of ocean wave spectra. A physically large, massive buoy would not move in response to very short wavelength ocean waves. The need for the buoy to respond omnidirectionally to waves dictates that the shape of the buoy must be cylindrical or spherical. In general, the resulting designs from a number of manufacturers have all been spherical with diameters between 1 and 2 meters. The WaveTrack buoy, manufactured by ENDECO YSI in Massachusetts, is typical of the available products. This buoy is spherical, with all of the electronics and batteries contained in a steel cylinder located along the polar axis of the sphere and having approximate dimensions of 40 cm dia. X 1 m length. The lower half of this cylinder contains batteries; the top being occupied by sensor electronics and data telemetry hardware. The buoy currently makes use of an FSK modulated VHF terrestrial radio link

# TABLE 3
# High Data Volume Buoys



***Directional Wave Buoy*** *- measures 3 sensors @ 12 bit @ 2 Hz for 20 mins. every 4 hrs*

***ADCP*** *- measures 2 current components @ 12 bits x 128 depth bins every 10 mins.*

***Directional Wave Buoy***

| | |
|---|---|
| Data Per Sample: | 5400 B |
| Samples Per Month:: | 180 |
| Data Per Month: | 972 KB |
| Data Latency: | Imp. |
| Energy Budget: | <1 kW-H |
| Location: | Coastal |

***ADCP***

| | |
|---|---|
| Data Per Sample: | 384 B |
| Samples Per Month: | 4320 |
| Data Per Month: | 1.7 MB |
| Latency: | Not Imp. |
| Energy Budget: | <1 kW-H |
| Location: | Coastal |

which provides 2 way packetized communications between the buoy and a pc-based receiving and processing station. If this telemetry radio was removed and replaced with a satellite terminal, there would be about 1000 cm3 available for the terminal. Most available terminals have volumes close to this, so it becomes important to compare exact dimensions and available spaces when selecting a satellite terminal.

Wave buoys are ballasted to ensure that they respond appropriately to surface waves. The weight of available low earth orbit satellite terminals would not significantly alter the ballast of a wave buoy, so weight does not become a strong descriminant in selecting a satellite telemetry terminal for such a buoy.

Surface buoys can be used as data collection and transmission nodes for one or more sub-surface acoustic Doppler current profilers (ADCPs). As with directional wave buoys, these buoys have not traditionally made use of satellite telemetry to transfer complete data sets, since these sets have not been economically transferable over existing satellites. ADCP surface buoys would have similar dimensions and interior volumes as those for directional wave buoys, so caution should be exercised in selecting a satellite terminal to fit into available buoys. Terminal weight is not a prime consideration since the surface floats typically have significant reserve buoyancy.

### 4.3.2 Data Requirements

Wave buoys measure directional wave spectra by taking a 17 minute sample of three orthogonal motions of the buoy (In the case of the ENDECO YSI buoy, the motions are vertical acceleration and two components of buoy tilt.) Each of these sensors is sampled at about 2 Hz with 12 bit resolution, resulting in the generation of 9180 bytes of data per 17 minute sample. These wave samples would normally be repeated every 4 hours, resulting in the generation of about 1.1 Mbytes of data per month.

Acoustic Doppler current meters measure two components of vector current, with 12 bit resolution, at each of up to 128 ranges from the instrument. Such measurements can be made at very fast sampling rates, however, typically the instrument is configured to provide one vector average for each range cell every 10 minutes. This will result in the generation of about 1.7 Mbytes per month of operation.

It would be useful to be able to control the collection of both wave buoy and ADCP data via a return telemetry connection. As with the previously discussed buoys, the bandwidth requirement is very small in the outbound direction.

### 4.3.3 Latency

Directional wave buoys are sometimes used as tools in offshore weather forecasting, however in most cases, the actual wave height is not used as an input to the forecasting model. There is therefore no significant requirement for real time data telemetry from wave buoys. Furthermore, the raw time domain data must be spectrally analysed once received, so there can be no useful wave statistical information until the full reception of a 17 minute wave sample. This removes the need for very low latency telemetry of wave buoy data.

ADCP data is usually collected as part of ocean circulation studies, so that latency in the satellite telemetry system is again not an important issue.

4.3.4 Deployment

Both directional wave buoys and ADCP moorings are usually deployed within several hundred kilometers of the major continents, and so could rely on "bent pipe" satellite systems for data telemetry.

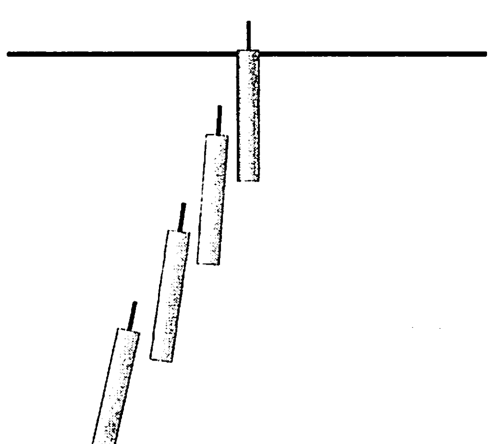
Often such devices are deployed as part of a limited duration experiment, in order to characterise ocean physics in a particular region.

4.3.5 Energy Constraints

Both wave buoys and ADCP surface buoys have limited battery capacity. The ENDECO Wave Track buoy, for example, is powered by alkaline lantern batteries having a nominal available energy of less than 1 KW-hour. Such a battery must power not only the satellite telemetry equipment but also motion sensors, and a data acquisition computer. Typical deployments, may only be for 30 to 60 days, however, battery life issues must certainly be considered in the selection of a satellite telemetry system for a wave buoy.

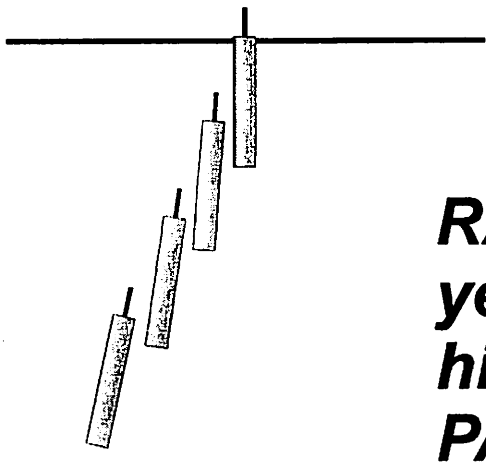
ADCP buoy systems are normally limited by the power requirements of the ADCP itself. However, the addition of an improperly selected satellite telemetry system, could further shorten the available battery life.

4.4 Pop-up Buoys



A number of recent experiments have used variable buoyancy or pop-up buoys to attempt to track ocean currents at depths deeper than can practically be monitored with drogued surface buoys. These pop-up buoys spend most of their deployed life free drifting at a pre-selected depth under the action of the current fields present at that depth. There are two different types of pop-up buoys in current use. The first of these, the so-called RAFOS float, continuously records its position, based on its own measurements of the relative time of arrival of acoustic signals from a number of high power sound sources deployed around the world. After a 1-2 year deployment, the RAFOS float ascends to the surface by dropping a weight and then transmits its drift record information using satellite telemetry. The RAFOS float has then completed its mission. The second type of pop-up buoy is the ALACE float. The ALACE device remains at the selected depth for only 1-4 weeks, then returns to the surface under the action of a variable buoyancy device (usually either a piston or variable volume bladder). During the ascent, some ALACE floats measure and record conductivity, temperature and depth (CTD). These are known as "profiling" ALACE or PALACE floats. When the PALACE float reaches the surface, it determines its current position using either a built-in GPS receiver or the telemetry satellite's own Doppler positioning system. The position along with the CTD profile are then transmitted via the telemetry satellite. Once transmission has been completed, the PALACE alters its buoyancy and returns to the pre-programmed track depth. This cycle may repeat for up to 2 years. Unlike the RAFOS float, the PALACE does not track its position at all while submerged. Instead, it relies on regular trips to the surface to determine its position. Any time spent at the surface, however, contaminates the drift record of the PALACE, since current fields can be quite different at different depths. One of the requirements is therefore to spend as little time as possible at the surface transmitting data.

Table 4 gives a list of operating characteristics for both RAFOS and PALACE floats. All of the size, weight, power, and deployment constraints that apply to simple drifters, apply equally to pop-up buoys.



# TABLE 4
# Variable Buoyancy "Pop-up" Buoys

***RAFOS* - deep drift for up to 2 years, then send track history;**
***PALACE* - deep drift for 1-4 weeks, then send profile & position**

| | |
|---|---|
| ***RAFOS*** | |
| Data Per Sample: | 20 KB |
| Samples Per Year: | 1 |
| Latency: | Not Imp. |
| Energy Budget: | 0.5 kW-H |
| Location: | Global |
| ***PALACE*** | |
| Data Per Sample: | 400 B |
| Samples Per Year: | 12 |
| Latency: | Imp. |
| Energy Budget: | 0.5 kW-H |
| Location: | Global |

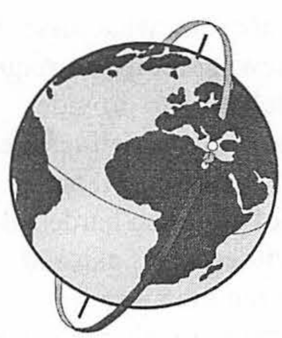
## Antenna / Buoyancy Issues

5.0 Introduction to Satellite Telemetry

This section of the paper is intended to serve as a broad overview of satellite systems.

There are four classes of satellites currently in common use. They are Low Earth Orbiting Satellites (LEOS), Medium Earth Orbiting Satellites (MEOS), Geostationary Satellites (GEOS) and Elliptical Orbiting Satellites. Each is discussed briefly below.

5.1 Low Earth Orbit Satellites (LEOS)

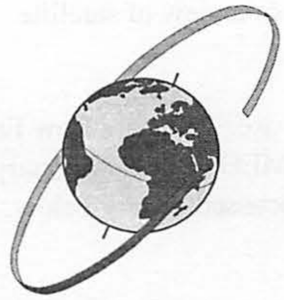


**Altitude: 700-1200 Km**
**Period: ~100 minutes**
**Footprint: ~4000 - 6000 km**
**In-View Time: Up to 15 min/orbit**
**Low Launch Cost Per Satellite**

The first man-made earth satellites were placed in low earth orbit (Sputnik - 1957). More recently, many military observation satellites and scientific satellites have been placed in low earth orbits. Generally, LEO satellites are placed in orbits having altitudes ranging from 750 to 1400 km. At these altitudes, satellites have orbital periods of approximately 100 minutes, and can view between 2.5% and 5% of the earth's surface at any instant. Launching satellites into low altitude orbits is relatively inexpensive when compared to launching to higher orbital altitudes. The amount of radio power required to communicate with satellites in low earth orbits is quite small; as little as 200 mW in the case of the ARGOS system, and directional antennas are generally not required to maintain links.

On the down side, satellites in low earth orbit suffer from atmospheric friction, which causes their orbits to decay more quickly than those of higher altitude satellites. With orbital periods of about 100 minutes, LEO satellites are only in view for up to 20 minutes per orbit from a fixed location on the earth's surface. Unless multiple satellites are employed in a distributed constellation, only intermittent coverage can be obtained from a LEOS. Also because of the high apparent radial velocities of LEOS, significant Doppler shifts are induced in radio signals to and from the satellites. This limits their usefulness at frequencies above 500 MHz, unless special receivers are designed.

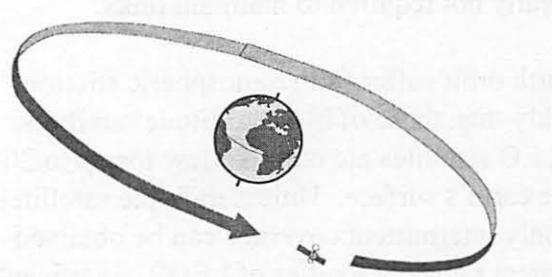
5.2 Medium Earth Orbit Satellites (MEOS)



**Altitude: ~10,000 Km**
**Period: ~5-6 Hours**
**Footprint: ~10,000 - 12,000 Kms.**
**In-view Time: Up to 2 hrs/ orbit**
**Radiation Effects drive costs up**
**Medium Launch Costs per Satellite**

Medium earth orbit satellites (MEOS) overcome some of the limitations of the LEOS systems. Notable examples of MEOS systems include the Global Positioning System satellite network, and the proposed ICO and Odyssey personal communications satellites. Typical MEO altitudes are about 10,000 km, with orbital periods of about 120 minutes, and viewing footprints of 25% of the earth's surface. MEOS launches require more resources than equivalent LEOS launches, but these costs are somewhat offset by the significantly larger viewing footprint; requiring fewer satellites in a constellation to provide adequate system coverage. MEO satellites are exposed to the Van Allen radiation belt and therefore require the use of radiation hardened components in their structures. This can add substantially to the cost of the MEO satellites. MEOS satellites require more transmission power, sophisticated data coding (CDMA, for example) or steerable gain antennas to cover the 8-10 times greater distance that signals must travel to reach the satellite. In the case of GPS receivers, for example, the satellites require substantially greater energy budgets to power radio transmitters. CDMA coding is also used to provide "processing gain" at the receiver end.

5.3 Geosynchronous Satellites



**Altitude: ~ 35,700 Km**
**Period: ~24 Hours**
**Footprint: ~15,000 Km**
**In-view Time: Continuous**
**High Launch Costs per Satellite**

In the late 1940's Arthur C. Clarke (of 2001 - A Space Odyssey fame) postulated the existence of an orbital altitude at which the gravitational pull of the earth is just balanced by the tangential inertia of a satellite travelling at the same angular velocity as that of the earth. A satellite orbiting in the earth's equatorial plane at that altitude would appear from the earth's surface to be stationary in the sky, or geostationary. This altitude is 35,700 km. The orbit is called the Clarke Belt in honour of Clarke's postulation. Satellites in this orbit have a continuous view of about 34% of the earth's surface, however this coverage is centered on the equator.

Almost no coverage is provided at latitudes above 75 degrees. Because of the great distance to and from GEO satellites, high power and directional antennas are required. For stationary terrestrial applications, however, the directional antennas need only be aligned once, since the GEO satellite will remain at a fixed azimuth and elevation in the sky. One of the GEO satellite systems that is widely known in the marine sector is INMARSAT.

5.4 Highly Elliptical Orbit Satellites

**Inclined Elliptical Orbit puts Satellite at high, almost static, Elevation Angles over Northern Population Centres**

In order to overcome the problems of poor coverage from GEO satellites at northern latitudes, a number of satellite constellations have been proposed that make use of highly elliptical orbits (HEO) , with apogee's (long radius) centered over the populated northern latitudes of Europe, North America and Asia and the perigee (short radius) centered over the lesser populated high latitudes of the Southern hemisphere. Because of Keplerian motion of the satellite, it spends a large portion of its orbital period at high, relatively constant, elevation angles in the areas of northern coverage. By synchronizing a constellation of such satellites to hand off communications as they return from high elevation apogee, almost continuous northern coverage can be achieved with a small number of satellites. Earth terminals for such satellite constellations can make use of high gain directional antennas pointed at a fixed point in the sky. Such satellite systems must contend with the significant variations in signal strength that result as the satellites change altitude. Ellipsat is an example of a proposed elliptical satellite constellation.

6.0 The Explosive Growth in the LEO Market

Of all the satellite classes discussed, the one that is projected to experience the fastest growth in the next 5-10 years, and the one with most direct relevance to the marine science market, is the LEO class of satellites. Some industry analysts have estimated that as much as $10 Billion US will be invested in the development of low earth orbit satellite systems over the next 10 years. This spectacular growth is the result of a number of factors including:

1) continuing high world market demand for "portable bandwidth" - ie cell phones and pagers

2) rapid advancement of newly developing nations that don't have established wire-based telecommunications infrastructures
3) technical developments allowing better spectrum use (spread spectrum, electronically steerable antenna beams, cell-based frequency re-use, etc)
4) refocusing of defence electronics firms on civilian applications.
5) competition in satellite launch vehicles and the availability of non-traditional launch vehicles such as Orbital Sciences' Pegasus system.

## 7.0 Little LEOS Versus Big LEOS

The LEOS category can be further subdivided into Big LEOS and Little LEOS systems. While both types of satellites share similar orbits, they are quite different in many other ways. Table 5 shows some of the major differences between these two types.

In many ways the distinction between big and little LEOS has arisen as a result of FCC regulatory issues. The FCC and WRC have defined the category of Non-Voice Non-Geosynchronous Mobile Satellite Services (NVNG MSS) operating below 1 GHz in their last rounds of spectrum allocations. This category defines the little LEOS - data only, low earth orbit satellites operating at frequencies below 1 GHz. The regulatory agencies, recognizing the very limited amount of radio spectrum available at these relatively low frequencies, has restricted licensed bandwidths and enforced re-use strategies. The result has been the creation of a number of competing systems that share a very limited bandwidth.

The little LEOS systems can be thought of as extensions to existing terrestrial digital pagers - able to communicate small text or data messages globally at reasonable cost. The satellites comprising these systems are quite simple in design and as a result are low in cost.

Big LEOS systems are not constrained by the NVNG MSS regulations and provide digital voice and data services using frequencies above 1 GHz. Big LEOS satellites are larger, more complex, and more expensive than little LEOS satellites. Big LEOS systems can be thought of as extensions to terrestrial cell phone systems. Because of the greater available bandwidth, near continuous digital communication becomes practical using big LEOS systems.

## 8.0 Some Examples of LEOS Satellite Systems

The following sections give general overviews on a number of proposed and existing LEOS systems.

### 8.1 ARGOS

Table 6 gives some details on the ARGOS system. ARGOS is a joint French - US

# TABLE 5
# LITTLE LEOS VS BIG LEOS

| LITTLE LEOS | BIG LEOS |
|---|---|
| ***Satellite Wt.***: 40 to 125 kg | ***Satellite Wt.***: 350 to 1200 kg |
| ***Frequencies***: VHF / UHF <500 MHz to limit req'd power and Doppler-induced Rx BW problems | ***Frequencies***: L, S & Ka 1.6 GHz, 2.5 GHz, 20 GHz to access req'd BW |
| ***Market Focus***: Messaging, Paging | ***Market Focus***: Global Cell Phone Service |
| ***Systems***: ARGOS, Orbcomm Starsys, Safir, IRIS | ***Systems***: Iridium, Globalstar, Teledesic |
| ***Low cost, "pager" bandwidth*** | ***Medium cost, "modem" bandwidth*** |

# *TABLE 6 ARGOS*

| | |
|---|---|
| **Class** | **Little LEOS** |
| **Coverage** | **Global** |
| **Comms:** | **401.65 MHz PSK** |
| **Data Throuput::** | **~1-2 kbit / day** |
| **Two Way?** | **No; ARGOS III yes** |
| **Latency:** | **1-4 hours typical** |
| **Buoy Terminal** | |
| **Size:** | **200 cc; 250 g** |
| **Power:** | **~50 mW avg** |
| **Costs:** | |
| **Terminal:** | **$500 - $1000 US** |
| **Basic Usage** | **~$10 US / day** |
| **Data Charges** | |
| **Availability:** | **Operational Now** |

government operated satellite telemetry system that is carried aboard the US NOAA series of polar orbiting weather satellites. The ARGOS system is primarily dedicated to the collection of environmental and earth science data. ARGOS is notable for being the first operational Little LEOS and for continuing to offer significant advantages to science users that require ultra low power and very small terminal sizes. The ARGOS system currently includes three globally operating near-polar orbit satellites, two of which provide store and forward capability. The third operates in a bent pipe mode when in view of the French ground station. The short message structure (32 bytes per message) and the need to repeat messages in order to assure reception by the satellite in the absence of two way communication limits the effective throughput to something less than 2 Kbytes per day at mid-latitudes.

One of the most limiting features of the ARGOS system is its one way communications. There is no provision for data transfer from the satellite to the buoy terminal. The system is proposing to increase effective bandwidth with the addition of more on-board receivers and with the addition of a two way system expected to be carried as payload aboard the Japanese ADEOS satellite in 1999. This new ARGOS III system will support limited bandwidth data transfers from the user, through the satellite and back to the buoy.

Because the ARGOS system is mandated to only provide services to a very small market sector - the earth and environmental science market, it cannot compete effectively with more commercial systems that can spread capital and operating costs over much larger customer bases. Never the less, ARGOS will continue to be the only viable solution for ultra low power , micro size applications such as small animal tracking. For most buoy applications, however, ARGOS will not be the only satellite telemetry system of choice.

There are about a dozen suppliers of ARGOS terminal equipment. The designs of these terminals have evolved over the past 15 years to the point where they have been well optimized for various science applications.

## 8.2 ORBCOMM

Orbital Sciences Corporation of Dulles Virginia, in partnership with Teleglobe Canada and with Technologies Resources Industries of Malaysia have begun operation of the ORBCOMM little LEOS system. Some of the salient features of this system are shown in Table 7. As of January 1997, ORBCOMM has two near polar orbit satellites operational, with a plan to deploy at least 2 more polar satellites plus 8 in a lower inclination orbit before the end of 1997. The eventual plan is to have 26 satellites in orbit, providing near continuous global coverage. Four ground stations are currently operational within the continental US providing direct bent pipe coverage over all of North America and surrounding ocean. A European ground station is expected to be operational in the later half of 1997. In addition to bent pipe communications, the polar orbiting ORBCOMM satellites also can provide limited (~200 byte) store and forward messaging. It is also possible that the later lower inclination satellites will also provide this service. ORBCOMM provides a variety of two-way messaging protocols, with

# TABLE 7 ORBCOMM

| | |
|---|---|
| Class | Little LEOS |
| Coverage | Global (Via Globalgram) |
| Comms: | 137-139 MHz downlink;<br>148-150.05 MHz uplink;<br>dynamically assigned channels |
| Data Throughput: | 2400 Baud uplink, 4800 baud downlink; ~50 KBytes / day with existing constellation |
| Two Way? | Yes |
| Latency: | depends on location;<br>seconds to 2-3 hours |
| Buoy Terminal | |
| Size: | 500-1000 cc; 500 g |
| Power: | Basic: 1 mW continuous<br>Rx: 1 W for ~10 min/day (about 7 mW avg)<br>Tx: 10 W for duration of data transmission |
| Costs: | |
| Terminal: | \$500 - \$1000 US |
| Basic Usage | ~\$50 US per month fixed fee |
| Store & Forward: | +\$1/message ~256 bytes<br>~1 MB total on-board storage |
| Availability: | 2 Satellites Now; eventually 26 |

global coverage through the use of the store and forward capability.

Terminals are currently manufactured by 5 companies. Access to the satellite system is provided by a network of data access resellers, who specialize in various market and geographic sectors. The ORBCOMM system is quite well integrated with the Internet network through an earth-based gateway. Terminals can be made to appear on the Internet as e-mail addresses to and from which messages and data can be sent. ORBCOMM is of particular current interest to the marine science community since it can potentially provide improved bandwidth, two way communication, and lower cost than the popular ARGOS system. As with any new system, however, there are interface and operational issues to be worked out. Seimac and others are beginning to make use of the ORBCOMM system in selected applications.

## 8.3 STARSYS

The French agency responsible for the ARGOS system proposed the launch of a commercial LEOS system called STARSYS about 4 years ago. The US FCC would not grant the required spectrum to the French group because of US laws precluding the licensing of groups with substantial non-US ownership. As a result of this, the majority ownership of the STARSYS system was shifted to General Electric. An FCC licence was subsequently obtained. The features of the resulting system are shown in Table 8.

STARSYS proposes to make use of CDMA (code division multiple access) or spread spectrum techniques in order to make optimal use of its assigned spectrum. The system is strictly bent pipe, with ground station coverage planned for the major population areas of the world. This may still provide some useful coverage for ocean science users, however there will not be any mid-ocean or polar coverage available from the STARSYS system.

STARSYS has contracted Alcatel to provide the satellites for the system, and has invited competitive bids from terminal manufacturers. Successful bidders have not been announced as of January 1997. There is some thought in the industry that GE STARSYS is not on a very aggressive time schedule, preferring instead to let ORBCOMM pave the way in developing the markets for little LEOS systems.

## 8.4 SAFIR

In 1994 the German company, OHB launched a little LEOS telecommunications package called SAFIR aboard one of the Russian polar orbiting weather satellites, in much the same way that ARGOS rides aboard the American polar satellites. A second package is tentatively planned for launch in 1997. The operating characteristics of this system are shown in Table 9. One of the unique features of this system is its lack of ground station. Communications through the SAFIR system is double ended, with the customer providing terminal equipment for both the buoy and the land based end of the link. Two way messages are exchanged between buoy and land station by using the SAFIR satellite package as a store and forward message drop. Only accounting and control functions are handled through the system ground station.

# TABLE 8 STARSYS

| | |
|---|---|
| Class | Little LEOS |
| Coverage | Coastal Only (Bent Pipe) |
| Comms: | 400.620 MHz TDMA Downlink<br>148-148.9 MHz CDMA Uplink |
| Data Throughput: | 2400 Baud; up to 4 MB/day per region with initial constellation |
| Two Way? | Yes |
| Latency: | seconds |
| Buoy Terminal | |
| Size: | 500-1000 cc; 500 g |
| Power: | Basic: 1 mW continuous<br>Rx: 1 W for ~10 min/day (about 7 mW avg)<br>Tx: 10 W for duration of data transmission |
| Costs: | |
| Terminal: | $500 - $1000 US |
| Basic Usage | ~$15 US / month |
| Data Charges | ~$0.15 per 64 bit message |

# TABLE 9 SAFIR

| | |
|---|---|
| Class | Little LEOS |
| Coverage | Global (licensed in Europe only) |
| Comms: | 400-401 MHz TDMA |
| Data Throughput: | 300 & 2400 Baud; 1 KB onboard storage per ID<br>implies 1 KB per day except when terminals in same footprint |
| Two Way? | Yes |
| Latency: | depends on position of terminals |
| Buoy Terminal | |
| Size: | ~300 cc; 1500 g |
| Power: | Basic: 30 mW continuous<br>Rx: 0.5 W for ~10 min/day (about 3 mW avg)<br>Tx: 24 W for duration of data transmission |
| Costs: | |
| Terminal: | ~$2,000 US per end |
| Basic Usage | ~$75 US / month (2 ends) |
| Data Charges | ~$30 per KB 1-3 KB/month<br>~$25 per KB 4-7 KB/month<br>~$16 per KB 8-15 KB/month<br>~$12 per KB 16-25 KB/month<br>~$3.5 per KB over 100 KB/mon. |

The SAFIR system has been targeted at scientific and governmental users, and a small number of marine science applications have been developed using the system. OHB determined that, for the science and governmental users they had targeted, there was no need to provide very fast, low latency, messaging. As a result, the SAFIR system consists of only 2 satellites. OHB has recently become involved in the establishment of ORBCOMM's European operating company, casting some doubt on the long term prospects for the SAFIR system.

## 8.5 IRIDIUM

Motorola has begun construction of the long awaited IRIDIUM system. Partners in this project include Lockheed Martin, Raytheon, and a large number of national phone companies. The first of 66 IRIDIUM satellites is due to launch during the first quarter of 1997, with the system predicted to be operational by late 1999. The overall characteristics of the IRIDIUM system are shown in Table 10.

IRIDIUM is a big LEOS system, with its primary target market being international cell phone users. The system can be thought of as a cell phone network in the sky, with all 66 satellites acting as cell phone repeaters. An interesting feature of the system is the use of inter-satellite communications links. Once a link has been established between a ground terminal and any satellite, the linking satellite can relay the communication from satellite to satellite until the desired second ground station is in view. This "cell switch in the sky" is potentially very threatening to both terrestrial cell phone companies and to cable-based national telephone companies. In order to avoid direct competition with the various national phone companies, Motorola has made them part of the team. As a result, IRIDUM services will likely be direct marketed by the various phone companies around the world.

While IRIDIUM's main market is portable voice communication, it is not precluded from carrying data traffic, and in fact it has defined data transfer and text-based messaging as a viable market component in its overall business plan. Because of the higher bandwidths and more sophisticated communication technology used in this big LEOS system, it can potentially offer much lower cost transfer of large data sets that can any of the little LEOS systems. The projected higher cost of the terminals, however, may only make this attractive for those marine science users requiring high data rates.

## 8.6 GLOBALSTAR

In contrast to IRIDIUM, Loral's GLOBALSTAR system does not make use of inter-satellite communications links. While IRIDIUM can operate with relatively few ground stations because of its switching in the sky, the proposed GLOBALSTAR satellite system operates in a strict bent-pipe, direct to ground relay mode. The major disadvantage of this approach is that it will not provide coverage in locations outside of

# *TABLE 10 IRIDIUM*

| | |
|---|---|
| Class | Big LEOS |
| Coverage | Global, switched in the sky |
| Comms: | 1610-1626.5 MHz TDMA 1/2 Dup |
| Data Throughput: | 2400 Baud continuous |
| Two Way? | Yes |
| Latency: | seconds |
| Buoy Terminal | |
| Size: | "handheld" |
| Power: | "Cell phone-like"<br>implies about 100 mW receive<br>for 10 mins/day<br>10W transmit<br>assume <100uW sleep |
| Costs: | |
| Terminal: | ~$2,000 US per end |
| Basic Usage | ~$3 / minute |
| Availability: | 1-2 Years; 1st Launch Dec. '96 |

pre-determined market areas. The advantage (for Loral) is that the system can be made operational gradually, without the need to launch a large portion of the proposed 26 satellite constellation before beginning operations. For marine data users that are located within the footprint of a GLOBALSTAR ground station, this system will offer data transmission capabilities that are similar to IRIDUM, at a projected usage fee substantially lower than that for IRIDIUM. Some of the major features of the GLOBALSTAR system are shown in Table 11.

## 8.7 System Comparisons

Table 12 summarizes the applicability of the satellite systems discussed in this paper to the four different buoy types defined in the paper. The table indicates which features to consider when doing a detailed evaluation of the various systems. Obviously, this comparison has been done for generic buoys. A similar table could be constructed for any specific buoy experiment. In that case a more quantitative approach would be appropriate.

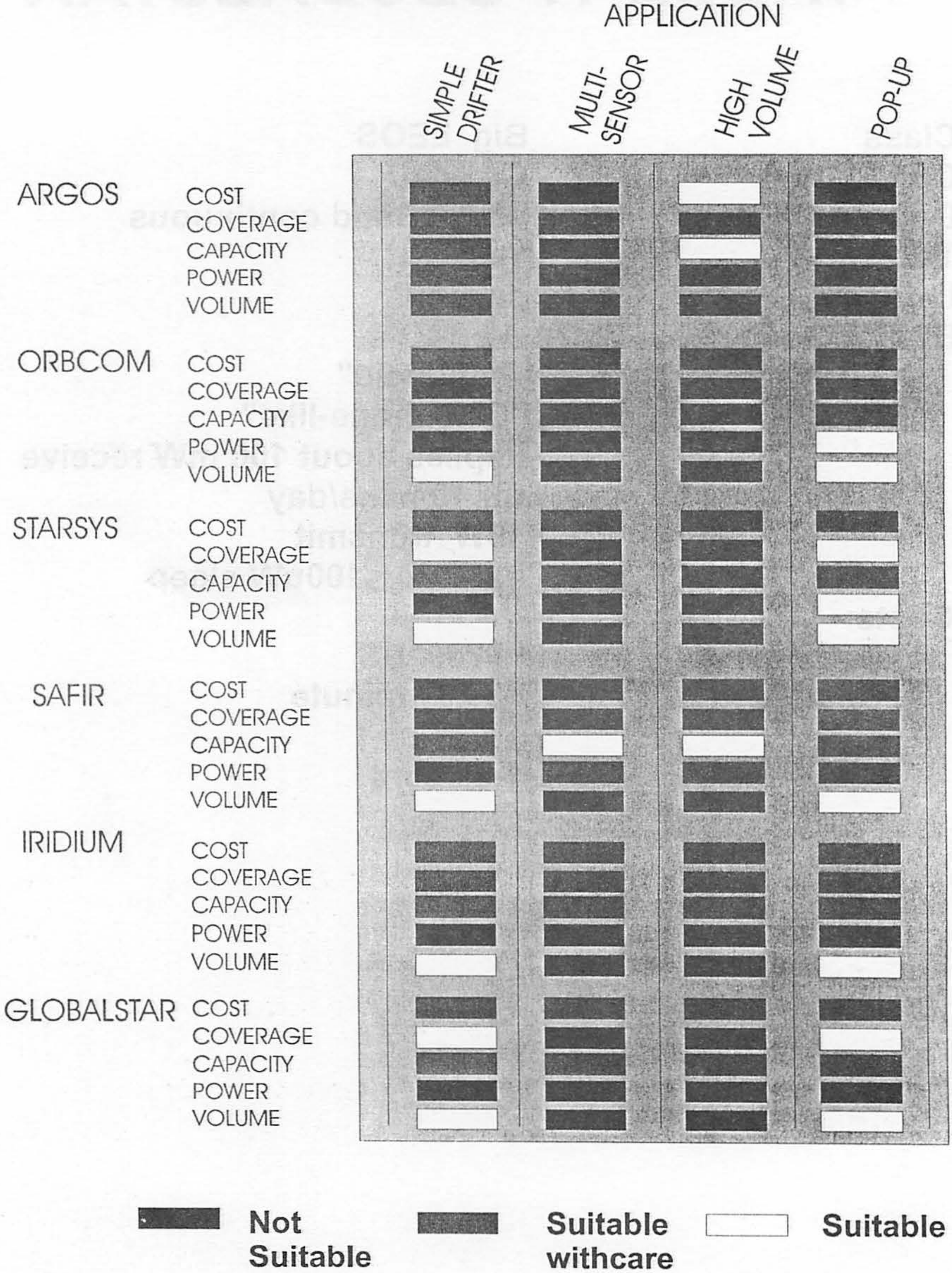
## 9.0 Conclusions and Recommendations

Over the next 5 years the marine science user will be presented with an increasingly large number of satellite telemetry options. As with most high technologies, these systems are in no way commodities. They each have their own features, advantages and disadvantages. With few exceptions, these systems are not specifically tailored for the marine science user. Therefore the user is left to select among available systems, with little or no ability to influence the operating specifications or even the market success of the individual satellite system. As a result there is both an opportunity and a risk. The opportunity exists for the provision of greatly improved data telemetry in the marine science community. The risk for the individual researcher, however, can be high since there is a great chance of choosing the wrong system for a given application. The best defence against this eventuality is to spend time following the developments in the fast moving low cost satellite market, or to solicit the assistance of a company that can understand the marine science application and provide an even-handed professional assessment of the appropriate satellite system for the application.

# *TABLE 11 GLOBALSTAR*

| | |
|---|---|
| Class | Big LEOS |
| Coverage | Coastal |
| Data Throughput: | ~2400 Baud continuous |
| Two Way? | Yes |
| Latency: | seconds |
| Buoy Terminal | |
| Size: | "handheld" |
| Power: | "Cell phone-like"<br>implies about 100 mW receive<br>for 10 mins/day<br>10W transmit<br>assume <100uW sleep |
| Costs: | |
| Terminal: | ~$700 US |
| Basic Usage | ~$0.3 / minute |
| Availability: | 1-2 Years |

# TABLE 12 - SYSTEM SUITABILITY MATRIX



# TAO DATA - DOES IT ARRIVE IN TIME TO BE USED IN THE NCEP OPERATIONAL MODELS??


## ABSTRACT

A first step in assessing the impact of TAO data on operational models is to determine what percentage of the available data is actually being used in the models. The atmospheric models at NOAA's National Centers for Environmental Prediction (NCEP) have well-defined observation time and data receipt time cut-off windows within which the data must arrive to be assimilated. Analysis of the wind observations from the TAO Array indicates that only 65% of the data set available to the models is being assimilated into the global atmospheric model suite at NCEP. The time of the observation, the on-off cycle times of the buoys, and the time between when the satellite is visible to the buoy and when it is visible to the ground station are the primary controlling factors of that percentage. The low percentage suggests that the method for real-time relay of data from the TAO array may not be optimum for operational applications. In this presentation the suite of global atmospheric models at NCEP, their data acceptance windows and how they differ among the models are described briefly. The quantity of TAO wind observations actually used in the models is shown for the period July/August 1996 and is compared to the total number of observations collected by the array during that same period. Illustrations are provided showing the number of observations used in the models displayed against several variables, including the time of the observation, the difference between the time of the observation and its time of arrival at NCEP, and the cycle times of the model. Recommendations are made on ways to increase the percentage of TAO observations used in the NCEP models.

# TAO DATA

## *"Does it arrive in time to be used in the NCEP Operational Models?"*


**Bill Woodward & Gary Soneira**
**NOAA/AOML**


**DBCP - 12**
**October 21, 1996**
**Henley on Thames**

## ◆ *OBJECTIVES* ◆

- INSURE THAT THE TAO DATA ARE FULLY UTILIZED FOR OPERATIONAL APPLICATIONS

- PROVIDE A QUANTITATIVE BASIS FOR ASSESSING THE IMPACT OF THE TAO DATA ON THE MODELS /ANALYSES

# *NCEP GLOBAL MODELS (ATMOSPH)*

## ANALYSIS -- FORECAST

## GDAS - GLOBAL DATA ASSIMILATION SYSTEM

* Global Analysis at Synoptic Hours
* Carries Atmospheric Physics Forward in Time
* Provides First Guess Field for Forecasts

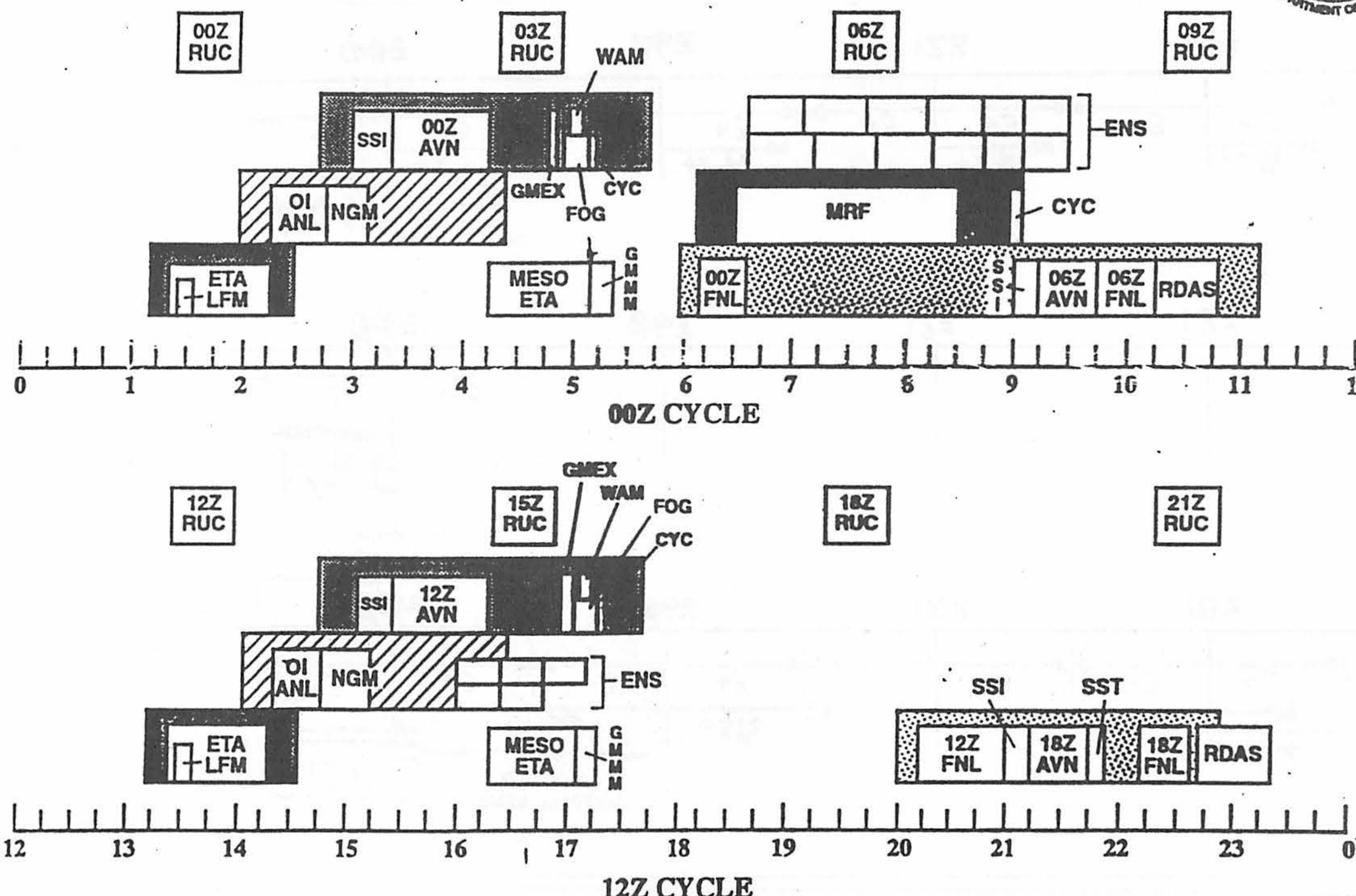
## MRF - MEDIUM RANGE FORECAST

* Run Once Daily [0000 z]
* 20 Day Forecast

## AVN - AVIATION

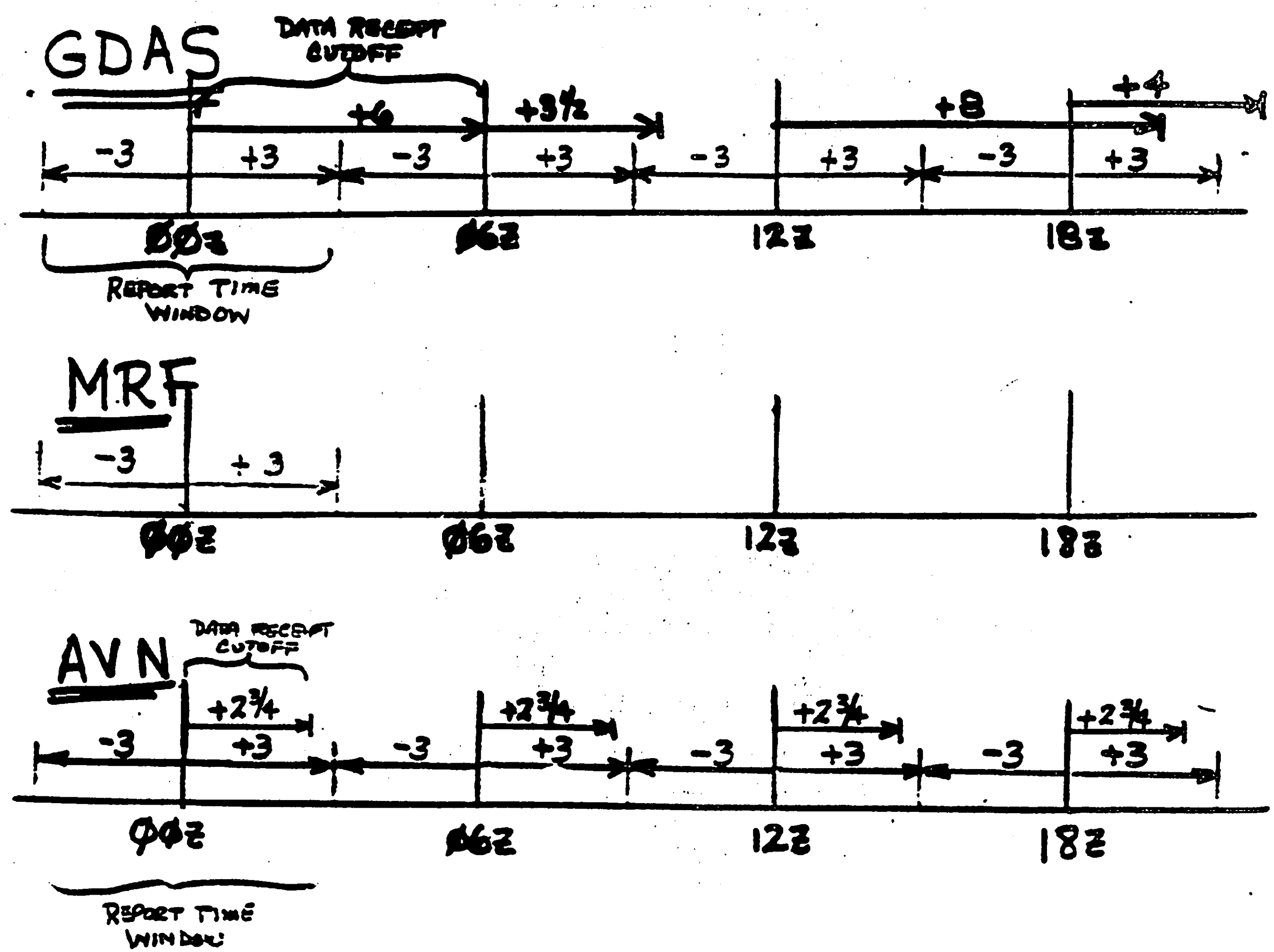
* Run Four Times Daily (0, 6, 12, 18 z)
* 72 Hour Forecast

# NCEP Production Suite




24 hour timeline for the atmospheric model suite that is run daily at NOAA's National Centers for Environmental Prediction (NCEP)

# MODEL TIMELINES




Detailed timeline showing report time windows and data receipt cutoff times for three applications of the NCEP global atmospheric model: GDAS (Global Data Assimilation System), MRF (Medium Range Forecast), AVN (Aviation Forecast).

# BUOY TRANSMISSION vs. SATELLITE CROSSINGS

| | Satellite Equator Crossing (local time) | Buoy Transmission (local time) |
| --- | --- | --- |
| **NOAA 12 (D)** | | |
| Descending | 0650 | 0600 - 1000 |
| Ascending | 1850 | —— |
| **NOAA 14 (J)** | | |
| Descending | 0155 | —— |
| Ascending | 1355 | 1200 - 1600 |

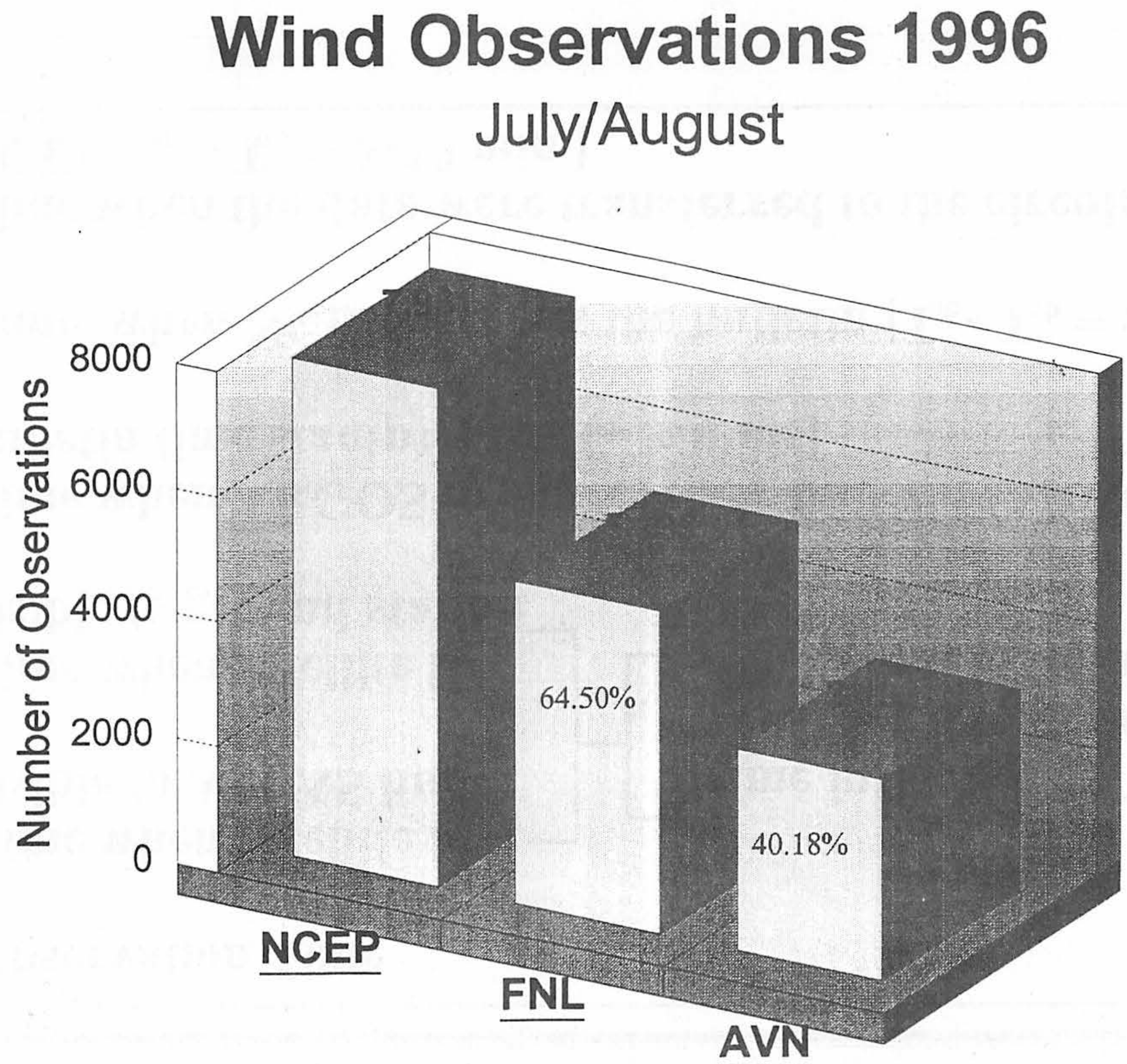
# ◆ *TIME PERIOD OF ANALYSIS* ◆

## 1996

| | | |
|---|---|---|
| *January* | *February* | *March* |
| *April* | *May* | *June* |
| **July** | **August** | *September* |
| *October* | *November* | *December* |

**Number of Active Buoys**

**56**



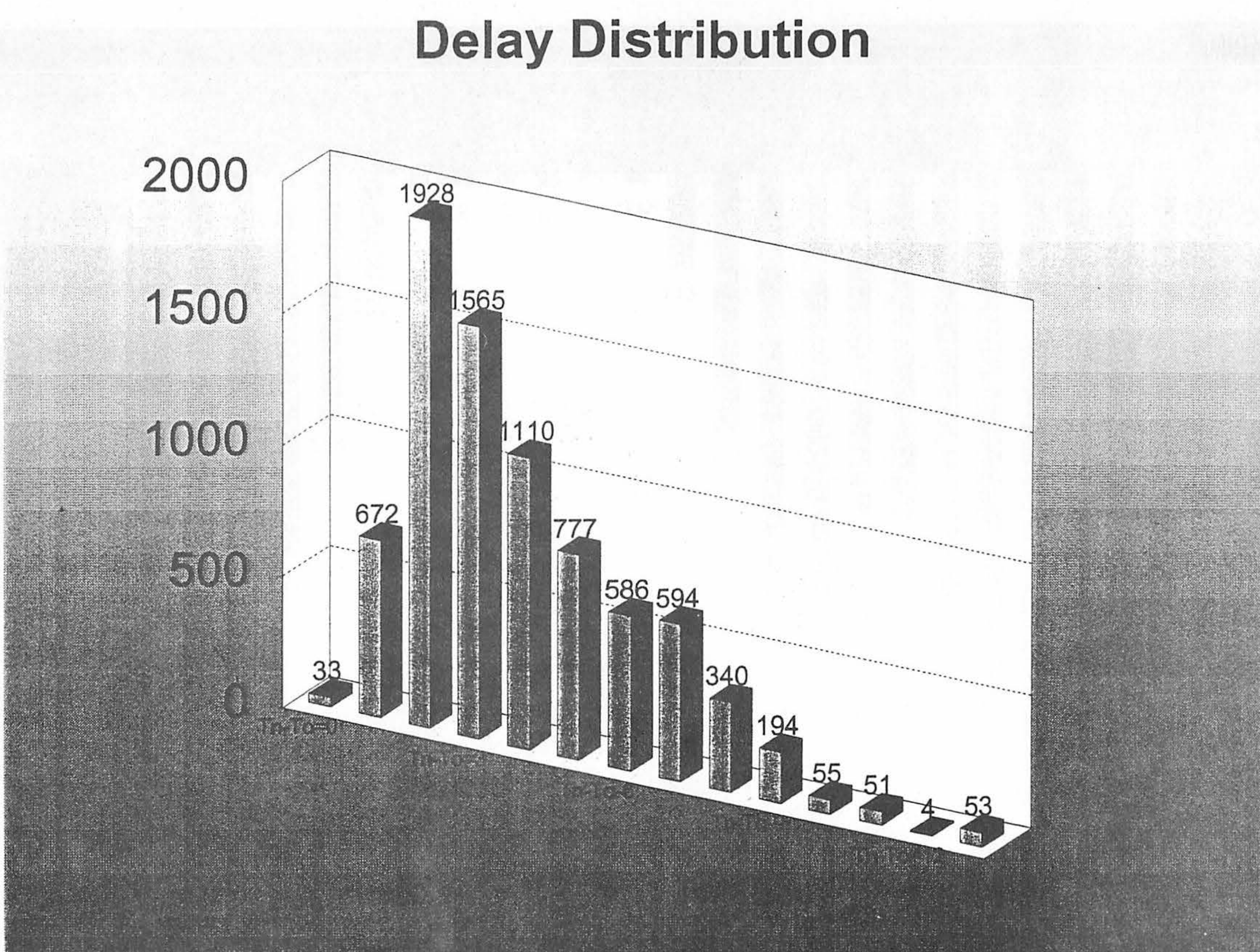

The numbers of TAO wind observations arriving at NCEP, accepted into the MRF (labelled FNL) and accepted into the AVN during July/August 1996

# *TIMELINE OF A TAO OBSERVATION*

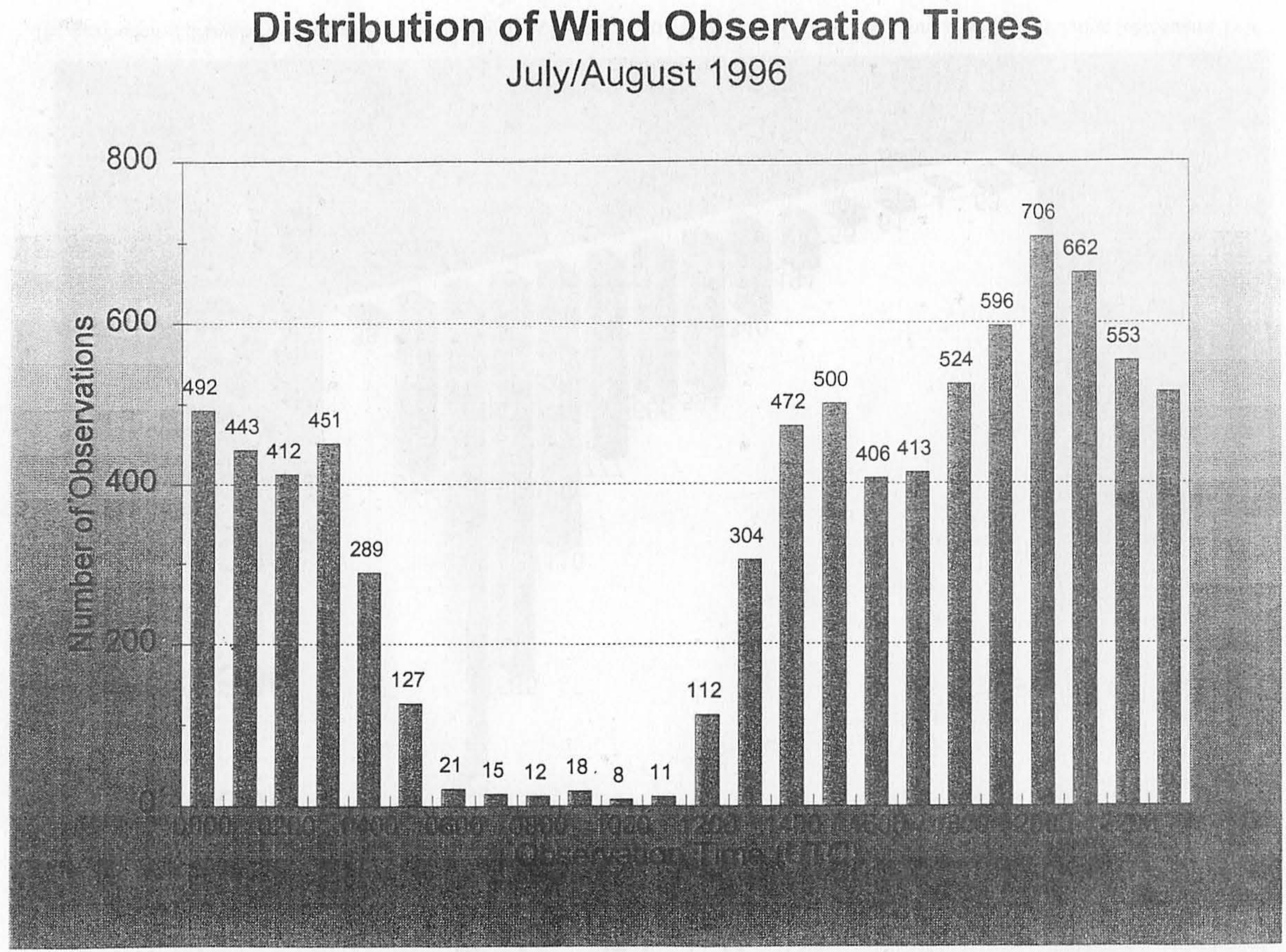
- $T_0$ = Observation Time
- $T_{vb}$ = Time when satellite is visible to ATLAS buoy
- $T_{vg}$ = Time when satellite is visible to ground station

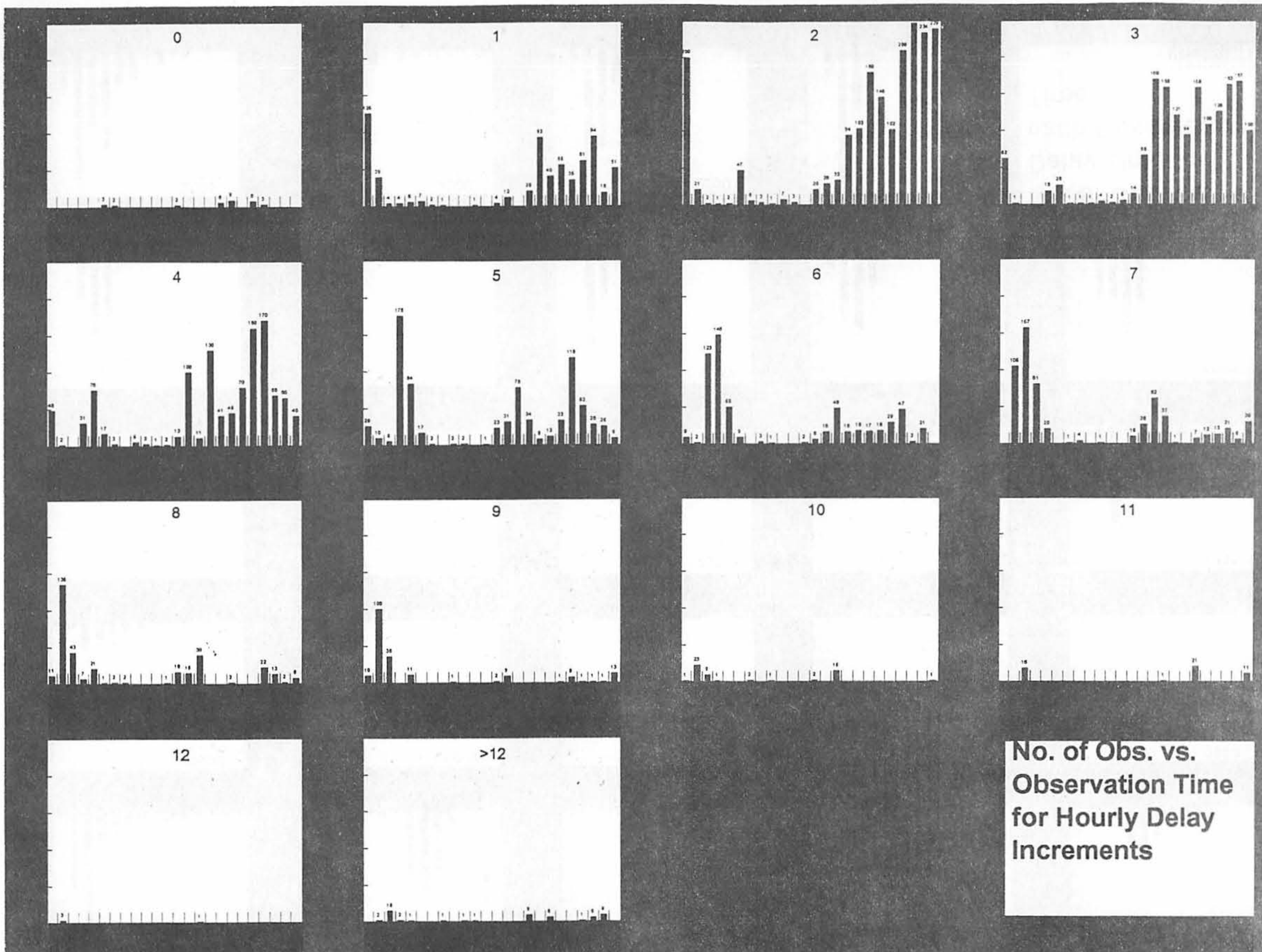
Prime influence on $T_{ab}$
$T_{vb} - T_0$ = 0 to hours
$T_{vg} - T_{vb}$ = 0 to hours

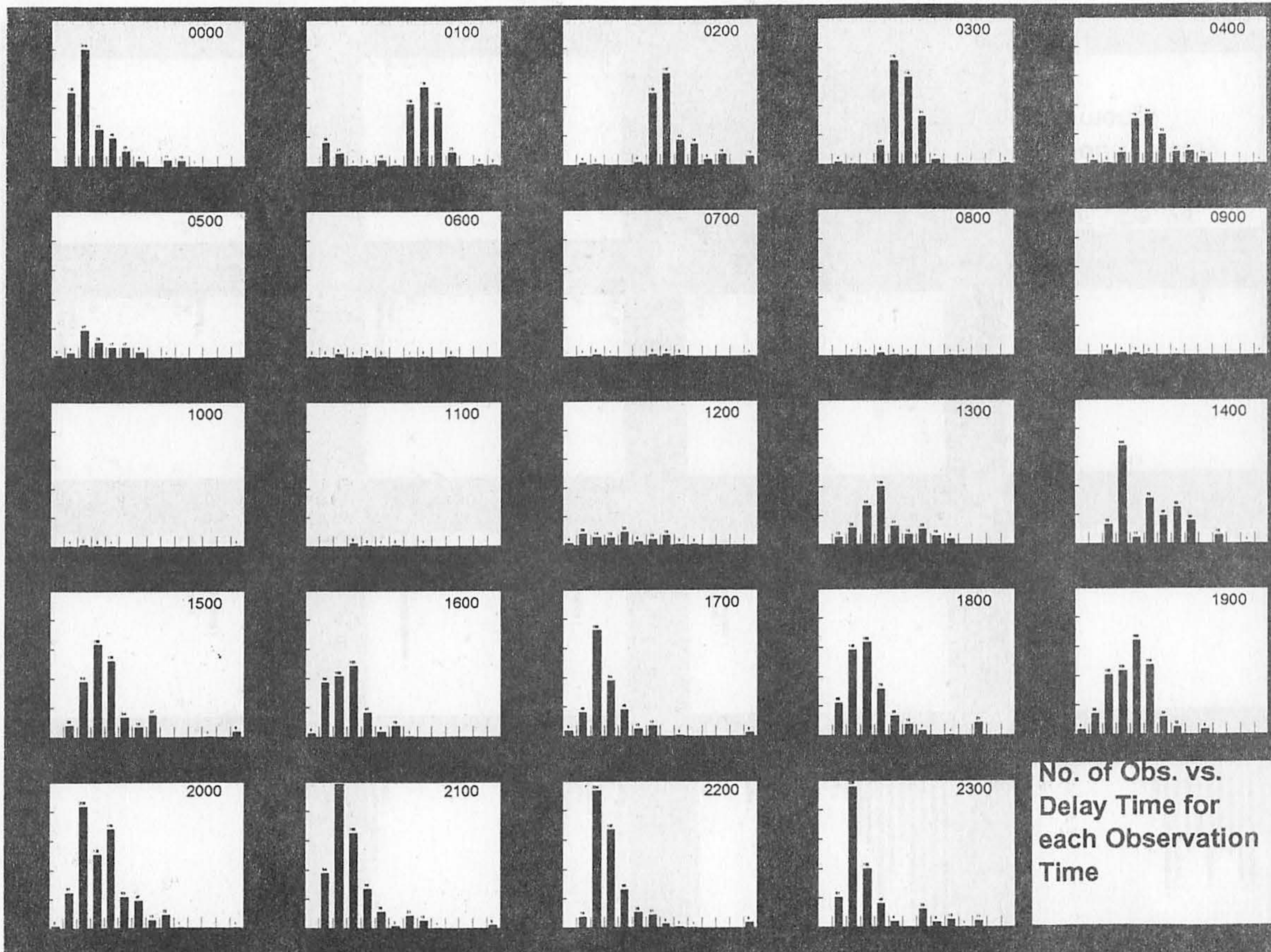
- $T_{ab}$ = Time when ARGOS produces their bulletin (ARGOS bulletin time stamp) [$T_{ab} - T_{vg}$ = mins]
- $T_{nb}$ = Time when NCEP receives the bulletin [$T_{nb} - T_{ab}$ = minutes]
- $T_n$ = Time when the data were transferred to the circular file at NCEP [$T_n - T_{nb}$ = 5-10 min.]




The distribution of delays between the time of the observation ($T_0$) and its arrival at NCEP ($T_n$) for TAO wind observations during July/August 1996

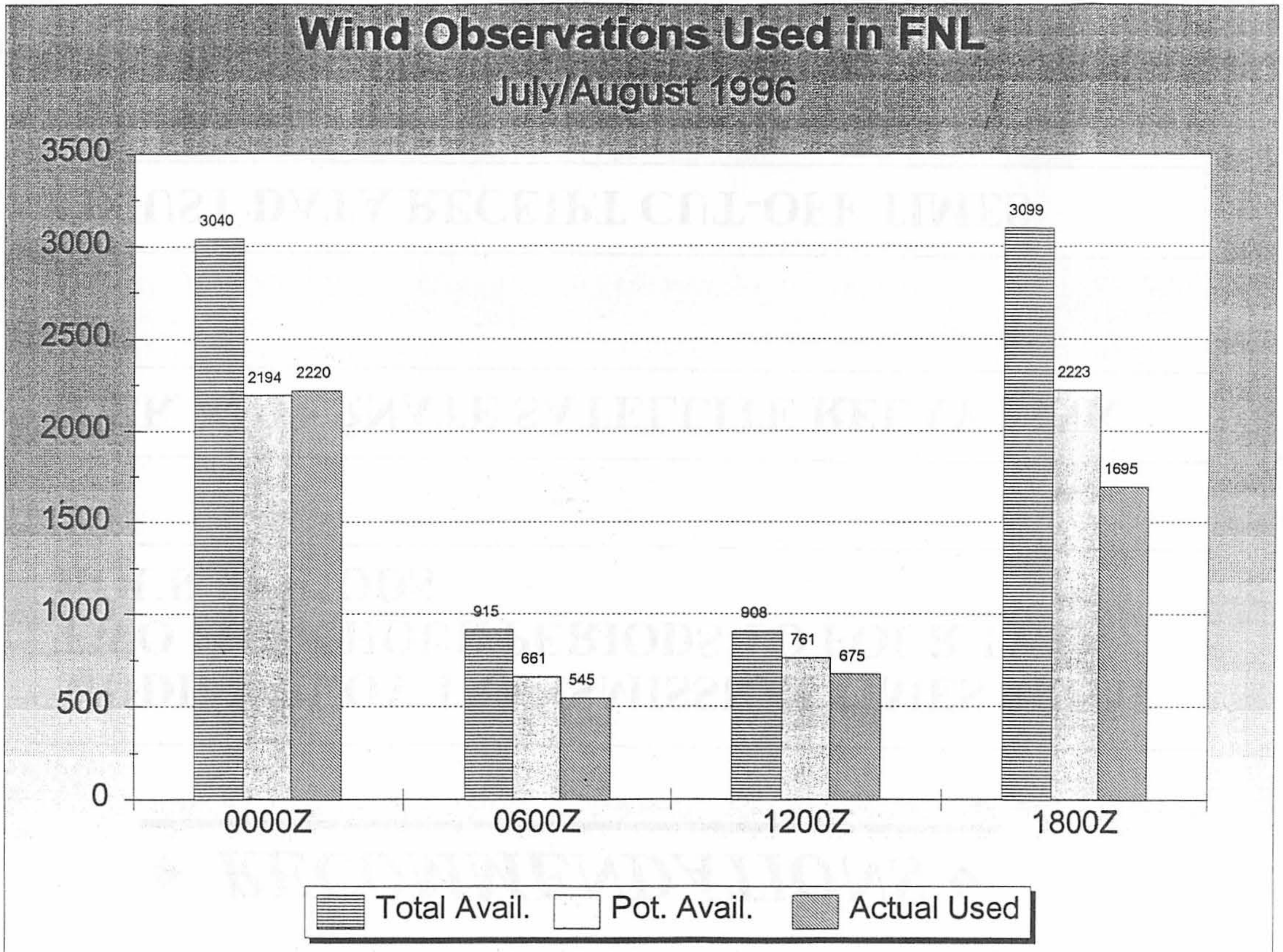

Distribution of Wind Observation Times
July/August 1996
Number of Observations
800
600
400
200
0
492
443
412
451
289
127
21
15
12
18
8
11
112
304
472
500
406
413
524
596
706
662
553
1200
Observation Time (UTC)


0
1
2
3
4
5
6
7
8
9
10
11
12
>12
No. of Obs. vs.
Observation Time
for Hourly Delay
Increments




No. of Obs. vs. Delay Time for each Observation Time

13-Jan-97




The number of TAO wind observations available at NCEP (left), the number that arrived in time to be assimilated (middle), and the number that were actually assimilated (right) for each synoptic cycle

# ◆ *RECOMMENDATIONS* ◆

- **MODIFY BUOY TRANSMISSION TIMES FROM TWO FOUR HOUR PERIODS TO FOUR TWO HOUR PERIODS**
- **SEEK ALTERNATE SATELLITE RELAY LINK**
- **ADJUST DATA RECEIPT CUT-OFF TIMES**

# THE NATIONAL CENTERS FOR ENVIRONMENTAL PREDICTION (NCEP) QUALITY IMPROVEMENT PERFORMANCE SYSTEM (QUIPS)

Christine Caruso

National Centers for Environmental Prediction (NCEP)
NCEP Central Operations (NCO)
National Weather Service (NWS)

QUIPS is the software used by the NCEP/Marine Prediction Center (MPC) to quality control (QC) global surface marine meteorological data. The parameters MPC quality checks are sea level pressure (slp), air temperature, wind direction and speed, and sea surface temperature (SST). Call signs of platforms and positions of platforms may also be corrected.

QUIPS currently runs on a VMS DEC VAXstation 4000/60 workstation. QUIPS has a history file that holds all surface marine data for the last 8 days. This includes not only the platform data but associated model and analysis field information as well. Also, QUIPS uses a land-sea table so that QUIPS may check to see if a platform is mistakenly on land when it should be in the water.

At the start of each synoptic period, a 6-hour forecast from either NWS's Global Data Assimilation System (GDAS) or Aviation (AVN) models and an SST analysis field updated daily are downloaded to the VAX from the NWS mainframe. The model/analysis fields are 2.5 x 2.5 degrees resolution and are global. Every 15 minutes, a job automatically checks to see if new surface marine data are present on the mainframe. If there are new data available, they are downloaded to the VAX, reformatted to BUFR format, and compared to the first guess/analysis fields. Flags are set on those data that differ from the model/analysis fields by more than specified amounts for each parameter (4 hPa for slp, 8 °C for air temperature, 140° for wind direction, 15 kn for wind speed, 6 °C for SST). Once this is complete, the MPC QC meteorologist may then run QUIPS and interactively perform QC on the platform data. The meteorologist may set keep or reject flags or correct the data as appropriate. Cruise tracks, line plots (showing the platform's data versus the model/analysis fields over the last 8 days), 8 days of history for each platform, and displays of each platform on a map background are available to the meteorologist for use in performing QC to compare the platform's data to neighboring platforms (buddy check). After all flagged platforms are quality checked, the meteorologist selects a menu option within QUIPS that creates a flag file. This flag file contains all keep and reject flags and corrections to data that has just been quality checked. The flag file is automatically uploaded to the NWS mainframe for use by the NWS numerical models.

MPC performs QC during two 8-hour shifts daily (one from 1200 UTC and one from 0000 UTC to 0800 UTC). QC is done to meet the start times of the various NWS numerical models. The manual flags and corrections set by the MPC meteorologist have priority over automated QC flags (i.e., those set the Optimum Interpolation QC (OIQC)). QUIPS software is maintained by NCO.

# Impact of Drifting Buoy Observations on NWP model evolution - a case study.

J Roger Grant[1], Richard J Graham and Michael J Bader

Observation Evaluation Group, NWP Division, UK Meteorological Office
Bracknell, Berkshire, UK

## 1. Introduction

The Observation Evaluation Group investigates cases in which the assimilation of certain observations is likely to have caused an impact on the forecast. The incentive for the work is partly to be cost-effective, partly to evaluate new observations and also to improve the NWP forecasts. The procedure may involve the Global, Local Area or Mesoscale configurations of the UK Met Office's Unified Model.

The numerical forecasts from 27th and early on the 28th of September 1995, valid for 29/1200, incorrectly brought rain from the Atlantic across southern England. The forecast for the southern UK in the Global and the Local Area Model (LAM) runs was not corrected until 28/1200.

The aim of this study was to identify the observations that corrected the numerical forecast. The major difference in the forecast occurred between the 28/0600 and 28/1200 runs of the LAM. The impact of observations assimilated between these two times was investigated. (The reasons for the error in the 28/0600 and previous runs are not addressed here.)

### 2. Synoptic situation

A small depression, Low U (Fig. 1), drifted north from the subtropics. It later decayed into a trough (Fig. 2) and was steered to the southwest of the UK in the flow on the forward side of an upper ridge, downstream of complex Low A. The rain area associated with Low U was therefore kept to the southwest of England.

In the 28/0600 run, Low U was analysed initially too deep and too far north, Low A did not develop enough and the upper ridge was less pronounced. Therefore the remnants of LOW U were steered on a more easterly track towards the UK. In the 28/1200 run the evolution of the upper ridge and Low U were closer to reality.

## 3. Model Experiments

The LAM was run to produce a 30 hour forecast from 28/1200 analysis. There was a 6-hour assimilation cycle between 28/0600 and 28/1200 during which various observation types were assimilated:

All observations (ALLOBS), corresponding to the operational run of 28/1200,
No observations (NOOBS), corresponding to the operational run of 28/0600,
Radio-sonde winds only, temperatures only, humidities only,
Aircraft winds only, temperatures only,
Surface observations only,
Satellite wind data only,
Satellite temperature data only.

The resulting forecasts were compared, mainly using fields of mean sea level pressure (MSLP), 850 hPa wet bulb potential temperature (WBPT) and 6-hour rainfall accumulations although other fields were also available. After the results of these initial runs were evaluated, others were performed as necessary, to identify more precisely the key observations giving the most significant improvement to the forecast.

## 4. Results

4.1 <u>Comparison between NOOBS and ALLOBS</u>

The NOOBS and ALLOBS runs produced the two extremes of the forecasts. The ALLOBS run held back the trough enclosing the remnants of Low U, resulting in a 9 hPa difference by t+24. It was significant that Low A, west of 30°W, had deepened more in the ALLOBS run and the

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downstream ridge was more pronounced.

Fig. 3 shows rainfall accumulations for a 6-hour period. Compared to the NOOBS run (Fig. 3a), the ALLOBS run (Fig. 3b) had less rainfall associated with Low U, the differences over Ireland reaching 8 mm. Later the rain area moved towards Brittany. This evolution, in the ALLOBS run, was much closer to what happened, although the weather radar showed that the actual rain had been advected more quickly to the southeast. The rainfall in the trough from Low A off SW Iceland was greater in the ALLOBS run but there are no data to verify which run is more accurate in this region.

4.2 Comparison between NOOBS and individual data types

Most of the runs using individual observation types did not improve the NOOBS forecast significantly. This result implies that in most cases, where there were observations, the values in the model background and the observations were similar or the differences were not significant.

Compared to the NOOBS run, the run with surface observations (Fig 3c) gave the most beneficial impact, producing significant improvements to the MSLP and the rainfall over Ireland. This run held back the trough, and rain was only forecast for the extreme southwest of Ireland. Comparison with the ALLOBS run (Fig. 3b) showed that most of the impact from all observations had been caught in this run. The surface observations had improved the analysis of Low U and moved it south by 1 degree. Even then, Low U was still about 1 degree north of the manually analysed position.

There were several drifting buoys and a few ships near Low U at 28/1200 and the impact of these observations was investigated. A run using drifting buoy data only (Fig. 3d) disclosed that the main impact was from buoy rather than ship data, both for Low U and Low A. At t+24 the position of the rain area and the accumulations were close to those in the run with full surface data. Another run (not shown) of surface data only but minus the drifting buoys confirmed that the faults of the NOOBS run were still present. It was therefore deduced that the observations from drifting buoys had significantly improved the forecast.

There were two drifting buoys near Low U. The details of the observed MSLP and the model background for the buoy with the most significant differences were:

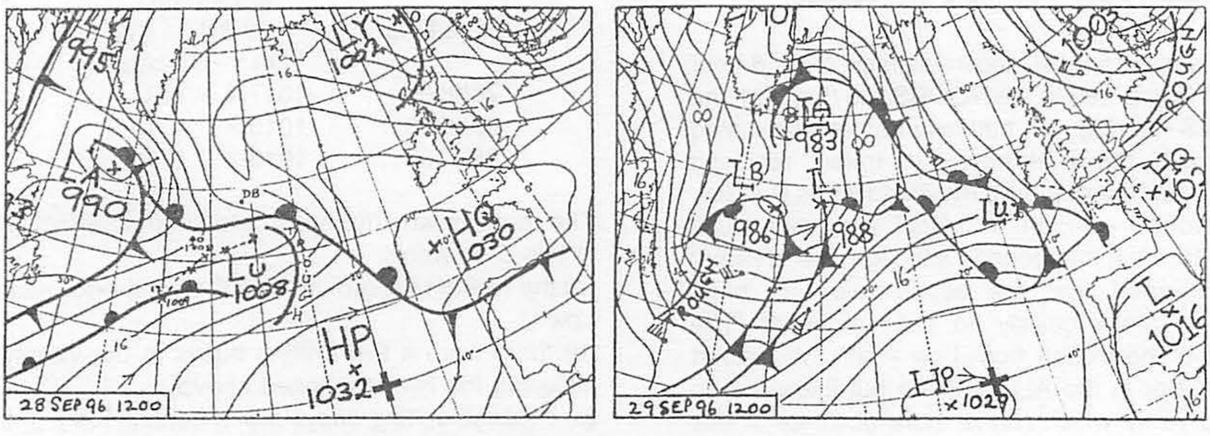
| | DB 44769 | |
|---|---|---|
| Date/time | 53.9N 31.4W | |
| | Ob | Ob-bkgd |
| 28/0600 | 1017.4 | 4.3 |
| 28/0900 | 1015.2 | 4.1 |
| 28/1200 | 1013.2 | 2.5 |

The reasons why the buoy data were so effective in this case were:
(a) the model background MSLP was in error near Low U;
(b) there were a few drifting buoys in the vicinity including the two mentioned above;
(c) because drifting buoys report continuously (the UK assimilation scheme filters these observations down to one per hour or less), they have more impact than ship observations which may only be received once every 6 hours;
(d) the forecast was sensitive to small errors in that area.

## 5. Conclusion

A significant improvement to the 24-hour forecast came from observations recorded by drifting buoys in the Atlantic. These data raised the MSLP analysed near a small depression, weakening its low-level circulation. Evidently the buoys were situated in a particularly sensitive region where small differences in the low-level analysis produced significant differences in the evolution. This case demonstrates the importance of surface data to NWP models.

For other cases these sensitive areas might be identified using ensemble forecasts or sensitivity studies. These areas need particular care in the analysis. One aim of the forthcoming Fronts and Atlantic Storm Tracks Experiment (FASTEX) is to investigate the impact of observations in sensitive areas. As well as having more aircraft reports and radio-sondes, extra ships and buoys will provide more extensive surface observations in the mid-Atlantic.




*Figs. 1 and 2. MSLP hand analyses for 1200 UTC on 28 and 29 September 1995.*
*In Fig. 1, x--x--x shows the track of Low U over the past 24 hours and DB the position of buoy DB 44769.*
*In Fig. 2, ----- shows the leading edge of the rain at 29/1200 deduced from weather radar.*

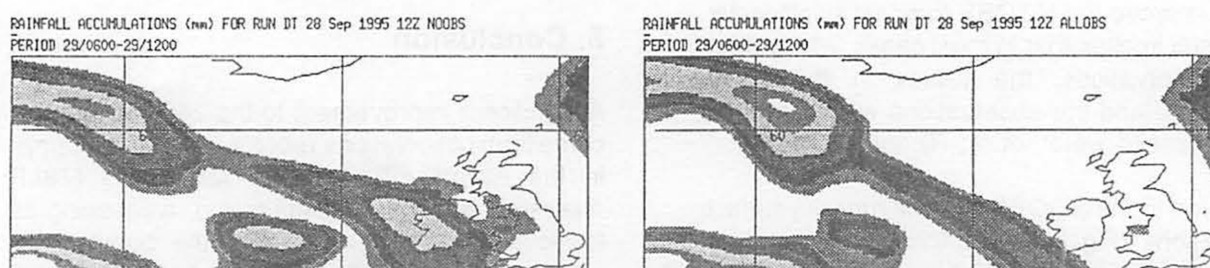



*Fig. 3. Forecast rainfall accumulations in mm for the period 0600 to 1200 UTC on 29 September 1995; runs with (a) no observations, (b) all observations, (c) surface observations only, and (d) drifting buoy observations only.*

## Abstract

*This research forms part of an MSc in Earth Observation Science undertaken at the University of Leicester, England. The European Space Agency's first environmental remote sensing satellite, ERS-1, was launched in July 1991. Amongst its suite of instruments for environmental research was the first of a series of Along Track Scanning Radiometers ATSR-1. Validation of this instrument is carried out with the use of the drifting buoy network. Supplementary data on surface wind magnitudes is provided by daily analysis fields obtained from the Climatological Diagnostic Center (CDC), Colorado USA. Reynolds Weekly Analysis data, also obtained from the CDC, is used to filter spikes in the buoy dataset. Anomalies in the buoy dataset were found. Further analysis on data of this type is considered essential for conclusive validation of spaceborne radiometers.*

## 1. Introduction

In mid July 1991 the European Space Agency (ESA) launched the first in a series of environmental remote sensing satellites, ESA Research Satellite 1 (ERS - 1). Part of the payload comprised the first Along Track Scanning Radiometer ATSR - 1, (here after referred to as ATSR ). The ATSR is a four channel infrared radiometer designed for the accurate retrieval of the Sea Surface Temperature (SST). The primary objective of the ATSR is to measure SSTs to an accuracy better than 0.3K. This is considered as the accepted prerequisite for effective climate research [e.g. *Barton et al.*, 1989 ; *Allen et al.*, 1994].

Measurements of SSTs by satellite borne radiometers utilise upwelling infrared radiances from the upper few micrometers of the sea surface only, termed the sea surface 'skin'. This layer constitutes the top of a millimetre thin molecular boundary layer through which vast quantities of heat are transferred between the atmosphere and the oceans [*Grassl*, 1976]. The ideal way to validate space borne radiometers would be by comparison with coincident sea surface measurements made by ship or buoy mounted radiometers. Logistic constraints both financially and physically, however, limit this type of validation to relatively small areas. For global validation insitu measurements have conventionally been obtained from drifting buoy and ship SST measurements. SSTs from these sources are not of the sea surface 'skin' but can be at several meters in depth. Such temperatures are, by convention, referred to as 'bulk' SSTs. In order to validate instruments, such as the ATSR, capable of measuring SSTs to within 0.3K using 'bulk' SSTs as insitu data it is essential that the nature of the temperature difference, if any, be taken into account.

Previous validation campaigns were conducted with unfavourable atmospheric conditions due to the eruption of Mount Pinatubo in the Philippines [*Thomas et al.*, 1993; *Forrester et al.*, 1993; *Smith et al.*, 1994; *Mutlow et al.*, 1994]. One of the objectives of this research is to extend the results of the earlier validation campaigns where the effect of volcanic aerosols is not a prominent factor. Much of the research centres on the acquisition of coincident data points. Interactive Data language (IDL) is employed for this purpose. IDL is also used for the analysis of the assimilated data. The analysis that is undertaken includes, comparison of ATSR's data products with the drifting buoys, brief comparison of Reynolds analysis fields with the drifting buoys and a brief investigation into the effect of introducing a stipulation that all valid data points be subject to wind speeds greater than $10ms^{-1}$ [*Donlon and Robinson*, 1996].

## 2. The Along Track Scanning Radiometer

The ATSR is a four channel, dual view, self calibrating infrared radiometer. Three of the four channels lie in the infrared region of the electromagnetic spectrum centred about wavelengths of 3.7, 10.8 and 12μm. At these wavelengths the atmosphere is relatively transparent and, in the absence of cloud, a high radiant flux can be received. An additional channel in the near infrared centred at 1.6μm provides information to enhance the cloud clearing algorithms only and has no direct part to play in SST measurements.

In order to achieve the accuracy requirements, the design team have incorporated several novel features. Calibration of the ATSR is achieved by referencing the sensors during each scan with two high precision on-board calibration targets, maintained at temperatures of near 305K and 265K. In order to minimise thermal noise the sensors are cooled using a Stirling cycle cooler to a value well below 95K, close to the theoretical optimum [*Werrett et al.*, 1985; *Bradshaw et al.*, 1985]. The ATSR owes its name to the last major innovation, along track scanning. In an extension to the multispectral retrieval methods developed for the Advanced Very High Resolution Radiometer (AVHRR) instruments [e.g. *Deschamps and Phulpin*, 1980 ; McClain, 1981]. ATSR scans the surface to obtain two views of the same area of sea surface through two different atmospheric paths. This is achieved by a rotating mirror which scribes a conical view of the Earth inclined at an angle such that a nadir view is obtained with a corresponding forward of nadir view. An angle of approximately 55° to the local zenith is obtained with the forward view as illustrated in figure 1. Forward motion of the satellite with respect to the surface allows the ATSR to correlate each instantaneous field of view (IFOV) on the forward swath with a corresponding nadir view. The viewing geometry provides an atmospheric path to the forward view of almost twice that to the nadir. Information can then be derived from the measured radiances as to the magnitude of the atmospheric attenuation, emission and level of scattering. The ATSR also includes an inbuilt microwave sounder which determines the total water vapour column. This data coupled with the previous atmospheric information allows for a high level of atmospheric correction and consequently a more accurate SST can be obtained. A detailed description of the ATSR's design features can be found in earlier papers [Delderfield et al., 1985; Edwards et al., 1990].

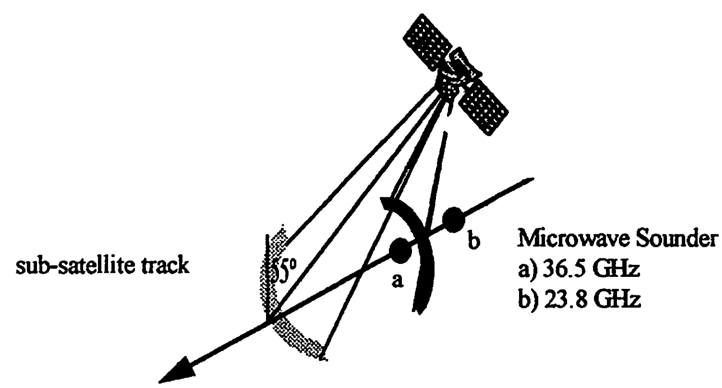



**Figure 1.** Diagram of the along track scanning radiometer (ATSR viewing scheme) showing the forward swath (coloured blue) comprising 371 alongtrack pixels with a resolution of 1.5 x 2km. and the nadir swath (coloured red) comprising 555 nadir pixels with a resolution of 1km. x 1km.

## 3. Cloud - Clearing

Although the chosen infrared regions are relatively unaffected by an uncontaminated atmosphere these regions are almost entirely absorbed by water vapour, severely affecting brightness temperatures. It is essential therefore to remove areas of where cloud cover is prevalent from the dataset. ATSR cloud clearing methods have been derived from those developed for the AVHRR for use over the North Atlantic [*Saunders and Kriebel*, 1988], extended for global coverage. The ATSR dual view and 1.6μm channel allows for several tests to be performed:-

- Nadir brightness temperatures for each channel are tested for consistency.
- Nadir - Forward view differences are recorded.
- Independent tests using the 1.6μm near infrared channel during the day-time.

The performance of the 3.7μm channel is greatly affected during day-time hours by specularly reflected sunlight, referred to as 'sunglint'. It was considered therefore that the telemetry band for the 3.7μm channel could be more productively employed, during daylight by an additional 1.6μm channel to supplement the cloud clearing algorithms. The switch between the channels is achieved automatically and unfortunately is still in effect (post 3.7μm channel failure May 1992). This explains the restriction of the 1.6μm channel to day-time hours. Cloud clearing is highly complex and is still a subject of considerable research.

## 4. Retrieval Algorithm

The SST retrieval algorithm has been shown both empirically [e.g. *Llewellyn-Jones et al.*, 1984; *McClain et al.*, 1985] and theoretically using atmospheric models [e.g. *Barton et al.*, 1989] that the SST can be reliably approximated by the general expression

$$SST_{ret} = a_0 + \sum_{i=1}^{n} a_i T_i \qquad (4.1)$$

where $SST_{ret}$ is the retrieved sea surface temperature, $a_i$ are the linear regression coefficients, and $T_i$ are the cloud free brightness temperatures. With the failure of the 3.7µm channel the algorithm can be confined to two brightness temperatures originating from the channels centred at 10.8 and 12µm. The coefficients are calculated by a standard method of multiple regression using an atmospheric radiation transfer model [e.g. *Zavody et al.*, 1995]. The model uses real atmospheric data provided by UKMO to develop three sets of coefficients to represent the tropical, mid and high latitude zones. Development of local regional coefficients are likely to yield further improvements in accuracy.

## 5. Datasets

### 5.1 The ATSR dataset

The ATSR dataset for this research has been processed at the Rutherford Appleton Laboratory (RAL), using SADIST (Synthesis of ATSR Data Into Sea-surface Temperatures), version 500 [ *Bailey*, 1993]. The SADIST product of concern to this research is the spatially Averaged Sea Surface Temperature (ASST). The ASST contains 512 x 512 collocated nadir and forward view brightness temperatures for the available infrared channels at 10.8 and 12µm and information on day-time cloud clearing from the 1.6µm channel. This image data is then averaged into sample bins of ½ ° latitude x ½ ° longitude. Each bin is further split into 9 ten arcminuite cells. Each of these cells are tested for cloud clearing and depending on cloud distribution within the forward and nadir views contribute to the derived sea surface temperatures within each half degree cell.

In order that a direct comparison of the relative merits of the Dual view verses Nadir view can be carried out it is necessary to restrict the Nadir SSTs to where the Dual SSTs are valid. Analysis of Dual view SST is only considered where greater than three of the ten-arcminuite cells have contributed to the ASST. The global Mixed ASST data for March 17th April is shown in Plate 1 plotted on a Mercator projection.

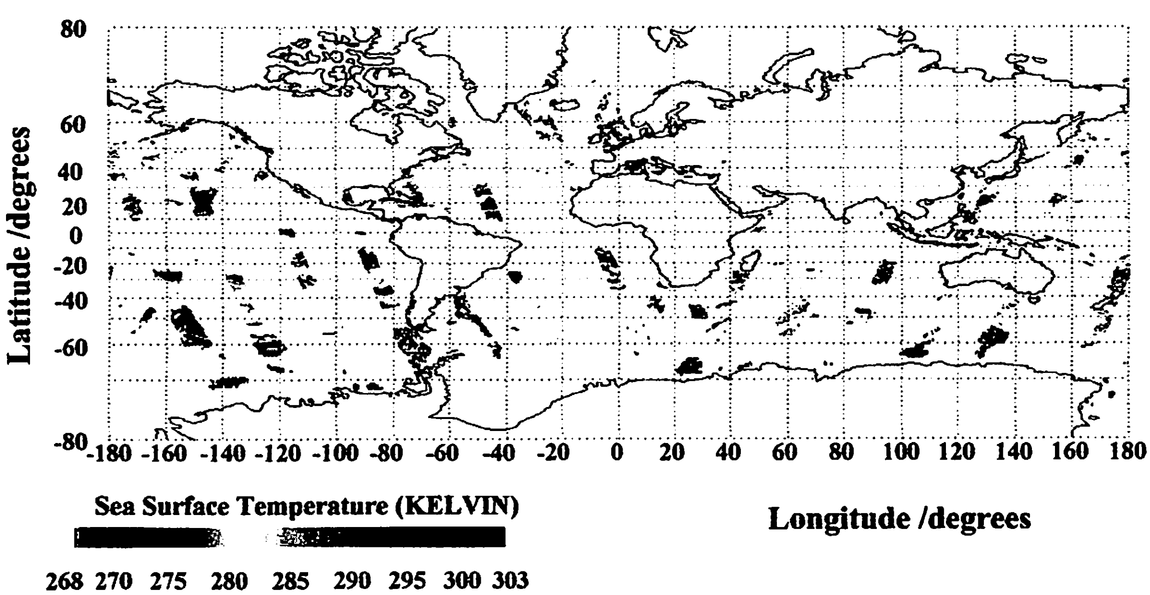



**Figure 2.** ATSR global map of ASST for the 17th March 1995 plotted on a Mercator projection.

**5.2 The Drifting Buoy Dataset**

The drifting buoy dataset was supplied by the United Kingdom Meteorological Office (UKMO) from the Global Telecommunication System (GTS) for the period of 17$^{th}$ March to 15$^{th}$ April 1995. Prior to quality control this dataset comprised some 26000 buoy records. This buoy data was subject to the following quality control procedures. The mean and standard deviation of the difference between Reynolds weekly analysis data (obtained from the Climate Diagnostic Centre (CDC), Colorado) from each buoy SST was used to generate a 3$\sigma$ limit. This limit eliminated any obvious spikes from the buoy dataset. Buoys reporting a constant temperature for the period of the research were also removed as a precaution against malfunctioning sensors. In order for comparisons to be drawn as to the effect of day and night on SST retrieval it is essential that the locations match. A filter was therefore carried out to compare only those buoys which returned measurements both by day and by night.

Global plots of the position of the successful coincident buoys for local day-time, with a sample size of 2883 records, can be seen in **figure 3**.

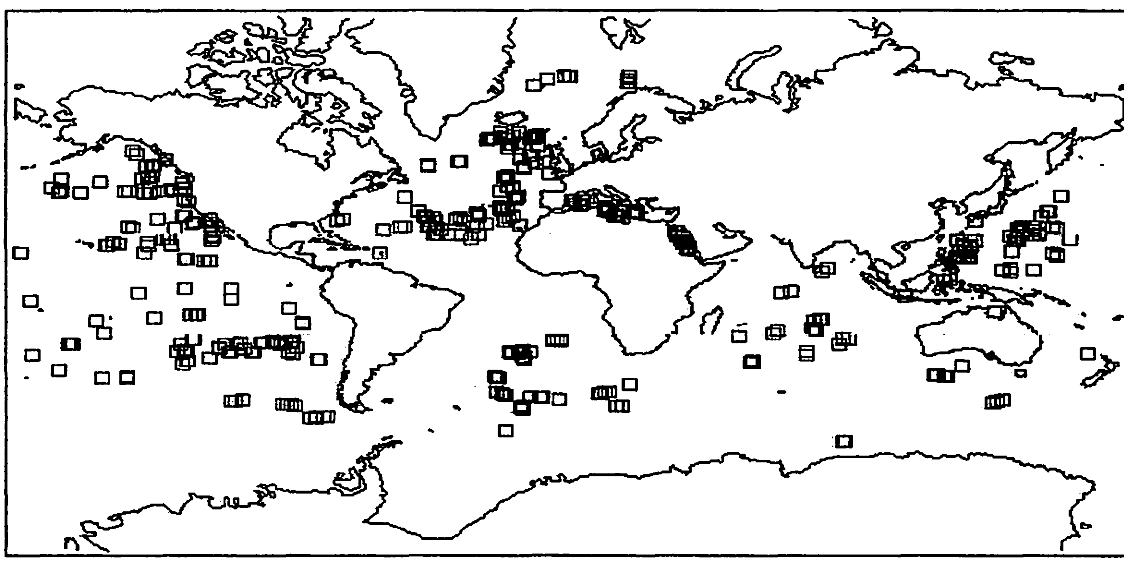


**Figure 3.** Global map of day-time coincident locations of the ATSR products with the drifting buoy network during the research period 17$^{th}$ March 1995 to 15$^{th}$ April 1995. For buoys that return both day and night values.

**5.3 The Resultant Wind Magnitude Reanalysis Dataset (4 x daily).**

The magnitude of the surface wind was calculated from global vector fields of surface winds supplied by National Meteorological Center (NMC), archived at the CDC. During this research the data was employed to investigate, briefly, the effect of magnitudes greater than 10ms$^{-1}$ on the bias of surface skin temperature against surface layer bulk temperatures. This difference has important implications as to the validation of satellite borne radiometers such as the ATSR. Magnitudes greater than 10ms$^{-1}$ have been chosen following recent research findings [e.g. *Donlon and Robinson*, 1996; *Wick*, 1995].

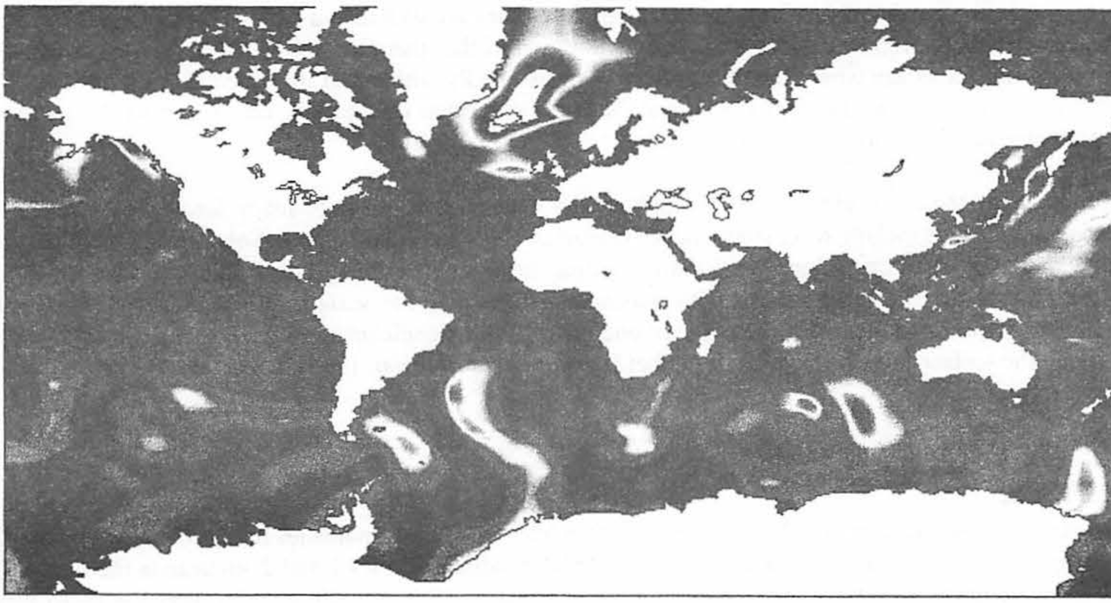
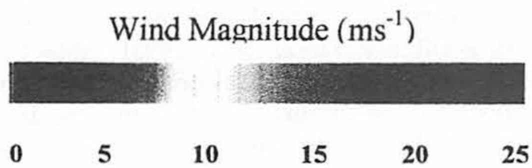


**Figure 4.** Resultant Wind Speed Data for the afternoon of 17th of March 1995.




## 6. The 'Bulk' to 'Skin' Temperature Difference

The surface layer of the ocean is considered to extend down to depths of several tens of metres. From the introduction we recall that the top millimetre of this surface layer represents the molecular boundary layer of which the upper few micrometers define the 'skin'. Although insignificant in terms of depth, it is essential to understand the process of heat transfer through the molecular boundary layer to determine the difference between the bulk and skin temperatures.

### 6.1. The Skin Effect

Between the fluid masses of the oceans and atmosphere there exists a 'no slip' boundary layer, i.e. at the molecular level the oceans are fixed to the atmosphere. As a consequence laminar flow exists within the boundary layer and viscose effects dominate. Heat transfer in this region are by slow molecular processes. Below the molecular boundary layer the fluid becomes turbulent and process of heat transfer quickens considerably. A strong temperature gradient can, therefore, exist across the molecular boundary layer. In general the ocean skin is cooler than the bulk SST as a result of the energy balance at the oceans interface. Solar radiation penetrates the entire surface layer of which only a fraction of the energy is retained by the skin. However, all the outgoing long wave radiation is emitted by the skin as are the sensible and latent heat flux. The net heat flux is in general out of the ocean with the effect of cooling the skin. A global comparison of ATSR skin SSTs - insitu bulk SSTs from drifting buoys should produce a negative bias for this reason.

**6.2. The Diurnal Thermocline**

In the region below the molecular boundary layer the oceans are well mixed and the temperature is relatively constant within the remainder of the surface layer down to the 'thermocline'. The thermocline is defined as the region of the ocean where the temperature changes rapidly with depth. Bulk temperature measurements are largely taken above the thermocline and, with the exception of the skin, can in general be considered representative of the surface layer temperature.

The depth of the themocline varies throughout the oceans as a result of many forcing parameters. The forcing parameters include wind stress, ocean dynamics, tides and solar heating. Solar heating is of particular concern to validation campaigns, particularly 'diurnal' heating. Short wave solar radiation is absorbed in the oceans increasing the temperature, with maximum effect near the surface, where a strong temperature gradient can occur to depths of the order of one metre. With significant wind mixing, rapid transfer of heat through the surface layer neutralises this effect [*Donlon and Robinson*, 1995].

## 7. Results

The results presented can only be regarded as preliminary and some anomalies need to be addressed before arriving at conclusions as to the accuracy of the ASST products. Tables 1 and 2 summarise the results. The results have been further split into a Tropical zone between 25°N and 25°S and a global zone to further investigate some spurious effects at high latitudes.

Day-time results should be more accurate than those obtained during the night in contrast to *Mutlow* [1994]. This is due to better cloud clearing during the day with the additional 1.6μm channel and in the absence of the 3.7μm channel the night-time retrieval algorithm is not as effective [*Zavody et al.*, 1995]. Tables 1 and 2 shows that all the Day - Night differences are positive indicating that the day-time algorithm is now the more accurate as expected. The rms differences before inclusion of the wind filter also show that the day-time algorithm is superior. Caution should be shown, however with the night-time all zone measurements where large rms differences were found.

| | Before the Wind Filter (all wind speeds) | | | |
|---|---|---|---|---|
| **Algorithm** | **Dual - Buoy SST** | | **Nadir - Buoy SST** | |
| **Latitude Zone** | **Tropical Zone** | **All Zones** | **Tropical Zone** | **All Zones** |
| **Day** | - 0.50 ± 0.56 | - 0.50 ± 0.70 | - 0.34 ± 0.62 | - 0.24 ± 0.73 |
| **Night** | - 0.62 ± 0.70 | - 0.82 ± 1.28 | - 0.53 ± 0.71 | - 0.12 ± 3.14 |
| **Day - Night** | 0.12 | 0.32 | 0.19 | 0.12 |

**Table 1** Summary of the Day-Night differences before the wind filter for each ASST Algorithm.

| | After the Wind Filter (wind speeds > $10ms^{-1}$) | | | |
|---|---|---|---|---|
| **Algorithm** | **Dual - Buoy SST** | | **Nadir - Buoy SST** | |
| **Latitude Zone** | **Tropical Zone** | **All Zones** | **Tropical Zone** | **All Zones** |
| **Day** | - 0.38 ± 0.56 | - 0.58 ± 0.66 | - 0.19 ± 0.60 | - 0.27 ± 0.63 |
| **Night** | - 0.49 ± 0.57 | - 0.64 ± 0.70 | - 0.42 ± 0.57 | - 0.45 ± 1.01 |
| **Day - Night** | 0.11 | 0.06 | 0.23 | 0.18 |

**Table 2** Summary of the Day-Night differences after the wind filter for each ASST Algorithm.

Figure 5 shows ASST - buoy data as a scattergraph. The graph illustrates the degree to which the data are attracted to the mean. With an accuracy of better than 0.3K sought, there ought to be a closer attraction than shown.

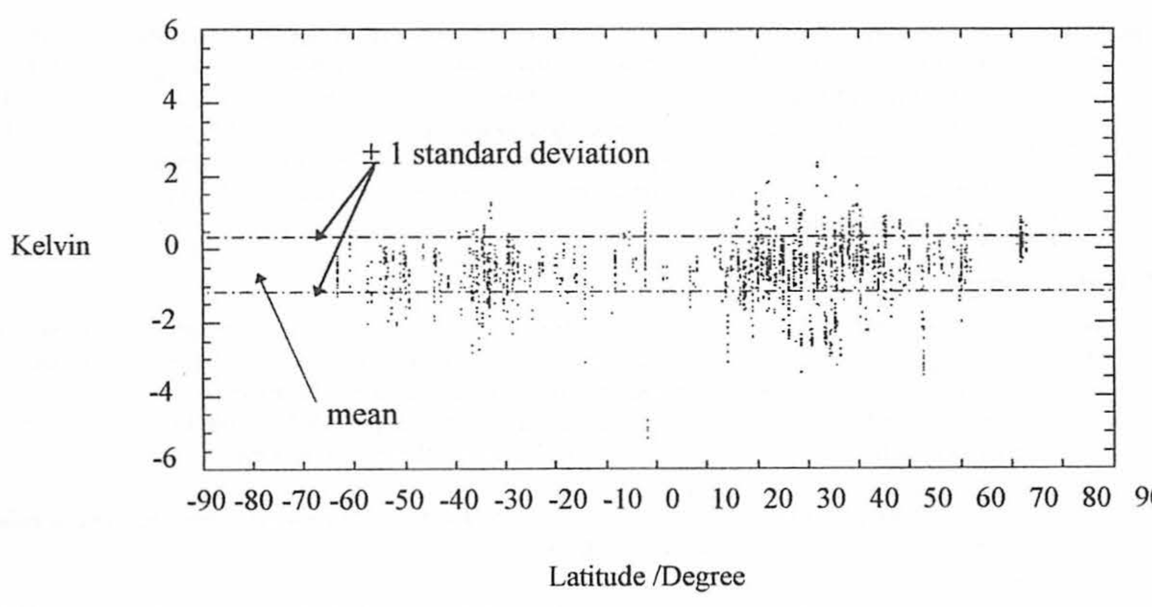



**Figure 5.** Scattergraph of the day-time dual view SST - drifting buoy SST for the time period of 17[th] March to 15[th] of April 1995 (all zones).

## 8. Conclusions

With a validation campaign using large insitu data sets such as the global drifting buoy network it is essential that the quality is ensured. The data set for this research certainly needs further control. One particularly irritating problem came to light late in the research. This involved occurrences of buoys with the same callsign returning plausible data from different parts of the globe at or around the same time. Some returns were noticed where buoys with the same callsign were giving plausible readings then a short time later giving slightly different, but also plausible, readings from a different location. An anomaly on the buoy dataset is therefore present, since a buoy cannot be in two places at or about the same time. A possible explanation is interference with each others transmission. With the demanding accuracy required this slight difference could be significant in areas of large buoy populations. The scattergraph of figure 5 shows little attraction to the mean bias indicating that even with elimination of anomalous buoy data the rms difference is unlikely to reduce significantly.

Although the buoy dataset needs further scrutiny all the expected characteristics of the ASST - buoy SST comparisons were apparent in the results. The day-time algorithm shows itself to be superior to the night - time algorithm in the absence of the 3.7μm channel. The Day - Night differences are all negative indicating that the SSTs are warmer during the day as expected. The Dual - Nadir differences indicate an improvement with the dual algorithm which is less apparent in the Tropical zone. With the introduction of the wind filter where only those coincident measurements are considered when the wind speed is greater than $10ms^{-1}$ the rms difference is, particularly in the Tropical zone, significantly reduced. This should, of course, be tempered by the fact that a very much reduced sample size is being analysed.

Mid and high latitude variation may be as a result of poor cloud clearing. This is the most likely source of errors of this magnitude and needs to be investigated.

This research cannot be specific about the accuracy of the performance of the ATSR instrument without confidence in the insitu buoy data. The buoy data is clearly producing streams of 'almost right' data that is unacceptable in validation campaigns of this accuracy. However it has been shown that, even with the limitations of the drifting buoy dataset, the day-time algorithm in the Tropical zone has an accuracy better than 0.6K. Perhaps the most disappointing aspect of the results was the lack of a firm indicator as to the performance of the dual view which produced only marginal improvements. The largest improvement was as a result of day-time cloud clearing.

## 9. Further work

In order to bring this research up to the standard required for publication it was necessary to improve my knowledge of drifting buoys and their associated datasets. This led me to Henley on Thames and the twelfth session of the DBCP where I obtained the necessary information to address the anomalies with the drifting buoy positions i.e. with reference to the buoy quality control statistics provided via the Internet by Meteo France. Further work shall begin, therefore, with the clarification of the buoy positions.

Restricting the valid ASST data to the case when both the nadir and forward views are clear for eight or nine of the ten-arcminute cells would ensure good cloud clearing.

The ASST data has a resolution of ½ x ½ degree and the buoy measurements are at specific points this highlights an inherent problem of validating spaceborne radiometers with insitu drifting buoy data. Future work may restrict comparison to cells with multiple buoy returns.

During the period of the MSc project the ATSR-2 ASST dataset was unavailable. However, comparison of this new dataset with the ATSR-1 dataset would be of value and a logical extension to this research.

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# Drifter deployments in the coastal waters of the Irish Sea.

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## Introduction

In principle, drifter use in semi-enclosed shelf seas is no different to that in the open ocean, but in practice significant modifications to the operational approach are required. Typically, the geographical extent of features in shelf seas is relatively small, as therefore are distances between buoys, making retrieval a cost effective proposition. Additionally, from an environmental perspective recovery is desirable. In regions where fishing effort is high instrument losses can be significantly increased, whilst rapidly changing bathymetry and shallow water means that drogues can easily become grounded. While there have been studies using drifters on the shelf edge (Meldrum, 1996), in terms of buoy numbers, deployments on the European shelf have been comparatively modest (e.g. Hill *et al.*, 1993).

Recently, the deployment of nine Argos tracked drifters in the western Irish Sea revealed the existence of a stably located seasonal cyclonic gyre above the deep (> 100 m) basin extending north-south through region (Hill *et al.*, 1994). In the Irish Sea, the tide has the form of a standing wave with its velocity node located in the western Irish Sea. For this reason, tidal currents are exceptionally weak (< 0.3 m $s^{-1}$) compared to the rest of the region. The combination of deep water and weak tides means that the western Irish Sea stratifies during the spring and summer heating cycle (Fig. 1) when there is insufficient tidally-generated turbulent energy to maintain mixing against the input of surface buoyancy (Simpson and Hunter, 1974). As stratification forms, the surrounding waters remain mixed and eventually a body of cold dense water remains trapped under the thermocline. Horizontal bottom fronts (Fig. 3) separate this relict winter water from the surrounding mixed waters, and these fronts drive a baroclinic cyclonic near-surface flow in accordance with the thermal-wind balance (Figs. 2 and 4). The gyre is located above a geographically isolated mud patch and in early summer acts to retain the pelagic larvae of the commercially valuable crustacean *Nephrops norvegicus*, which must settle back to the mud to be recruited to the population. Additionally, the circulation may act to retain contaminants in the event of a spring or summer time spill. Knowledge of the system, with these retentive properties, combined with the increase in biological activity that accompanies the development of seasonal stratification and the spin up of the gyre, is crucial for effective management of the region.

In the study of the system, a combination of techniques were used, principally drifters, acoustic Doppler current profiler (ADCP), undulating and conventional CTD measurements and modelling (Hill, 1993; Brown *et al.*, 1996; Hill *et al.*, 1997). In this, satellite tracked Argos drifters played a crucial role in defining the long term circulation and its spatial extent. The deployments peaked in 1995 at 46 drifters, the largest number on the European continental shelf.

During the programme a number of drifter/drogue combinations were used. Here, we review the response of the drifters in relation to the prevailing stratification and techniques used for ship board tracking. In the region, the high fishing effort resulted in significant drifter loss, and a number of strategies to reduce this are discussed.

**Lagrangian circulation in relation to the physical structure**

Prior to 1995, the buoys used were of the IDB/SMBA type (Roberts *et al.*, 1991), fitted with Holey-sock WOCE style drogues 7 m long and 1.5 diameter, centred 23.5 m below the surface. During the 1995 deployments, additional instruments patterned after the Davis CODE drifters (Davis *et al.*, 1982) were used, with drogues of length 2.5 m and 0.7 m diameter.

A survey of the region was undertaken in June 1994 using Scanfish (Brown *et al.*, 1996), a towed undulating CTD, and ship mounted 153.6 k Hz broad band ADCP. Above the deep central basin the water column was strongly stratified (Fig. 1), with two well defined centres ($\phi > 30$ J m$^{-3}$). Contemporaneous drifter tracks (Fig. 2) demonstrate the associated cyclonic circulation, the trajectories corresponding to the maximum gradients in $\phi$. Notably, the drifter deployed in the southern centre (•) moved little over the thirteen days of deployment.

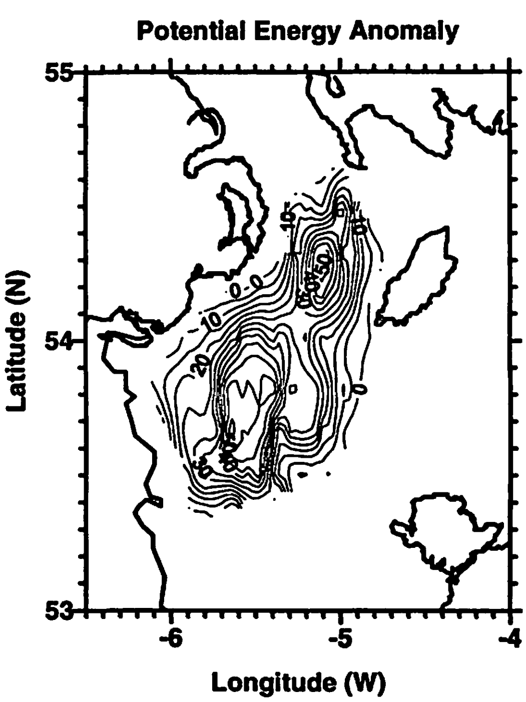



Fig. 1. Stratification (potential energy anomaly, $\phi$ J m$^{-3}$ ), derived from a Scanfish survey of the western Irish Sea 18-22 June 1994. A value of 0 represents mixed water.

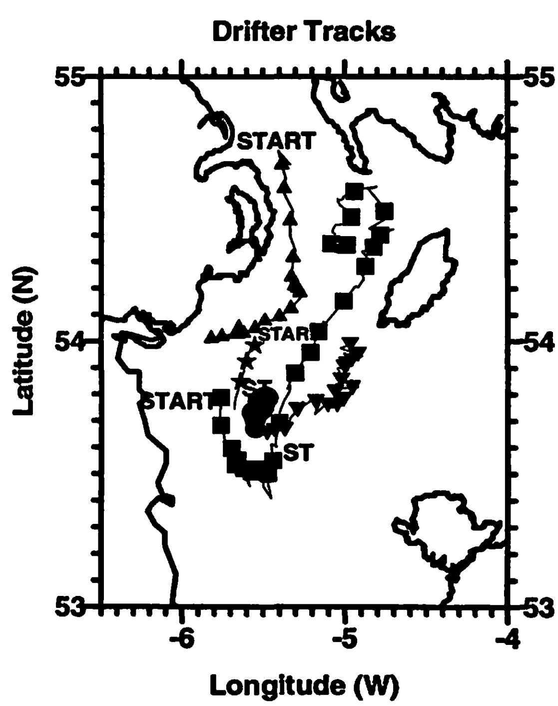
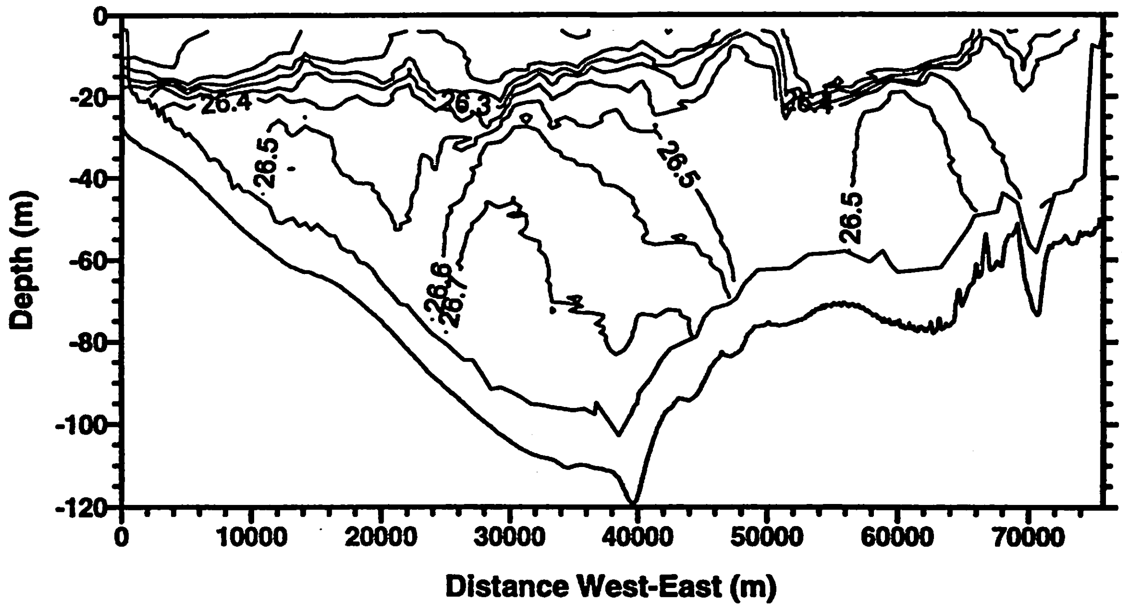



Fig. 2. Trajectories of 5 Argos drifters during the period 13 June - 7 July 1994, symbols showing positions at midnight.

**FIG. 3. Density (sigma-t) Scanfish Leg 59 19 June 1994**
**Start: 53° 40' N 4° 55' W, End 53° 40' N 6° 03' W**




A Scanfish section across the southern centre shows the cold dense bottom water in the central basin, below the surface thermocline and separated from the surrounding waters by horizontal near-bottom gradients (Fig. 3). It is these bottom density gradients that drive the cyclonic near-surface flow in accordance with the thermal-wind balance. The corresponding detided ADCP data (Fig. 4) reveals two cores of flow associated with the bottom fronts, about an essentially stagnant centre.

**Detided ADCP velocities (cm/s)**

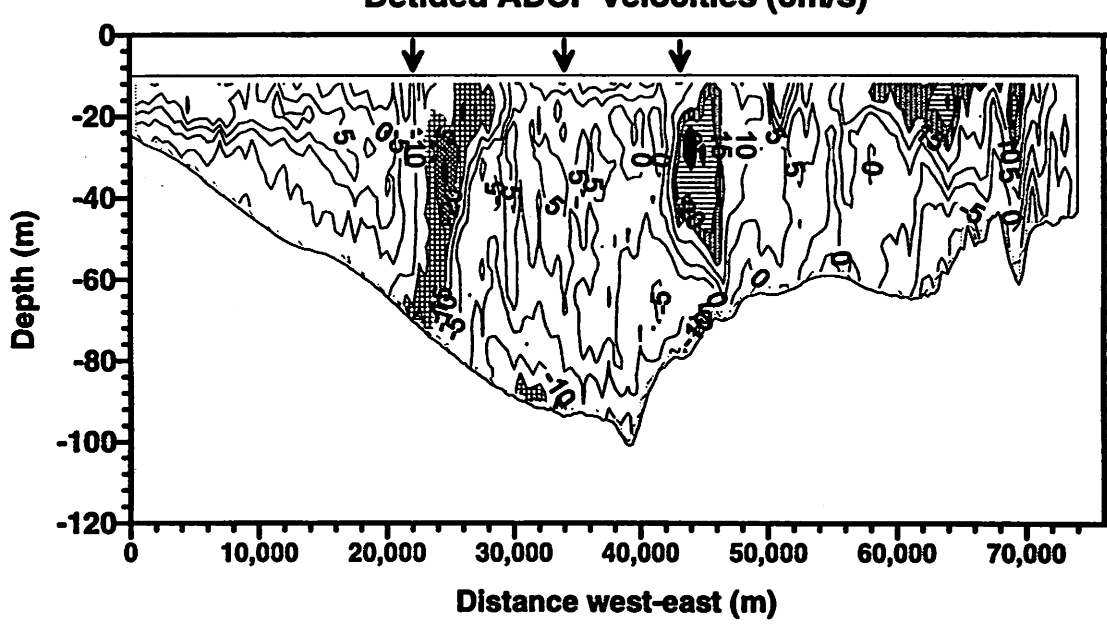


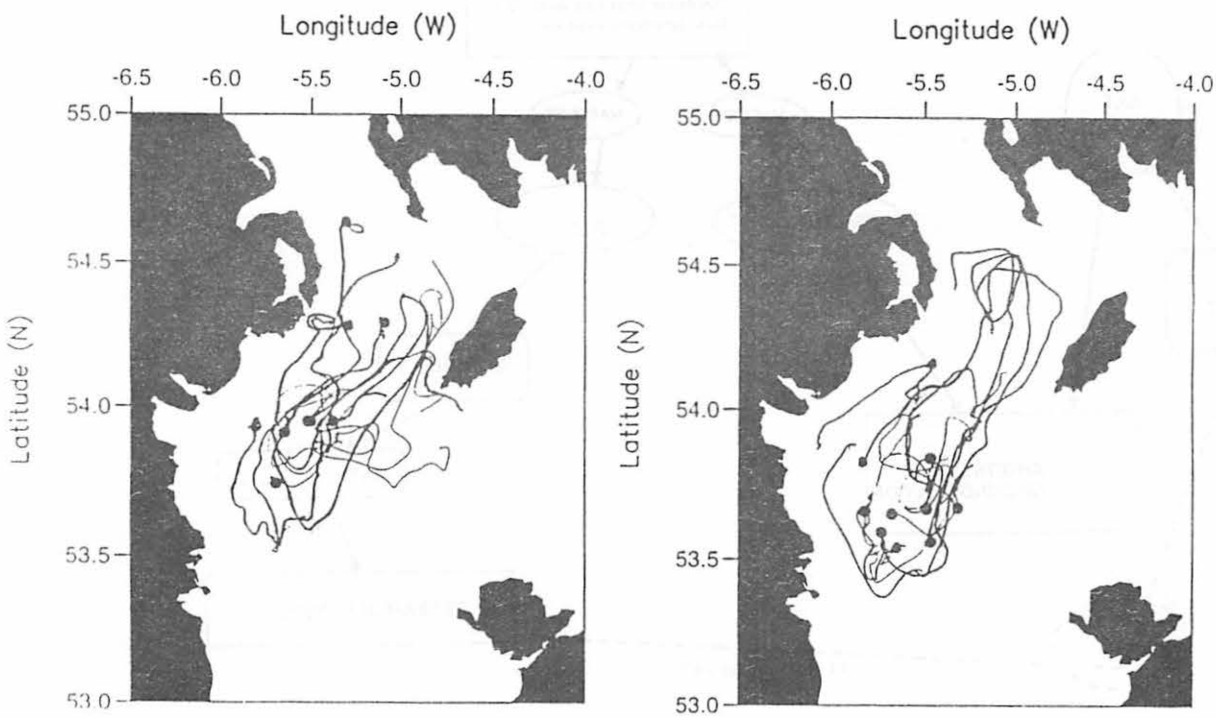

Fig. 4. Detided ADCP data (north/south direction), the hashed areas showing cores of > 20 cm $s^{-1}$, southward on the western side and northward on the eastern side.

Indicated in Fig. 4 are the positions of three drifter crossings (↓) of the section, the speeds of which corresponded closely to those derived from the ADCP data. Deployments in 1995

(Figs. 5a and b; • start position) show a similar pattern of flow. In the early stages of the heating cycle in May, the drifter trajectories largely describe the cyclonic circulation and with increased heating density gradients sharpen and the circulation pattern becomes better defined and less 'leaky'. Here, a combination of IDB drifters and those patterned on the CODE drifters were used, with the drogues previously discussed. The IDB surface platforms are pear shaped, designed to reduce wave rectification. The platforms of the other instruments are cylindrical with buoyancy supplied by four surface floats attached by spars and were also designed to reduce wave rectification. Initially, there was concern that the instrument configurations might respond differently to the flow. Although difficult to confirm absolutely, this did not appear to be the case. In a 120 hour joint deployment of two instruments types, started within 120 m of one another in a region dominated by strong, essentially rectilinear tidal flows, the trajectories corresponded closely and the buoys were separated by only 2.7 km on recovery. Such separation is not at variance with that expected from diffusion processes. Further, the trajectories of the buoys deployed in the gyre are consistent with each other and the ancillary data.

**Drifter tracks**

**May 1995** **June - August 1995**



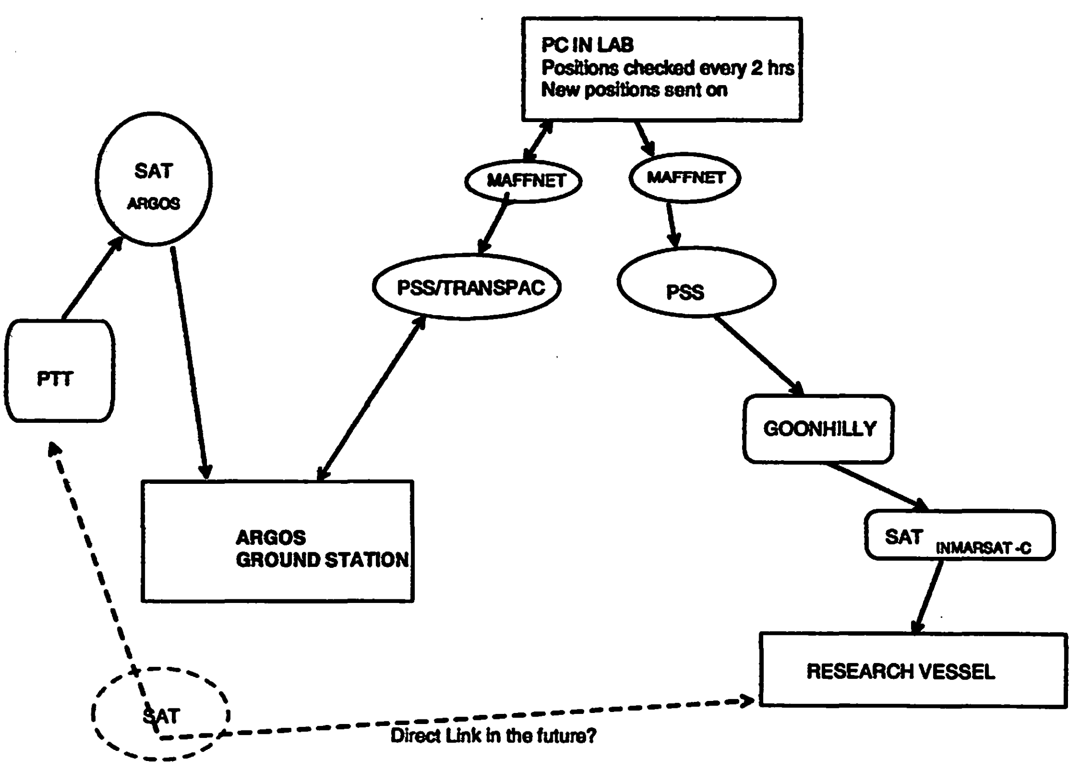

| **1995 Argos Drifters** | |
|---|---|
| **Deployments** | 46 |
| Lost | 7 |
| Cyclonic | 27 |
| Anticyclonic | 3 |
| Southern turn | 9 |
| Northern turn | 3 |
| **Speeds** (August average) | cm $s^{-1}$ |
| East Flank | 15 |
| West Flank | 9 |

Once established, the density structure persists until the autumnal break down in September/October. The deployments in the western Irish Sea show the utility of drifters in defining persistent coherent circulations. This is demonstrated in Fig. 5 and summarised opposite. The trajectories highlight the details and boundaries of the circulation, for example, circulation around the two centres of stratification in addition to the whole area and the tighter and faster eastern flow when compared to the western flank. One drifter performed a complete circuit of the system, taking 42 days at an average of 9 cm $s^{-1}$.

**Operational Considerations**

In shelf seas a number of factors combine to make recovery of drifters desirable and possible. Geographically, regions are comparatively small so that collection is viable and economic and allows further deployments. Environmentally, it is also necessary that an effort be made to retrieve instruments. Efficient recovery requires reliable and current information on buoy positions and because of their size, an accurate means of homing into them when approaching the last recorded position. This information also enables the associated sampling programme to be modified in the light of the buoy trajectories. The *R.V. Corystes* is fitted with Inmarsat C, offering a store and forward utility, which unfortunately does not allow for interactive communication. We have adopted an approach based on PC control of the retrieval and supply of information from our home laboratory (Fig. 6). A program on the PC interrogates the Argos ground station in Toulouse for positional information at pre-determined intervals. It then searches for new up dates, strips out unwanted information and transmits the data to the *Corystes.*

**Data path for position data of buoys to the RV Corystes**




CLS/ARGOS operate an Inmarsat C data distribution service, but the cost associated with the transfer of data to the ship is high, particularly as much of it is redundant for our purposes. At one stage, before refining our programme it cost approximately £2250 to relay the information to the ship for a month, a sum we have now trimmed to about £250. As many network links are required, high traffic loads can occasionally cause the system to fail. In principle, a better approach would be to communicate with the buoys directly or to interact on line with the Argos ground stations. As yet, this is not available to us and might be a more expensive option in terms of satellite time, although this may in part be offset by more flexible use of ship time. Even with our current approach, the latest position for a buoy may be 12 hours old, thereby guaranteeing only a rough fix. To accurately home in on the buoy a GONIO 400 direction finder is used, with a range of typically 10 km. In an attempt to improve signal quality, we have included a length of elastic 'bungee' rubber in the tether between the buoy and drogue providing a degree of decoupling. We had found that in swell the drag imposed by the drogue tended to prevent the transmitter platform from riding the waves. Once in the vicinity of the last known position the buoy is generally recovered within two hours.

As we work in areas where bathymetry can change over short distances a number of drogues have grounded. When this happens, during peak tidal flow the drag on the buoy forces it below the surface, hence ARGOS positions are only received at high and low water. Eventually grounding may constrain buoy recovery to low water as sandy/muddy substrates gradually fill the drogue and often retrieval needs to be from Sea Rider. On one occasion we received VHF signals from a buoy over 2 m beneath the surface. With regular positional information it is possible to assess whether instruments are grounded, enabling rapid retrieval and reducing losses.

Fishing activity, both trawling and static nets, can result in significant data loss, particularly as we work on issues with direct relevance to recruitment and stock management issues and must sample in areas of high effort. To minimise this, considerable steps are taken to liase with representatives of the industry and avoid wherever possible areas of intense fishing effort. We issue daily radio broadcasts giving details of the latest positions. Also, the use of small transmitter platforms is more acceptable.

## Summary

- Drogued satellite tracked Argos buoys are an extremely effect method of describing coherent long term flow patterns in shelf seas, providing information not possible by conventional Eulerian techniques without prohibitive resources. Used in tandem with other measurements they provide a powerful tool for describing the flow field.
- There does not appear to be a significant difference between the response of the two buoy/drogue combinations to the flow.
- Reliable, efficient and current transmission of buoy locations to ships facilitates buoy recovery and pro-active sampling strategies.
- Liaison with other interested parties is necessary to the success of the observations.

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# Satellite Tracking of Marine Mammals

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## INTRODUCTION

In order to understand how marine mammals find and exploit food resources we need first to be able to describe their movements and dive behaviour. To achieve this we have designed and built the Satellite Relay Data Logger (SRDL). This device collects dive behaviour data and relays them via the Service Argos system. We describe below some design considerations and discuss its performance, using Southern Elephant seals (*Mirounga leonina*) as an example.

## SOUTHERN ELEPHANT SEALS

Southern elephant seals spend about ten months at sea, interrupted by two bouts on land of around 3-4 weeks each: in November when they breed, and between January and March when they moult. The largest moult and breeding site is at South Georgia in the South Atlantic. At the start of the study we were aware of some aspects of elephant seal behaviour which influenced the design of a telemetry system:

1. They are capable of long distance travel (>1000 km) and thus a global data collection and location determining system is needed. Only Argos could satisfy this requirement.

2. They can dive to over 1500 m, thus the package must be robust, but small enough not to impede swimming.

3. On average dives last 20 - 30 minutes (although they can last up to two hours). Thus data collected during a dive must be stored in memory.

4. Surface periods last about 2 minutes. Thus transmission sequences must be triggered immediately upon surfacing.

5. While at sea, only ten percent of their time at sea is at the surface, restricting the uplink rate. Thus data, rather than being sent in their raw form, must be processed into *dive, summary* and *haulout* records and compressed to a high degree.

### SATELLITE RELAY DATA LOGGER (SRDL)

The resulting SRDLs consisted of a datalogger interfaced to an Argos RF unit (Microwave, US). Data from a depth sensor and a submergence sensor were used to determine the activity of the seal: either a '*dive*' (deeper than 6 m for at least 6 s), a '*haulout*' (dry for at least 240 s) , or else at the '*surface*'. Distance swum was determined by a turbine odometer. Individual dive records included information on maximum depth, depth profile, distance swum, and dive and previous surface duration. Dive and haulout records stored in memory were selected for transmission, such that those times of day, when the Argos satellites were unavailable, were adequately represented. The current (1996) SRDL model weighs 0.45 kg and is 130 cm long.

On elephant seals the SRDLs were attached with a two-part rapid setting epoxy resin on the back of the neck just behind the head, so that the aerial would emerge when the seal surfaced.

### DATA PROCESSING AND ANALYSIS

Uplink and location, and derived dive, summary and haulout data, were stored on an Oracle database. A location filtering algorithm (McConnell *et al.*, 1992) was used to flag inferior quality locations. The resulting track and behaviour data were visualised and explored using a specially written visualisation system (MAMVIS, Fedak *et al.*, 1996) running on a Sun Sparc 10/30 with a Freedom 1000 graphics accelerator.

### SYSTEM PERFORMANCE

Twelve seals tagged on South Georgia between 1990 and 1994, each produced an average of 119 days of data. Their tracks are shown in Fig. 1 (McConnell & Fedak, 1996). Females either travelled eastward, up to 3000 km away to the open Southern Ocean, or to the continental shelf on or near to the Antarctic Peninsula. Males either stayed close to South Georgia or used South Georgia as a base for shorter trips.

The Argos system performance data have been analysed for a similar study of the movements of 34 elephant seals at Macquarie Island, Australia, in 1995 and are presented in Fig 2. The mean transmitter longevity was 66 days. Failures though, were bimodally distributed through time (Fig. 2a), the second peak at around 130 to 150 days was probably due to battery exhaustion. The mean daily uplink and location rate was 13.1 and 3.0, respectively (Fig. 2b,c). The higher uplink and location rates occurred when the seals were still ashore before departure.

Despite the low uplink and location rates, we have found Argos to be an appropriate tool to study at-sea behaviour of seals. Future planned improvements, such as higher data transfer rate and increased receiver sensitivity, will certainly improve the utility of Argos to marine mammal scientists.

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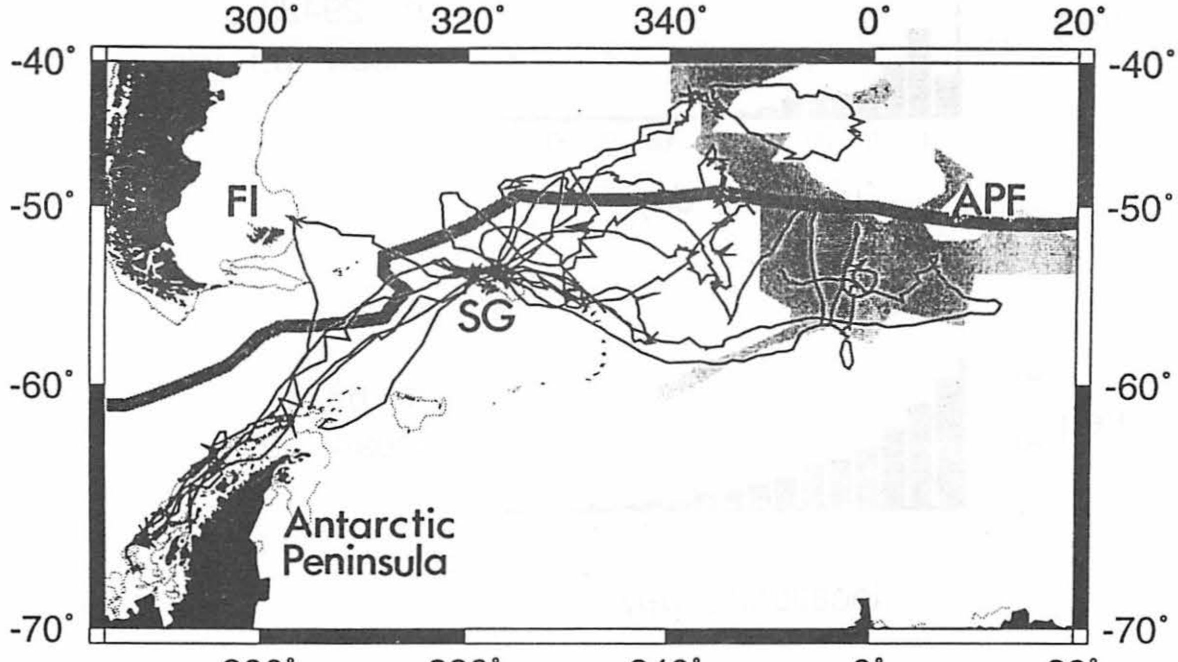


Fig. 1. Tracks of twelve southern elephant seals tracked from South Georgia (SG). The thick line represents the Atnarctic Polar Front. The hatched area represents the mid Atlantic Ridge.

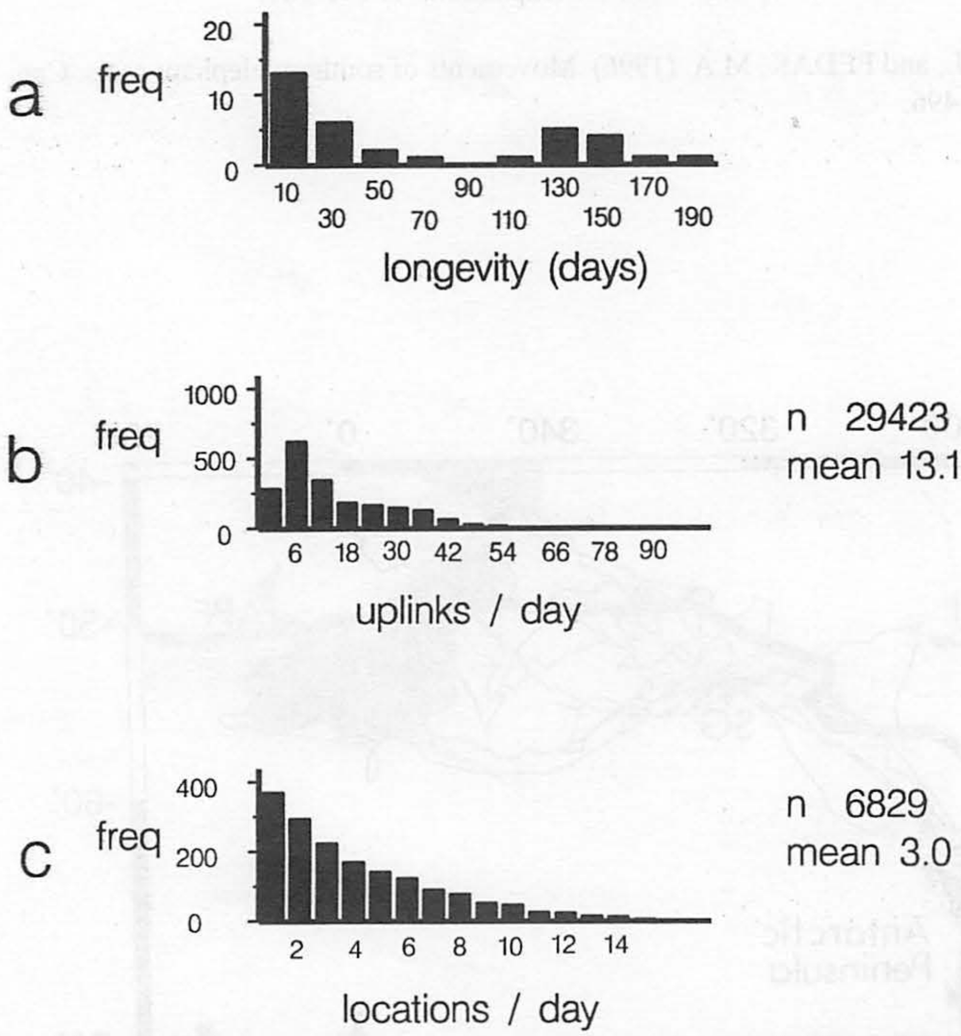


Fig 2. System performance from a deployment of SRDLs on 34 southern elephant seals at Macquarie Island in 1995. The three graphs show frequency distributions of SRDL longevity (a.) and daily uplink and location rate (b. and c.).

# LOCATION ACCURACY OF GLOBAL LAGRANGIAN DRIFTERS

Mark Bushnell, NOAA/AOML-Global Drifter Center

To determine the accuracy of Argos locations for drifting buoys, test data prior to deployment has been examined. Drifters of the SVP type described by Sybrandy and Niiler (1991) and the SVPB type (Sybrandy et al, 1995) were activated for several days in order to test the transmitters. In many cases, assistance from Argos and Telonics personnel confirmed that the transmitters were satisfactorily operational, and their help is gratefully acknowledged. In fact, all tested transmitters passed the test.

Initially, the tests were conducted by providing the drifter's transmitter with the clearest possible transmission path. They were removed from the shipping containers and shrink wrap, and moved to a clear open field. However, it soon became apparent that the drifters easily transmitted from within the storage warehouse, and by the end of the test drifters were left in the cardboard boxes. A small incision in the shrink wrap allowed removal of the starting magnet while retaining the packaging integrity. Drifters were left inside the warehouse, which has a wooden roof. While far from replicating a drifter deployed in the open ocean, the impediments to these drifter transmissions were offset by several advantages they had over a deployed drifter, such as; a) an entirely dry surface float, never submerging during a satellite pass, b) by holding the drifter motionless, there are no motion induced errors from currents and waves to degrade the determination of the Doppler shift, and c) fresh batteries. To their disadvantage, transmissions from the tested drifters not only experienced impediments from the packing and the warehouse, but the background RF levels in the city of Miami are considerably higher than would be seen in the open ocean. It is a testimony to the sensitivity of the Argos receiver that the test transmissions were received so well.

To examine the impact of these advantages and disadvantage, the distribution of location classes was examined during the test and again after deployment. If the drifters experienced hindered transmissions during the test, it should be seen as a shift towards a lower position class. Figure 1. shows histograms of the Argos classes 0, 1, 2, and 3 before deployment (left panel) and after deployment (right panel), for standard drifters (top), drifters fitted with barometers (middle), and the combination of the two (lower). In all cases, positions prior to deployment had higher location classes (more accurate positions) than after deployment. Consequently there is no valid reason to expect higher accuracies after deployment, and the values given below should be interpreted as the best case expectations.

Additional historical tests from the period 1982-1989 were also examined for comparison to these recent results. These tests were conducted using an earlier drifter design described by Bitterman et al (1990) and built at NOAA/AOML, again using Telonics transmitters. Over 14,000 positions from more than 400 drifters were used to compute the standard deviations.

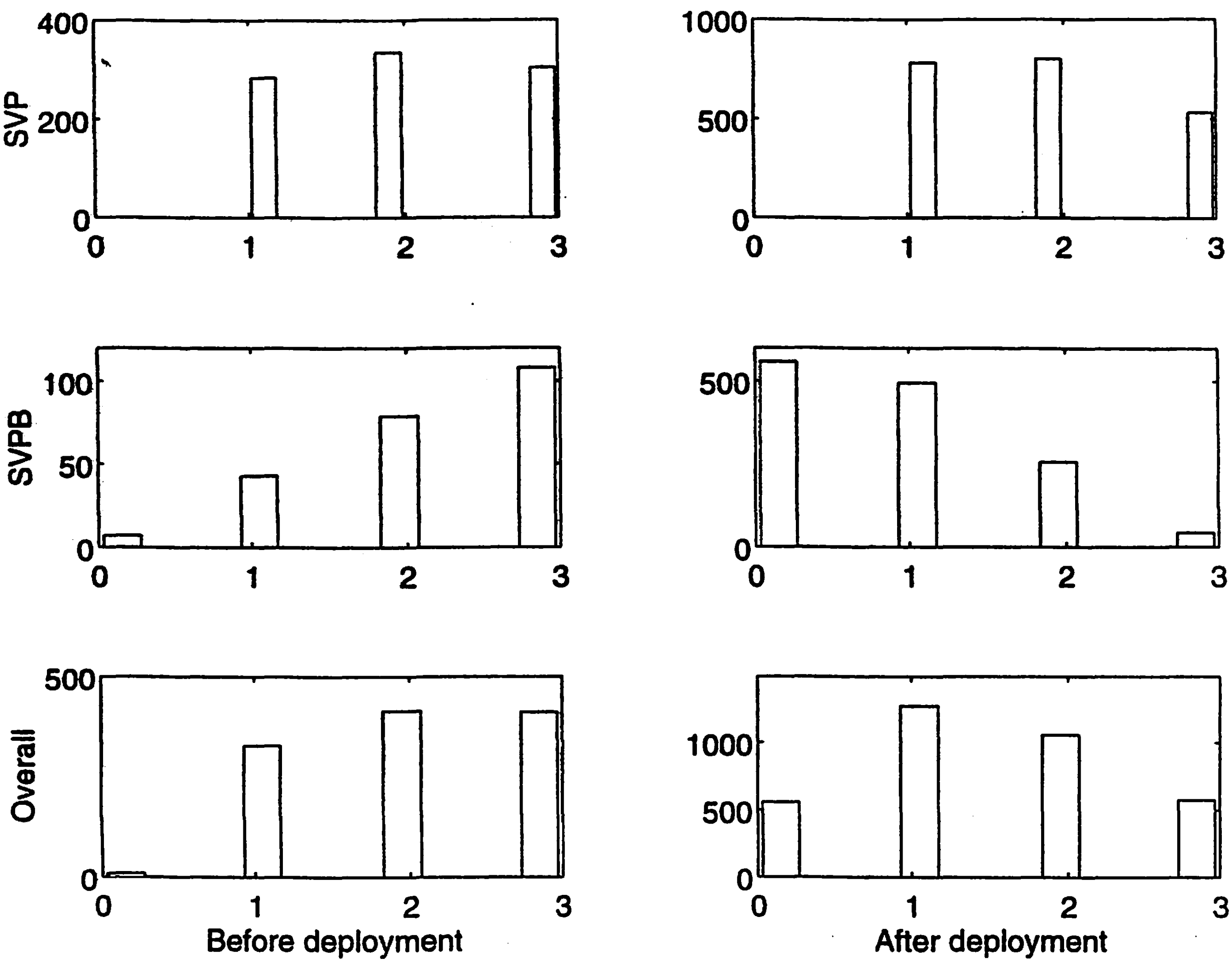


Figure 1. Histograms show the distribution of Argos classes 0, 1, 2, and 3 before deployment (left panel) and after deployment (right panel), for standard drifters (top), drifters with barometers (middle), and the combination of the two (lower). In all cases, positions prior to deployment had higher location classes (more accurate positions) than after deployment.

The results are summarized in Table 1. For the recent tests, class 2 and 3 positions show standard deviations slightly higher than the Argos estimates. Class 1 positions have standard deviations slightly lower than the estimated Argos values, and the standard deviations of class 0 positions do in fact exceed 1000 meters. Curiously, the SVPB drifters appear to provide more slightly accurate positions than the SVP drifters prior to deployment, but after deployment the performance of these SVPB drifters is considerably degraded, seen as a large shift towards lower classes after deployment in Figure 1. Combining the classes to compute an overall standard deviation yields about a 500 meter error. Since few investigators can afford to further reduce data holdings by selecting only the highest location classes, this overall value should be used when making generalized statements regarding the accuracy of the drifting buoy positions. When comparing this overall value to the overall standard deviations of the positions from the older drifters, no significant change is noted.

TABLE 1.

| Argos location class | n | observed standard deviation (meters) | | Argos estimated accuracy (meters) |
|---|---|---|---|---|
| | | lat | lon | |
| 3 | 411 | 233 | 244 | 150 |
| 2 | 413 | 377 | 400 | 350 |
| 1 | 326 | 755 | 978 | 1000 |
| 0 | 9 | 1645 | 6589 | >1000 |
| SVPB | 237 (41 PTTs) | 275 | 462 | na |
| SVP | 920 (89 PTTs) | 528 | 616 | na |
| Overall (recent) | 1157 | 500 | 594 | na |
| Overall (historical) | 14362 | 367 | 656 | na |

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# Applications of GPS within the LOIS Shelf Edge Study drifter programme

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## INTRODUCTION

The Land-Ocean Interaction Study (LOIS) drifter programme was designed to investigate the Hebrides slope current and nearby circulation patterns, with particular emphasis on exchanges between the shelf and the deep ocean. The vast majority of the 49 drifters released used the WOCE Surface Velocity Programme (SVP) drifter as the basic design element, modified to accommodate additional sensors and processing. These drifters have been tracked using the well-established Argos satellite system. The system has many limitations, and it was decided to modify a small number of drifters to demonstrate the advantages that could accrue from incorporating a Global Positioning System (GPS) antenna and receiver. The design goals to be addressed using GPS were:

- Fix accuracy of 50 m or better (c.f. ~500 m with Argos)
- Fix interval of 20 minutes (c.f. ~2-3 hours with Argos)
- No gaps in the fix record, despite gaps in the satellite passes (c.f. gaps of up to 6 or more hours with Argos)

## SOME RELEVANT FEATURES OF THE ARGOS SYSTEM

### Gaps in coverage

It should not be forgotten that the Argos data collection system is carried as a passenger on board the NOAA weather-imaging satellites. The prime purpose of these 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 1, which shows every pass of the two operational NOAA satellites that would be seen by a drifter at 57° N during September 1995. A salient 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 ensure that a sufficiently large stack of historical data is transmitted to bridge the largest expected gap in the satellite coverage. In our case, at a latitude of approximately 57°N, gaps in coverage can exceed five hours (Figure 2), which implies a stack of at least that length. The situation is, however, better for experiments lying closer to the poles, because of the convergence of the sub-satellite tracks of polar orbiters at high latitudes.

**Location accuracy**

Because of the data that we have accumulated over the last year from Argos transmitters (Seimac and Telonics) under test at our laboratory, an opportunity arose to perform an independent verification of Argos accuracy. Figure 3 shows the ensemble of 412 fixes of classes 1, 2 and 3 that were collected. Table 1 lists the measured accuracy for the various location classes, and for GPS.

| | East (m) | North (m) | No of fixes |
|---|---|---|---|
| ARGOS | | | |
| Location quality 1 | 1440 | 790 | 130 |
| Location quality 2 | 540 | 390 | 150 |
| Location quality 3 | 310 | 390 | 132 |
| GPS | | | |
| Uncorrected for SA | 36 | 21 | 94 |
| Post-corrected for SA (DGPS) | 4 | 6 | 94 |

**Table 1.** Measured standard deviations of various systems.

## THE GLOBAL POSITIONING SYSTEM (GPS)

The system is implemented using a constellation of 24 or so satellites in high orbit, ensuring global operability round the clock. The GPS receiver is passive - it does not transmit - and estimates its range from each satellite in view 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 message, 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 operated by the US Department of Defense, who currently exercise 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-$\sigma$ error in computed GPS locations from a few metres to about 100 m. In our application, these errors can be removed by post-processing if required.

## A GPS-ARGOS DRIFTER

A five-hour stack of GPS fixes plus other sensor data at 20 minute intervals is too big to transmit over Argos in a simple-minded way. The solution we have employed is to compress the GPS data by transmitting only the significant parts of it, namely the fine-scale resolution which is not achievable by Argos, and by using the Argos location to define the coarse position, or 'lane'. Full technical details are given in the DBCP Technical Document No 7 - Developments in Buoy Technology and Enabling Methods - obtainable from the Technical Co-ordinator of the Data Buoy Co-operation Panel, c/o CLS Argos, 8-10 rue Hermès, 31526 Ramonville St. Agne, France.

Three prototype GPS drifters have been built (see Figure 4) and deployed in the north Atlantic. Figure 5 shows Argos and GPS tracks over a period of about five days; Figure 6 expands the scale to show a one-day section of track. In both cases the greatly improved resolution of the GPS track in both space and time is evident. Data recovery exceeds 95%, though some loss of data around midnight is still evident.

## DIFFERENTIAL GPS (DGPS)

The intentional errors introduced by Selective Availability may be largely removed by noting the position errors at a fixed base station, and subtracting them from drifter positions computed using the same set of satellites at the same time. This form of DGPS was implemented in the SES GPS drifters by inserting the satellite IDs and exact time of fix into the data stream sent over Argos. Figure 7 shows the improvement in location accuracy that results from DGPS. The noise in the position measurements is probably below 10 m.

## SUMMARY OF SOME POSSIBILITIES OF GPS FOR DRIFTERS

The fundamental point is that both position and precise time are known to a drifter carrying a GPS receiver. This opens up a whole host of possibilities for the drifter of the future, capable of adapting its behaviour in response to this knowledge. Some of these potential capabilities are listed below:

- Accurate Argos satellite pass prediction, permitting transmitter scheduling and dynamic data stack management;
- Activity control according to position, permitting (for example) the drifter to shut down when leaving a pre-defined area of interest, and to re-start on re-entering it;
- Activity control according to time (of day, of year);
- More accurate locations, at user-defined intervals (ideal for small- and meso-scale studies), with the possibility of achieving 10-m precision using differential post-processing.

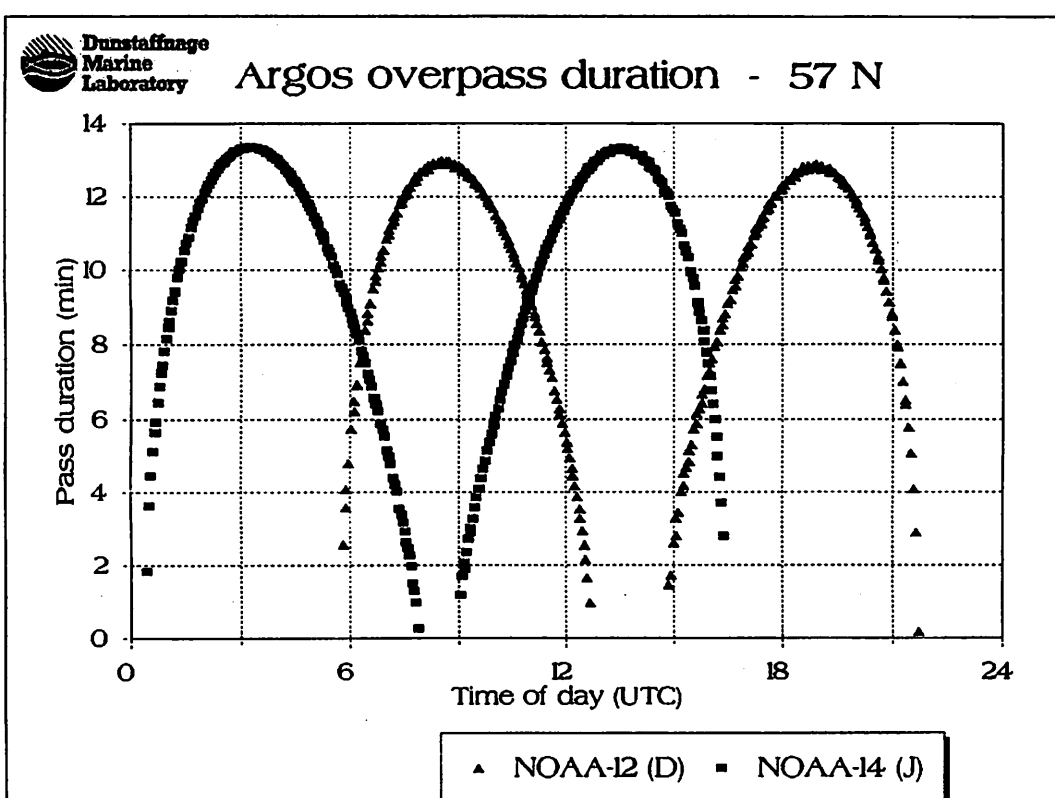


**Figure 1.** Overpass durations for the month of September 1995 at 57°N. Note the gap of several hours around midnight, which normally means that no data are collected at these times.

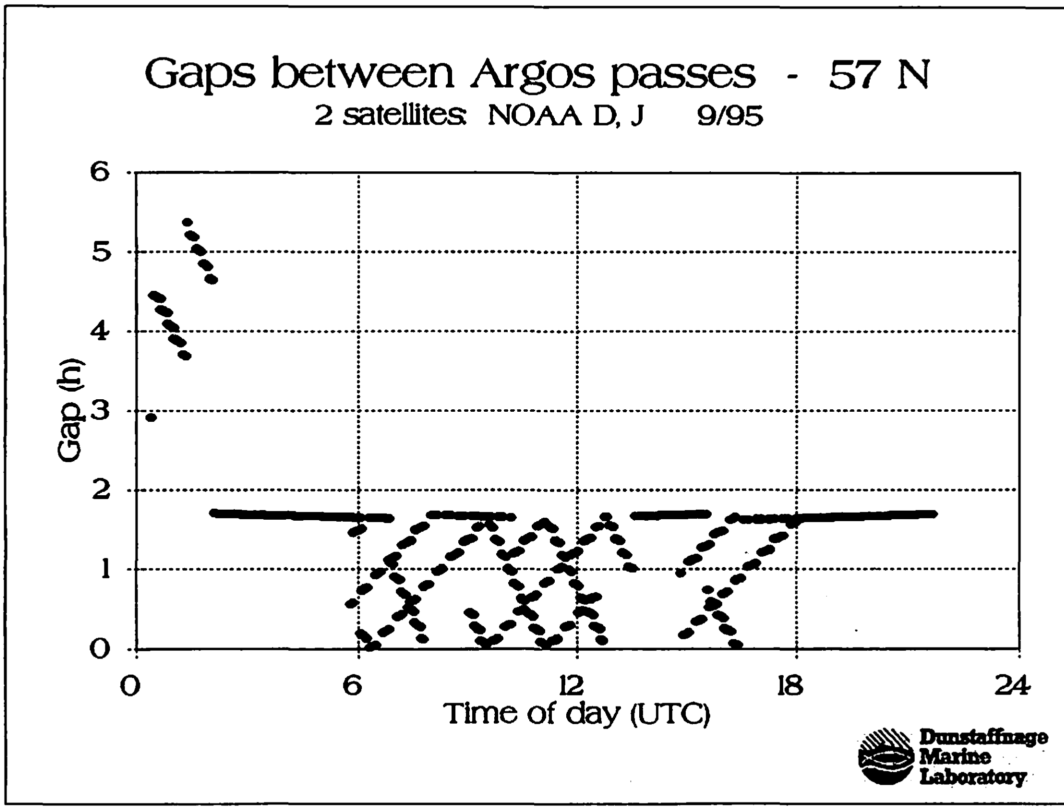


**Figure 2.** Gap size as a function of time of day. The size of the midnight hole is more than five hours on occasion, and will be worse at lower latitudes.

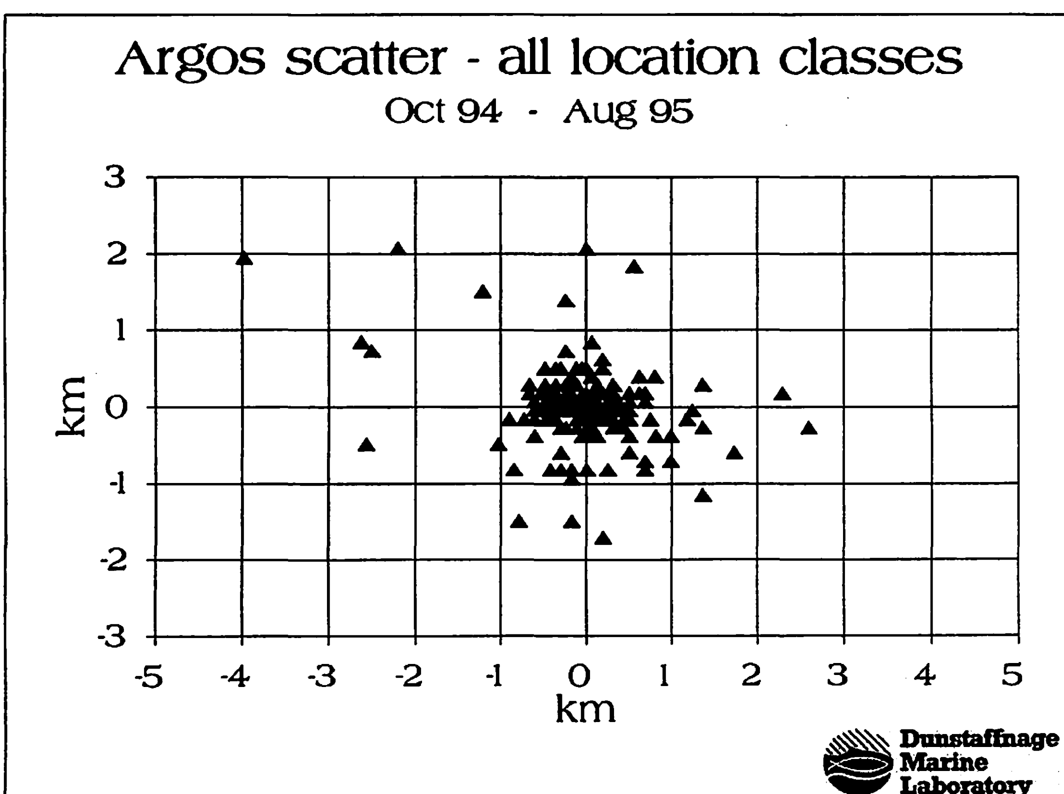


**Figure 3.** Measured Argos accuracies at Dunstaffnage for transmitters under test. Location classes are 1, 2 and 3.

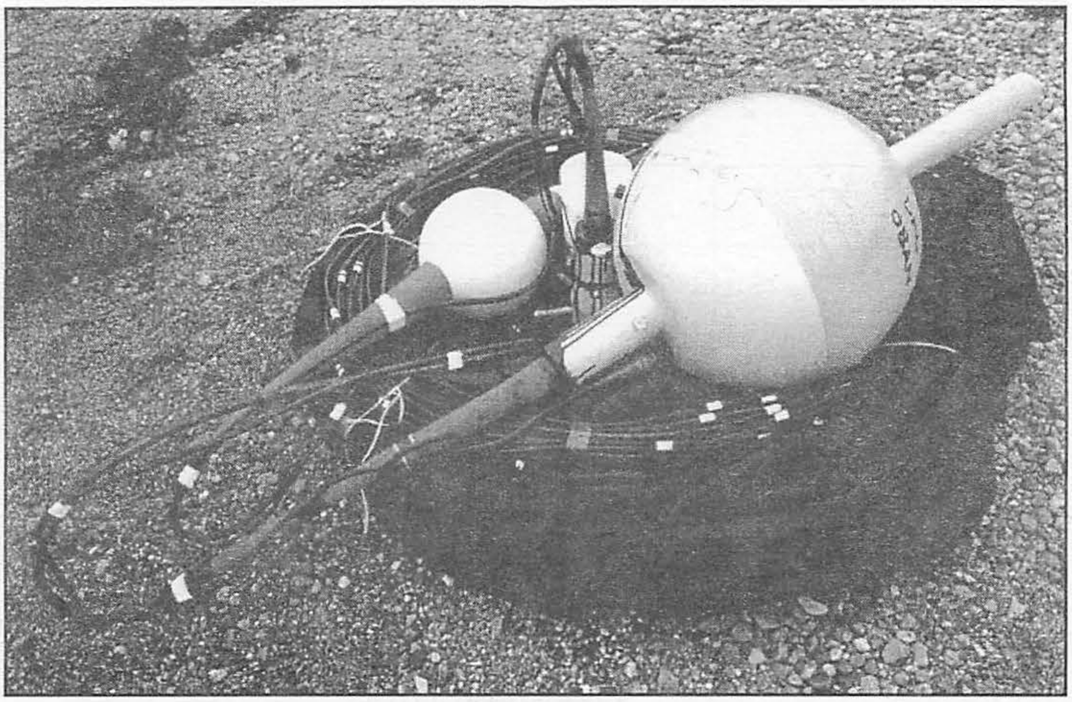

**Figure 4.** A prototype GPS-Argos drifter, generally conforming to the WOCE SVP standard, on the beach at Dunstaffnage.

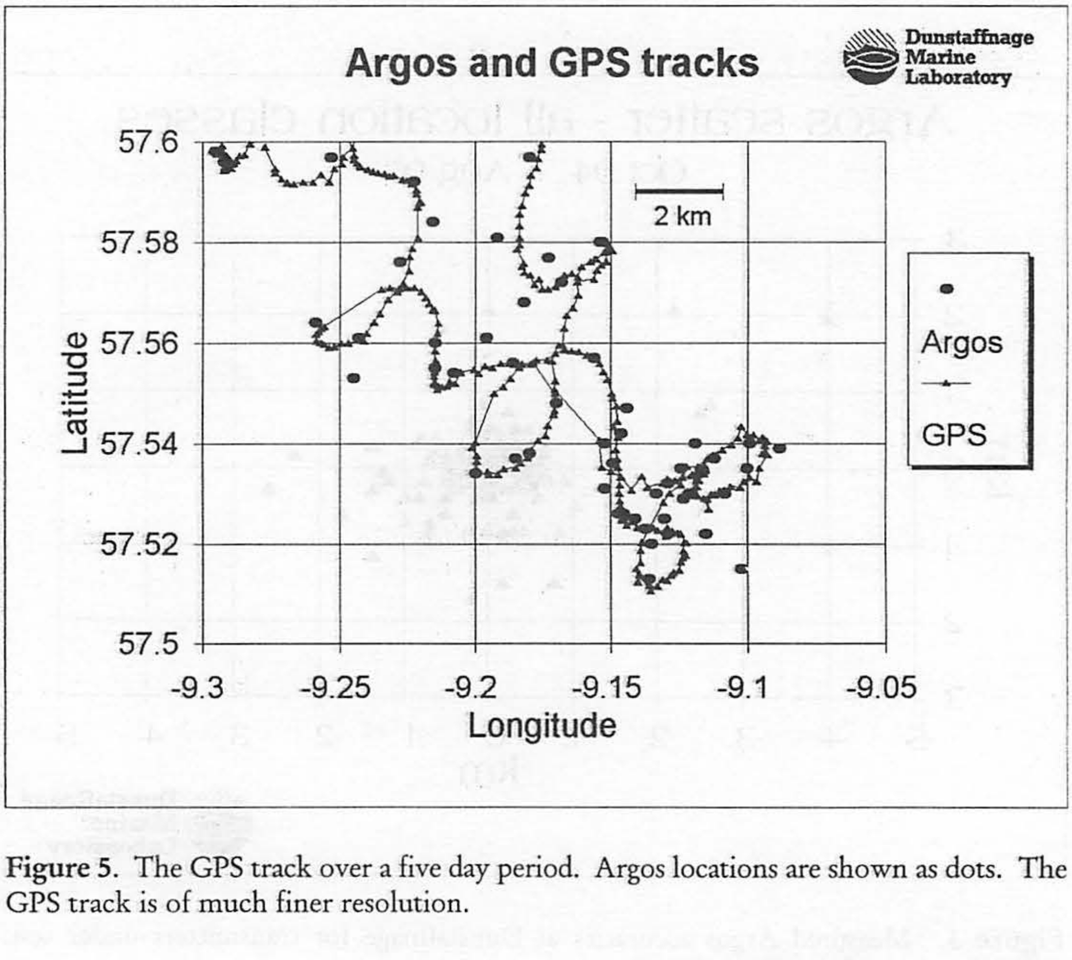


**Figure 5.** The GPS track over a five day period. Argos locations are shown as dots. The GPS track is of much finer resolution.

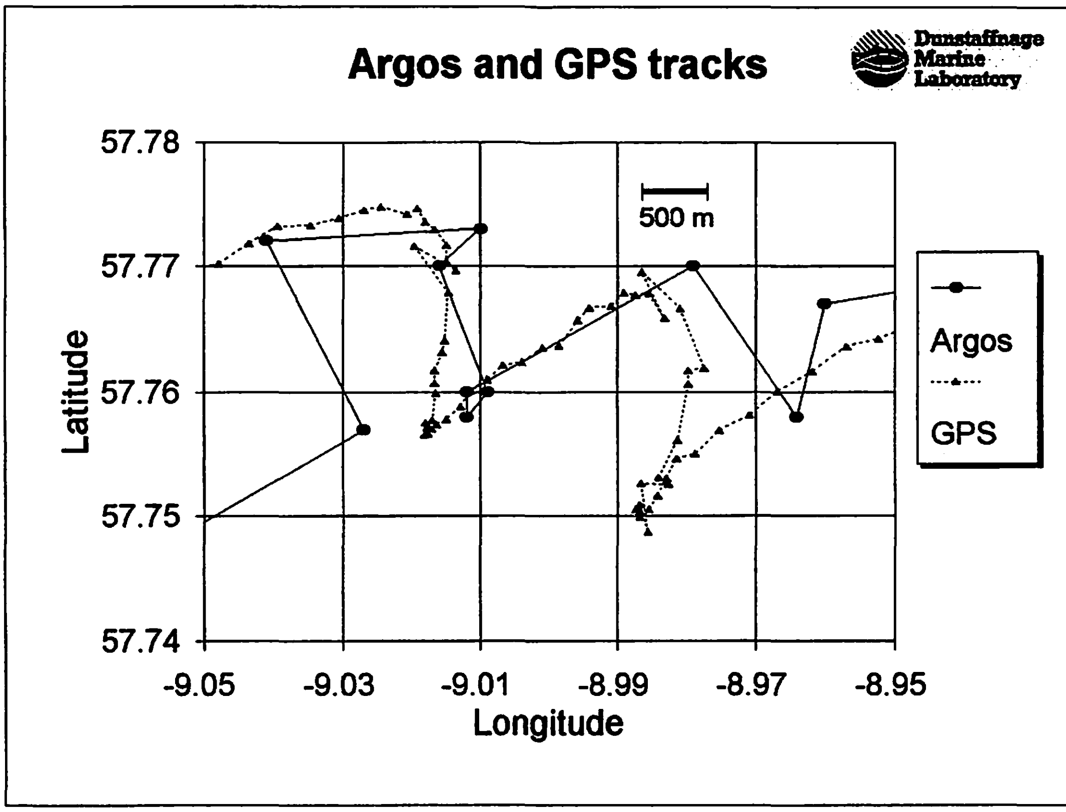


**Figure 6.** GPS and Argos tracks over a one day period. The detailed drift is very difficult to infer from the Argos locations alone.

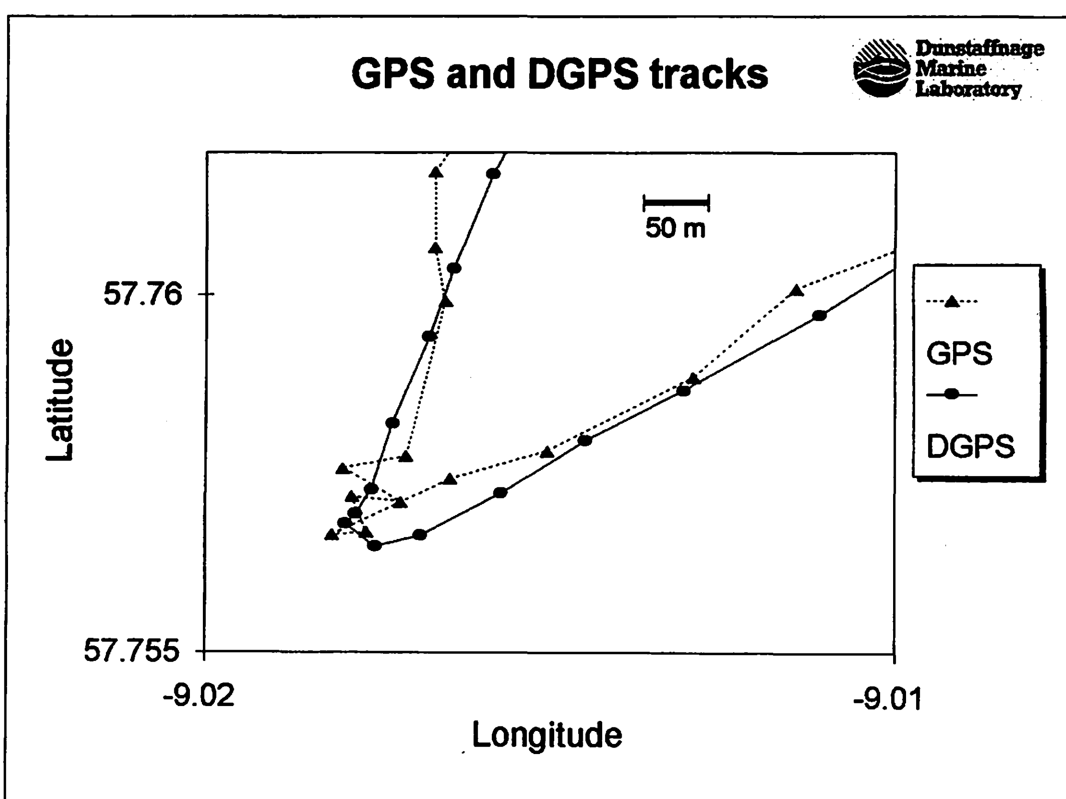


**Figure 7.** A small section of track showing both GPS and DGPS positions. The increased accuracy available frm DGPS is evident in the smoothness of the DGPS track.

# PAPERS WHICH WERE ACCEPTED, BUT NOT READ AT THE SESSION

## SHORT NOTE ON THE INDIAN OCEAN BUOY COMMUNICATIONS PROGRAMME

**M R Nayak**, National Institute of Oceanography, India

ABSTRACT

The satellite communication facility with the buoys is considered an important aspect of the Data Buoys as far data transmission/reception is concerned. In this direction, though we depend entirely on the ARGOS system presently for all our drifting and moored buoys, a new facility as been proposed to draw the attention of global partners for joint ventures with the commercial arm of this research organisation, namely *The Oceanographic Company* (TOC). The purpose of the financial support scheme is to encourage global enterprises to establish production and manufacturing industries in India in co-operation with local partners. We have proposed support for preliminary studies, soft loans and guarantee facilities, support for basic infrastructure investments, part financing of initial training and equity investment guarantee.

The countries which could derive maximum benefits are at present those in the Indian Ocean region whose satellite coverages are over these geographical areas, particularly the Indian National Satellite (INSAT). This satellite presently caters for the Indian Meteorological Departments weather monitoring requirements for data communication from Data Collection Platforms (DCPs) over several locations from Leh (near the Himalayas) to Maitri (an Antarctic Station).

Issues involved in the establishment of this infrastructure to cover the entire 'Blue Triangle' (India, South Africa and Australia) water mass could fruitfully benefit from this concept of global co-operation. Alternatively, mechanisms such as INMARSAT, METEOSAT, GOES, METEOR-burst, INSAT, UHF-two way communication link vis-a-vis ARGOS could be compared for dollar per bit rate communication, based on technical feasibility studies of their suitability as a reliable communication scheme.

# DEVELOPMENTS IN BUOY TECHNOLOGY IN 1996

**Sergey Motyzhev**, Marine Hydrophysical Institute, Ukraine

## ABSTRACT

1. SVP barometer (SVP-B) drifter. A new fibreglass surface float (41 cm diameter) was developed, as well as new equipment for another parts of the drifter (the wire rope between surface and subsurface floats, polyurethane strain-relief 'carrots', etc). The air pressure port has been designed according to DBCP Technical Document No. 4, and a complete prototype buoy has been assembled. Some final work remains to be done on the air pressure sensor and air/water (moisture) filter. We currently plan to buy air pressure sensors for our buoys, and samples of filter materials have been sent for testing.

2. Electronics. A major effort was devoted to Argos transmitter development, and a new design was created in 1996 using radio components obtained from the West. This was type-approved as a COSPAS/SARSAT transmitter in September this year. The next step will be to produce another version of the transmitter in 1997 for Argos applications.

3. Diving buoy. The low-cost diving drifter was developed this year as a complete carrier of scientific and electronic devices. The all-important parts of the buoy (air pressure sensor, automatic control electronics, etc) have been carefully tested in the marine division of our institute near Kachively village in the Crimea. The efficiency of the diving buoy was demonstrated to Piet Le Roux, when he was in Sebastopol in the summer of this year. The next steps in the diving buoy development await the completion of the Argos transmitter. We plan to use the diving buoy for the investigation of the upper profile of the hydrogen sulphide zone in the Black Sea, and have made proposals to use these buoys to study the horizontal and vertical circulation of Dnepr river water in the western part of the Black Sea.

It is necessary to add that we have had no financial support from the Ukrainian government this year because the economic situation in the Ukraine is very far from perfect. We are ready to collaborate with any specialist who has an interest in our work.

# The possibilities of transferring Sea Level data from the South Atlantic and Antarctic using satellite communications

**Peter Foden,** Proudman Oceanographic Laboratory UK, E-mail: prf@wpo.nerc.ac.uk

**Abstract**
Proudman Oceanographic Laboratory has had a network of island based Sea Level stations in the South Atlantic since 1984 and in the Antarctic since 1988. They have been used in conjunction with deep-sea pressure recorders deployed at depths down to 4000 metres. This project is part of POL's contribution to the World Ocean Circulation Experiment (WOCE) and is called ACCLAIM (Antarctic Circumpolar Current Levels by Altimetry and Island Measurements) [1]

Data retrieval has been one of the greatest logistical problems, and routine maintenance of the instruments is difficult in these remote areas. With the improvement in satellite communication technology it is now commonplace to have daily reports from these remote stations and recover relatively large amounts of data between the occasional site visits.

New opportunities are offered by the latest two-way communication systems, and it is now possible to interrogate remote sites and alter data logging regimes to suit requirements, or to carry out fault finding and repair at distance.

**Remote data logging**
When instrumentation is installed at remote locations one of the biggest problems is accessibility. It is not always possible to visit remotes sites such as islands in the Southern Ocean and the Antarctic. Ideally for our project, it is desirable to have two-way communication with the instrumentation and the ability to send back several Megabytes of stored data. Systems are available to give one way communication such as ARGOS and METEOSAT, from remote instrument to base but nothing to give direct communication to the remote instrument. Inmarsat satellite links are available but their cost is prohibitive for several remote stations and the power requirements too high for continued battery operation.

A major problem is lack of data capacity, ARGOS offers very low data capacity - limited to a maximum of 32 bytes per transmission, although this can be improved by using multiple ID's. METEOSAT offers better capacity at approximately 600 bytes per transmission and the possibility of multiple transmissions per day, but has to have an accurately aligned antenna (within ±5 degrees) and is therefore not suitable for floating buoys. It does however have the added benefit of being in contact with the satellite continuously ensuring a high probability of the reception of any particular transmission.

Another problem is the reassembly of the data from the individual transmissions, this is a particular problem with ARGOS since because the transmissions cannot be guaranteed to get through each time due to the periodic availability of the satellite, there are gaps in the data and also duplicate data. Patching the data back together can be difficult. METEOSAT processed data is better in that it is all in sequence and in relatively large chunks, but still has to be further processed to remove header information from each transmission. Both systems lack two-way communication so remote diagnostics and software update are not possible with either systems.

**Recent LEO systems**
More recently two LEO (Low Earth Orbit) systems came into service, both of which offer two-way data communication. The first system to be launched was SAFIR (SAtellite For Information Relay) designed and built by OHB in Bremen, Germany, it is a segment on a Russian satellite launched in November 1994. This system offers two-way communication at 401 MHz between two SAFIR ground stations, one usually the home station and the other the remote station. Communication is between the two stations via the satellite, and is of the store and forward type of operation. There is no third party involved in the data delivery but OHB retain control of the system by organising 'scheduling' for the satellite to ground station contacts. Unless your station is scheduled for a contact it will be 'ignored' by

the satellite. SAFIR has two sorts of message systems, firstly the short message 'Service B3' where messages of up to 128 characters can be sent. They are like a post-it pad where quick notices can be sent. The B3 level messages are not stored and just appear like a bulletin on the screen, if they are not printed immediately they are lost. The second message system 'Service A' sends data files that can be quite long, if they are too long for a single satellite pass they are continued on subsequent passes until the data transfer is complete. It is not possible to have simultaneous communications between two SAFIR stations because in most cases the stations will not both be in sight of the satellite at the same time. At the moment the data transfer rate is 300 baud but it is hoped to be upgraded to 2400 baud. The original idea for the SAFIR system was to have small sized Micro stations with tiny antennae and also larger, more powerful Macro stations. The Micro station idea has been scrapped and only the Macro stations are now available.

POL has purchased two Macro stations in order to evaluate the SAFIR system and is the first to use the system in the United Kingdom. The antenna for the home Macro station is quite large but light weight, it consists of a fibreglass cylinder about 100 mm diameter and 420 mm long. The Macro station is housed in a diecast box 100x80x220 mm and weighs 1.5 Kg (including optional GPS receiver). There is also an additional UHF power amplifier which boosts the output power to 35 Watts and is housed in a case 200x160x72 mm and weighs 2.7 Kg. The remote Macro station is identical to the home Macro station except that it does not have the power amplifier and the antenna is of the planar type 300x300x10 mm. An optional extra is a GPS receiver, the antenna of which is bonded to the centre of the planar antenna. Each Macro station requires to be connected via a serial port to an IBM PC compatible, a program called SFTERM is run on each station PC which looks after initialisation and message transfer. It is possible to run the Macro stations without the PC connected but the data logging instrumentation connected to the Macro station must duplicate the SAFIR data transfer protocol based on X.25. The overall current requirements for the system are quite high, up to six Amperes whilst transmitting and 330 MilliAmperes in quiescent mode, making the system unsuitable for data buoy use. It is however suitable for remote shore based use at polar latitudes. At these latitudes it is almost impossible to use the geostationary satellites such as METEOSAT and the SAFIR system has the advantage. However with only one satellite available at the moment the number of scheduled contacts in a day is low.

The second, presently available two-way communication system is ORBCOMM offering a simpler messaging system than SAFIR. The lower powered 'communicators' provide a similar store and forward system to SAFIR. The maximum data message size is 250 bytes and the data rate is 2400 baud inbound and 4800 baud outbound. The data protocol is based on the INTERNET and X.400 types. The typical weight of a communicator is 340 grammes and the antenna size is a 50 centimetre whip. The uplink and downlink frequencies are in the VHF band and are 148.00 - 149.90 MHz and 137.00 - 138.00 MHz respectively. RF power output is typically 5 Watts. Although the service has been intermittently operational in the United States since February 1996 it is hoped to be operational near real time in 1997. There is no service in the United Kingdom at the moment but a company called SatCom in London has been set up to co-ordinate ORBCOMM subscription in Western Europe. The ORBCOMM system looks more suitable for floating data buoys and when more satellites are launched coverage should be greatly improved. It is less suitable for remote sea level use where it's small message size makes it necessary to send many messages a day. There will also be limited coverage at the polar latitudes where there will only be a maximum of 4 satellites in polar orbits, when finally launched.

There are several other satellite communication systems being developed such as GE-STARSYS, IRIS and IRIDIUM, they may bring real time data communication, but they are not planned to be fully operational until the next century. IRIDIUM will be a tremendous step forward because it will offer for the first time point-to-point telephone communication anywhere on the earth's surface. It is also the first LLEO satellite system to offer global voice, data and facsimile services. The dual mode telephone handsets should automatically route the call via terrestrial mobile services where available and through IRIDIUM satellites where they are not available.

Specifications of the various systems are briefly listed below:

**GE-STARSYS**
Short messages up to 25 characters
Full constellation of satellites - 24 Little Low Earth Orbit (LLEO)
Frequency of operation - uplink 149 MHz, downlink 401 MHz
First satellites to be launched - late 1997
Satellite contact time: 6 satellites - 15 minutes each hour, 24 satellites - almost continuous
Positioning accuracy: 1 km
RF power output 2 - 5 Watts

**IRIS**
Medium size message files 1 kilobytes upwards
Full constellation - only 2 LLEO satellites
Parts of this system are based on the SAFIR satellite segment
Space segment ready for launch mid 1997 attached to Russian "Resource 01 N4" satellite
Frequency of operation - 388 MHz uplink, 400 MHz downlink
Satellite contact time - 2 times per day

**IRIDIUM**
Handheld dual mode telephone, satellite and terrestrial wireless compatible
Digital voice: includes data port for transmitting facsimile and computer files
Transmission rates: voice; data (2400 baud)
First satellite launch: 1996, Commercial service: 1998
Constellation of 66 satellites in six orbital planes of 11 satellites, and one on-orbit spare per plane
Polar orbit: 780 kilometres (421.5 miles)
System designed by Motorola, Inc.
Dual-mode IRIDIUM handsets allow users to access local cellular networks, if available, and the IRIDIUM satellite network when outside local cellular coverage.
Communication Frequencies: L-band (1616-1626.5 MHz) for voice communication with IRIDIUM subscribers; and the Ka-band (19.4-19.6 GHz for downlinks, 29.1-29.3 GHz for uplinks) for gateway and earth terminal transmissions.

**Alternative techniques**
Another approach is to utilise ARGOS but have a multiple ID transmitter, this enables a data logger to transmit it's data back on up to 8 separate ARGOS PTT numbers. The maximum number of data bytes per transmission is 32 bytes but with a multiple ID transmitter this is increased to 256 bytes. The problem of this system is reconstructing the data file afterwards. ARGOS data is stored by ID number and is not always received in sequence. By allotting a unique identifier number to each transmission, the recovered data set can be reordered and duplicate transmissions removed, it is a useful method but at the expense of some of the data bytes which are used for the identifier. This type of transmitter has been employed in POL's Releasable Data Capsules (RDC) [2], which form the data retrieval system for MYRTLE (Multi Year Return Tidal Level Equipment) [3]. The MYRTLE system is a long term sea level measuring instrument that can operate on the sea bed at 5000 metres water depth for up to 4 years. The data is passed from the main data logger via an infra red link to four RDCs and stored in solid state memory. After a pre-set length of time, usually a year, the RDC is released from the main instrument to float to the surface. This allows the datum of the sea level measurements to be preserved but still have yearly data return. After release the data from the RDC is transmitted back via ARGOS, the data set is repeatedly broadcast until the batteries deteriorate and the unit becomes disposable.

One problem is how to make best use of the ARGOS transmitter batteries, this means not transmitting when a satellite is not present. It is possible to calculate the orbital positions and transmit when the satellite should be in view, but an accurate clock would be required and even then the time would be incorrect by several minutes after four years on the sea bed, making it possible to miss a satellite pass entirely.

A better idea is to use an ARGOS downlink receiver/detector which switches on the RDC ARGOS transmitter when a satellite is in view. Unfortunately the downlink receiver would also add to the total cost of the RDC and drain more power from the battery pack. It is hoped to try this technique on later versions of the RDC. At the moment ORBCOMM would not offer better performance than using

ARGOS for this application but when the full constellation of 36 spacecraft are launched and come on line, the system would allow almost real-time data retrieval and the advantage of the data being delivered directly over the INTERNET. The two-way link may be of limited advantage to this application and in polar latitudes the benefit of the extra satellites would be reduced, since there will only be four craft in polar orbit.

**High speed data modems**
As more remote places are being connected to the global telephone system and as modem development increases in pace, it is becoming a reality to have high speed, relatively low cost data communications with places such as these. This is of particular interest to POL because of our network of sea level stations in the Antarctic and Southern Ocean. We have stations at Ascension, St Helena, Tristan Da Cunha and Port Stanley that report back four times daily via METEOSAT transmitters. We have three further stations at Signy in the South Orkneys, Rothera and at Vernadsky (Ukrainian base - ex Faraday). All these Antarctic stations have their data sent back manually via British Antarctic Survey's Inmarsat link. Most of these Southern Ocean islands are now connected to the direct dial telephone system by Cable and Wireless satellite dishes. It is now planned to connect high speed modems (33.6k baud) to our remote island sea level network, and make use of the fast two-way communications offered by the Cable and Wireless system. In a recent test from Port Stanley in the Falkland Islands to POL at Birkenhead UK, two 33.6k baud modems were used and it was possible to have control of a remote PC at Stanley from POL. As a further test a 1.2 Megabyte file was downloaded error free in a little over 5 minutes. (Data compression used). It would be relatively easy to modify the present sea level instrumentation to offer this extended accessibility at low cost. The advantages of this system would be that remote diagnostics of the instrumentation could be carried out and the software easily upgraded at distance. With such a high speed, high capacity link the data retrieval could be carried out weekly or monthly instead of four times daily via a telex machine as with the present one-way METEOSAT link.

**Summary**
Although low-cost, two-way satellite telemetry links are becoming available, they are all of the store and forward message type. No direct point-to-point connection will be available until the full constellation of craft are launched. When the next generation of communication satellites are launched (IRIDIUM), allowing telephone communication, high speed, high capacity point-to-point data transmission will become available for use with remote instrumentation.

**Web page information**
Iridium: http://www.iridium.com/ Orbcomm: http://www.orbcomm.net/
POL: http://www.pol.ac.uk/ Satellite News:
http://www.mediabiz.com/skyreport/news.htm
Surrey University SSTL: http://www.ee.surrey.ac.uk/CSER/UOSAT/index.html

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[2] Foden, P.R., Spencer, R., 1995. A Releasable Data Capsule for the Deep Ocean. Oceans '95 MTS/IEEE, October 9-12, 1995, San Diego, California. Vol. 2, pp 1240-1246.

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