DEVELOPMENTS IN BUOY TECHNOLOGY, COMMUNICATIONS AND DATA APPLICATIONS

PRESENTATIONS AT THE DBCP SCIENTIFIC AND TECHNICAL WORKSHOP

(Victoria, Canada, October 2000)

DBCP Technical Document No. 19

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WORLD METEOROLOGICAL
ORGANIZATION

DATA BUOY COOPERATION PANEL

DEVELOPMENTS IN BUOY TECHNOLOGY, COMMUNICATIONS AND DATA APPLICATIONS

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N O T E

FOREWORD

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

Consequently, a technical workshop on *Developments in Buoy Technology, Communications and Data Applications* took place during the first day and a half of the sixteenth session of the panel, held in Victoria, British Columbia, Canada, October 2000. A total of twenty-five papers were presented to more than sixty participants during the workshop. The texts of seventeen papers and four abstracts, and slides of four presentations are included in this DBCP technical publication. In all cases the papers and slides have been reprinted as received, without additional editorial intervention.

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VENUE: Victoria, British Columbia, Canada
DATE: 16th-17th October 2000

THEME: DEVELOPMENTS IN BUOY TECHNOLOGY, COMMUNICATIONS AND DATA APPLICATIONS

WORKSHOP CHAIR: Wynn Jones, The Met. Office, UK

Monday, October 16, 2000

Session 1 **Developments in moored and drifting buoy design, sub-surface floats, sensors, communications, and operational programs**
Chair: Julie Fletcher, Metservice, NZ

Developments in the Technocean SVP-Barometer Drifter
Jeffrey Wingenroth, Henry White, Technocean, Inc., Cape Coral, Florida, USA

Calibrated Minimet Technology
Andy Sybrandy, Pacific Gyre
Peter Niiler, Scripps Institution of Oceanography, USA

Marlin SVP-B drifters evaluation after one-year operation in situ
Sergey Motyzhev, Marlin Scientific Manufacturing Company, Ukraine
Elizabeth Horton, Naval Oceanographic Office, USA

New generation of Argos-2(3) SVP buoy series as instrument for DBCP Implementation Strategy. Matter for discussing
Sergey Motyzhev, Marine Hydrophysical Institute NASU, Ukraine
Elizabeth Horton, Naval Oceanographic Office, USA

An update to results on SVP-B performance and cost analysis presented at DBCP XII, Henley 1996
Eric Meindl, NOAA/NDBC, Stennis, USA

Autonomous Ocean Observing System (ADOS)
W. Gary Williams, Clearwater Instrumentation, Inc. Watertown, MA, USA

Getting ready for the Argos Downlink
Michel Taillade, CLS General Manager, Toulouse France

Drifting Wave Buoy using ORBCOMM Data Transmission
Tetsuya Uwai, Japan Meteorological Agency, Japan

ORBCOMM Performance - results of an Antarctic evaluation
D T Meldrum, D J L Mercer and O C Peppe, Dunstaffnage Marine Laboratory, UK

A New High Data Rate GOES Satellite Transmitter for Buoy Applications
Jim Hanlon, President, Seimac Limited
Brian Day, General Manager, Campbell Scientific Corp., Canada

Preliminary results from a Met. Office Open Ocean Buoy fitted with a TRIAXYS Wave Sensor
D W Jones and S J Keogh, The Met. Office, UK

Neptune- METOCEAN Data Systems Limited 's Deep diving profiling floats
Bernard G. Petolas, P. Eng, METOCEAN data Systems Ltd., Dartmouth, NS, Canada

Session 2 Data requirements relating to operational oceanography and meteorology, including, in particular, case studies related to weather forecasting
Chair: Jean Rolland, Météo-France, France

Project Argo, moving towards the implementation phase.
Howard Freeland, Institute of Ocean Sciences, Sidney, B.C., Canada

Specific Contributions to the Observing System: Sea Surface Temperatures
Richard W. Reynolds, D.E. Harrison, and Diane C. Stokes, NOAA/OGP, USA

The potential of data buoys in support of numerical weather prediction: The EUCOS initiative
François Gerard, EUCOS Programme manager, Météo-France, France

World Ocean Surface Circulation
Peter Niiler, Scripps Institution of Oceanography, USA

SEA SURFACE TEMPERATURE MEASUREMENT from ODAS Buoys
Jim Gower, Institute of Ocean Sciences, Sidney, BC, Canada
Simon Skey and Mark Blaseckie, Axys Environmental Systems, Sidney, BC, Canada
Val Swail, Meteorological Service of Canada, Downview, ON, Canada

Tuesday, October 17, 2000

Session 3 Buoy data applications in oceanographic and meteorological modelling, global climate studies, and as a complement to remote sensing.
Chair: Louis Vermaak, SAWB, South Africa

New Argos User interface on the Web
Christian Ortega, CLS, Toulouse, France

Inter comparison of sea surface meteorological data from two different buoys and with ship observations
M. Ravichandran, M. Harikrishnan, Tata Sudhakar, M. Muralidhar and K. Premkumar
National Institute of Ocean Technology, IIT Campus, Chennai, India

Use of GPS drifters for measurement of near surface currents in a wide strait
Dario Stucchi, Institute of Ocean Sciences, Sidney, B.C., Canada

A full buoy network for complex mesoscale weather
Owen S. Lange, Environment Canada, MSC, Vancouver, BC, Canada

Physical and biological monitoring with the western Canadian ODAS marine buoy network
Jim Gower, Institute of Ocean Sciences, Sidney, BC, Canada

Status of the global drifter array, and the Hurricane array deployments
Craig Engler, AOML, Miami, FL, USA

The Global Drifter Array- New Data products and the Year 2000 Hurricane Drifter Array
Mayra Pazos, AOML, Miami, FL, USA

Observed Changes in Arctic Climate
Ignatius Rigor, Department of Atmospheric Science, University of Washington, Seattle, USA

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The Scientific and Technical Workshop of the Data Buoy Cooperation Panel, Sixteenth Session (Victoria, BC, Canada, 16-17 October 2000)

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Developments in the Technocean SVP-Barometer Drifter

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Technocean

Technocean, Inc.

- One of the first manufacturers of satellite-tracked Lagrangian drifting buoys (began in 1983)
- Early participant in the construction of SVP and SVP-B drifters

Drogue Delivery

GPS ArgoDrifter

- Currently involved in the design and construction of various drifting buoy types integrating environmental sensors and GPS with Argos

Major SVP-B Drifter Developments

- New barometric pressure sensor
- Redesigned barometer port
- Modified electronics

Barometric Pressure Sensor

- Integrated a Honeywell HPB-200 pressure sensor. Sensor adapted from military/aerospace applications for civilian use

- Production units feature:
  - Operating Temp. range: -40 to +85° C
  - +/- .4 hPa maximum error
  - stability of .25 hPa / year

- Probable cost increase in Dec. 2000

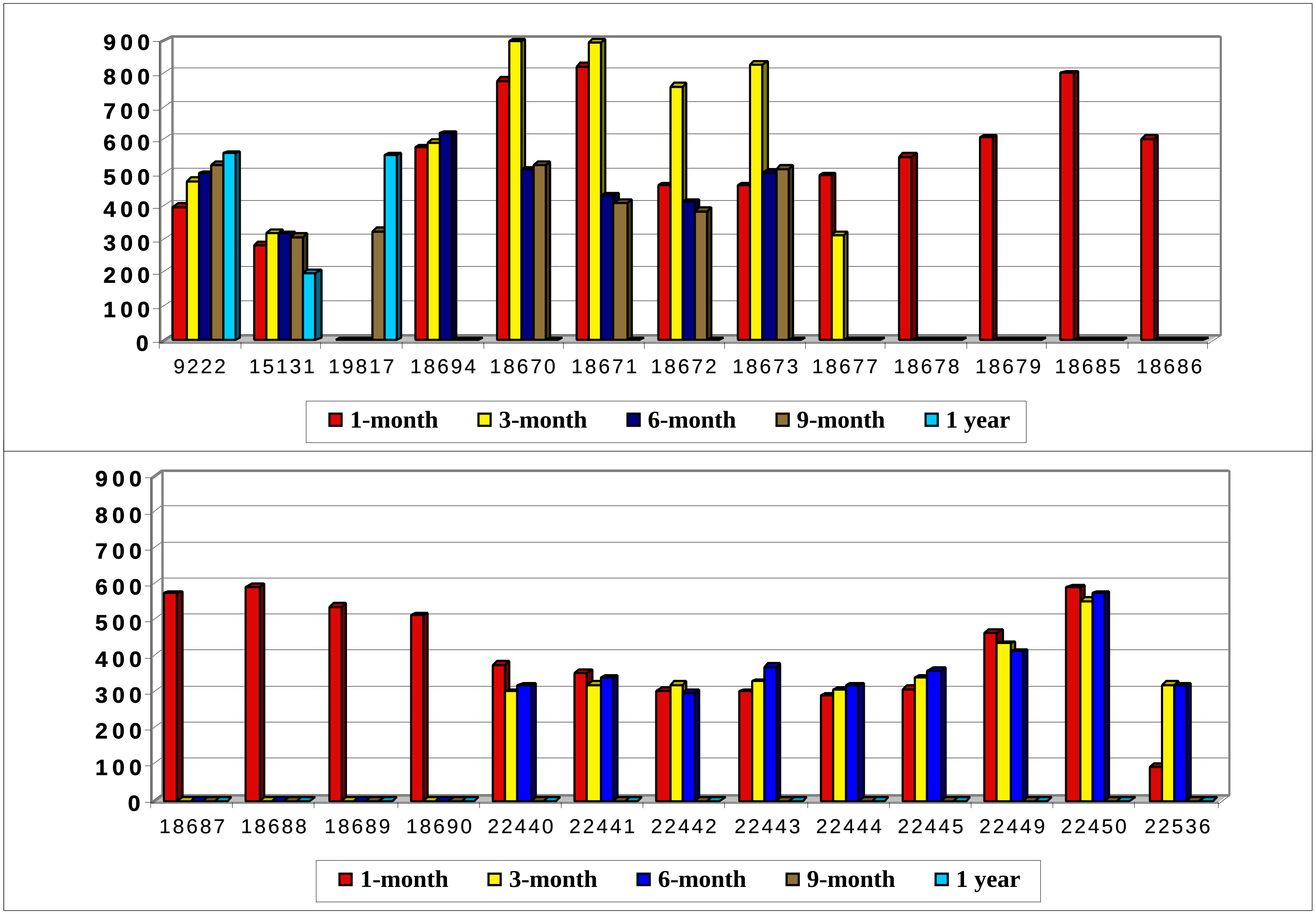
Barometer Port

- Modified the Barometer Port to extend life
- Monolithic construction (no "O" rings)
- Includes inhibitor valve to reduce amount of water reaching the GORTEX - facilitates testing for watertight integrity
- GORTEX oriented vertically so that water runs off and out of the port

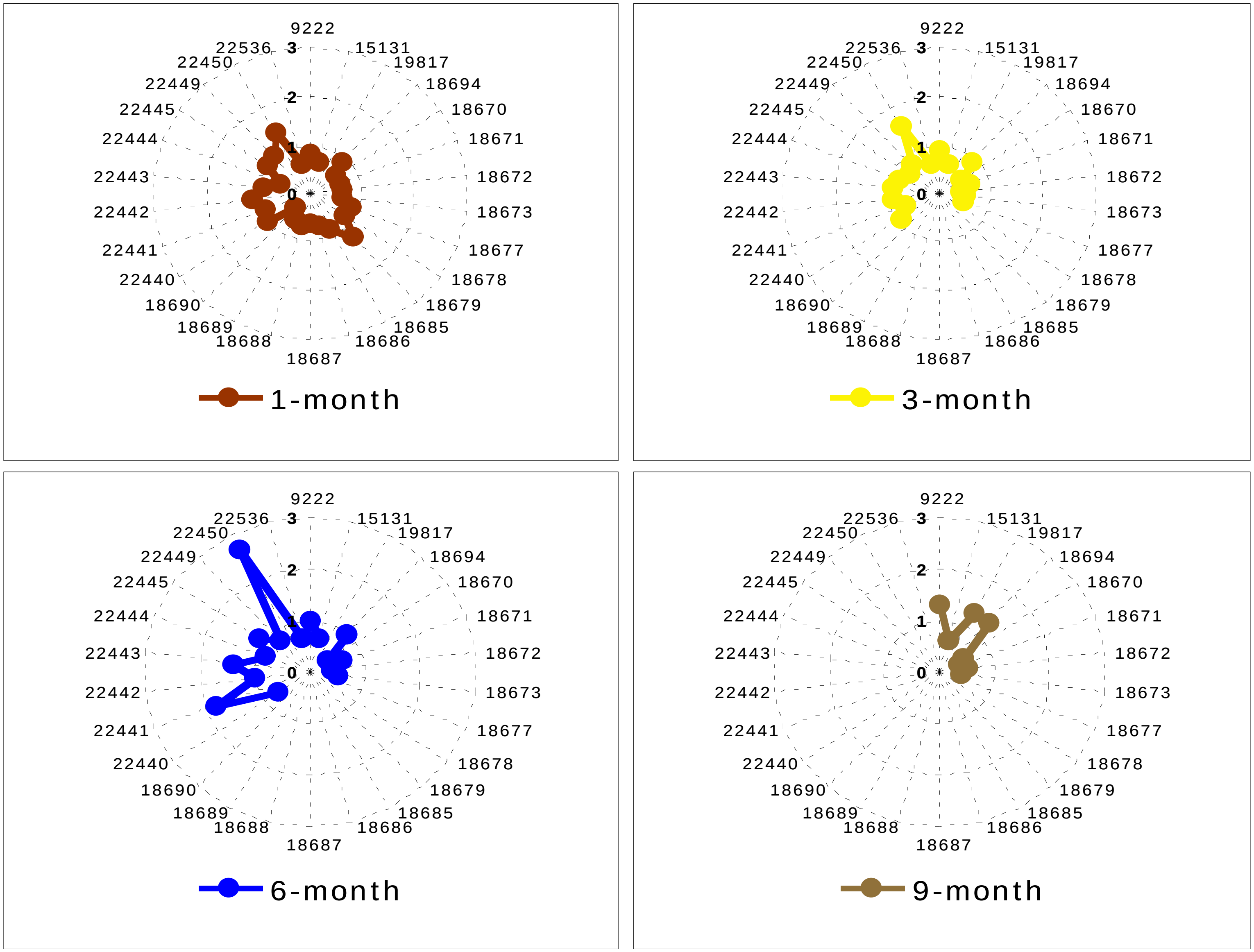
Modified Electronics

- Technocean Mac-1 controller certified by Argos in 1998
- Incorporates software for sampling, de-spiking, etc.
- Enables in-house modifications to s/w code, data formats, new sensor integration, GPS integration, troubleshooting, etc.
- Reduced power consumption

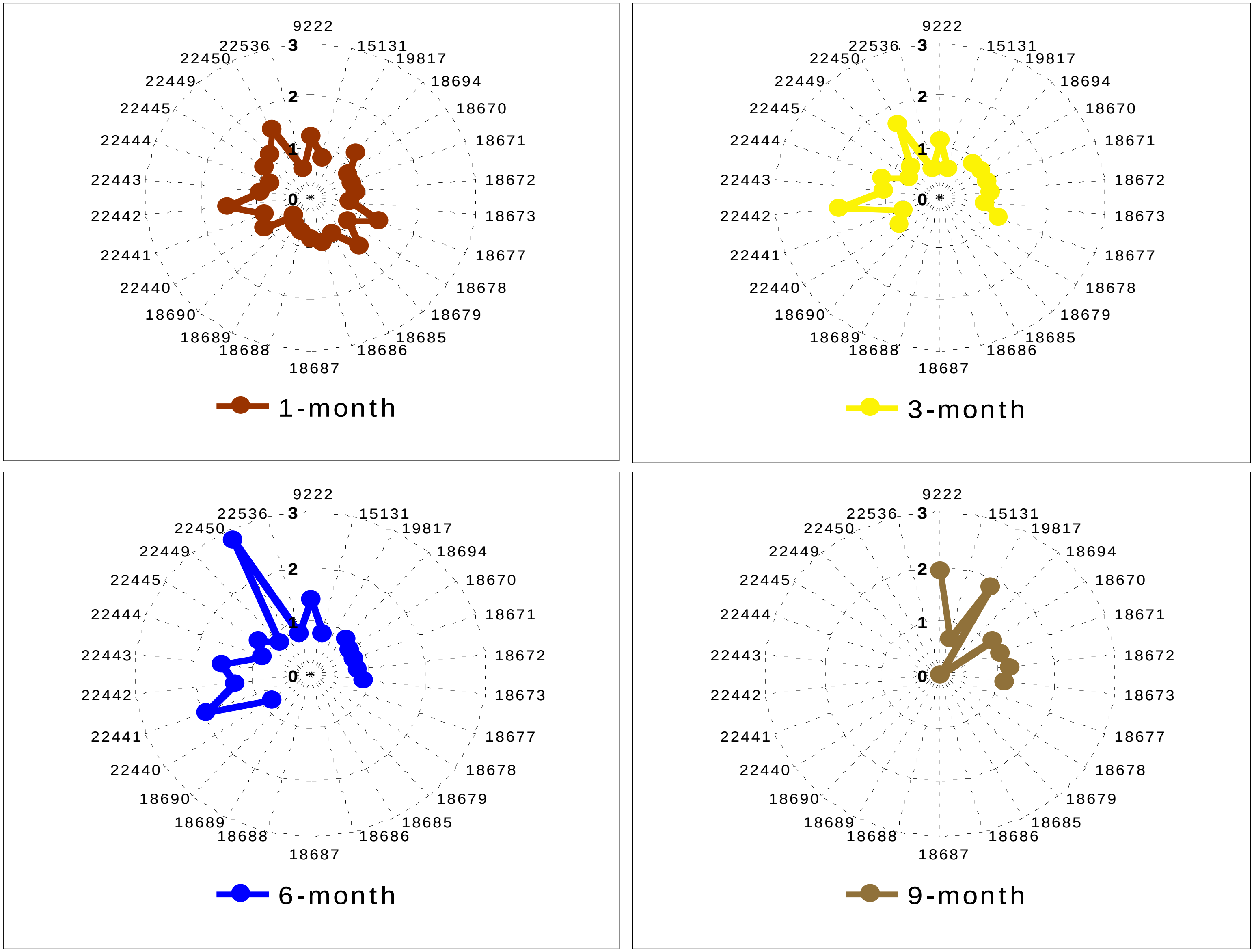
Number of Obs (ECMWF)



Standard Deviation(ECMWF)



RMS (ECMWF)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9-month

Calibrated Minimet Technology

By: Andy Sybrandy (Pacific Gyre) and Peter Niiler (SIO)

Scripps Institution of Oceanography (SIO) has developed the calibrated Minimet drifter technology using thorough comparisons of wind speed and direction with research vessel data and long term deployments at sea with satellite scatterometer data. The first operational field experiments were undertaken in the winter of 1996-97 with the deployment of 30 Minimet drifters into the Labrador Sea. The wind velocity data from 12 MINIMETS was compared with data from the NASA/NSCAT scatterometer. This comparison showed that consistent wind speeds from 2-30 M/SEC can be derived from acoustic power in the 1KHz frequency band. This data is derived from the Fast Fourier Transform (FFT) analysis of the ambient noise signal using a calibrated hydrophone mounted 10m below the surface. It was found that saturation of frequencies greater than 7 KHz in the ambient noise signal occur at wind speeds greater than 7 m/s. The wind direction was derived from conditional sampling of a calibrated compass aligned with a vane on the surface float. These initial deployments uncovered various problems in the construction, calibration and deployment techniques. Additional in situ data was obtained from deployments of 31 Minimets in the East Sea in 1999 and 20 Minimets in the tropical Pacific in April 2000. This data was compared to the NASA/QuikSCAT scatterometer. Engineering changes made to the 1996 model Minimet improved survival rates and data quality of the 1999-2000 model. Also, comparison of acoustic power at different frequency bands helps identify ship noise or precipitation effects. SIO will continue to deploy calibrated Minimet drifters in the East Sea in 2000 and the East Pacific in 2001. AOML/NOAA and NAVOCEANO will begin evaluating the calibrated MINIMETSin 2001.

Marlin SVP-B drifters evaluation after one-year operation in situ.

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Between the DBCP meetings the intensive cooperation for evaluation of new generation of Marlin SVP-B buoy was being provided. Marlin implements the concept, that reliable low-cost buoy may be created by the joint team of experts in all the directions of buoy building. As result, both buoy's hardware and software were being projected so that to decrease the power consumption and to optimize the electrical and mechanical connections between the parts of buoy. The transmitter, antenna, and seawater were being considered as the unified system, where the radio signal is being formed and transmitted. The mechanical strength of buoy should be suitable for air deployment, long-lived operation in ocean, and decreasing of payment for transporting.

The feature of evaluation of autonomous drifters is that any significant conclusions about its operation can be made after the sufficient temporary interval comparable to its theoretical life-time. As for to the SVP-B drifter, such interval is one year. Thus, it is possible to say, that moment of buoys evaluation deployed year ago is exactly now.

For the study of technical and operating performances of buoys it was designed a method, which one permits comprehensively to estimate the parameters of SVP-B buoy. This method was presented to DBCP Evaluation Sub-group and it was favored as the instrument, on the basis of which one it is possible to evaluate buoys and to compare them among themselves. The selected parameters, which are being a matter for evaluation, and also their practical significance, are submitted in the Table 1.

Table 1

Valued parameters and their performance for the drifter projects

(two-satellite service)

Estimated group of parameters	Parameter, estimated by monthly	Practical performance of estimated parameter
PTT	♦ Monthly total number of satellite passes with data collection and tendency of this parameter ♦ Monthly total number of the received messages and tendency of this parameter; ♦ Number of the received messages per pass and tendency of this parameter; ♦ Monthly total number of satellite passes with locations and tendency of this parameter; ♦ Monthly number of locations of 321 classes and tendency of this parameter; ♦ Evaluation of all the parameters above for Argos-1 and Argos-2 generations.	♦ Space and temporary resolution of drifter measurements; ♦ Quality of temporary resolution; ♦ More data per pass ♦ Quality of space resolution; ♦ High-quality of space resolution ♦ Effect of satellite K (Argos-2) greater receiver sensitivity with respect to satellite J (Argos-1)
Sensors	♦ Air pressure (current status and temporary variability); ♦ Sea Surface Temperature (current status and temporary variability);	♦ Reliability of weather forecasting; ♦ Estimation of heat balance in ocean;

	♦ Battery Voltage (current status and temporary variability); ♦ Submergence (current status and temporary variability).	♦ Life-time of buoy; ♦ Presence of Holey-Sock
Buoy as a whole	♦ Correspondence for air deployment; ♦ Real life-time; ♦ Compact packing.	♦ Creation of buoy networks; ♦ Time of observations; ♦ Economy when storage and transportation.

The offered method of drifter evaluation had been used for five Марлин SVP-B buoys, which ones were air deployed by Navoceano November 9, 1999 in the central part of Indian Ocean. The tracks of buoys are presented on the Figure 1.

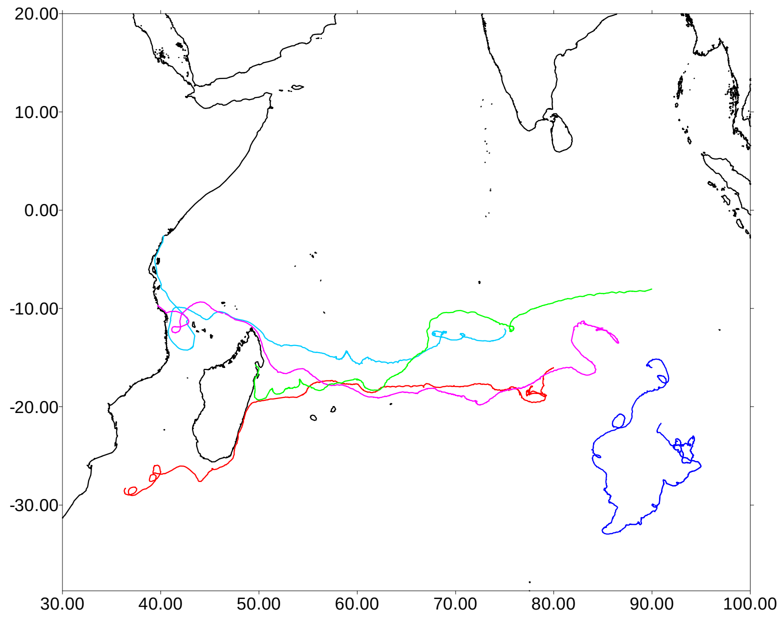

Fig.1 Tracks of five Marlin buoys air deployed in Indian Ocean (9 Nov 1999 – 1 Dec 2000)

The current status of drifters on the time of estimation (1.12.2000) is submitted in the Table 2.

Table 2

The current status of evaluated drifters as of December 1, 2000.

Parameters of buoys					**Life-time**		
Argos ID	**WMO ID**	**Deployed**	**Status as of 1.12.00**	**Date**	**Final**	**Cur.**	**Theor.**
26216	53513	9.11.99	In operation			389	490
26218	53509	9.11.99	Destroyed in Kenya	13.06.00	218		490
26219	53510	9.11.99	Destroyed in Tanzania	6.08.00	272		490
26220	53511	9.11.99	Ashore in Kenya	21.08.00*		389	490
26221	53512	9.11.99	Ashore in Madagascar	17.06.00*		389	490
Mean life-time as for to 1.12.00						**331**	

Symbol * means that the buoy continue be in operation, what allows to evaluate such parameters, as a lifetime and air pressure, while the information from these buoys is removed from GTS distribution. As it follows of the Tabl.2 the basic reason of buoys removal from an operating status were the exterior reasons. It is connected with the problems so-called "fishermen's vandalism" or ashore. Completely was in working status the buoy ID26216, which one was drifting in the central part of Indian Ocean. In the practice of buoy application it is accepted to evaluate a mean life-time of all the buoys, which ones stopped the operation as according to the exterior (independent of a buoy) reasons, as in the case of buoy failures. The mean life-time of all the Marlin buoys presented in Table 2 was 331 days.

This analysis was carried out for the technical evaluation of the used drifters for the purpose of definition of positive and negative sides of the new engineering and technological solutions on number of connections, and also quality and quantity of buoys locations via satellites NOAA-J and NOAA-K equipped by Argos-1 and Argos-2 instrumentation accordingly. The results of this evaluation was combined into three groups: real parameters as for to theoretical possible; parameters of Marlin buoys as for to nearest other buoys; and estimation of effect of Argos-2 greater receiver sensitivity.

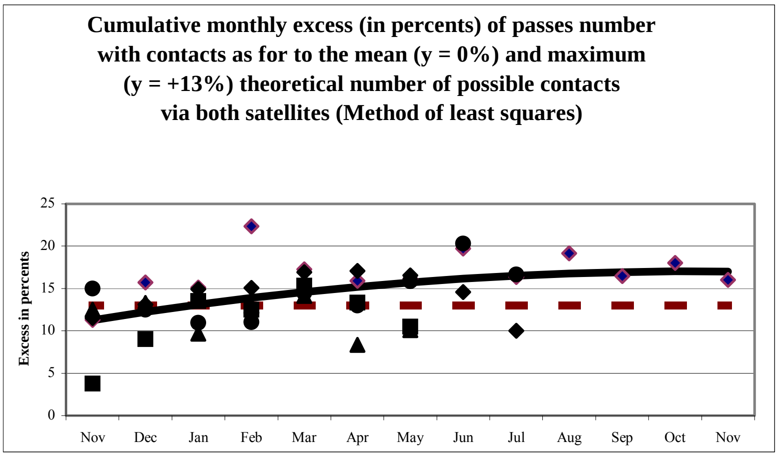

Fig.2. Cumulative monthly number of passes with contacts for two satellites service

The cumulative monthly number of passes with contacts for two satellite service is presented on Fig.2. This normalized parameter (relatively to the current latitude of the each buoy) characterizes the number of satellite passes with data collections in percents. Ordinate is the excess in percents as for to the mean theoretical number of passes with contacts (y = 0%). Result: Marlin drifters had provided the number of passes with contacts 1-7% more than maximum theoretical possible level.

Same method of Marlin PTT evaluation was done for other points of Table 1. This testing had indicated that all the parameters of Marlin PTT were mainly on the maximum theoretical possible levels and had monthly stability.

The interesting results were obtained by means of the direct comparison of each Marlin drifter's PTT parameters with appropriate group of other nearest buoys inside the area ±1° as for to the current latitude of Marlin buoy (Data of other IBPIO buoys were kindly presented by Technical Co-ordinator DBCP). So, the mean excess of satellite passes number with contacts was 41 %, and excess of location numbers was 33 %.

It was provided the estimation of Argos-2 receiver better sensitivity. In result is detected, that the actual advantage of Argos-2 in relation to Argos-1 appears only for satellite passes with 6-11 received messages per pass. It means, that Argos-2 can supply the greater volume of transmitted data. It was the real advantage of K as for to J (for 2W PTT radiated power), and taking into account also the better theoretical visibility of J as for to K.

The very important issue was the evaluation of AP channel. This parameter is very complex for the any manufacturer. The cost of AP channel is approximately half of the SVP-B buoy cost. The problem of creation of low cost AP channel, which could has the life-time same to life-time of buoy, continue be very important. Marlin made the attempt to create the low cost AP channel, using the Motorola sensor as sensitive element. But sensor is one side of reliable AP channel. Another side, very important one also, is the reliability of completed air passing system including barometric port with membrane. The membrane should provide the following parameters:

1. Possibility of the air crossing.
2. Impossibility of the water crossing.
3. Non-dampening.
4. Fast restoration of possibility of air cross after contact of membrane with water.
5. Impossibility of surface pollution by sea salt.
6. Mechanical stability to effect of the hydrostatic pressure.
7. Chemical stability to effect of the ocean water.
8. Time stability of parameters during one year minimum.

Of course, the membrane with these parameters is ideal variant. The 7 plastic membranes and 3 metal ones were tested before the buoys manufacturing. The best plastic membrane was used for these five buoys. Some buoys had not the problems for AP channel during the one-year operation in ocean (ID26216 and 26221). Other buoys had the non-correct AP data during 3-4 months. Reason of this non-correct work was the heat phenomenon of closing of baroport's flexible tube by the compressed rubber pad. It was the error of buoy designer which was taken into account for future generation of buoys. As for to the group for evaluation the correct AP measurements of all buoys had been independently restored from April 2000. Reason was the rubber fatigue and restoration of air access via flexible tube.

Fig.3 demonstrates that mean-square error of low cost Marlin AP channel didn't exceed +/-1hPa during the buoy's lifetime.

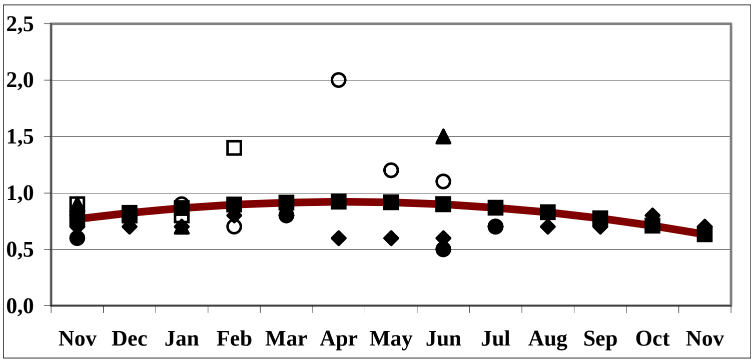

Fig.3. Cumulative accuracy of AP sensors (hPa) during life-time of buoys (without non-correct data, when data wasn't being distributed via GTS and QC)

It wasn't marked the problems for SST and BV sensors. Monthly cumulative mean SST error was less than 0,6°C. The removable lacks of the submergence channel were disclosed.

The developed system of buoy compact packing had provided 35 % total economy of expense when air transportation and 50% total economy of volume when storage. The mechanical strength of this configuration was identical with usual buoy.
The new scheme of hardware attachment inside the surface float meets to the requirements of air deployment. As result the Marlin SVP-Bs were fully

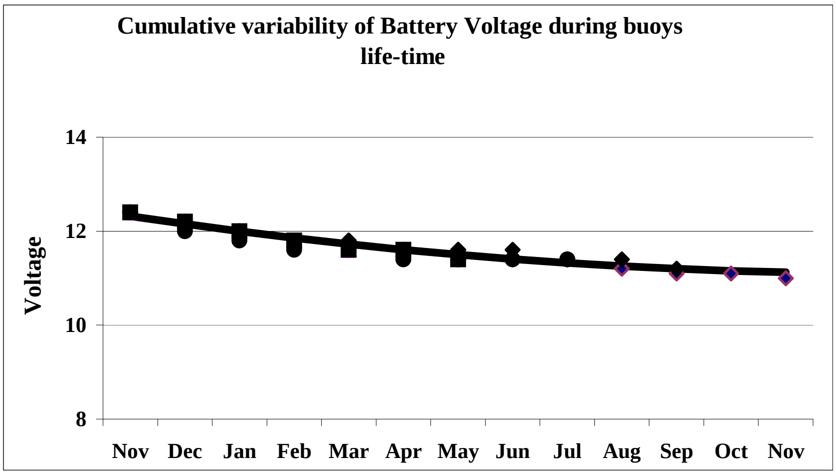

Fig.4. Cumulative battery voltage during buoy’s life-time

approved for air deployment by Navoceano. Stability of BV presented on Fig.4 indicates that Marlin SVP-B provides the life-time more than one-year. The level of 8V is the minimum level of Marlin buoy capacity for work.
Additional up-dating of Marlin SVP-Bs were done for the next modification of Marlin buoy. It was created the new scheme of air tube connection inside the barometer port. Some up-dating of submergence sensor electronics was done. The different kinds of plastic and metal membranes were additionally tested. After kindly permission E. Horton, two new buoys were equipped by metallic membranes. New vacuum technology was created and used for testing of baroport and buoy hemispheres during the manufacturing process.

Summary.

1. Marlin PTT has demonstrated that its parameters were mainly on the maximum theoretical possible levels.
2. Comparison testing with other buoys has shown, that Marlin point of buoy building provides the better spatial and temporary resolution when study of ocean.
3. Argos-2 better sensitivity has provided in Argos-1 frequency band the same number of passes with 6-11 messages per pass as for to this parameter for Argos-1. It was the real advantage of K as for to J, taking into account the better theoretical visibility of J as for to K.
4. Chosen types of low-cost AP sensor and baroport's membrane can provide the AP measurements during one year life-time with mean total error no more than 1 hPa.
5. Practice of buoys using has confirmed the advantage of compact packing buoy as for to usual packing buoy.
6. The mechanical scheme of buoy corresponds to its reliable operation after air deployment.
7. Testing of Marlin SVP-B buoys during 1999-2000 has shown, that this buoy as completed device can successfully work in ocean during one year and more.

New generation of Argos-2(3) SVP buoy series as instrument for DBCP Implementation Strategy. Matter for discussing.

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The communication system Argos continues the development of own technical and operational capabilities. Simultaneously it was presented the CLS understanding on the probable applications of the new systems [1, 2]. Irrespective of this process DBCP has developed and presented the Implementation Strategy of Global Drifting Buoy Observation in Ocean [3]. Goal of both sides is the creation of drifting buoy networks according to GCOS/GOOS requirements.

Each side has the own point of view for solution of this problem. DBCP wishes to create and maintain the drifter network with the 500*500 km resolution by means of increasing the annual hardware commitment of 2400 SVP-B and 1000 SVP drifters. CLS offers the widened bandwidth and increased sensitivity of Argos-2. So, Argos wishes to have the mixture of drifters with different carry frequencies in one area, while the users wish to have the optimal configuration of the drifter networks. As variant for solution of this problem CLS proposes the distribution of buoy's carry frequencies inside the area of drifter networks for optimal load of Argos-2 bandwidth, by means of the distribution of buoy's carry frequencies among the manufacturers. It seems that proposal about distribution of the fixed carry frequencies among the manufacturers will have the small effect. For example, if Coordinator of the Action Group wishes to deploy the large number of buoys and he will order the drifters from one manufacturer, it will be a problem for Argos, when all these buoys will be deployed at the quasi-same area.

Mainly, the oceanographers and meteorologists are very far from radio-techniques problems and they don't understand what they would have when using the new communication instruments. Of course, there are many users, which have the beautiful understanding of new Argos essence and have the plans of the future applications of these systems. However there are many people, who would like to know the different points for development of the own understanding and creation of the new scientific programs.

This paper is the co-authors point of view on the possible future of new generation Argos-2 (3) SVP buoy series. Of course, this point is open for discussing and we will be happy to let any question and proposals. The entire project could get the title "Sleeping Buoy". Project includes three main directions: scientific, technical, and organizational one. Scientific part describes the possible areas of the project application. Technical part presents the instrumentation essence of the project. Organizational part refers to procedures how the new buoys could be used. The project "Sleeping Buoy" includes two parts: Argos-2 SVP series and Argos-3 SVP series.

What is the new Argos for users and what are the new possibilities of system? Very shortly these parameters are presented in Table 1.

Table 1

New technical possibilities of Argos-2 (3) systems

Argos-2	Argos-3
1. Greater receiver sensitivity onboard 2. Wider receiver bandwidth 3. More receiving channels	1. Two-way communications 2. More data per pass 4. Lower power transmission

Argos-2 SVP buoy series

Scientific issue of the project:

Continuous maintaining of the resolution ability of the drifter network according to the plans of GOOS and GCOS.

Goal of project:

Choosing the necessary status of buoy before its deployment

Practical significance of project:

- Flexible plans of buoy deployments;
- Transfer of buoy from program to program;
- Repeated using of Argos ID;
- Creation of buoy warehouses in different Earth's points for fast restoration of buoy network structure;
- Etc.

The maintaining of global drifter network with the necessary resolution requires the fast buoy exchanging if it will be the failure of some buoys, ashore or other problems. The new buoy for replacing should have the technical parameters same to the replaced buoy. The preparation of new buoy and procedure of its deployment should be done during the short term.

Taking into account the global area for buoy deployments it seems that creation of buoy warehouses in the different Earth's points makes sense. These buoys should have the different technical status for deployment in different programs. For example, if there is a warehouse in RSA, the buoys could be deployed as for ISABP, and as for IBPIO. The essence of "Sleeping Buoy" project in Argos-2 mode is the fast preparation of buoy before its deployment. For this the drifter should provide the following parameters:

1. The buoy should have a power budget to remain operational for a full one year deployment after being stored for periods of up to two years.
2. The manufacturer is building the completed buoy without the inside program (ID, format of message, technical file, dynamic range of sensors, repetition period, etc.) and without carry frequency. The completed buoys "are sleeping" on the warehouse after manufacturing. Owner of buoy or Coordinator of Action Group will program buoy directly before deployment. For example, the optic pen can be used for the programming of the completed hermetic buoy. The following parameters should be entered in the buoy, using the PC with developed software:
   - Chosen carry frequency (one of 401.650 MHz, 401.648 MHz, or 401.652 MHz).
   - Format of message.
   - Repetition period (it can be variable inside the range from 81 to 99 sec. PTT will analyze the data of submergence sensor and switch on the transmitter, when buoy will be on the water surface).
   - Argos ID.

Technical issue of project includes the following parts:

1. Programmable (Re-Programmable) Sleeping Buoy.
2. Software for programming of buoy before deployment.
3. Pocket-checking device for buoy.
4. Software for the checking device.

Programmable (Re-Programmable) Sleeping Buoy is being stored on warehouse in completed mode, but without inserted program. When it is necessary, the operator connects the buoy to PC via optic pen and enters in buoy the parameters above. This method of buoy preparation before deployment allows to choose the current status of buoy in the any Earth's point. Pocket-checking device for buoy will allow to test the following parameters of buoy after the preparatory procedures (Table.2):

Table 2

Tested parameters of buoy by pocket checking device

Radio parameters	**Informational parameters:**
▪ Carry frequency ▪ Approximately the power of transmitter ▪ Repetition period ▪ Frequency of modulation signal ▪ Duration of pure carrier ▪ Duration of modulated carrier ▪ Duration of transmission	▪ Preamble of message ▪ Message length ▪ Argos ID (hex and decimal modes) ▪ Message in hex and decimal formats ▪ Data of sensors

Organizational part of project

The using of "Sleeping buoy" project will allow to do the plans of air deployment more flexible. For example, if the air or ship deployment opportunity is being appeared, the buoy or buoys will be programmed and sent for deployment with the necessary status.

Argos-3 SVP buoy series

Scientific issue of the project

Optimization of buoy field in area of program interests by means of remote control.

Goal of project:

Choosing of buoy's current status after its deployment in Ocean.

Practical significance of project:

New economic methods of Ocean study by drifters.

Organizational part of project

New capabilities will be opened for users with buoys equipped by Argos-3 PTT. New scientific projects can be started. For example:

1. Optimization of buoys constellation.

The technical coordinator of Action Group checks the current status of drifter configuration after each ten days. He uses the some algorithm for determination of superfluous buoys inside the configuration. These buoys should be switched off via Argos-3 two-way communication possibility. The cutting of some number of buoys will not distort the fields of physical parameters (AP, SST, etc), what is being reached by usage of optimizing algorithm of the superfluous buoys selection. Simultaneously, the necessary carry frequency should be established for the operational buoys. This procedure should be implemented in coordination with the operator of CLS Argos.

The advantages of offered project are that when its realization it will be reached:

- Optimum configuration of the drifter fields for the study of oceanographic and meteorological parameters;
- Optimum load of Argos-2 frequency band occupation;
- Increasing of the buoy life-time;
- Decreasing of payment for the Argos.

2. Quasi-mooring.

For realization of this project the drifters are used for the some ocean areas, which one should be intersected by drifters. The direction of these buoys moving should be known beforehand. Such buoys should be equipped by padding sensors, which ones has large energy consumption or short lifetime. For example, it can be an optical sensor. The actuation of such sensors will be made, when the buoys intersect these regions. When the buoy will fall outside the region, the sensor will be switched off. At entering of another buoy in the given region the similar sensor of this buoy will be switched on. Thus, the drifters can be used for the observation in the fixed regions.

Summery.

1. Philosophy of "Sleeping buoy" project is based on new Argos capabilities, analysis of results of past and present SVP buoy series applications, and also on the co-authors point of view on the probable future of this instrument.
2. "Sleeping buoy" project in Argos-2 SVP buoy mode will allow to form quickly the drifter fields in Ocean for realization of DBCP Implementation Strategy in interests of meteorologists and oceanographers.
3. "Sleeping buoy" project in Argos-3 SVP buoy mode will allow to provide the observations with optimal spatial and temporary resolution, when decreasing the financial expenses and increasing the buoys life-time.
4. The matter presented here is a co-authors point, which is open for any discussing.

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3. Review of the DBCP Implementation Strategy. Mod. 2000 of Global Drifting buoy Observation. A Global Implementation Strategy. DBCP Technical Document Series, No.15, 1999.

An Update to an SVP-B Performance and Cost Analysis

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National Data Buoy Center (NDBC)
Office of Operational Systems
National Weather Service (NOAA)
U.S.A.

ABSTRACT

The surface velocity profiler with barometer (SVP-B) drifting buoy was developed in the early and mid-1990's as an *in situ* ocean observation tool. Its primary benefits were: 1) significantly lower per buoy costs compared with other drifting buoy types; and 2) its ability to satisfy some measurement requirements of both meteorologists and oceanographers. This analysis, which updates a similar evaluation presented to the twelfth session of the Data Buoy Co-Operation Panel (DBCP XII), finds the SVP-B performance, in terms of buoy infant mortality and mean-time-to-failure (MTTF), improved significantly. In addition, the number of barometric pressure observations per buoy per day more than tripled. These factors led to significantly lower direct costs as measured in terms of buoy cost and cost per observation compared with other operational drifting buoy types.

INTRODUCTION

The SVP-B drifting buoy was developed in the early 1990's and deployed in significant numbers during the remainder of the decade. During 1994, the National Weather Service (NWS) of the United States (U.S.) of America, in cooperation with the Atlantic Oceanographic and Meteorological Laboratories (AOML), a sister agency in NOAA, deployed several SVP-B’s in the Pacific Ocean off the U.S. west coast. Because the cost of each buoy was so low (approximately $3.8 K), NWS wished to examine whether establishing an SVP-B network to supplement moored buoy observations deserved consideration as part of its operational marine network. A further advantage of the SVP-B was its benefit to oceanographers, since its primary purpose was measuring ocean surface currents.

The NWS’s Office of Meteorology, which coordinated the experiment, requested another of its offices, National Data Buoy Center (NDBC), to evaluate the cost and performance of the SVP-B network and compare the systems with the operational technology at the time: the Tropical Ocean Global Atmosphere (TOGA) and wind speed and direction (WSD) drifting buoys and NDBC 3-m moored discus buoys.

A report was presented at DBCP XII, Henly-on-Thames, United Kingdom (UK), based on the performance of 43 SVP-B's deployed after July 18, 1995, and reporting through August 6, 1996.[1] Since NWS's interest was in meteorological measurements, the study focused on delivery of atmospheric pressure observations to end users, such as numerical modelers and NWS Forecast Offices (NWSFO), for marine forecast operations. The analysis for DBCP XII addressed only direct annualized costs and did not attempt to quantify the value of observation capabilities of different buoy varieties since any "value" varies significantly by user. Among its findings, the report concluded:

- MTTF of the SVP-B was 185 days, compared with 477 days and 655 days for TOGA and WSD drifting buoys, respectively.
- SVP-B failure at deployment (infant mortality) was 26 percent.
- The annualized SVP-B buoy cost, adjusted to account for MTTF and infant mortality, was 32 percent lower than both TOGA and WSD drifting buoys.
- The cost per message for the SVP-B was $5.54 (U.S.), compared with $3.86 for the TOGA type, $3.97 for the WSD, and $7.74 for the 3-discus moored buoys.

To the extent possible, this study reevaluates SVP-B direct costs and performance in a manner nearly identical to the earlier study, comparing data collected for SVP-B buoys deployed from January 1, 1998, through August 2000, with results of the DBCP XII study. It does not reevaluate direct costs for TOGA and WSD drifting buoys since no later data are available, nor on the 3-m buoys.

DATA SOURCES AND METHODOLOGY

Information was obtained from the Global Drifter Center (GDC) Deployment Log posted on AOML's Web site; yearly and monthly reporting statistics from Marine Environmental Data Service (MEDS), Canada; WMO lists from Service Argos; and NWS's National Centers for Environmental Prediction (NCEP) monthly statistics. These sources provided buoy deployment information, including identification numbers (ID), from January 1, 1998, through June 2000. The MEDS inventories provided the match between buoy transmitter ID and World Meteorological Organization (WMO) ID numbers. The most recent yearly MEDS inventory was for 1999, so the Service Argos WMO

[1] Meindl, Eric A. NWS West Coast Forecast System (CFS) Evaluation of SVP-B Costs and Performance. Proceedings of Technical Workshop of the Twelfth Data Buoy Co-Operation Panel 1996, DBCP Technical Document No. 10, 1997.

lists were used to obtain information for January through June 2000. These permitted determination of buoy service life. MEDS monthly reports provided information whether sea level pressure (SLP) was delivered, and, where applicable, approximate date of failure.

Care was necessary in cases where WMO ID was reused after the buoys stopped reporting, and where extended discontinuities were in the SLP record. In addition, many SVP-B buoys shown on the yearly inventories were not listed on the monthly reports as ever having reported. This made it difficult to determine whether the barometer failed or the SLP reports were simply not recorded. As a result, the data were cross-checked with NCEP statistics for the first half of 2000 to see if they were reasonable. Although the results may not be precisely correct, they are believed to be representative of actual performance.

The data since 1998 were analyzed to determine:

- MTTF/operating life
- Failure rate at deployment
- Annualized direct cost per buoy
- Cost per observation

RESULTS

Figure 1 shows that 486 SVP-B's were deployed from January 1998 through June 2000. Of that number, 107 were deployed by air. A significant percentage, approximately 12 percent, failed at deployment, particularly those that were deployed by air in 1998 and 1999. In fact, the 25.8 percent failure rate of air-deployed SVP-B's in 1998 is nearly identical to the DBCP XII study results. With implementation in 2000 of better packaging, including an improved air-deployment rigging designed and built by the U.S. Naval Oceanographic Office (NAVOCEANO) at a cost of $1.7 K per buoy,[2] the deployment failure rate dropped dramatically to less than 5 percent. Thus, the failure at deployment problem appears to be solved. It was also found that the MTTF increased significantly to 246 days, compared with 185 days in the earlier study if failures at deployment were not counted.

As a result of improved service life and reduced infant mortality, the annualized direct cost per buoy deployed by ship fell 31 percent, from $7.2 K to $5.0 K. The addition of the $1.7 K air-deployment package by NAVOCEANO to achieve perfect deployment success in 2000 caused the annualized cost to increase approximately 3 percent to $7.4 K for air-deployed

[2]Personal communication with Elizabeth Horton, NAVOCEANO Aircraft Operations.

buoys. The cost of the deployment package, which was not included in the previous study, was added here because it was required by the U.S. Navy to recertify them for air deployment.

A somewhat surprising benefit also occurred by changing Service Argos processing to "full on" from "one-third", as it had been configured in the earlier study. That is, the number of observations received, determined by multiplying the average observations per month multiplied by 12, increased by a factor of 3.39 instead of an expected 3.33. The direct buoy system costs (i.e., SVP-B unit cost normalized to a full year of service, and adjusted for "infant mortality", air-deployment package, and Service Argos costs), are shown in Table 1. It shows that total annualized direct costs for the buoy system actually rose since 1996, mainly due to tripling of Argos charges for standard service. Conversely, the product cost (i.e., cost per observation) was reduced by a factor of 3.2 for ship deployments to $1.69 per message, and a factor 2.6 to $2.14 per message for air deployments. Obviously, when compared with the TOGA, WSD, and 3-m moored buoy systems, the value compares even more favorably (Table 2).

Further, a bonus program for Argos services was instituted in 1997 for SVP-B buoys enrolled in the Global Drifter Program (GDP). The details of the bonus program changed slightly since it was implemented, but essentially it requires payment of the full tariff, approximately $3.7 K (U.S.), up to a specified commitment to Argos of buoy-years of service. Above that level, buoys added to the GDP in that year transmit through Argos for no added charge. GDP agreed to (i.e., paid for) 130 buoy-years ($481 K U.S.) in 1999 but used 314.8 buoy-years.[3] Therefore, it is reasonable to also calculate cost per message at this reduced rate for buoys enrolled in the "bonus" program. When the committed Argos charges ($481 K) are divided by the total usage by GDP (314.8 buoy-years), the effective Argos tariff for full service is reduced to approximately $1.7 K. Therefore, the effective cost per message for SVP-B's entered in the GDP drops to $0.78 per message for ship-deployed buoys and $0.98 per message for those that were air deployed.

CONCLUSION

The direct costs and performance of SVP-B drifting buoys for reporting atmospheric pressure have been reanalyzed based on data between January 1, 1998, and June 6, 2000. They were compared with results presented at DBCP XII, Henley, UK, in 1996.

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[3]Personal communication with Stephen Auer, NOAA Office of Global Programs and U.S. Representative of Country to the Argos Joint Tariff Agreement.

It was found that MTTF/mean operating time of SVP-B buoys increased to 246 days, a 33 percent improvement. Although 21 percent of all buoys deployed since 1998 provided no pressure reports, apparently due to failure at deployment, statistics show infant mortality was reduced to only 3 percent by the first half of 2000. The annualized direct cost per buoy fell to $5.0 K per buoy, except costs increased slightly to $7.4 K for a new rigging required for air-deployed buoys to maintain U.S. Navy certification. The product cost (i.e., cost per message) decreased by 60 and 70 percent since 1996. For operational meteorologists, SVP-B technology clearly has matured to the point where it is a better observing system value than other buoy systems for measuring barometric pressure.

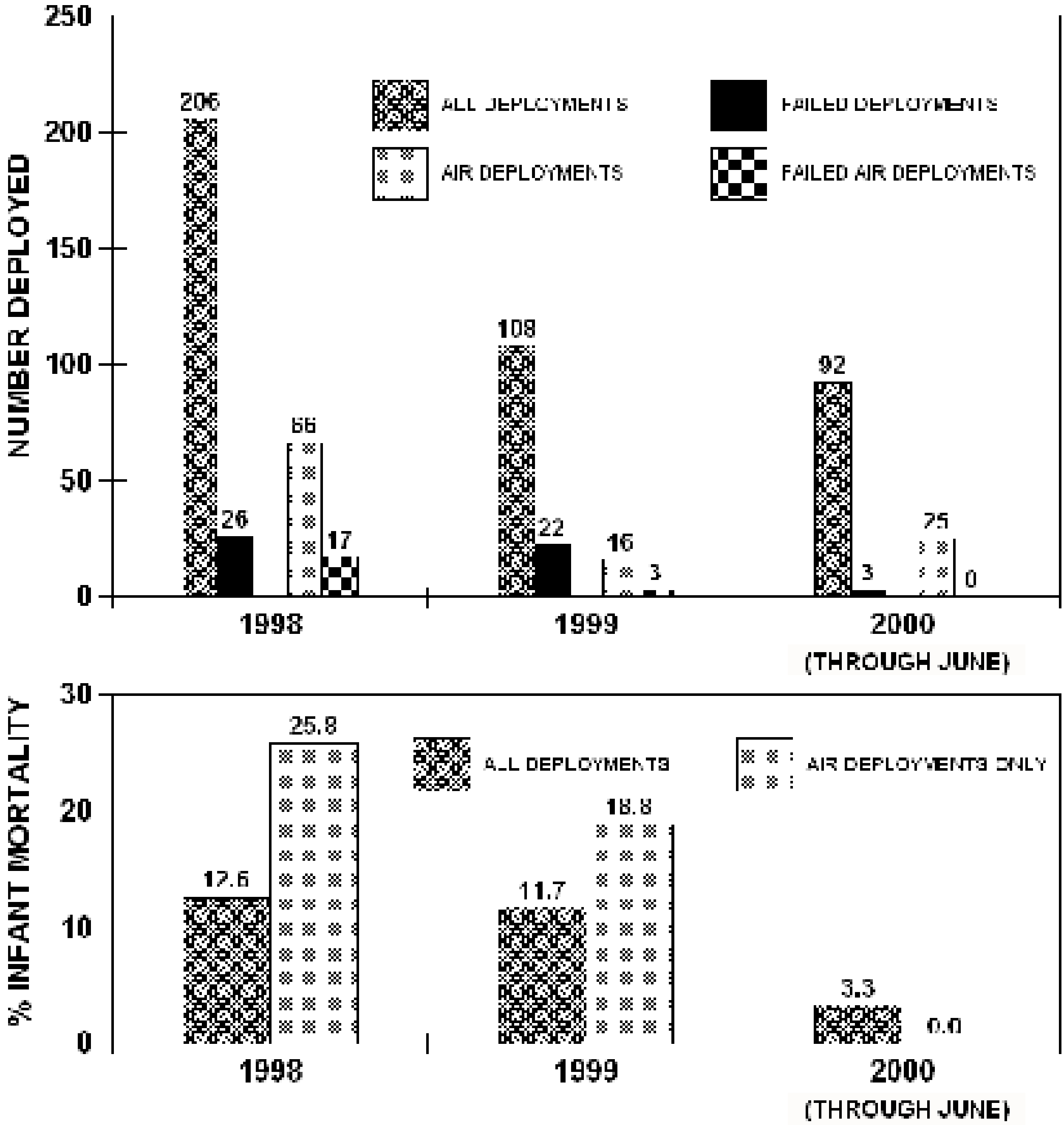

Figure 1. Number of SVP-B drifting buoys deployed by year from 1998 through June 6, 2000. The top graph shows total number of buoys deployed by all means compared with those deployed by air. The bottom graph is percent of failures at deployment (i.e., no data received from the buoy) by year of all buoys compared with percent of failures for air deployments.

Table 1. Direct costs per buoy for ship- and air-deployed SVP-B drifting buoys compared with 1996.

Cost Component	1996	2000	(Air Deploy.) 2000
Hardware	$3.8K	$3.2K	$3.2K
Deployment Package	$0.0K	$0.0K	$1.7K
Total (Buoy)	$3.8K	$3.2K	$4.9K
Annualized Factor	1.9	1.5	1.5
Annualized Cost	$7.2K	$5.0K	$7.4K
"Infant mortality" Adjustment	$0.0K	$0.1K	$0.0K
Comms (PTT--Yr)	$1.3K	$3.7K	$3.7K
Total (System--Yr)	$8.5K	$8.8K	$11.1K
Avg. No. Msg.	917	2,208	2,208
No. Msg. Per Yr	1,533	5,195	5,195
Cost Per Msg.	$5.54	$1.69	$2.14
Percent of 1996	100	31	39

Table 2. Calculated cost per message from SVP-B drifting buoy compared with other buoy types. Numbers in parentheses reflect the effect of the Service Argos "bonus" program on cost per message, based on 1999 usage, for buoys enrolled in the GDP.

SVP-B	SVP-B*	TOGA	WSD	3-m Moored Buoy
1.69	2.14	3.86	3.97	7.74

*Includes $1.7K air deployment package

Autonomous Drifting Ocean Station (ADOS)

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Low-cost drifter platforms can be used to gather an enhanced suite of data that is essential for integrating present and future satellite measurements of biological and physical processes with *in situ* observations. Working together, Clearwater Instrumentation, Inc. and Scripps Institution of Oceanography have successfully completed a program implementing a novel thermistor data-chain and a novel biological irradiance sensor system for Lagrangian drifters, which have been successfully used in WOCE in large numbers. These new sensors have been integrated with WOTAN, a digital, acoustic wind sensor already developed by SIO into an AUTONOMOUS DRIFTING OCEAN STATION (ADOS). ADOS facilitates simultaneous *in situ* observation of winds, surface layer thermal structure response to mixing, and productivity resulting from nutrient upwelling. ADOS features a thermistor string of SmartSensors that measures seawater temperature at 13 levels from the surface to 120 meters and pressure at four levels. SmartSensors are autonomous mini-instruments that communicate with the ADOS surface float by inductive signals sent through hydrographic cable. ADOS measures irradiance and ocean color at SeaWiFs frequencies. Three sets of SeaWiFs sensors are mounted on the surface sphere in closed housings which protect the sensors from bio-fouling until the caps are pushed off at pre-programmed intervals. ADOS implements WOTAN placing it on the thermistor string and by adapting the SmartSensor inductive modem to communicate between WOTAN and the surface sphere. An in-situ calibration and testing program and recovery of instruments at sea has been completed. ADOS were deployed off the California coast along with Minimet drifters from Scripps and followed in a research vessel outfitted with data telemetry and meteorological instrumentation. Results from this cruise verified sensor operation.

1 Introduction

We were confronted with the challenge of making concurrent measurements to enhance NASA observations of the physical forcing of biological response in the ocean surface layer. Our solution was to place a highly integrated sensor suite in a ruggedly constructed surface drifter to make an Autonomous Drifting Ocean Station - ADOS.

The Autonomous Drifting Ocean Station ADOS is an innovative drifter that represents a major step in the level of integration of sensors on a single instrument that will allow concurrent observation of ocean physical and biological processes. ADOS measures, surface wind velocity, ocean surface thermal structure, and ocean color. The data from these sensors will be used together with funded NASA scientific study to enhance observations of the physical forcing of biological response in the ocean surface layer. Besides integrating three sensor systems ADOS performs two of these measurements, ocean color and surface layer thermal structure with novel systems developed under this contract.

1.1 ADOS Ocean Color Sensors

ADOS' approach to ocean color measurement places SeaWiFs color sensors in housing with removable caps, which can be programmed to be pushed off at specific intervals allowing aged sensors to be compared with a fresh sensor. One of the ocean color sensors can be seen in Figure 1 that shows the ADOS surface sphere with all of the caps removed. Caps are removed with very high torque electric motors, which can break tough bio-fouling, if it should occur. A sensor in the mast at the top of the surface sphere measures incident solar radiation.

1.2 ADOS SmartSensor Thermistor String

ADOS' solution to measuring ocean surface layer thermal structure is achieved by placing self-contained electronic thermometers called SmartSensors on ordinary steel-core oceanographic wire. SmartSensors communicate with the ADOS surface float by inductive modem. SmartSensors are battery-powered thermistor sensor with miniature controllers to perform measurements and modem communications. Because SmartSensors are on hydrographic wire, the thermistor string is very rugged; it does not require multi-conductor cables with complicated, sensitive, waterproof breakouts for sensor power and communication.

1.3 WOTAN Wind Sensor

The ADOS thermistor string includes the WOTAN (Weather Observations through Ambient Noise) developed by the Scripps Institution of Oceanography. The SIO WOTAN measures wind speed by implementing digital signal processing of ocean sound. As the case is with SmartSensors, WOTAN is a stand-alone instrument with its own power supply; WOTAN data is transmitted using the inductive modem circuitry of the SmartSensor.

2 ADOS Instrumentation and Sampling

ADOS is a sophisticated oceanographic instrument employing the latest microprocessor technology to make measurements in the ocean surface layer and satellite telecommunications to return the data to the user.

The MasterModem located in the ADOS surface sphere manages sampling of WOTAN, PAR sensor, ocean color sensors, and SmartSensors. PAR and ocean color sensors are located on the surface sphere. WOTAN and SmartSensors are placed on hydrographic wire suspended below the surface float. Commands and data communication between the surface float the subsurface instrumentation are accomplished by inductive modem. All sensors report calibrated outputs except for WOTAN which must be post-converted to obtain wind speeds. Minimal conversion is required to convert Argos messages to engineering units.

Figure 1 ADOS surface sphere.

A PAR sensor is located in the black mast on top of the ADOS surface float (see Figure 1). Each ADOS sphere is fitted with three ocean color sensors in housing in the lower hemisphere. The housing are covered by caps, which are pushed off the first when ADOS is deployed, then at predetermined intervals. The housings protect the ocean color sensors from fouling until the caps are removed and the sensors exposed.

The SmartSensor thermistor string including the WOTAN case hangs below the ADOS surface float. Figure 2 shows the SmartSensor thermistor string, but not the WOTAN case with its acoustic transducer.

2.1 SmartSensor Temperature and Pressure Thermistor String

Twelve SmartSensors measure temperature with thermistors between 10 and 120 meters. The SmartSensor at 10 meters is located inside the WOTAN; it senses *in situ* conditions with a thermistor in a stainless steel probe. Sea surface temperature is measured with a sensor mounted on the surface float. Depth is measured at 20, 50 80 and 110 meters along the thermistor string with stainless steel absolute pressure transducers. SmartSensors are located Temperature is measured by digitizing the voltage across a thermistor in series with a precision resistor. The SmartSensor temperature measurement is the mean of four digitized voltage measurements made across the thermistor over approximately 200 ms.

SmartSensor pressure measurements are the mean of four 16-bit A/D measurements of the output voltage of the pressure transducers. Measured pressure is the ratio of the digitized measurement divided by the full-scale measurement times the full-scale pressure

Surface layer temperature is sampled once a minute. The MasterModem sends a command to the SmartSensors to take temperature and pressure measurements. These are returned to the MasterModem where the five most recent readings for each sensor are averaged then formatted for the Argos message. Thermistor response in the SmartSensor circuit has been characterized by a table of digitized values stored in the MasterModem for the voltage across the thermistor at temperatures between –5 to 44 degrees. MasterModem software determines the appropriate temperature by linear interpolation.

Figure 2 SmartSensor thermistor string. WOTAN pressure case is not shown.

SmartSensors measure temperature with a thermistor mounted at the just inside the SmartSensor hull. This placement gives the SmartSensor an approximately 20-minute time constant which smoothes rapid temperature fluctuation. Figure 6.12 shows the approach of the 110 and 120-meter SmartSensors to *in situ* temperature. The figure also includes estimated data for the 120-meter sensor with the fitted time constant of 19 minutes.

2.2 Irradiance and Ocean Color

The ADOS surface sphere has a Satlantic ED-20 downwelling irradiance sensor and three Satlantic Lu-50 radiance sensors for measuring light and color at SeaWiFs bandwidths. Satlantic sensors meet specifications for SeaWiFs sensors on drifting buoys.

The ED-20 is mounted in the top of the mast on the ADOS surface sphere and points skyward. The ED-20 is a single channel sensor measuring incident radiation with a cosine response field of view for the spectral range 400 – 700 nm.

Each Lu-50 has three sensors; two of the Lu-50's have discrete sensors for 443, 490, and 555 nm; a third Lu-50 has sensors for 490, 670, and 683 nm. The Lu-50's have a 7-degree field of view and are mounted on the bottom of the sphere aiming 10 degrees from normal. The Lu-50's spectral bandwidth is 10 nm. The three LU-50's are contained in the housings on the bottom half of the surface sphere. Initially, caps cover all of the housing. The first cap is programmed to be removed within an hour after ADOS is started. Caps two and three are programmed to be removed 1 month and three months after the initiation of the ADOS mission.

Incident solar radiation and ocean color are sampled once per minute; the previous 32 samples are averaged every minute, then the mean and standard deviation are placed in the Argos message buffer.

2.3 WOTAN Wind Speed

ADOS measures wind speed by measuring the intensity of ocean noise from 0 to 20 kHz in six discrete frequency bands. A WOTAN unit made by Pacific Gyre, Inc. is installed in a pressure case and mounted on the thermistor string at 10 m. WOTAN digitally samples an acoustic transducer for 300 seconds to record ocean noise. The acoustic information is then processed on a DSP board to determine the acoustic power spectrum, certain components of which are proportional to wind speed. WOTAN communicates to the surface sphere through a SmartSensor inductive modem. WOTAN is queried at 20, 15, 10, and 5 minutes before the hour (arbitrary to starting of ADOS). The Argos message is revised on the hour.

2.4 Wind Direction

ADOS measures wind direction by sensing the heading of the ADOS surface float that is fitted with a vane that causes it to turn into the wind. A Precision Navigation electronic compass in the ADOS surface float senses its orientation relative to magnetic North. The compass is sampled 160 times at a rate of one a second. The headings are binned and the largest bin count is reported as the wind direction.

2.5 Location and Data Transmission

ADOS communicate its data to the user via the Argos satellite data telemetry system. Argos is a LEO system employing 2-3 satellites in orbits inclined 15 degrees from the pole. Argos platform transmitter terminals broadcast at 401.65 MHz. Argos satellite telemetry establishes a position derived from the Doppler shift of the received signal. Incident solar radiation and ocean color, surface layer temperature structure, and wind velocity data are each placed into a 256-bit message, or page, which is transmitted in turn. Argos message formats are described in Figures 6.32 and 6.33. One message is sent every 90 +/- 6 seconds. The block diagram for transmission is shown in Figure 6.3. The user probably can expect to receive daily from ADOS between 10 to 15 pages for each group of sensors.

3 Sea Trials

Scripps Institution of Oceanography and Clearwater Instrumentation, Inc. jointly conducted a cruise off the coast of Santa Barbara, California between 26 and 29 April 2000. Two complete ADOS were deployed along with two Minimets, SIO instruments fitted with barometers and WOTAN acoustic wind sensors. The cruise plan was to deploy the equipment and to heave to at least a mile from them to avoid contaminating the acoustic data obtained by the WOTAN, and to record data with an Argos uplink receiver. The RV McGaw would steam out to the Santa Barbara Channel in the early morning. When we could be reasonably assured of being able to retrieve the instruments in the evening, we would deploy one, or more instruments. At the end of the day we picked up the instruments to ensure that they did not become lost or too dispersed to permit intensive logging data. In addition to logging data on the Argos Uplink receiver, some data also were received by the Argos satellites.

It was noticed that ADOS rode roughly, bobbing considerably as the sea state increased. The motion was characterized by ADOS tipping in the direction of the vane as much as 45 degrees, and then snapping back to vertical. This motion, which had not been observed, previously has been attributed to an unbalanced distribution of mass in the surface sphere, specifically the batteries and wind vane, and reduced tension on the tether caused by supplying some additional buoyancy in the WOTAN pressure case. In future ADOS batteries must be positioned to offset the weight of the wind vane and the buoyancy of the WOTAN case will be reduced.

3.1 Study Area

All of the deployments of ADOS and Minimets were within a small area near 34.27 N and 119 85 W. Approximate locations of deployments and stations for 27 April are typical and are shown in Figure 3. Positions were determined by Service Argos from the equipment transmissions. Tracks leaving the mapped area indicate steaming two and from the deployment area.

Because of the rough conditions, one Minimet and one ADOS were deployed on 26 April, 2000, the first day of the cruise. The second day, conditions were less trying; two Minimets and two ADOS were deployed for the longest duration of the cruise. On the third day, conditions were deteriorating as the day progressed and although all four instruments were deployed, the deployment was shorter.

3.2 PAR and Ocean Color

Both ADOS were in the water and operating before local noon. They remained in the water until 5 pm local time. Data for 25681 and 25688 for 27 – 28 April 2000 are in Figures 4 and 5. The color of the ocean was observed to be primarily blue. Outliers at the beginning and ends of the charts represent intervals before ADOS were launched and after they were brought back on board the McGaw.

3.2.1 Solar Irradiance.

On April 26 ADOS 25688 was in the water for after local noon and irradiance decreases from 125 to less than 25 $\mu W/cm^2/nm/sr$. On April 27 both ADOS were in the water from one hour before local noon to three hours after. Both irradiance sensors peak out at approximately 150 25 $\mu W/cm^2/nm/sr$. On April 28 ADOS 25681 went in the water shortly after sunrise and was removed shortly before local noon; 25688 was launched about three hours after 25681 and came out after a little more than one hour. Agreement between the irradiance sensors is reasonable.

3.2.2 670 and 683 nm (Red).

These bands in red have the lowest values. Values for 670 consistently are lower than those for 683. On April 26 both bands are at their highest, 0.16 to 0.20 $\mu W/cm^2/nm$ respectively, and their difference is greatest, approximately .04$\mu W/cm^2/nm$. On April 27 during the middle hours of the day, both bands hover around 0.1 $\mu W/cm^2/nm$. On April 28 both bands have approximately the same values and are slightly lower than the previous day, although the time was earlier in the morning and the irradiance was not as strong.

3.2.3 555 nm (Yellow).

This band has the highest values reported for the sensors. All 555 sensors compare well between ADOS and on each ADOS where there are two sensors on different LU-50’s. The maximum values at midday are .65 $\mu W/cm^2/nm$.

3.2.4 490 nm (Blue).

490 nm cells are in each of the Satlantic LU-50’s, so there are three on each ADOS. Blue light levels are run 10% lower than yellow (555 nm). On April 26, the two operational sensors did not track as well as on subsequent days. Maximum values in this band are about 0.55 $\mu W/cm^2/nm$.

3.2.5 443 nm (Indigo).

443 values generally run about 50% of 555 nm values. These bands which are present in two of the LU-50’s, did tracked reasonably well. Maximum values attained 0.4 $\mu W/cm^2/nm$.

3.3 Surface Layer Temperature Structure.

Surface layer temperature structure is measured at the sea surface (SST) with a thermistor probe, at 10 meters with a SmartSensor probe mounted on the WOTAN pressure case; and at 11 depths below WOTAN by SmartSensors fitted with imbedded thermistor sensors.

3.3.1 SmartSensor Temperature Response.

While the SST probe has a fast response, the SmartSensor thermistor has a slower response since it is imbedded in the potting material near the outer wall of the SmartSensor. Figure 6 shows the response of SmartSensors at 110 and 120 meters where the temperature structure was stable for the length of the deployments. SmartSensor temperature response was modeled with exponential decay and a response factor of 19 minutes provided the best fit. Fitted data for 120 meters is shown in Figure 6.12. SmartSensors could be fitted with thermistors in probes to increase their response time.

3.3.2 XBT

Two XBT cast were made on April 26 and one cast on April 27. Results of XBT casts are reported in the Figures for surface layer temperature structure.

3.3.3 Temperature Profiles for April 26, 2000.

Figure 7 shows the temperature structure for April 26 for selected times at approximately half hour intervals. XBT's were taken earlier that the profiles reported in the Figure; earlier were available but the SmartSensors had not yet stabilized. The SmartSensor temperatures closest to the time of the XBT's agree well, particularly below 30 meters. SmartSensors failed at 70, 90, 100, 120 meters. These SmartSensors were of an early design that had not been pressure tested and had a design flaw in sealing the pressure sensor fitting. Later models have been tested and have an improved seal which is believed to eliminate the flaw..

3.3.4 Temperature Profiles for April 27, 2000.

Figure 8 shows a much longer record extending for over five hours for 25681. At the surface, the temperature advances from 14.5 C to almost 17 C at 2100 UT. The SST is a probe with faster response than the SmartSensors; even so, there is similar motion at 20 and 30 meters. Notice the stability of the temperature at 120 meters; it varies only a few hundredths of a degree over the time of the observations. The agreement between the XBT and SmartSensors is very good; this is well illustrated by the fit at the greater depths where there is less variability.

3.4 Wind April 27, 2000

ADOS have two acoustic transducers on them. They were deployed along with Minimet drifters built by SIO. ADOS and Minimet use the same systems for measuring acoustic winds speeds. Both also have an electronic compass in the surface float for measuring wind direction by sensing the heading of the surface float. All directions are magnetic; corrected directions have had measured compass error removed.

3.4.1 Winds April 28, 2000.

Minimets and ADOS reported winds from just after 1400 UT until 2000. During this time the wind turned from northwest to west by southwest (Figure 9). All wind heading are within reasonable agreement.

Acoustic power results are presented for Minimet 15941 and ADOS 25681-0, 25681-1, and 25688-1 in Figures 10 and 11. Results for the dual sensors on ADOS 25681 give reasonable agreement.

4 Conclusions and Future Work

ADOS development can be considered complete now that fully functional systems have been deployed and operated for a limited period of time. Correctable problems were found with SmartSensors and the ADOS surface sphere. A leak was found in some of the early SmartSensors that were not pressure tested. Later SmartSensors have been pressure tested and fitted with seals to correct the problem. The ADOS surface float needed better mass distribution of batteries and less buoyancy in the subsurface WOTAN housing. These changes have been made.

4.1 ADOS April 2001 Deployment.

What remains to be done is to deploy ADOS to obtain sufficient data to assess long-term viability and to inform sampling procedures, especially for removal of ocean color sensor housing. Deployments in 2001 will be made after incorporating any necessary changes in measurement techniques and sampling strategies.

5 Acknowledgements

We are pleased to acknowledge the generous support of NASA through SBIR Contract NAS5-98056 and purchase orders from the Scripps Institute of Oceanography.

6 Figures and Tables

Figure 3. Argos Positions 27 April 2000
Universal Time

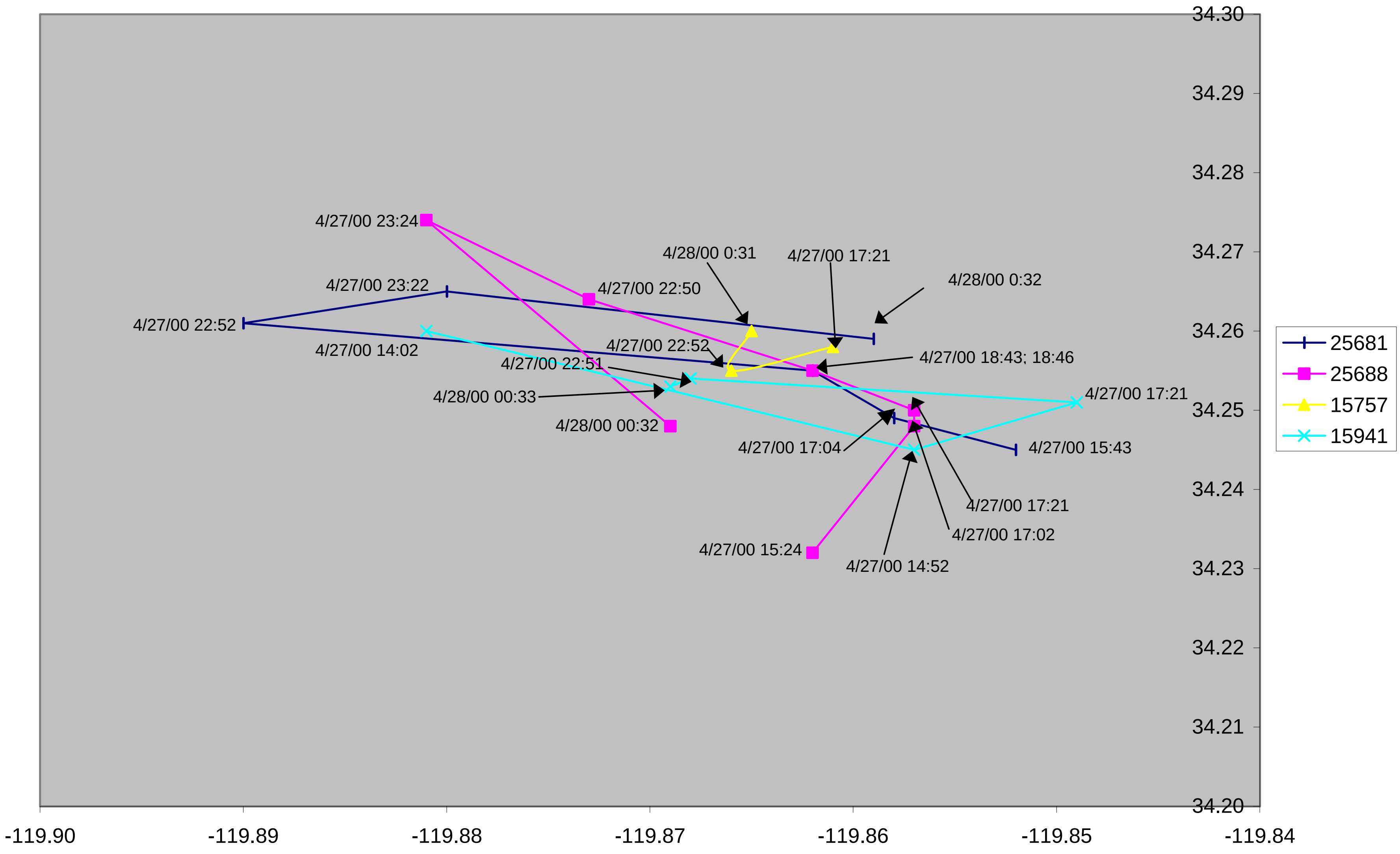


Figure 4. 27 - 28 April 2000
25681 PAR and Ocean Color

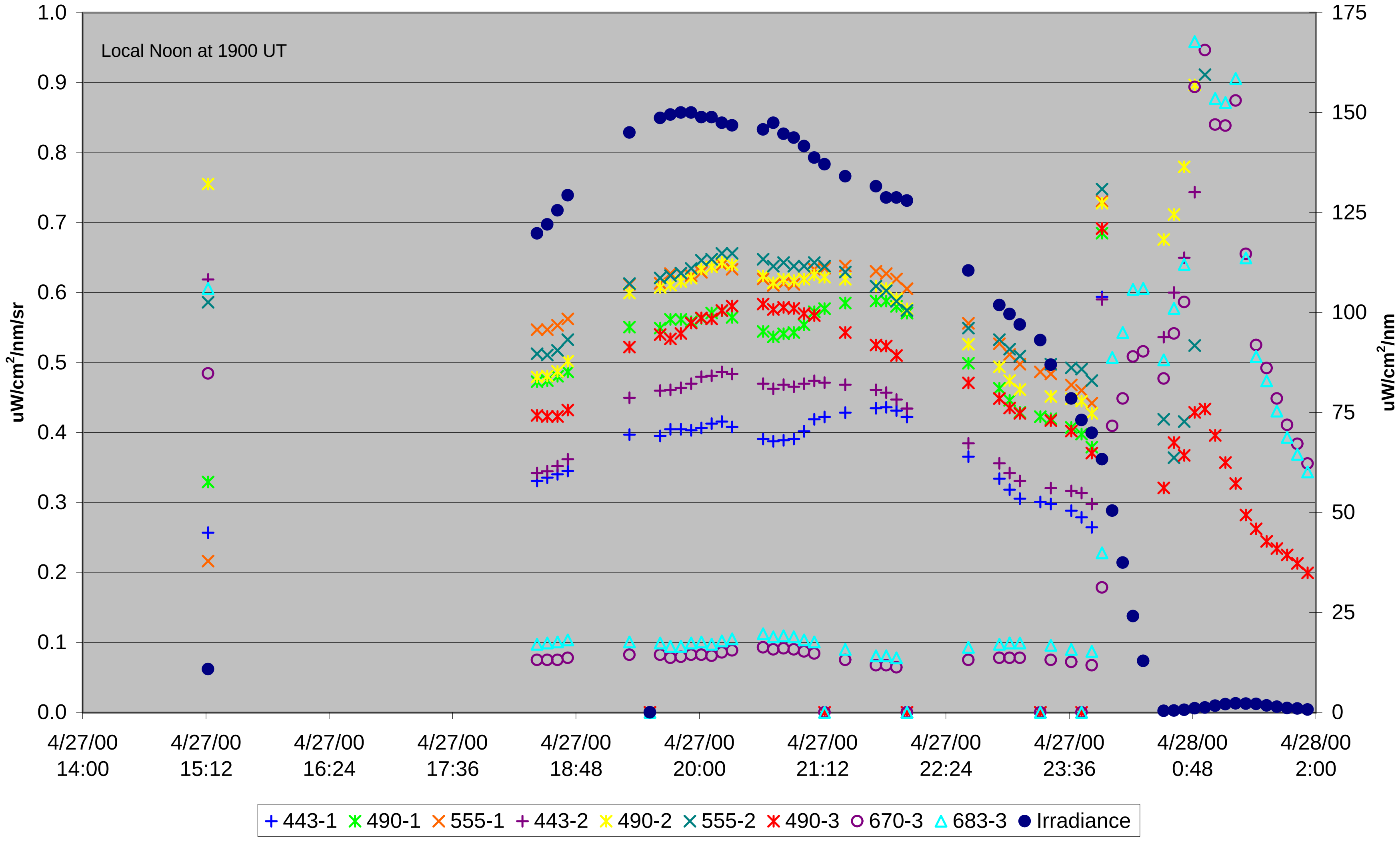


Figure 5. 27 - 28 April 2000
25688 PAR and Ocean Color

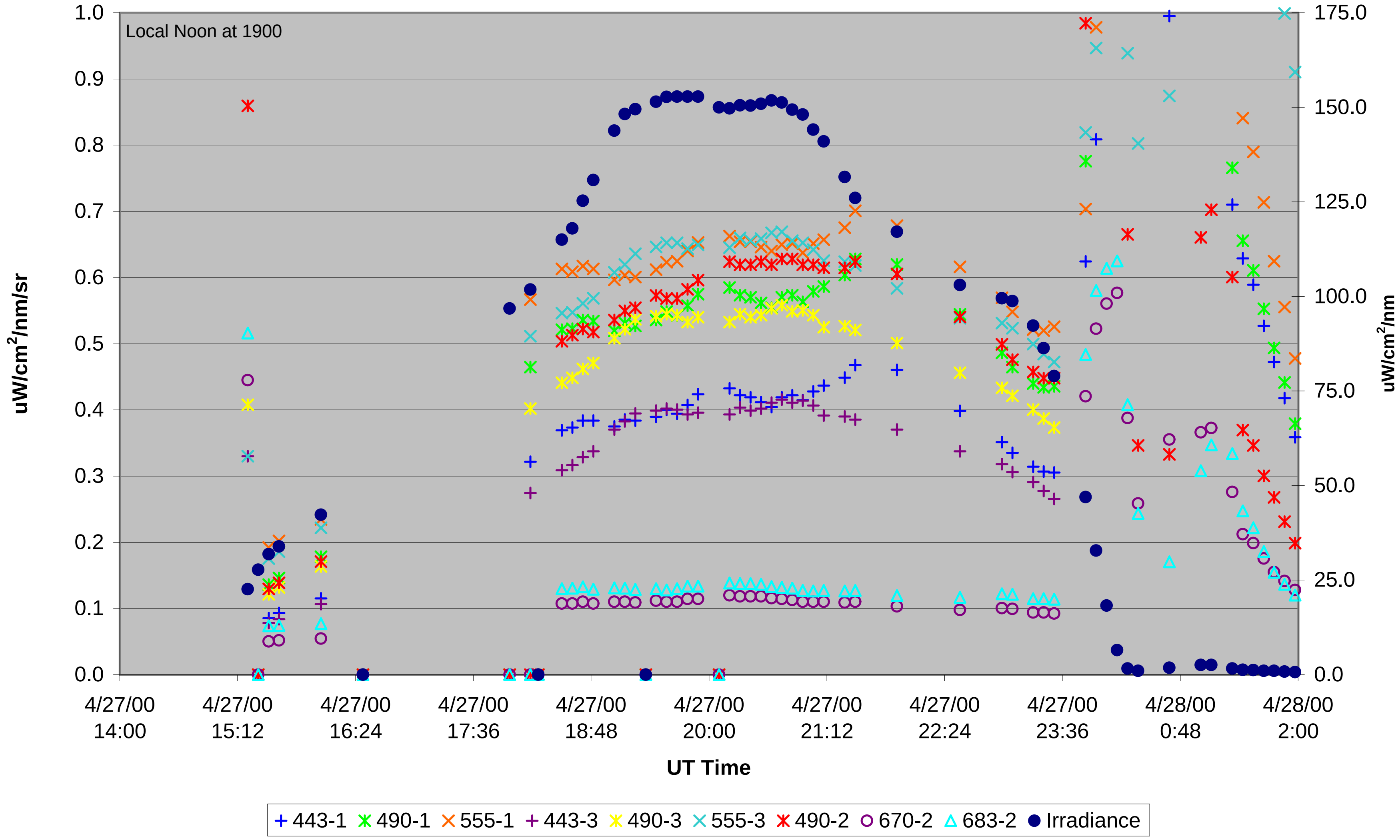


Figure 6. Temperature Response 25681
28 April 2000

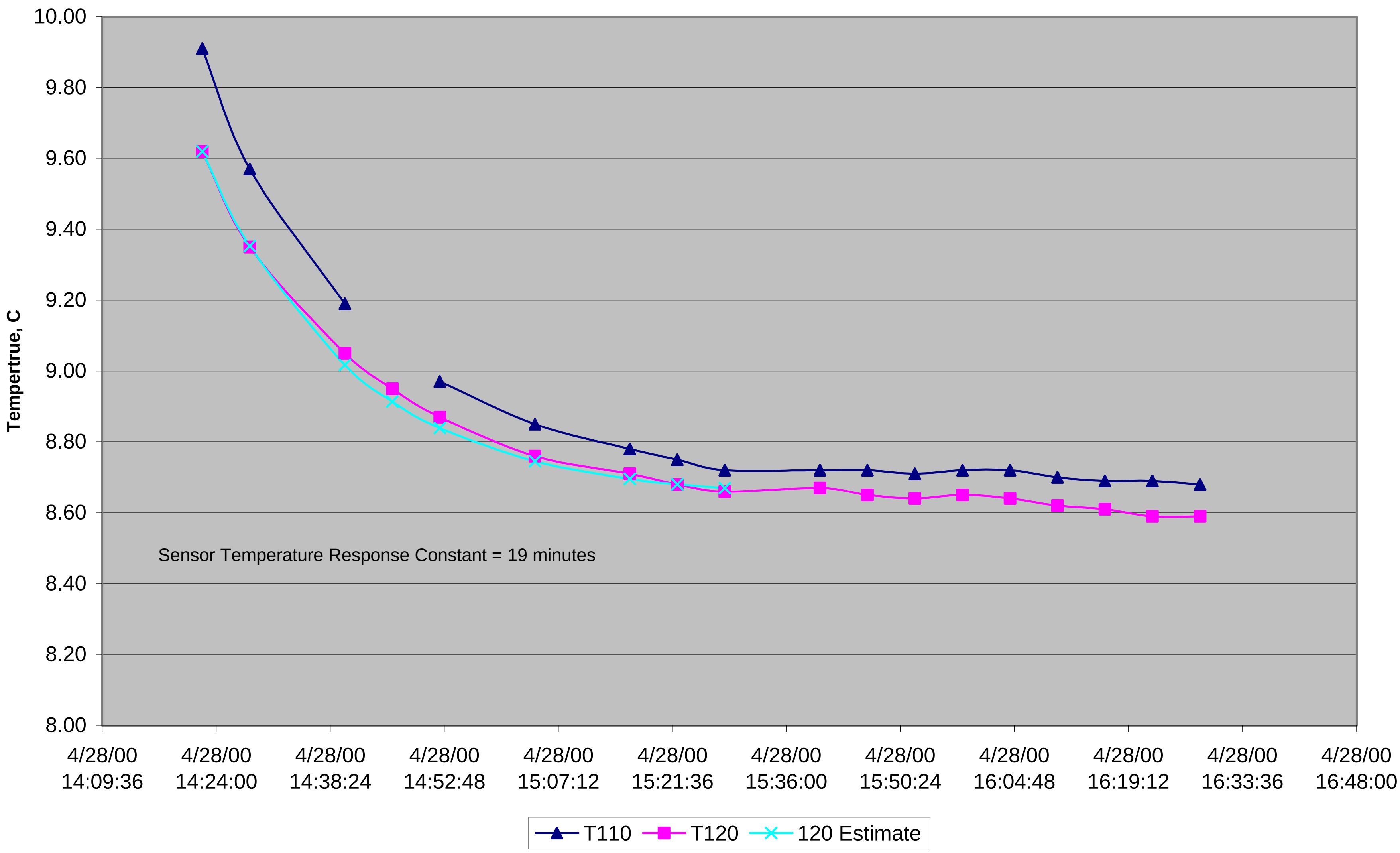


Figure 7. 25688 Temperature Profile
26 - 27 April 2000 UT

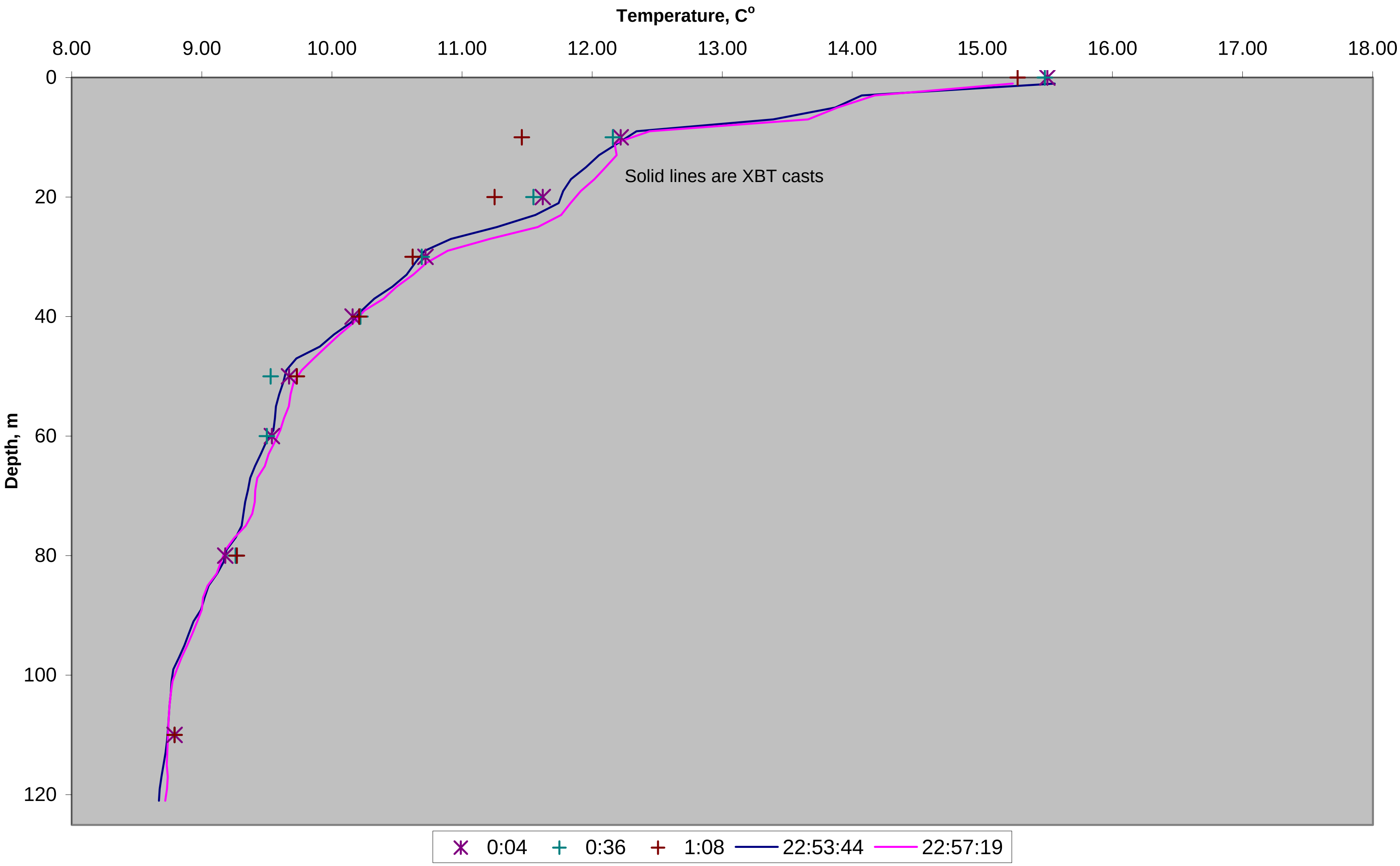


Figure 8. 25688 Temperature Profile
27 - 28 April 2000 UT

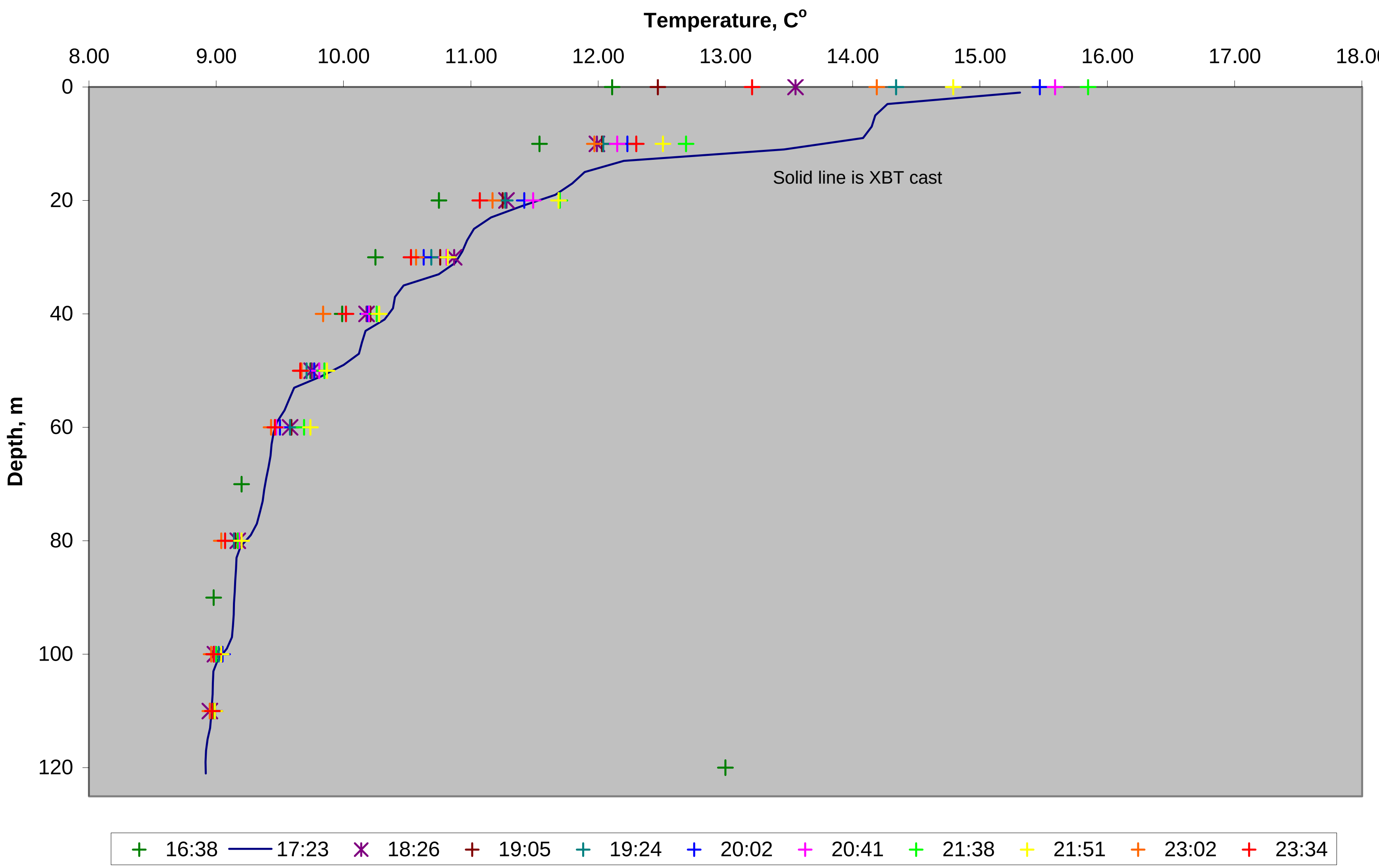
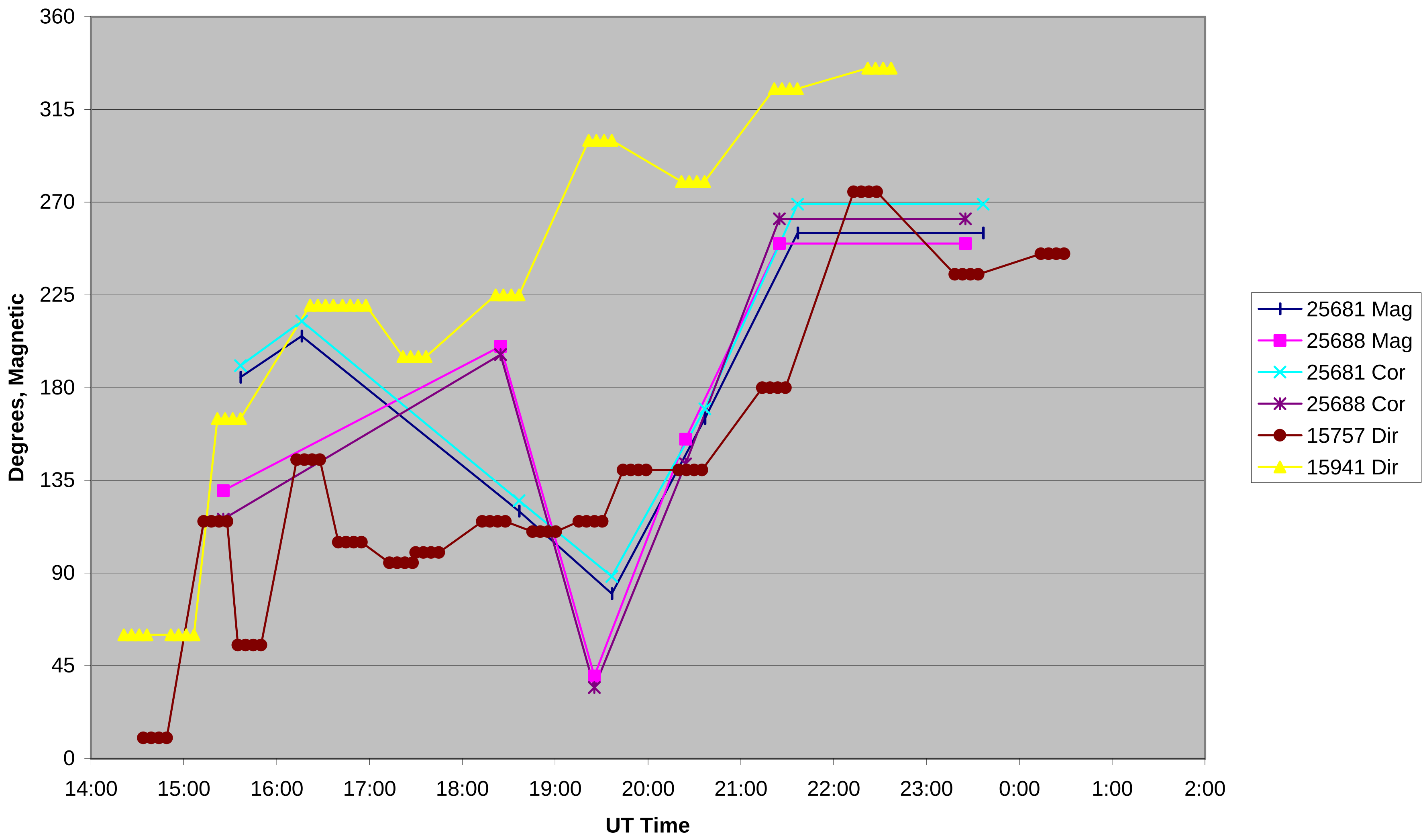


Figure 9. Wind Direction
27 - 28 April 2000



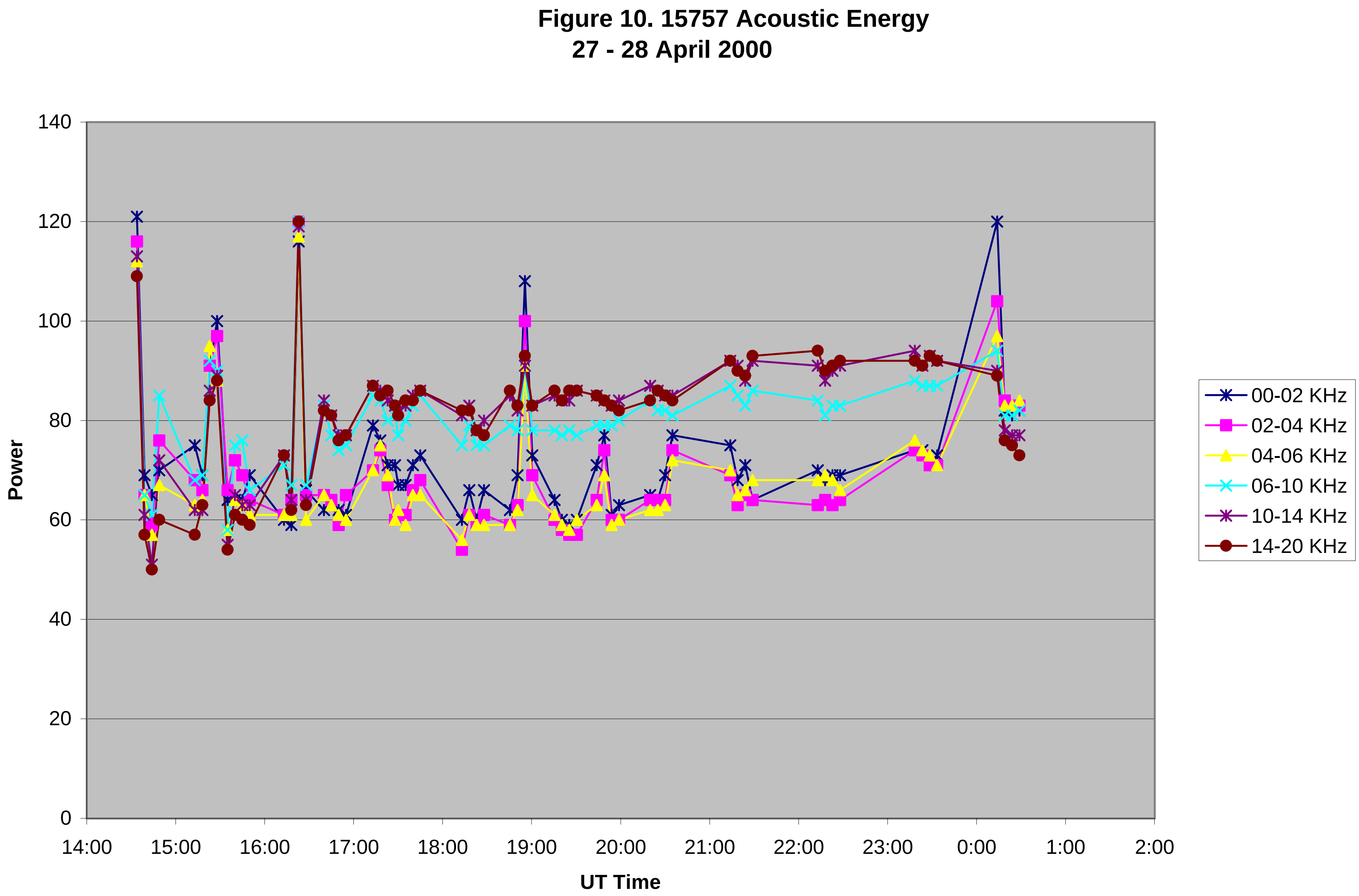
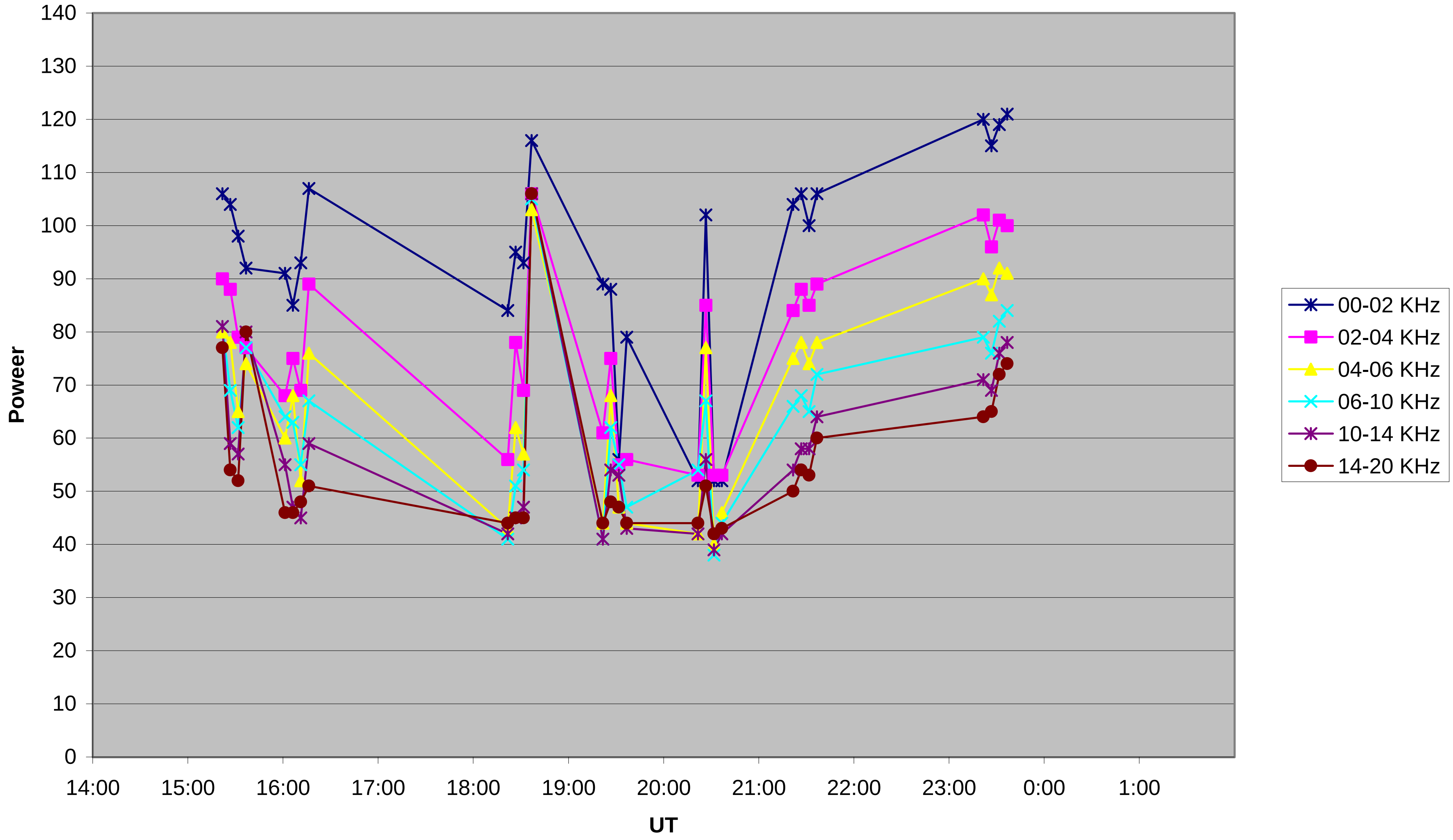


Figure 10. 15757 Acoustic Energy
27 - 28 April 2000
Power
UT Time
0
20
40
60
80
100
120
140
14:00
15:00
16:00
17:00
18:00
19:00
20:00
21:00
22:00
23:00
0:00
1:00
2:00
00-02 KHz
02-04 KHz
04-06 KHz
06-10 KHz
10-14 KHz
14-20 KHz

Figure 11. 25681 - 0 Acoustic Power
27 - 28 April 2000



Getting ready for the Argos Downlink

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ARGOS
COLLECTE LOCALISATION SATELLITES

Argos system enhancements

May 2001:

After the launch of NOAA L in 2000 and NOAA M in 2001, three satellites will be flying second-generation Argos instruments.

Frequency spreading will be introduced for platform transmissions. In particular, bandwidth will be reserved for low-power platforms in order to take advantage of the spaceborne instrument's increased sensitivity.

System capacity will increase fourfold, thus allowing more data to be transmitted.

November 2001 +:

A new second-generation Argos instrument will be launched on ADEOS II.

This launch will mark the beginning of a new partnership with Japan and bring a major new innovation by providing downlink messaging capability.

Downlink messaging will allow Argos users to dialog with their platforms.

It will also provide a new transmission mode called interactive data collection, which may be used instead of or as a complement to random-access data collection.

This major enhancement will be added on to standard Argos functions so that users can continue operating their platforms as before or switch progressively to downlink messaging.

1) System development strategy

The Argos system’s future development must take the following factors into account.

a) Certain users investing in platforms over the long term do not want any changes. Conversely, others using platforms with very short operating lifetimes expect Argos to provide continuous performance enhancements.

b) New satellites will be launched over a period of several years, so service enhancements will be phased in progressively.

c) Enhancements and changes to the Argos system must not compromise stability and continuity of service.

2) System development strategy

Maintain upward compatibility

System upgrades must continue to support existing operating modes.

For users who are satisfied with the current service or do not see any need to upgrade, Argos will evolve but remain compatible with their platforms.

For example, users will not be obliged to switch to downlink messaging. Users will be able to continue operating platforms without receivers or to fit certain platforms with a receiver to take advantage of downlink messaging and interactive data collection.

Give users a choice

The system will be developed by adding on new functions that users may choose to adopt or not, depending on their requirements.

For example, if users decide to switch to downlink messaging, they do not have to use it all the time. They may choose to switch on their platform receivers periodically (say, 12 hours per week). At all other times, platforms could operate in transmission-only mode. Users may switch between interactive data collection and random-access data collection at any time.

3) System development strategy

Gradual evolution

The system will evolve gradually by flying Argos instruments on a number of satellites at the same time.

Each new satellite will thus offer new features that will not be exploited fully from the outset, since they will be available initially on one satellite only.

Users will be able to experiment with new functions or use them operationally in combination with existing functions by switching between satellites. Platforms will be designed to revert automatically to existing operating modes to minimize the risk of failures when using new functions.

For example, interactive data collection will only be available to begin with on ADEOS II. This mode will improve performance when ADEOS II is within view, but platforms will operate in random-access mode with the four other satellites.

System evolution will therefore be a gradual process, ensuring graceful degradation in the event of a failure to maintain the system’s operational capability

Platform terminals

A platform may be fitted with two kinds of terminal:

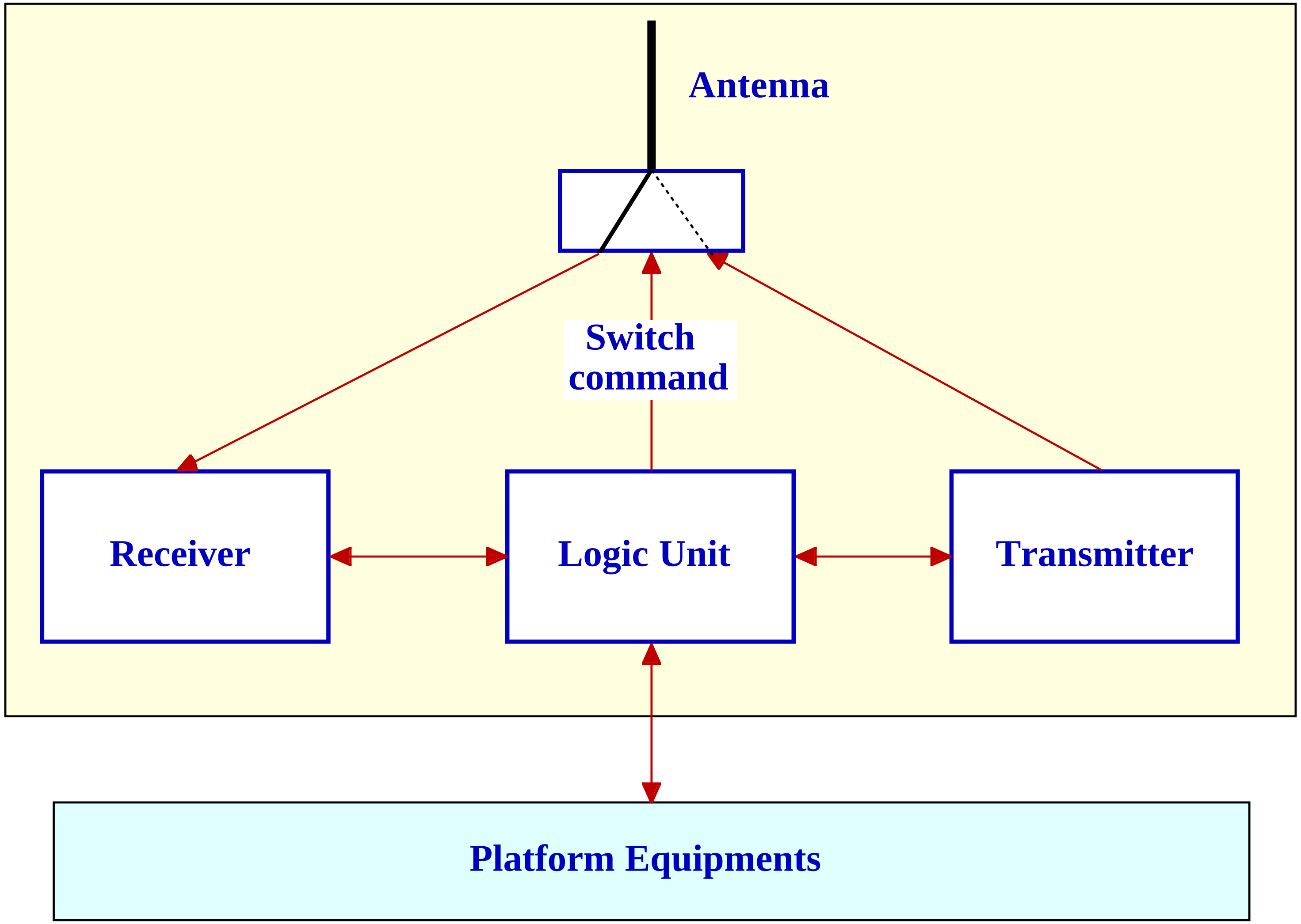
- **a platform terminal transmitter (PTT)**, comprising a transmitter and associated logic circuitry. A PTT communicates with the satellite one way (uplink) and operates in random-access data collection mode;

- **a platform messaging transceiver (PMT)**, comprising a transmitter, a receiver, and associated logic circuitry. A PMT communicates with the satellite two ways (uplink and downlink).

It can operate in random-access or interactive data collection mode, and can receive downlink messages from the user.

The Argos system operator considers PTTs and PMTs as complete units that must be certified by an organization approved by the Argos Operations Committee before they can operate within the Argos system.

Platform Messaging Transceiver (PMT)



Downlink messaging

Downlink messaging is an enhancement requested by Argos users that will offer a great many potential new applications for the Argos system.

Downlink messaging will allow users to perform actions within a closed loop, provided they have properly understood the capabilities and limits of the service.

With downlink messaging, platforms fitted with a suitable transmitter will be able to:

- receive messages from users for closer control over scientific and technical parameters;

- receive messages from the Argos system operator to optimize performance, i.e.:
  . general information such as the time (UTC), Argos constellation status, satellite orbit parameters, etc.;
  . specific information such as platform positions.

However, we must take care to manage the increased degree of complexity Downlink Messaging will entail, at the risk of damaging Argos's reputation as a system that is easy to use, robust, and reliable.

Data collection

When downlink messaging enters service two data collection modes will operate in parallel:

Random-access data collection mode

This mode has proven simple, robust, and able to function in difficult conditions; it operates one way only, i.e., platforms uplink messages to the satellite, so there is no protocol or dialog between platform transmitters and the spaceborne Argos receiver.

However, it does have some drawbacks. In particular, there is a limit of 800 bits of useful information that can be uplinked on each satellite pass.

Interactive data collection mode

Interactive data collection only works with satellites carrying an Argos instrument with downlink messaging capability.

The Argos instrument checks each message sent by a platform and responds with an acknowledgement if the message checks out OK. On receiving the acknowledgement, the platform then sends the next message. If it receives no acknowledgement, it resends the message.

Interactive mode differs from random-access mode in that it:

- confirms if messages have been successfully sent and received; this represents a significant change for Argos;
- sends more useful messages during each satellite pass, since only messages not acknowledged by the Argos instrument are resent.

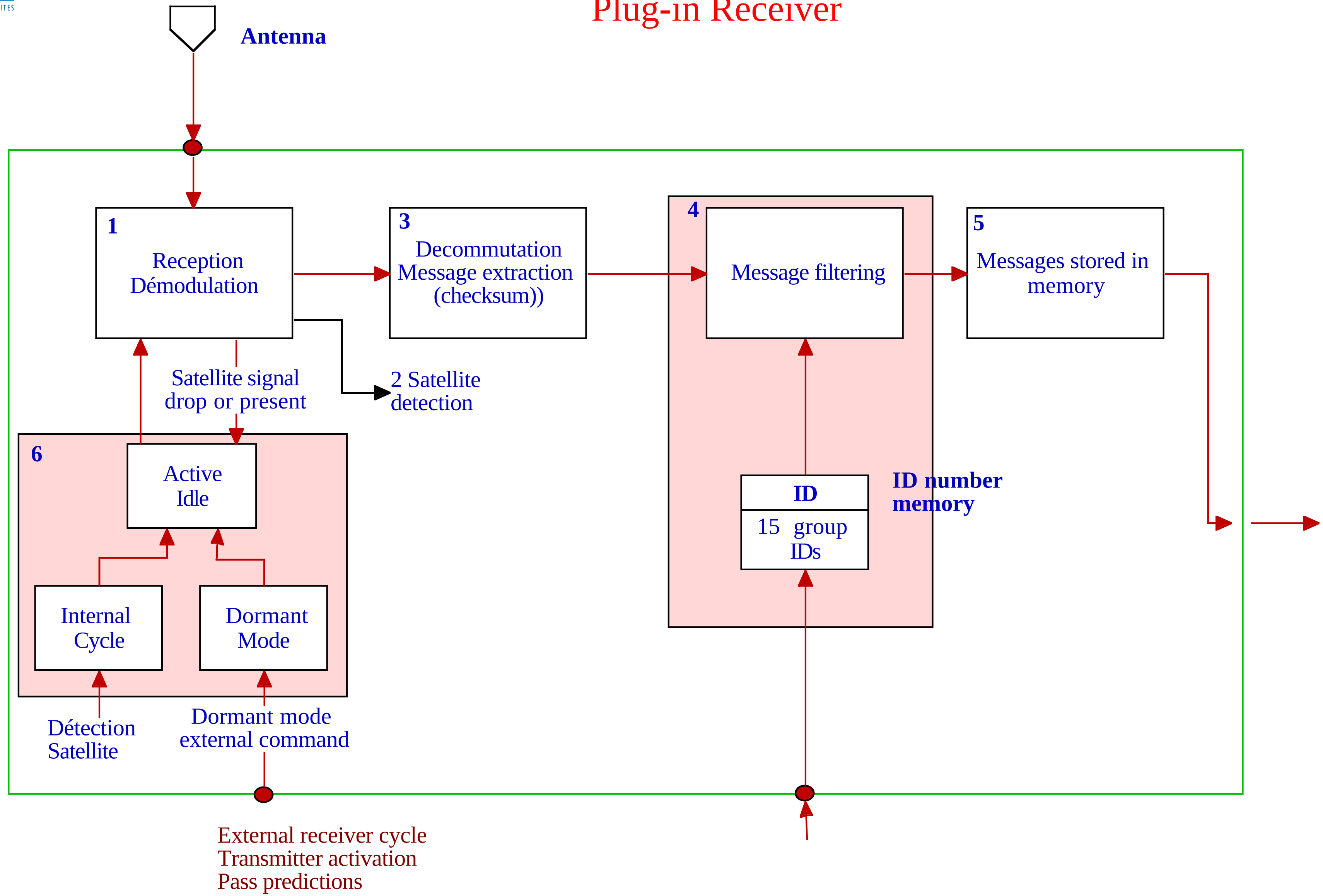
Put simply, a satellite communicating with a platform in interactive mode offers a transmission capacity equivalent to three satellites operating in random-access mode (in fact, given that the number of successfully sent messages is known, the actual gain in capacity over random-access transmission strategies may be even higher).

How random-access and interactive modes will co-exist:

Both modes will operate in parallel all the time.

Satellites without downlink messaging capability will operate in random-access mode only, whereas those with the capability will offer users the choice between the two modes.

Plug-in Receiver



Service Argos Strategy for Argos Downlink Messaging Function development

1) Downlink Messaging Function general promotion

   Présentations, Documentation

   Explore different types of application in contact with users

   Service opening strategies

   Tariffs

2) Distribute and explain PMT Receiver technical specifications

   Promotion of the receiver development by several manufacturers

3) Line production of a "Plug In " receiver during the transition period before the launch of the first satellite equipped with the Downlink Messaging Function and two years after

   Close contact with manufacturesr to integrate the receiver in their PMT

   Documentation, Technical help

   Development of Simulation Equipments of the Downlink function and the receiver to develop PMT

   Management of the production line

4) Development of PMTs

Select potential applications (Floats, Drifting buoys, Fishing vessels ...)

Discuss and Write adapted specifications

Develop a complete PMT for one or several application (same strategy than for the receiver)

5) Service Argos participation to the Qualification of the Downlink Function in close contact with CNES

Proposition of different types of test according to User potential applications

6) Early Entry Program

Joint projects between Users, Manufacturers and Service Argos to develop and test different type of applications

Short term Agenda

Downlink Function Development short term Agenda	September	October	November	Décember	January	February	March	April
"Plug-in" Receiver line development								
Simulation equipment		Tests	Ready					
6 prototypes								
50 PMTs line production								
150 PMTs line production								
Documentation								
Technical Specifications	Ready							
Simulation Equipment Doc.								
PMT Functional Description								
Contats with Manufacturers					To be convened			
PMT development								
Application analysis and specifications			Start					
Contacts for use of "Plug-in "receiver					To be convened			
CLS PMT Development						Start		

Drifting Wave Buoy using ORBCOMM Data Transmission

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Abstract

The Japan Meteorological Agency developed a new type of buoy, and initiated operational observations in adjacent seas of Japan using the buoys on May 2000. The buoy measures air pressure, sea surface temperature and significant wave height and period. Observed data are transmitted to the JMA via ORBCOMM satellites three hourly. In case of wave height is higher than preset threshold, it changes hourly basis observation. It also allows us to send some commands to buoys such as “change the threshold to xx meters” or “continue one hourly observations”. The JMA encodes the data to WMO code (FM-18 BUOY), then places them onto GTS network immediately. No data were missing since the beginning of the operation (for about 1,900 reports in four months), while most data were received within ten minutes after the observation.

Introduction -- background --

The Japan Meteorological Agency has been operating 10m discus moored buoys since 1973, under the framework of World Weather Watch promoted by the World Meteorological Organization. Their mission is to monitor severe weather conditions for prevention of meteorological disasters. Recently, it became harder to maintain the buoys, as they grew old. On the other hand, other technologies have been developed, such as satellite observations, computer models/analyses and so on.

Then the JMA decided to replace the buoys with new type ones.

Requirements and limitations

The JMA’s former 10m buoys made observations every three hours for 11 meteorological/oceanographic elements (variables).

- The mission (prevention of disasters) is not changed.
- It is requested at least to observe wave height.
- Real time telecommunication is essential.
- Costs must be cut down sharply.

So it is impossible to construct a large buoy, or to charter any work ships. Only JMA research vessels should be used for the operation.

Then we designed the new buoy as a drifting type.

Basic design

The main features are as follows,

- Maintenance free.
  - Once deployed, the buoy will not be recovered.
- Small size and light weight for easy deployment.
  - So as to require neither special equipment nor skills to deploy.
- Long lifetime enough to survive through the period drifting around within the target area.
  - That is estimated at about three months.
  - The battery is Li/MnO_2 cells (ULTRALIFE BATTERIES INC. UK).
- Eco-friendly (environmentally friendly) materials.
  - The hull is made of metal (aluminum alloy) instead of plastic. It will dissolve in water.
- Limited variables.
  - Air pressure, sea surface temperature and waves (significant wave height and period).
- Hull shape.
  - Designed to fit onto sea surface as always as possible for wave observation.

The cost which required to manufacture the first lot was about US$28,000 for each buoy.

Sensors and measurements

- Air pressure;
  - The buoy has a barometer port on the top plane. It looks like that of standard SVP-B's, but more simple. A micro-filter (GORE-TEX) inside the port prevents water entering.
  - The sensor is a silicon capacitive absolute pressure sensor (VAISALA PTB-100A) mounted in the hull on sea level.
  - Sampling is 2 Hz for the period of 30 seconds.
  - The output value is the average of medial (middle) 40 values in the 60 samples.
- Sea surface temperature;
  - A platinum resistance thermometer is attached under the float block.
  - Sampling and averaging are the same process as air pressure.
- Significant wave height and period;
  - A one-axis accelerometer is mounted in the hull (about on the center of gravity).
  - It is supported by gimbals to keep it vertical.
  - The output is integrated twice to change into vertical displacement.
  - Then individual waves are extracted applying "zero-up-cross" method to the 1,024 samples for the period of 512 seconds.
  - Significant wave height and period are calculated as the averages of upper third of the individual waves.
- GPS
  - The buoy is equipped with a GPS receiver. And uses it also for time correction besides the position determination.

Telecommunications

Some factors were considered when choosing the communication means. We evaluated for the ORBCOMM system to have some advantage.

Those are as follows;

- Cost
  - 5,000 Japanese yen / 6 KB / month + 0.5 yen / bite.
    - (about US$50, US$0.005 respectively)

  It is a reasonable level for our short messages of low frequency.
- Service area

  At present, ORBCOMM JAPAN provides only bent-pipe mode. But the service area is wide enough to cover our target area (adjacent seas to Japan).

- Two way communication

  Usually, the buoy works every three hours, and the data are transmitted to the JMA. When the weather is severe, it is useful for the synoptic analysis to obtain the meteorological data more frequently. When waves are higher than thresholds set beforehand, the buoy changes automatically to the hourly observation.

  The threshold can be changed at any time by using the two way communication function of ORBCOMM system.

  It is also possible to send a command to keep hourly observation regardless of the wave height.

  In addition, the buoy can correspond also to some more commands.

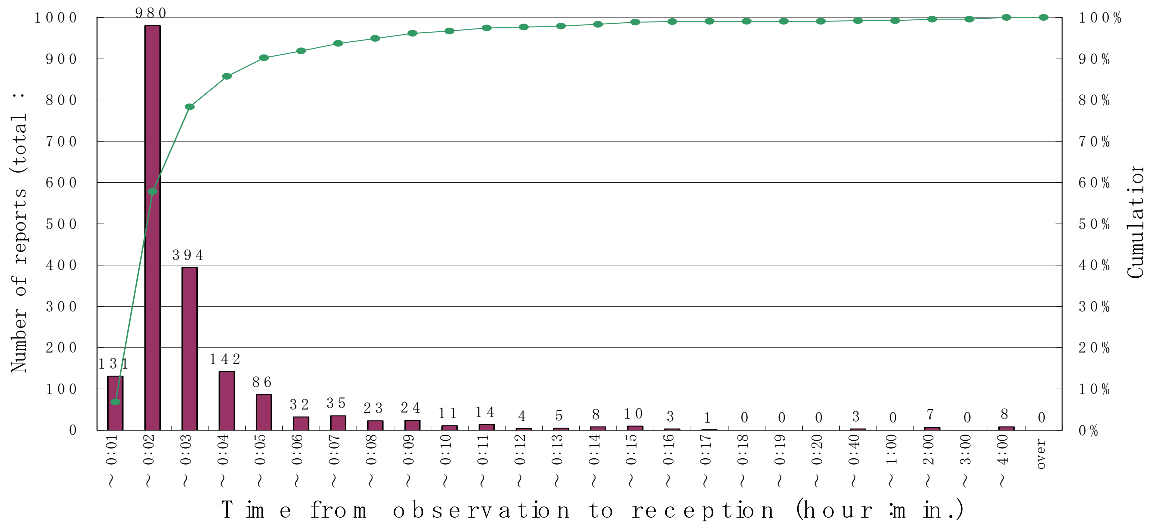
  - Change to three hourly observation
  - Inform of the operation situation (last data, voltage of batteries)
  - Terminate operation
  - Sink (unscrew two bolts on top and bottom plate of the hull)

- Timeliness and reliability

  The buoy of this type was deployed for the first time on May 11, 2000. Four buoys have been already deployed by the end of September. About 1,900 times of observation were made.

  Almost all (about 99%) data were received within 15minutes after it had observed. A few data were received with about 3 hours delay, probably because there were no satellite over the buoy at the time. Most of the delays over three hours were due to our machine trouble (mail server or LAN in the office).

  Up to now, the data loss which originates in the satellite system has never occurred



Data utilization and the quality

The JMA encodes the received data to WMO code (FM-13 SHIP and FM-18 BUOY), then places them onto GTS network immediately. These observation values are very good according to the result of the quality control at some centers such as UKMO, METEO FRANCE, NOAA and ECMWF. At present, our data are placed on the GTS in the format of FM-13 SHIP with the header SXVB and FM-18 BUOY with the header SSVB. It is scheduled to distribute these data only in FM-18 BUOY for the future. It should be noted that these data in FM-18 BUOY on the GTS are applied the header named SSVB01 – 19 RJTD instead of SSVX.

Summary

- JMA started the operation of a new drift type buoy this year.
- The buoy observes air pressure, sea surface temperature and waves (significant wave height and period).
- The observation is done with sufficient accuracy.
- The ORBCOMM system which is adopted as a communication system has a good performance for our operational use.

ORBCOMM – AN ANTARCTIC EVALUATION

David Meldrum, Duncan Mercer and Oli Peppe[1]

ABSTRACT

Dunstaffnage Marine Laboratory and the University of Cambridge Scott Polar Research Institute have jointly developed a new ice drifter for studies of ice dynamics and deformation during the critical early growth phase, which is not well imaged by satellites. The buoys use a novel pancake-shaped hull that mimics the shape of young floes, and incorporate both GPS and Argos for position finding. GPS data, transmitted via the new Orbcomm store-and-forward messaging service, are being post-processed to yield accurate velocity fields. The meteorological sensor package is an embedded SVP-B using Argos, entirely separate from other buoy systems to facilitate message insertion on the GTS and ensure data integrity. Other sensors transmit wave spectral data and oceanographic information over the Orbcomm channel. Deployments were made in the Weddell Sea in April 2000.

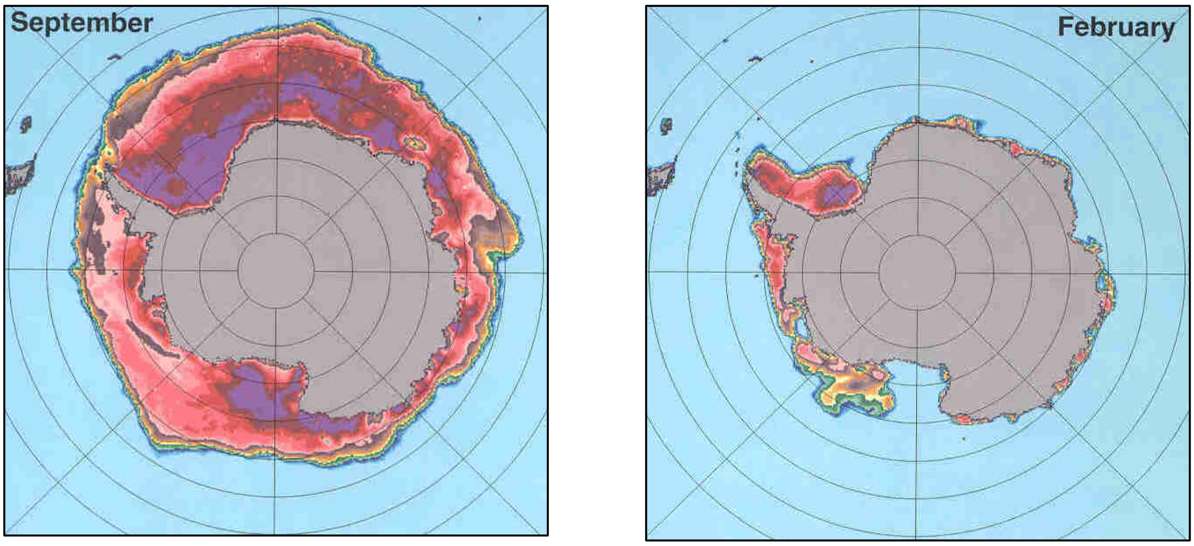


***Figure 1**. Passive microwave images of maximum and minimum sea ice extent around Antarctica in 1987 from NASA's Nimbus-7 satellite.*

INTRODUCTION

Sea ice influences the Earth's climate in many ways: its high albedo affects the planet's heat budget; its thermal insulation controls heat and mass fluxes between the atmosphere and the polar oceans, and its role in destabilising the water column through brine rejection may drive deep convection. In addition, variations in the seasonal pattern of sea ice distribution are likely to be sensitive indicators of changes in the heat content of the upper ocean, itself a key marker for climatic change (Wadhams, 1991). The area of the planet's surface involved is enormous: the sea ice extent in the Antarctic alone varies from a minimum of 4×10^6 km^2 at the end of summer to a maximum of 19×10^6 km^2 in winter (Figure 1, Gloersen *et al*, 1992). However, the processes governing ice formation, especially in the outer part of the pack, are not well understood. Moreover, young ice is not well imaged by satellites, thus placing increased reliance on *in situ* studies such as the one described here.

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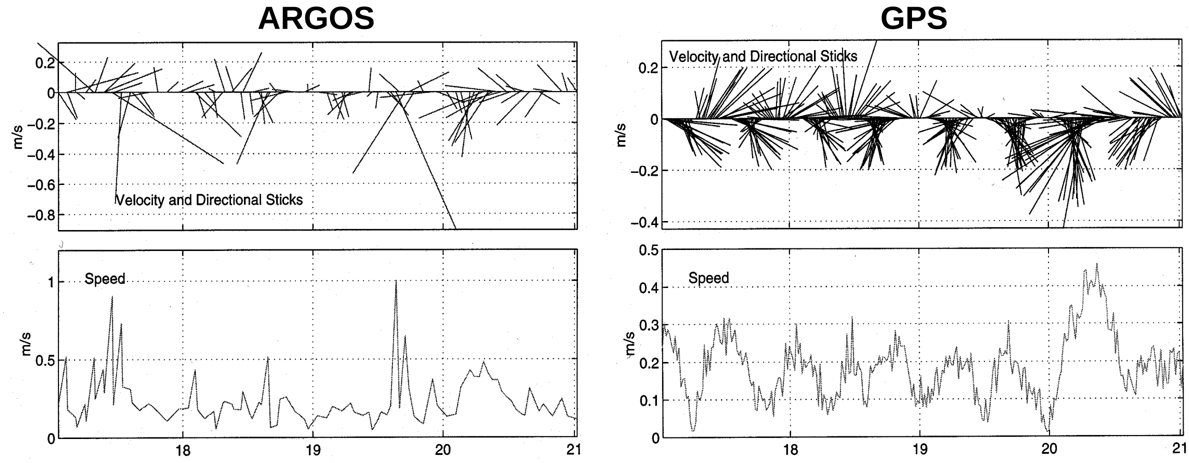


__Figure 2__. A comparison between Argos-derived and GPS-derived velocities. The increased resolution and accuracy of GPS locations leads to a much better velocity signal. Post processing of the GPS locations to remove errors associated with Selective Availability will yield a further order of magnitude improvement.

In our study, called STiMPI (Short Timescale Motion of Pancake Ice) we deployed an array of drifters in the Antarctic marginal ice zone (MIZ) during the period of ice formation. The array was designed to measure the deformation of the young ice pack and its response to wind forcing and wave action, thus giving an insight into the mechanisms of sea ice growth, and the likely impact on regional heat and mass fluxes. The drifters incorporate wind and temperature sensors, a vertical accelerometer, a GPS receiver and Orbcomm satellite transceiver. Using techniques previously developed during the NERC Land-Ocean Interaction Study (Meldrum 1997, 1999), GPS locations will be post processed to remove the major error components and yield highly accurate relative displacements and velocities (Figure 2). A totally independent meteorological package (a Metocean SVP-B, minus its drogue, but complete with its own batteries and Argos satellite transmitter) is installed to transmit weather data. These data have been disseminated globally in near real time via the GTS for use by national meteorological centres. Data distribution will continue after the drifters have left the ice and entered the Antarctic Circumpolar Current (ACC) and the open waters of the Southern Ocean (Figure 3).

SEA ICE FORMATION

The general mechanism of Antarctic sea ice formation is as follows. At the approach of austral winter, from March onwards, the sea surface cools and freezing begins seaward of

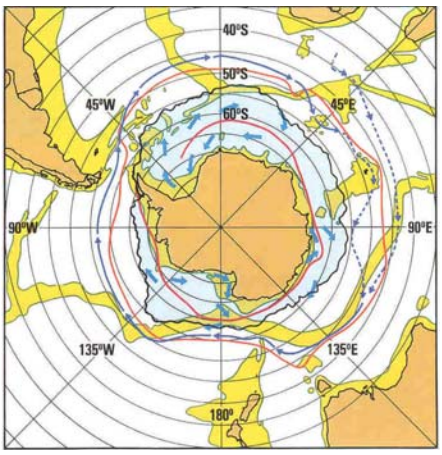


__Figure 3__. The principal currents in the Southern Ocean, showing the eastward flowing ACC (from Gloersen, Campbell et al, 1992).

__Figure 4__. Pancake ice in a young icefield. The raised edges are caused by repeated collisions between cakes of frazil ice.

the existing summer ice edge. However, the high turbulence levels in the rough Southern Ocean cause the ice to form as a suspension of small unconsolidated crystals, called frazil or grease ice, which cannot congeal to form a coherent young ice sheet. Cyclic compression in the ocean wave field causes the frazil, as it grows denser, to clump together into small cakes, which acquire raised rims from the pumping of frazil on to their edges during further collisions. This is pancake ice (Figure 4). Initially the cakes are only a few cm in diameter, but grow in size and thickness with distance from the ice edge, until they reach 3-5 m in diameter and a thickness of 50 cm (Wadhams, 1991). As the penetrating wave field moves through this ice edge pancake zone it gradually loses energy, but (in the case of the Weddell Sea) only after some 270 km are the waves damped enough to allow the pancakes to freeze together to form a continuous ice sheet (Wadhams *et al*, 1987). This process of ice sheet formation is called the frazil-pancake cycle (Lange *et al,* 1989) and is responsible for a significant percentage of ice production in the Antarctic. The pack expands until September-October, followed by retreat and break-up due to warmer temperatures and the effects of the wave field.

The nature of pancake icefields makes study of their detailed motion very difficult. The small size of the cakes and their constantly changing aggregations (Wadhams *et al,* 1996) precludes the use of satellite feature-tracking methods, such as that of Kwok *et al* (1998). The International Programme for Antarctic Buoys (IPAB) maintains collaboration among national groups deploying buoys on the sea ice, but all buoys currently in this programme are designed to be deployed on solid pack ice. Further, conventional satellite-tracked Argos drifters cannot resolve the short time-scales of pancake motion (Martinson and Wamser, 1990) due to long gaps between position fixes. It is possible that short time-scale alternations of convergence and divergence have important implications for overall ice production rates through exposure of new sea surface. Studies by Leppäranta and Hibler (1987), for instance, suggest that more than 25% of the energy of the strain rate invariants in sea ice may occur at periods between 0.5 and 3 hours.

USE OF SATELLITE TECHNOLOGY

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

Argos

The Argos system, carried on board the NOAA weather-imaging satellites, has been the system of choice for low-power environmental data collection and position tracking for more than 20 years. However, the prime purpose of the NOAA polar-orbiting satellites is to collect daytime imagery of the earth and its weather systems, and the orbits of the spacecraft are arranged to image a swath on either side of a given point on the earth's surface at roughly the same local solar times each day. The general picture can be seen in Figure 5, which shows every pass of the two operational NOAA satellites that

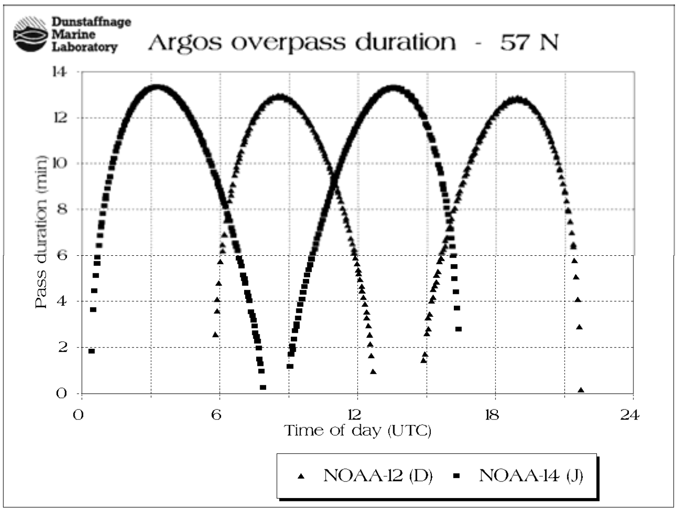


***Figure 5**. Pass durations at latitude 57° for the two NOAA satellites used by the Argos system in 1995, as a function of local mean time. The several hour gap around local midnight can be troublesome.*

would have been seen by a drifter at 57°N during September 1995. An important feature of the graph, and one of concern to many users of Argos, is the several hour gap in coverage around midnight local time, a direct consequence of the orbital configuration described above. An experiment that aims to recover an uninterrupted time series must therefore ensure that a sufficiently large stack of historical data is transmitted to bridge the largest expected gap in the satellite coverage. The situation is worst at the equator but improves for experiments lying closer to the poles because of the convergence of the sub-satellite tracks of polar orbiters at high latitudes.

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

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

GPS

The Global Positioning System (GPS) is a US-operated military satellite navigation system, implemented using a constellation of 24 or more satellites in high orbit to ensure global operability round the clock. The GPS user equipment is passive - unlike Argos it does not transmit. Range from each satellite in view is estimated by measuring the transit time of signals broadcast by the satellites. Ranges thus determined are called pseudo-ranges as the receiver's clock is not initially synchronised to the satellites' clocks. The receiver computes the position of each satellite using a set of orbital parameters (the ephemeris) contained in the broadcast signal, and thus is able to infer its own position. A 2-dimensional solution (latitude, longitude and time) requires ranging to three satellites. The system is currently operated by the US Departments of Defense and Transportation; the former exercising the right to degrade the accuracy available to civilian users by introducing errors into the satellite clocks, the broadcast ephemeris, or both. Full accuracy denial is termed Selective Availability (SA), and increases the 2-σ error in computed GPS locations from a few metres to about 100 m. In our application, these errors will largely be removed by differential post-processing techniques (Figure 6). SA was turned off on 1 May 2000, but has affected the early part of our experiment. For a fuller description of GPS, see, for example, Daly (1993).

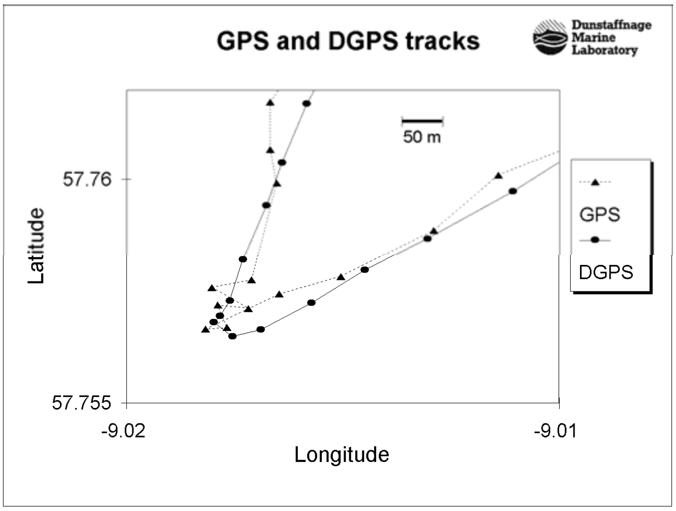


***Figure 6**. In certain circumstances, GPS locations computed by on board a drifter may be differentially post processed (DGPS) to remove the main error terms. Location and velocity accuracies typically increase by an order of magnitude.*

Orbcomm

This is the first of the new generation of Low Earth Orbit (LEO) satellite messaging systems to be licensed. Satellites consist of discs about one metre in diameter prior to deployment of solar panels and antenna. Two satellites were launched into polar orbit during 1995, using a Pegasus rocket piggy-backed on to a Lockheed L-1011 aircraft. After a prolonged period of launcher problems, 35 satellites are now in orbit, making up the complete constellation (although Orbcomm have been awarded a licence for an expansion to a 48 satellite constellation). Of the 35 satellites, 32 have been declared operational. The A, B, C and D planes are at 45° inclination and therefore have poor coverage at high latitudes: only three satellites, in the F and G planes (70°), offer a near-polar service (Figure 7). A further launch, possibly to an equatorial orbit, is planned for late 2000.

The system offers both bent-pipe and store-and-forward two-way messaging capabilities, operating in the VHF (138-148 MHz) band. User terminals are known as 'Subscriber Communicators' (SCs). Although there have been significant problems with interference close to urban areas, this is not expected to impact offshore operations, and trials of the system have been encouraging. Operational experience of the system is growing rapidly, although it remains difficult to obtain detailed technical information from Orbcomm.

The message structure currently consists of packets transmitted at 2400 bps (scheduled to rise to 4800 bps), and coverage is now global and near-continuous between the polar circles. Messages are acknowledged by the system when correctly received and delivered to a user-nominated mailbox. The platform position is determined, if required, using propagation delay data and doppler shift, or by an on-board GPS receiver. Position accuracy without GPS is similar to that offered by Argos, i.e. km-scale.

The limitations on the store-and-forward mode messages (known as globalgrams) have become apparent, with SC originated messages limited to 229 bytes and SC terminated messages limited to 182 bytes. Each SC can theoretically have a maximum of 16 globalgrams stored on each satellite. Currently, satellites will not accept or process

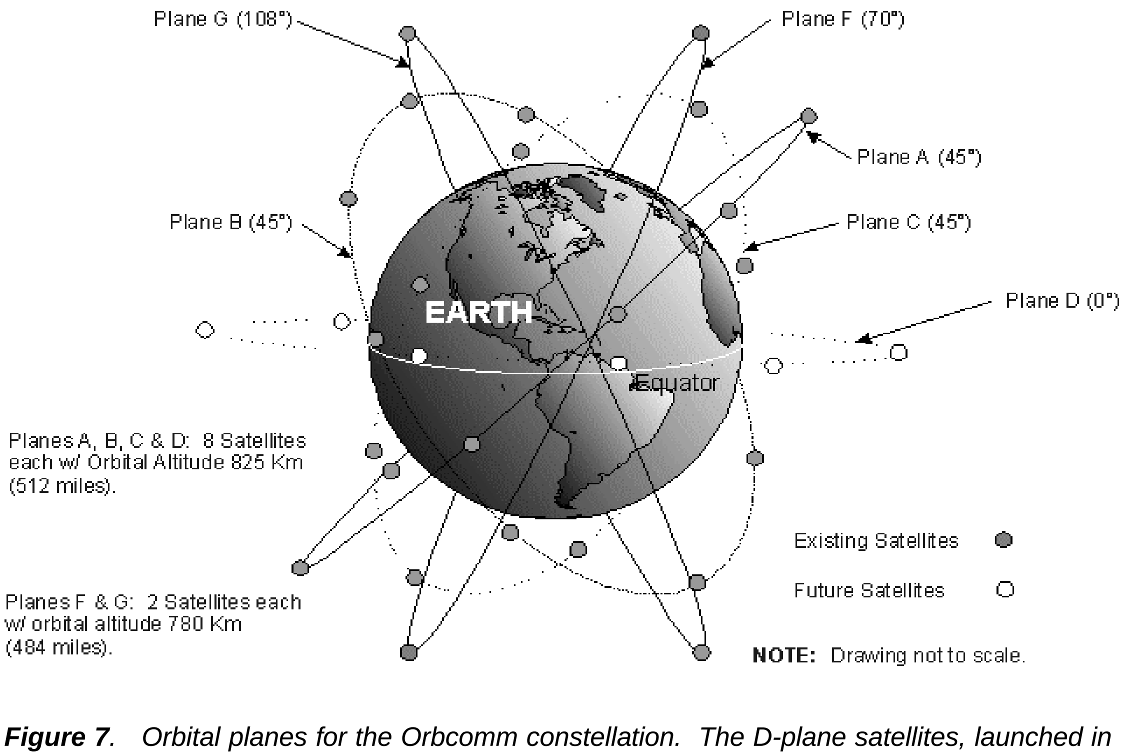


***Figure 7**. Orbital planes for the Orbcomm constellation. The D-plane satellites, launched in December 1999, have been placed in an inclined orbit. At present, only the three operational satellites in the F and G planes give polar coverage.*

globalgrams when in view of a ground ('gateway') station. As messages have to be designated as globalgrams or bent-pipe by the SC at the moment of origination, this presently limits the flexibility of the system to adapt to different coverage situations. Work-arounds do, however, exist, and it is expected that the next generation of SCs will be able to adapt more readily to changes in satellite communications mode.

Authorised transceiver manufacturers include Panasonic, Elisra (Stellar), Torrey Science, Magellan and Scientific Atlanta. Elisra were the first to offer a transceiver with a fully integrated GPS engine, although Panasonic now also have one available. Scientific Atlanta have made a chip-set available to third-party integrators. Prices of most units are between $600 - $1000.

The ground segment has started to expand, and there are now active stations in Italy, Argentina, Brazil, Japan and Korea in addition to the four in the US. However the Japanese and Korean stations are not available for international registrations. Further stations are under construction in Malaysia, Morocco, and Brazil, and potential sites have been identified in Russia, Ukraine, Philippines, Botswana, Australia and Oman. 16 international service distribution partners have been licensed. Non-US customers have faced considerable difficulties because of the absence of ground stations, lack of spectrum licensing and the presence of other in-band users. However the situation is improving rapidly. Currently subscription costs are on a fixed cost per unit with two bands of usage (above and below 4 kbytes per month with a typical monthly rate for the higher band being $70). A fully metered billing system based on users' actual data throughput was to be implemented in July 2000 but was postponed, officially due to technical problems. If this billing system is implemented with the planned charges ($6/kbyte) then it will result in a massive increase in airtime costs for any user with data rates over 0.5 kbytes/day.

Orbcomm have been suffering financial difficulties, and recently (Sept 2000) filed for 'Chapter 11' bankruptcy protection. The outstanding debts are believed to stem largely from the system rollout phase, with net running costs being of much smaller concern. Industry opinion is that Orbcomm will prevail, largely because of the commitment of many third-party equipment and system manufacturers to the success of the system, and evidence of increasing service take-up by a diverse range of customers.

ICE DRIFTER DESIGN

Hulls

The buoy was designed to mimic as closely as practicable the properties of the pancakes being studied. DML and SPRI have already built such a buoy in fibreglass for the Odden region of the Greenland Sea (Meldrum, 1998). Ice conditions in the Antarctic, however, demand a rather different approach since, unlike the Odden, Antarctic pancakes consolidate into large ice sheets that exert a much greater force on the buoy. The design must withstand repeated impacts with pancakes and larger floes, as well as static pressure from convergent ice conditions. The buoy was therefore fabricated from 3 mm thick stainless steel sheet, with sensors and antennae supported by a stainless steel tripod (Figure 8). The design also features sloping sides, allowing the buoy to rise up and avoid being crushed between ice floes.

Sensors

The sensor fit included three Betatherm thermistors (narrow and wide range sea temperature, air temperature), a Motorola GPS receiver (position and time), a gimballed vertical accelerometer (wave energy spectrum), a KVH fluxgate compass (buoy orientation) and an R M Young anemometer (wind speed and direction). Custom signal conditioning electronics was designed and built at DML to interface the analogue sensors to the processor module. Meteorological data (atmospheric pressure and sea surface temperature)

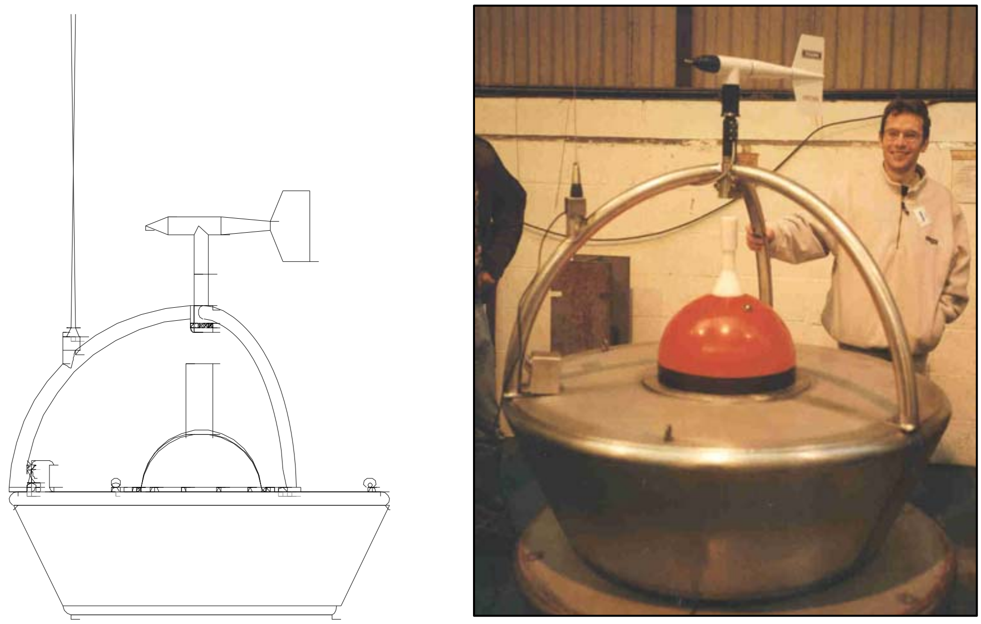


Figure 8. The ice buoy during construction. Overall diameter is 1.25 m. The main electronics package lies below the central SVP-B meteorological sphere. Sensor and antenna cables run inside the tripod legs.

were collected and transmitted by an entirely independent package consisting of a standard Metocean WOCE SVP-B drifter hull embedded in a well in the main hull. This has the appealing advantage of minimum engineering effort coupled to a high expectation of data integrity.

Processor

The Persistor CF1 processor was chosen because of its computing power, low energy requirements, ease of programming and flexibility as regards memory and interfacing. It is also available in an extended temperature version suitable for use during the polar winter. In addition to sampling the various sensors in appropriate ways, the processor computed the wave spectrum, formatted the data, constructed the message stack and controlled the Orbcomm transceiver. It was also designed to alter sampling strategy according to latitude, and to respond to a simple set of external commands received from the user over the Orbcomm link. Figure 9 shows the general layout of modules within the electronics package.

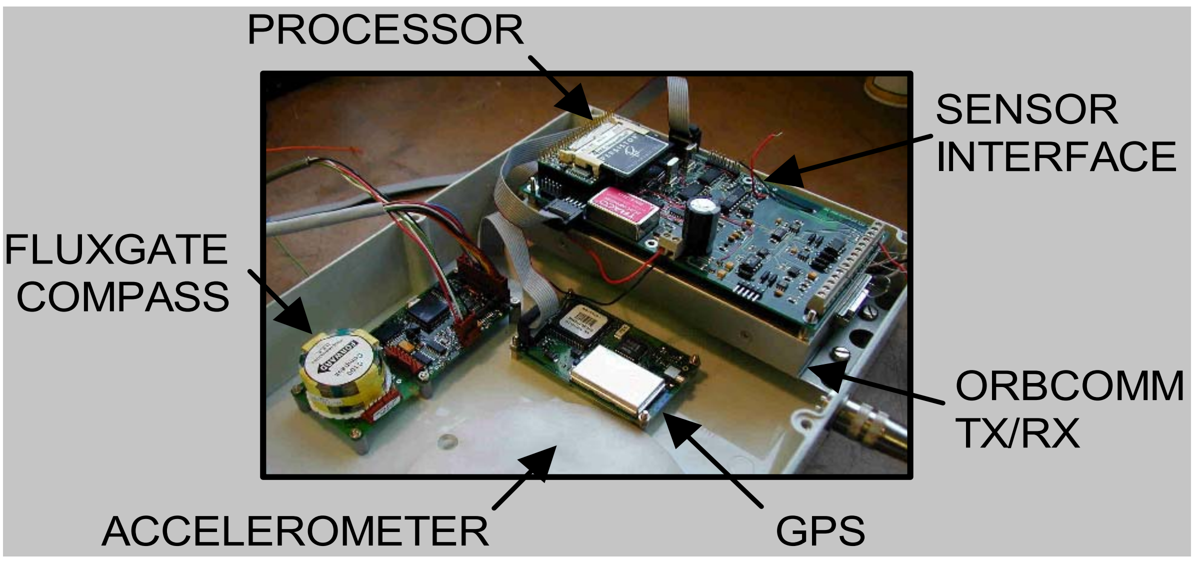


Figure 9. Layout of components within the DML sensor and electronics package.

Communications

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

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

DEPLOYMENTS

Six buoys hulls were constructed in Cambridge and shipped on board RV *Polarstern* (Figure 10). Simultaneously, sensor and processors units were built at Dunstaffnage and air-freighted to Cape Town. Final assembly and testing was completed on board *Polarstern* during the voyage south. A brief trip ashore at the Neumayer Antarctic base allowed a GPS base station to be installed for post-processing purposes. Deployments into the pancake-ice zone were successfully completed in mid April 2000 (Figures 11 and 12), and meteorological data were disseminated via Argos and the GTS shortly afterwards.

Figure 10. *RV Polarstern at Neumayer.*

ORBCOMM EVALUATION

We have chosen to evaluate the Orbcomm system, and intercompare it with Argos, on the basis of the following criteria:

- Data quality
- Data quantity
- Data timeliness
- Energy requirements
- Cost
- Ease of use
- Present and future reliability

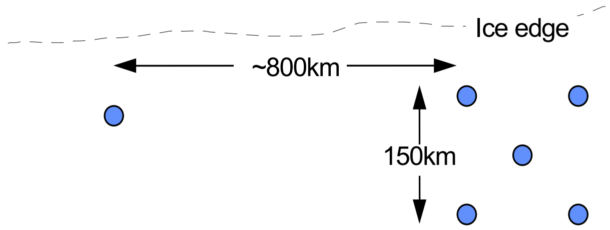


***Figure 11**. Layout of the deployment array.*

***Figure 12**. Buoy release amongst pancake ice.*

Data quality

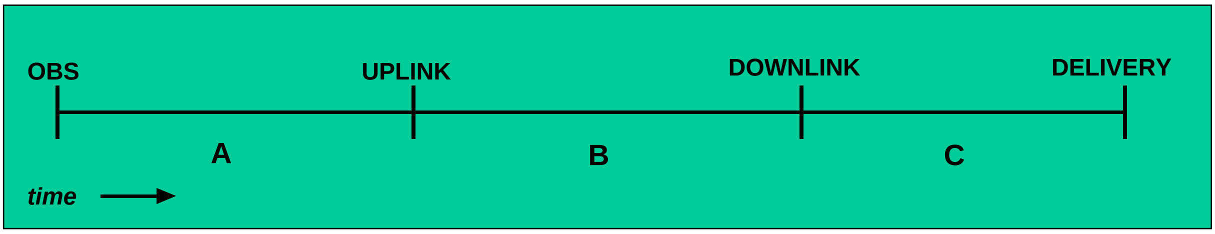
Orbcomm implements a packet checksum and acknowledgement protocol which is normally implemented within the SC firmware and is transparent to the user. In fact, because of the architecture of the serial data transfer implemented in the Panasonic SC, we chose to retain control over this function and to generate the required checksums within the Persistor. In the event, no corrupt messages were ever received in our Orbcomm mailboxes. This compares very favourably with Argos, where bit errors occur in a significant percentage of received data packets. It should be pointed out, however, that Orbcomm performs no quality control (e.g. to check for erroneous sensor values) on the actual content of the message, and so is unsuitable as it stands for direct insertion of data on to the GTS.

Data quantity

We routinely transmitted 6.6 kbyte per buoy per day using the store and forward (globalgram) mode. The limitation is 16 globalgrams on each satellite per ID, with each globalgram being up to 229 bytes long. This translates to a maximum of approximately 3.6 kbyte of data from a given buoy being stored on a given satellite at any time. It should thus be relatively straightforward to transmit several tens of kbytes per day, even at polar latitudes. Each satellite is capable of storing about 1000 globalgrams, so system saturation could reduce the achievable throughput should many SCs generate globalgrams. The practical data throughput of the Argos system (a few kbyte per day under the most favourable circumstances) is an order of magnitude less than can be achieved with Orbcomm.

Data timeliness

Timeliness is of crucial importance to the weather forecasting community, in that late-arriving data will not be accepted by the forecast model. Acceptable delays are generally of the order of a few hours at most. With typical low-earth orbit periods being of the order of two hours, it becomes important that the data are not stored on the satellite for more than one orbit. The Argos system minimises the impact of orbit delays by collecting significant amounts of data from ‘direct readout’ stations. This is analogous to ‘bent-pipe’ mode in that both the mobile and the ground station must lie within the satellite footprint at the instant of data transmission. All data collected by the Argos satellites are also replayed to the major NOAA ground stations at Wallops Island and Fairbanks. This typically takes place one or more orbit periods after data collection, and so may render such data useless for forecasting purposes.



A: sensor averaging, processing, wait for sat, handshake with sat...

B: ‘bent pipe’ = no delay; ‘store and forward’ = up to 10+ hours...

C: creation and delivery of e-mail, no quality control...

Figure 13. *Elements of the Orbcomm data path from observation to end user.*

Orbcomm implements an identical architecture in that there are two routes for data through the space segment – ‘bent-pipe’ and ‘store-and-forward’, the latter being known as ‘globalgram’ mode. There are important differences that flow from the relative numbers of satellites and groundstations in the two systems, and the lower inclination orbital planes used by Orbcomm. In essence this means that while there is little difference in the delay between downlink and delivery for bent-pipe data, bent-pipe observations being transmitted via Argos may have to wait many hours for a satellite overpass, particularly in low latitudes. On the other hand, the high orbital inclination of the Argos satellites means that the majority of orbits are seen by the Fairbanks ground station, whereas the low-inclination Orbcomm satellites may have to store data for many orbits before downlinking. Orbcomm store-and-forward data may in consequence be delayed by more than 10 hours. The general picture is shown in Figure 14, with our particular results with Orbcomm presented as Figure 15. Delays shown in the latter figure include queuing time on board the mobile and so are in general longer than the true figures for the Orbcomm space segment. This is particularly true for the mobile DML6, where queue times were rather long owing to a problem on board the buoy.

Data timeliness close to a ground station:

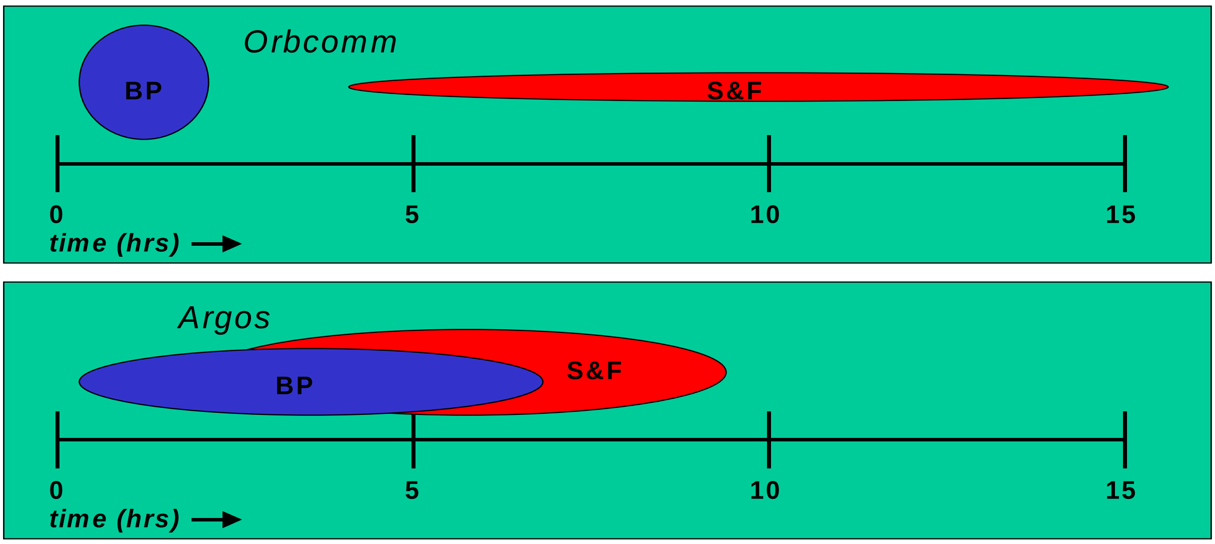


Figure 14. *Close to a ground station, Orbcomm will relay the majority of data in near-real-time. Messages classed as store-and-forward are liable to be delayed by many hours, and will be refused by the satellite if it is bent-pipe mode. For Argos, all bent-pipe traffic will also appear a few hours later in the store-and-forward datasets. Bent-pipe data may suffer additional delays because of the significant time that can elapse between the observation and the next satellite overpass.*

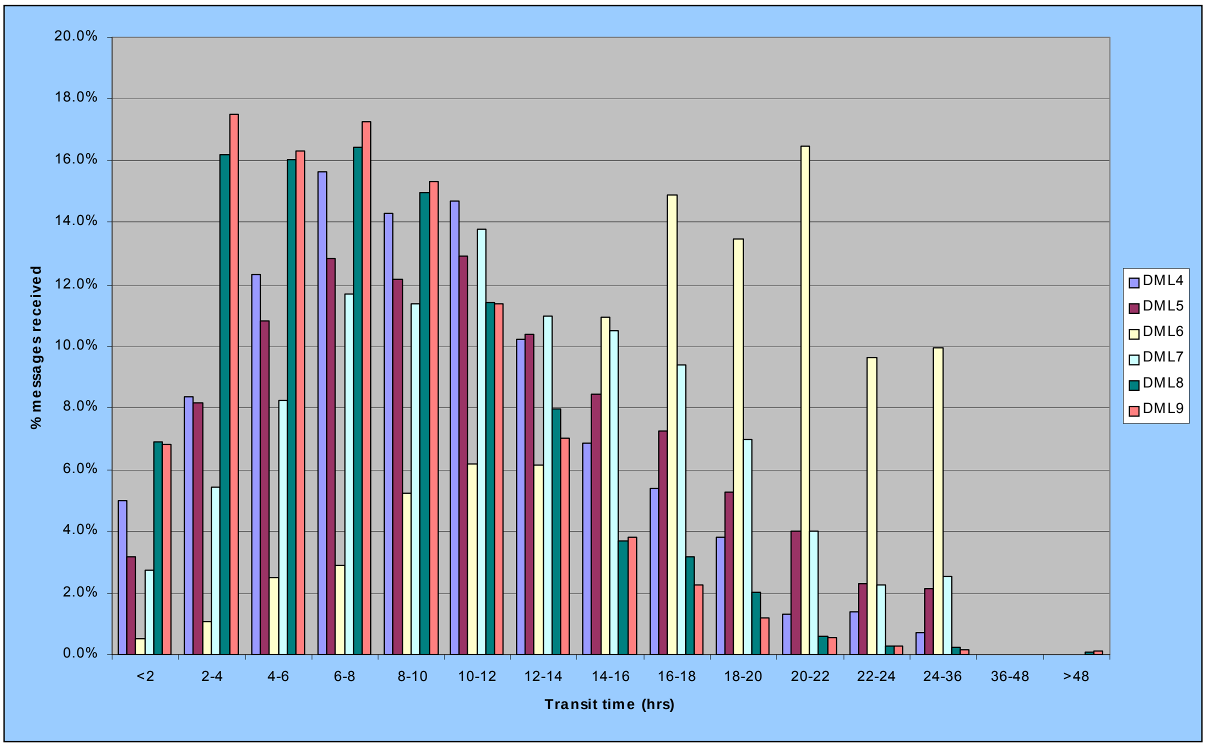


Figure 15. *Actual data delays experienced by six Orbcomm mobiles. The figures include the time that the data remained in the message queue on board the mobile.*

A further key distinction lies in the differentiation between bent-pipe and store-and-forward message classes at the point of origination on the mobile. For Argos, no such differentiation exists, in that all messages are available for direct readout and for deferred playback. For Orbcomm, however, each message must be designated as bent-pipe or store-and-forward before being queued to the satellite. This poses operational difficulties, particularly if the mobile is moderately close to a ground station, in that store-and-forward messages are refused by the satellite when it is operating in bent-pipe mode. Workarounds do exist, but the situation is not ideal.

Energy requirements

To a first approximation, the energy consumed by a satellite communication system such as Argos or Orbcomm is proportional to the amount of data transmitted. Argos is currently a one-way system - the mobile transmits ‘blind’ with the consequence that most of the data are never received by a satellite, and much of the mobile’s energy is wasted. Orbcomm is two-way, with full handshaking between the mobile and the satellite. Transmissions are only initiated when a satellite is in view, and messages are acknowledged when correctly received. There is an energy penalty in that the mobile communicator must also contain a receiver. In our system, approximately half of the system energy is consumed in the receiver, but this is more than offset by the much more efficient two-way communication protocol. In practice we found the Orbcomm system to be about 10 times as efficient as Argos in energy terms, at about 2 kbytes per kJ (a standard D-cell contains about 50 kJ).

Usage costs

Hardware costs for Argos and Orbcomm are similar at a few hundred dollars per mobile terminal. The major difference in operating costs lies in the way in which system usage, or data throughput, is charged. Argos charges a fixed daily cost, regardless of the quantity of data transmitted through the system. Currently this cost is in the region of US$10 per day, the exact figure depending on a number of factors including discounting arrangements, the type of mobile, the mode of data delivery and so on. Orbcomm charges a much lower fixed daily cost of about US$1 per day, plus a usage charge of US$6 per kbyte. Thus the net cost per kbyte for both systems depends on the data rate (see Figure 16), with Argos being much more expensive for data rates of less than 1 kbyte per day. Argos becomes significantly cheaper than Orbcomm as data rates move above 2 kbyte per day, but this level of performance is difficult to achieve from Argos, particularly at lower latitudes where overpasses are less frequent.

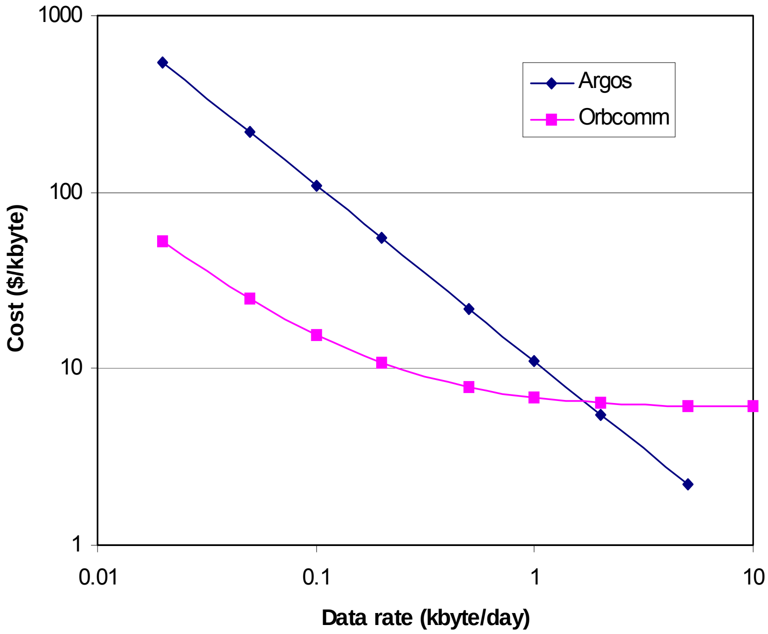


Figure 16. *Approximate costs of Orbcomm and Argos as a function of data rate. Note that both scales are logarithmic.*

Ease of use and long-term reliability

In general, the non-expert user will find Orbcomm easier than Argos to implement as a communications system, although Argos are making considerable efforts to improve the user-friendliness of their service. In most cases, the Orbcomm user deals with a single point of contact (the Orbcomm reseller) to purchase hardware, pay for airtime and resolve any operational difficulties. Data are delivered to unique e-mail addresses and can be as easily accessed via the Internet as standard e-mail. In contrast, the Argos user has first to obtain programme authorisation and an allocation of platform IDs from Argos, pass these ID numbers (and a purchase order) to his chosen hardware supplier, negotiate an airtime agreement and raise a purchase order with his national airtime reseller (ROC in Argos terminology), and finally raise a purchase order to Argos for ID charges, data delivery and other added value services. Data are generally delivered offline, although the most recent 10 days of data may be consulted online via an Internet connection to the Argos processing centres in Toulouse, France or Largo, USA.

On the debit side Orbcomm, as a relatively new system, does suffer from a couple of technical problems, and the company has not been particularly good at dealing with technical requests. Problems include the necessity, already described, to post messages as explicitly bent-pipe or store-and-forward, with the risk that store-and-forward messages may be refused by the satellite. Argos does not require the user to make this distinction. A further problem with early Orbcomm satellites is the susceptibility of the subscriber downlink transmitter to solar flare radiation. As a result, these transmitters are turned off while the affected satellites are at high magnetic latitudes (see Figure 17), and communications with mobiles are handled by the gateway transmitter. Transmissions in this ‘hybrid’ mode are much less likely to be heard by the mobile, and consequently there is a much lower probability of passing messages through a satellite when in hybrid mode. This can be seen in Figure 18, where the hybrid mode A-plane satellites seldom managed to pass any traffic from the Antarctic buoys. Moreover it should be noted that Orbcomm uses a much lower - and wider - band of frequencies than Argos. This in general means a much larger antenna, and a greater susceptibility to in-band interference, especially close to centres of population.

Finally, any potential user of either system must be satisfied that his chosen system will be financially viable for the duration of his application. Argos, with the substantial commitment of both French and US government agencies (CNES and NOAA), seems to have an assured future. For Orbcomm the picture is much less clear, with the company having entered Chapter 11 bankruptcy protection in the US, and user sign-up being much lower than predicted. However many companies have committed to Orbcomm-based products, and it is likely that the system will survive.

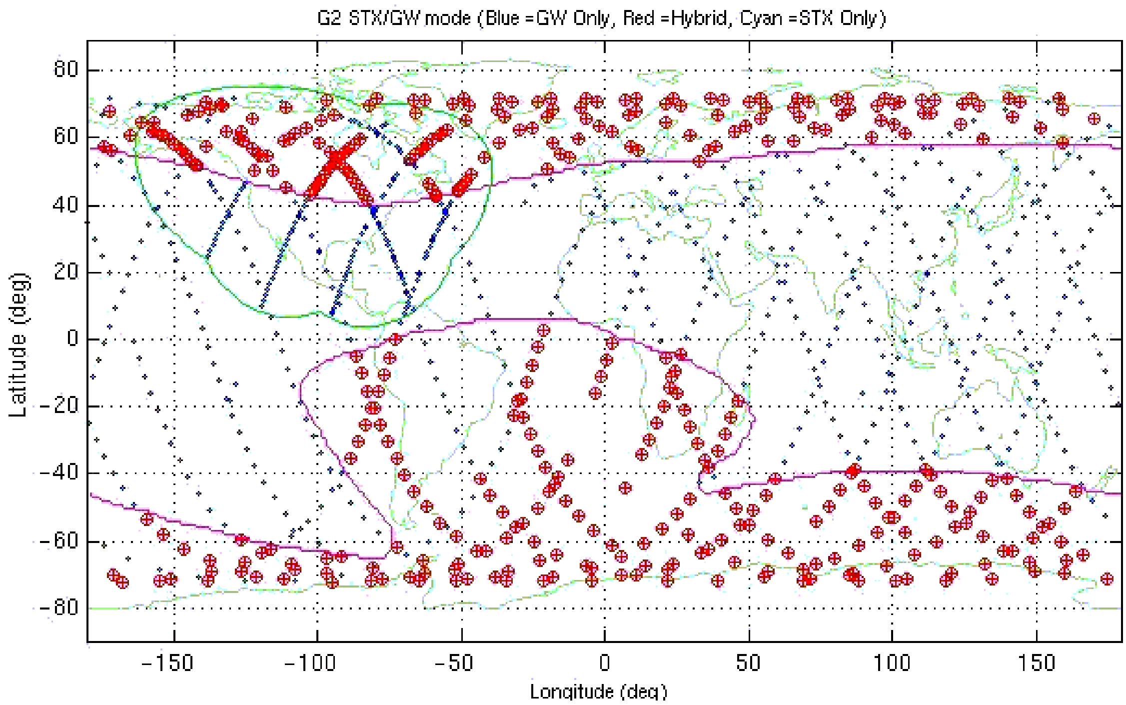


Figure 17. *Geographical areas in which early Orbcomm satellites operate in hybrid mode, with reduced chance of successful communication with mobiles. Much of the South Atlantic and both polar regions are affected.*

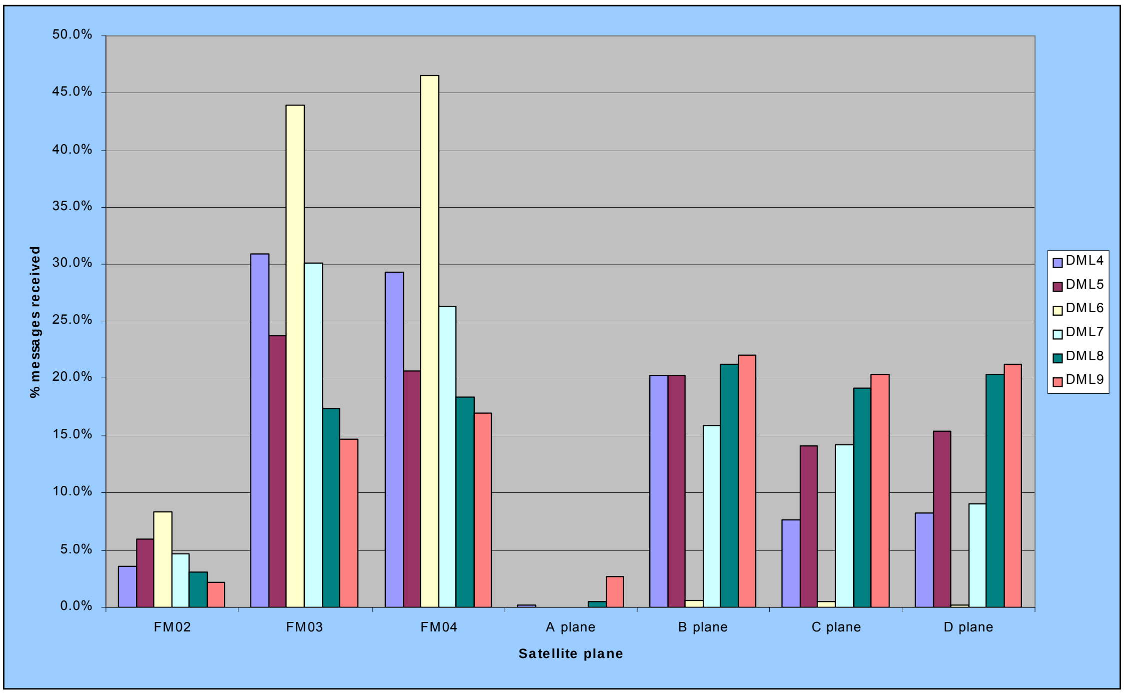


Figure 18. *Data throughput as a function of Orbcomm satellite plane. The polar orbiters FM03 and FM04 proved to be the most useful. The A-plane satellites, which operate in hybrid mode over the south Atlantic and polar regions, were practically unusable in our area.*

CONCLUSIONS

We were fortunate in this study to be able to depend on a reliable and well-tested communications system (Argos) for part of our data recovery. This allowed us the freedom to experiment with a new and largely untried system (Orbcomm) in an area which desperately needs new communications technologies to support environmental data collection.

As is usual, each system proved to have its own advantages and disadvantages, and the user will have to weigh these up alongside his own priorities. Our conclusions, in many cases specific to our particular application, are summarised in Table 1.

	Orbcomm	Argos
Data quality	• No transmission errors because of acknowledgment protocol • No quality control of physical values before dissemination to user	• Frequent transmission errors: same data must be repeated many times to ensure correct reception • Quality control may be requested, e.g. prior to insertion of data onto the GTS
Data quantity	• >10 kbyte per day easily achievable, even in store-and-forward mode	• Difficult to achieve more than a few kbyte per day, even in ideal circumstances
Data timeliness	• Store-and-forward can be poor (> 10 hours) • Bent-pipe timeliness known be good (< 10 minutes), though not tested in this study	• Store-and-forward generally of the order of 2 hours, but can occasionally be much longer • Bent-pipe < 20 minutes, but not available round the clock owing to limited number of overpasses
Energy requirements	• Energy penalty of receiver more than offset by implementation of full handshake protocol • Consumption ~0.5kJ/kbyte	• Blind transmission means that most messages are never received and energy is wasted • Consumption ~5kJ/kbyte
Usage costs	• ~US$1/day + US$6/kbyte • Costly for high volume users	• ~US$10/day + US$0/kbyte • Costly for low volume users
Ease of use	• Simple procedure • Single point of contact	• Generally complex procedure, though good help available from Argos • Multiple points of contact for many users
Future reliability	• Dependent on financial success	• Assured

Table 1. *Comparison of key attributes of Orbcomm and Argos. For a fuller explanation refer to preceding paragraphs.*

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the UK Natural Environment Research Council in funding this experiment through research grant GR3/12592, the UK Meteorological Office for material assistance in procuring and operating the SVP-B meteorological packages, the Alfred Wegener Institute, Bremerhaven, for logistical support aboard the RV *Polarstern*, and the UK Defence Evaluation and Research Agency for the loan of shipboard oceanographic equipment. Invaluable technical assistance was provided by Etienne Charpentier of the DBCP, Pierre Blouch of Météo France and Richard Winterburn of MES Communications Ltd.

ABBREVIATIONS AND ACRONYMS

ACC	Antarctic Circumpolar Current
AVHRR	Advanced Very High Resolution Radiometer
AWI	Alfred Wegener Institute
CCMS	Centre for Coastal and Marine Sciences
CNES	Centre National d'Etudes Spatiales
DML	Dunstaffnage Marine Laboratory
DKP	Differential Kinetic Parameters
ENVISAT	Environmental Satellite
ERS	European Space Agency Remote Sensing
ESOP	European Subpolar Ocean Programme
GCOS	Global Climate Observing System
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GTS	Global Telecommunication System
IPAB	International Programme for Antarctic Buoys
LOIS	Land-Ocean Interaction Study
NERC	Natural Environment Research Council
MIZ(EX)	Marginal Ice Zone (Experiment)
NASA	National Aeronautic and Space Agency
NOAA	National Oceanographic and Atmospheric Administration
SA	Selective Availability
SAMS	Scottish Association for Marine Science
SAR	Synthetic Aperture Radar
SIMIP	Sea Ice Model Intercomparison Programme
SPRI	Scott Polar Research Institute
STiMPI	Short Timescale Motion of Pancake Ice
SVP-B	Surface Velocity Programme – Barometer drifter
VHF	Very High Frequency
WOCE	World Ocean Circulation Experiment

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A New High Data Rate GOES DCP

Presented by

Brian Day - CSI

Jim Hanlon - Seimac

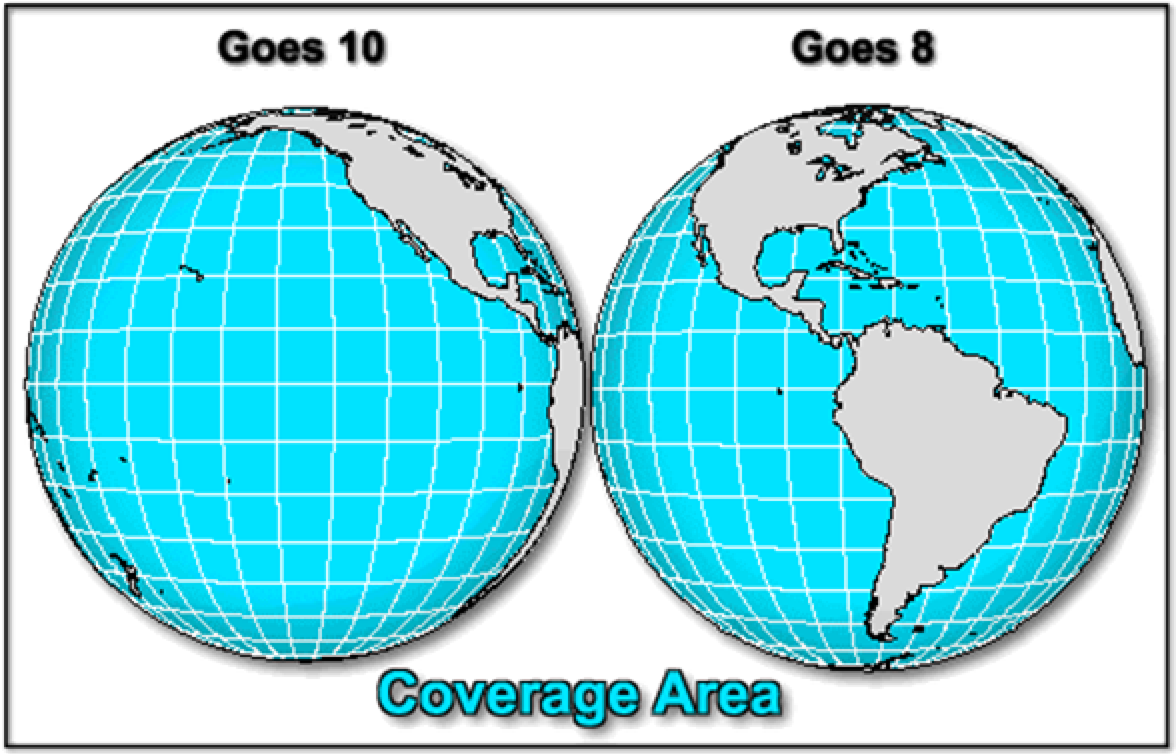
Seimac

DBCP Scientific & Technical Workshop – Victoria, B.C. Oct 16, 2000

CAMPBELL SCIENTIFIC, INC.

GOES Overview

- Intended Use is Government-sponsored Environmental Data Collection
- Operated by NOAA - NESDIS
- Geostationary
- GOES East - GOES West
- Sister Satellites


Goes 10
Goes 8
Coverage Area

GOES Usage

- Requires EIRP of ~47 dBm
  - For Land-based - 15 Watt Tx. + Yagi
  - For Buoy-based - 30-40 Watt Tx + Omni
- Frequency Channels - 266 Channels
- Time Slot Assignments - 1 minute slots

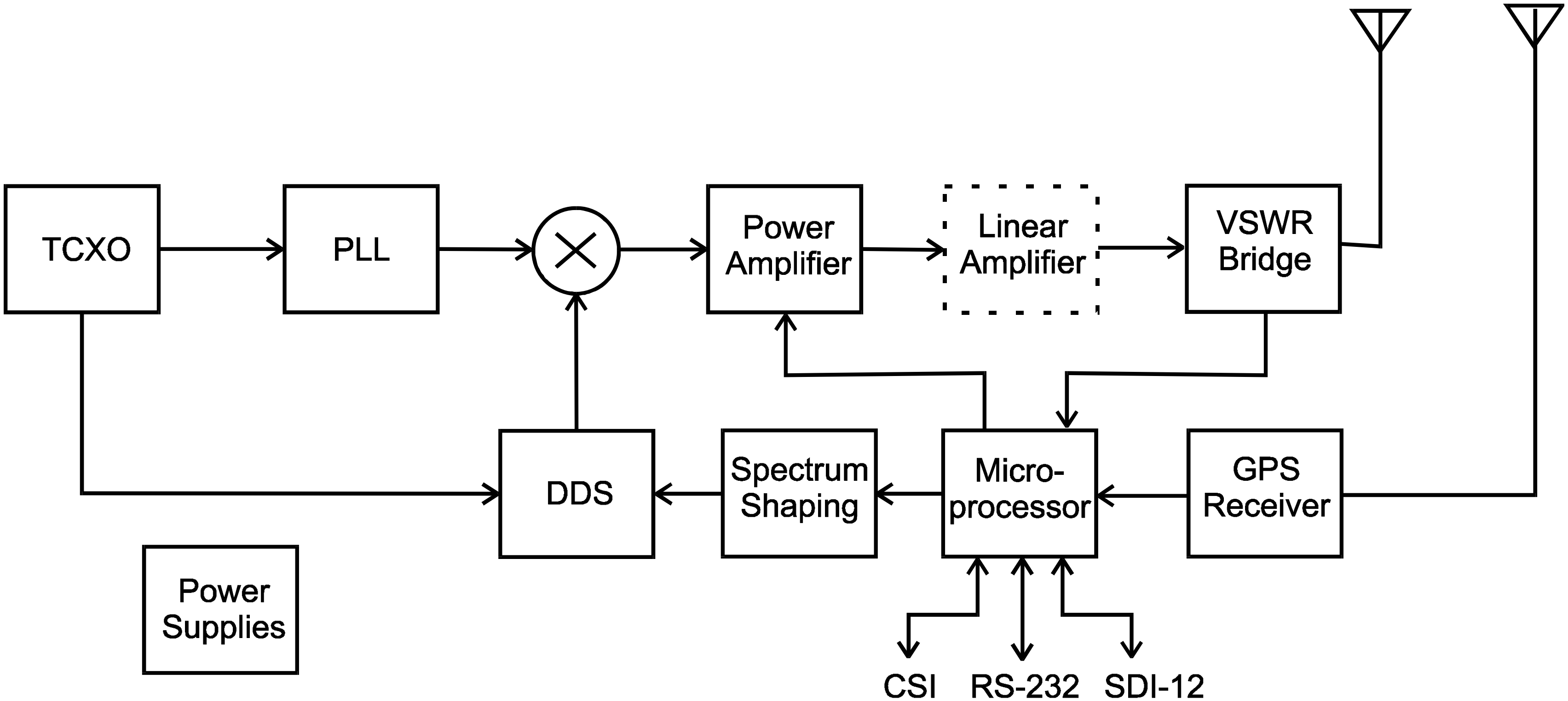
Low Data Rate Versus High Data Rate

- Traditionally, Data Rate was 100 BPS
- New High Data Rate Standard supports 300 BPS and 1200 BPS using 8-ary Phase Modulation
- CSI / Seimac are First to Market High Data Rate Data Collection Platform (HDR DCP)

Features of the CSI / Seimac GOES High Data Rate Terminal

- Supports 100, 300 and 1200 baud transmissions
- RS-232, CSI & SDI-12 User Interfaces
- Built-in VSWR Monitor
- GPS Time Synchronization & Frequency Correction
- 15 Watt and 40 Watt versions available

Description of the CSI / Seimac GOES High Data Rate Terminal



Availability

- NESDIS Certification Testing in Halifax Week of Oct 16, 2000.
- Units Shipping October, 2000

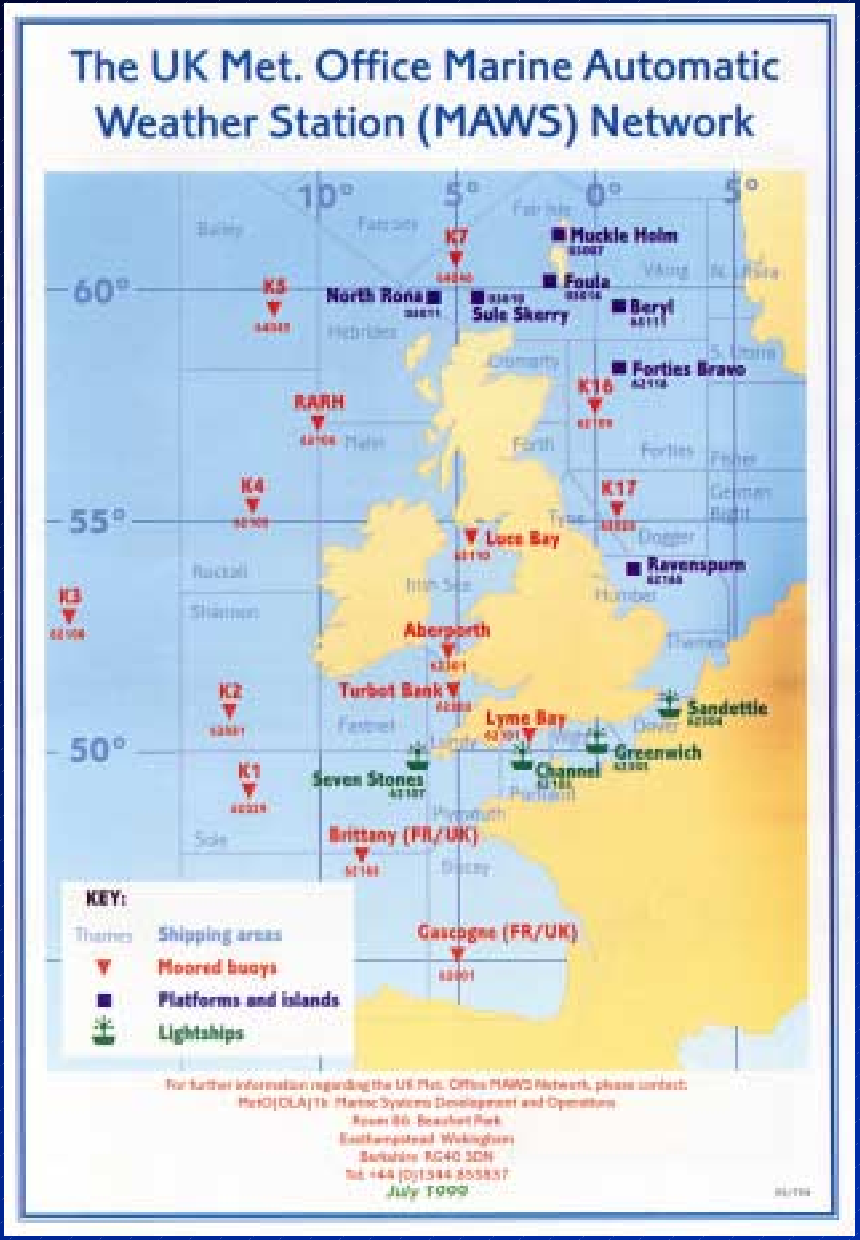
The Met.Office

Some preliminary results from a Met. Office Open Ocean Buoy fitted with a TRIAXYS wave sensor

By

Wynn Jones, Simon Keogh

The Met. Office marine AWS network



Open Ocean Buoy

- 3m diameter hull
- 6m overall height
- 4m sensor exposure height
- Closed cell foam floatation + self coloured elastomer skin
- Stainless steel superstructure
- Single point lifting eye
- 1.5m diameter sensor ring
- Duplicate sensors attached with quick release clamps
- ARGOS antenna on hatch cover

The Met.Office

Open Ocean Buoy

Variables Measured

- Wind speed & direction
- Barometric pressure
- Air temperature
- Relative humidity
- Sea temperature
- Significant wave height and period

Wave measurements

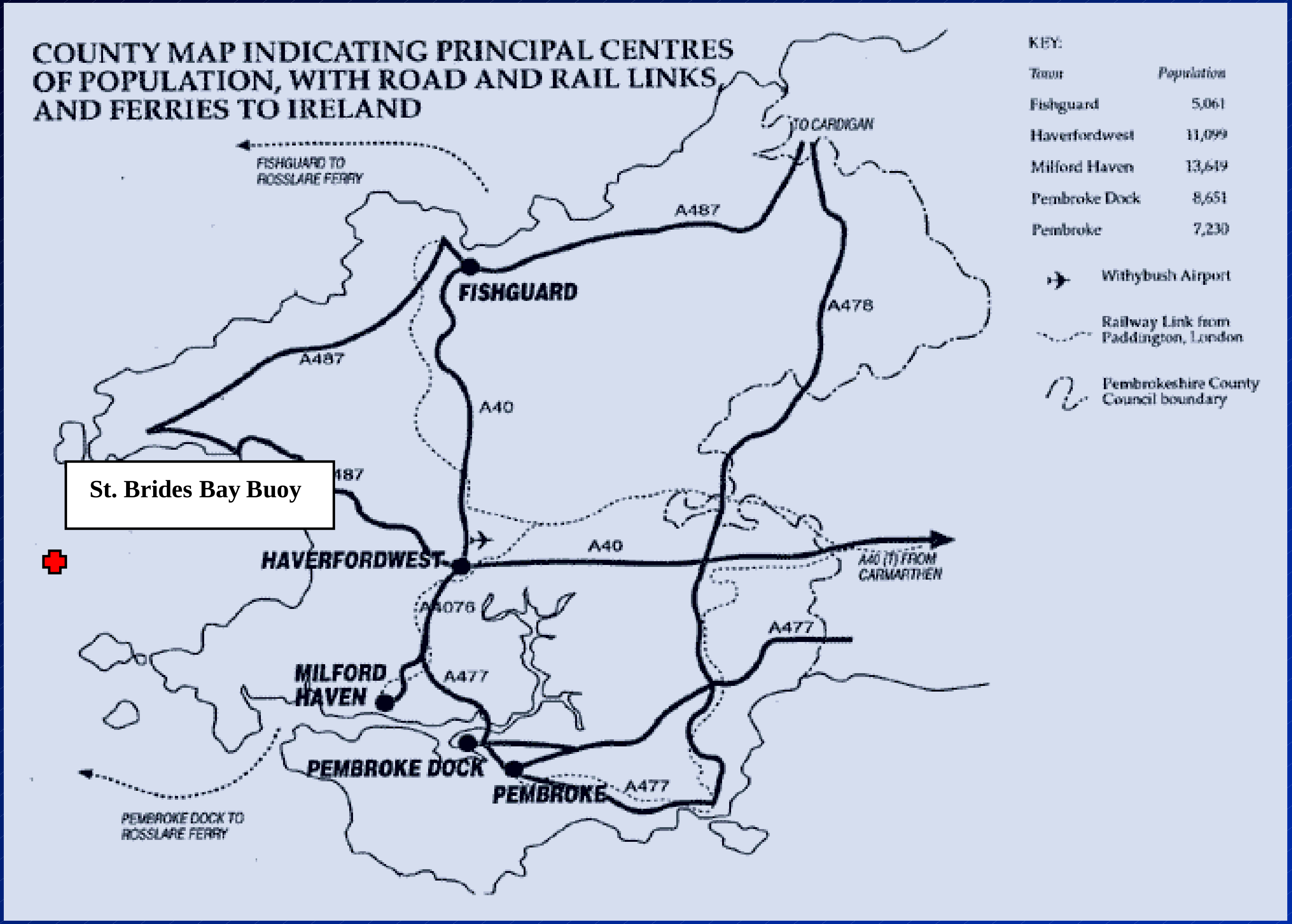
- At present, significant wave height and period derived from a single Datawell heave sensor fitted inside the buoy hull

- To determine the suitability of the buoy for directional spectral wave measurements The Met.Office commissioned an analysis of the buoy's dynamics in a variety of wave and current conditions for the standard mooring configurations

Wave sensor trials

- TRIAXYS wave package selected as a suitable sensor for directional spectral measurements
- Fitted to an Open Ocean Buoy within the superstructure.
- Buoy deployed in St Bride's Bay, SW Wales (51º47.8'N, 5º19.3'W)
  - Open to the South West
  - co-located with a datawell wave-rider buoy owned by the countryside council for Wales
  - suitable shore site available for radio telemetry of the TRIAXYS wave data
  - relatively accessible

St. Brides Bay, SW Wales.



The Met.Office

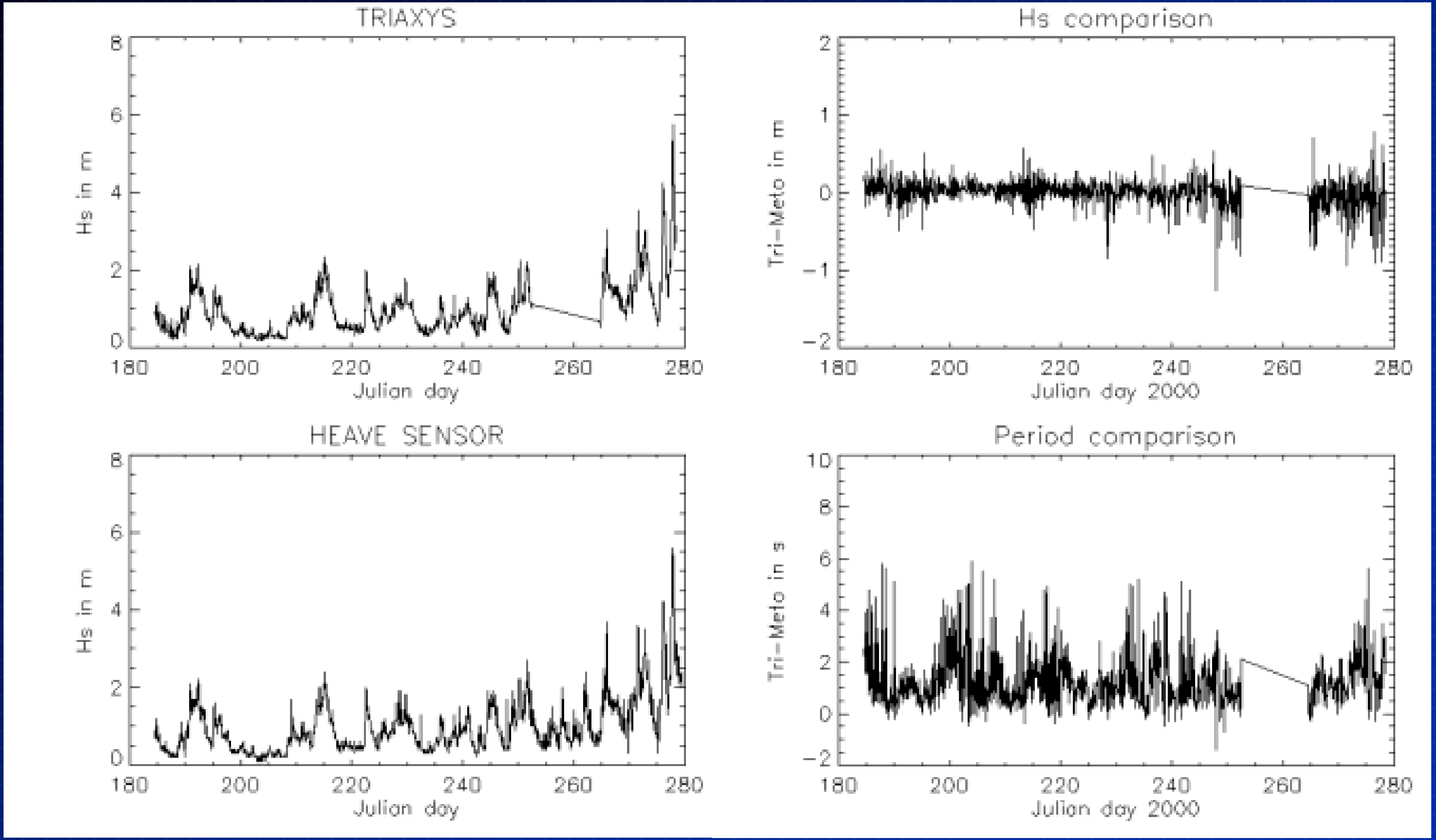
TRIAXYS wave buoy

Data analysis

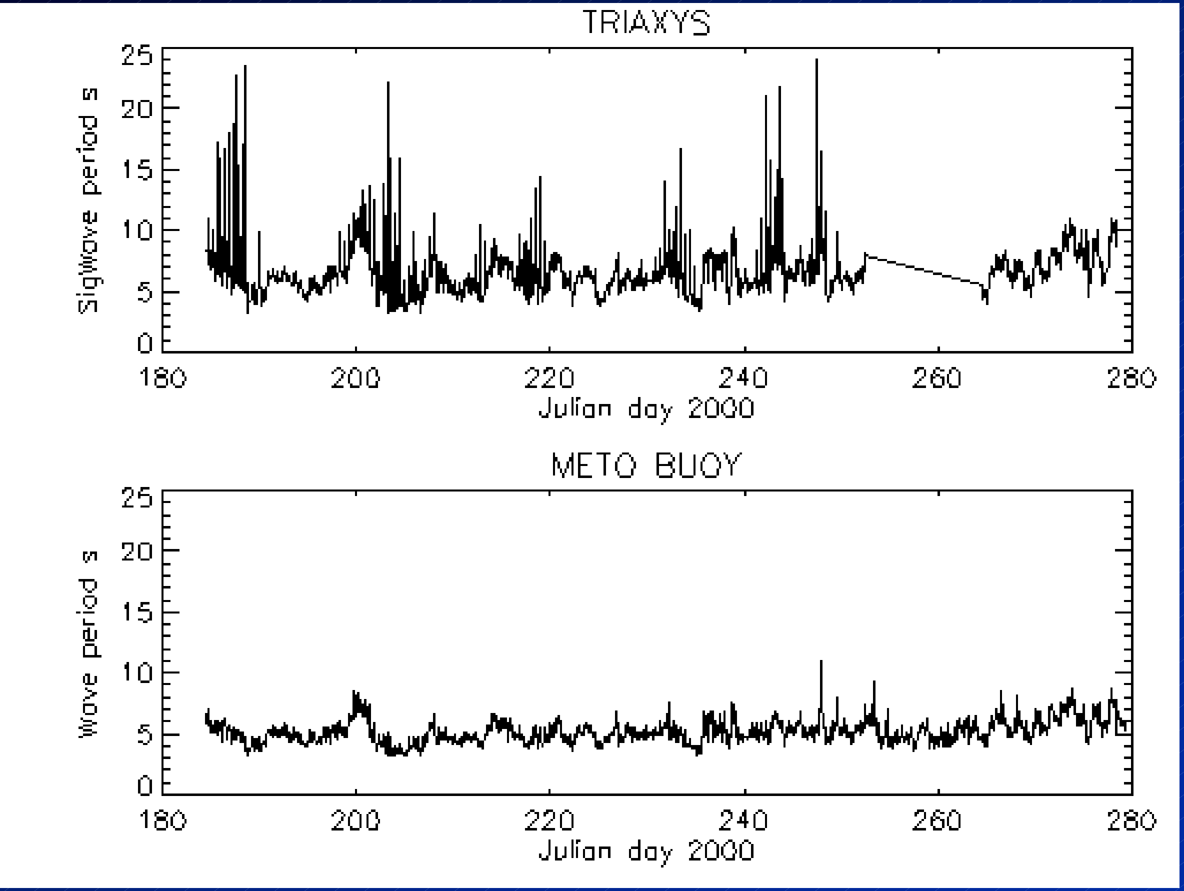
Results will include:-

- comparison of sig wave height and period from TRIAXYS wave sensor and on board heave sensor
- comparison of sig wave height and period from TRIAXYS wave sensor and nearby waverider
- comparison of wave direction from TRIAXYS wave sensor and waverider
- examples of spectral wave measurements from TRIAXYS sensor

comparison of significant wave height from OOB/TRIAXYS wave sensor and on board heave sensor

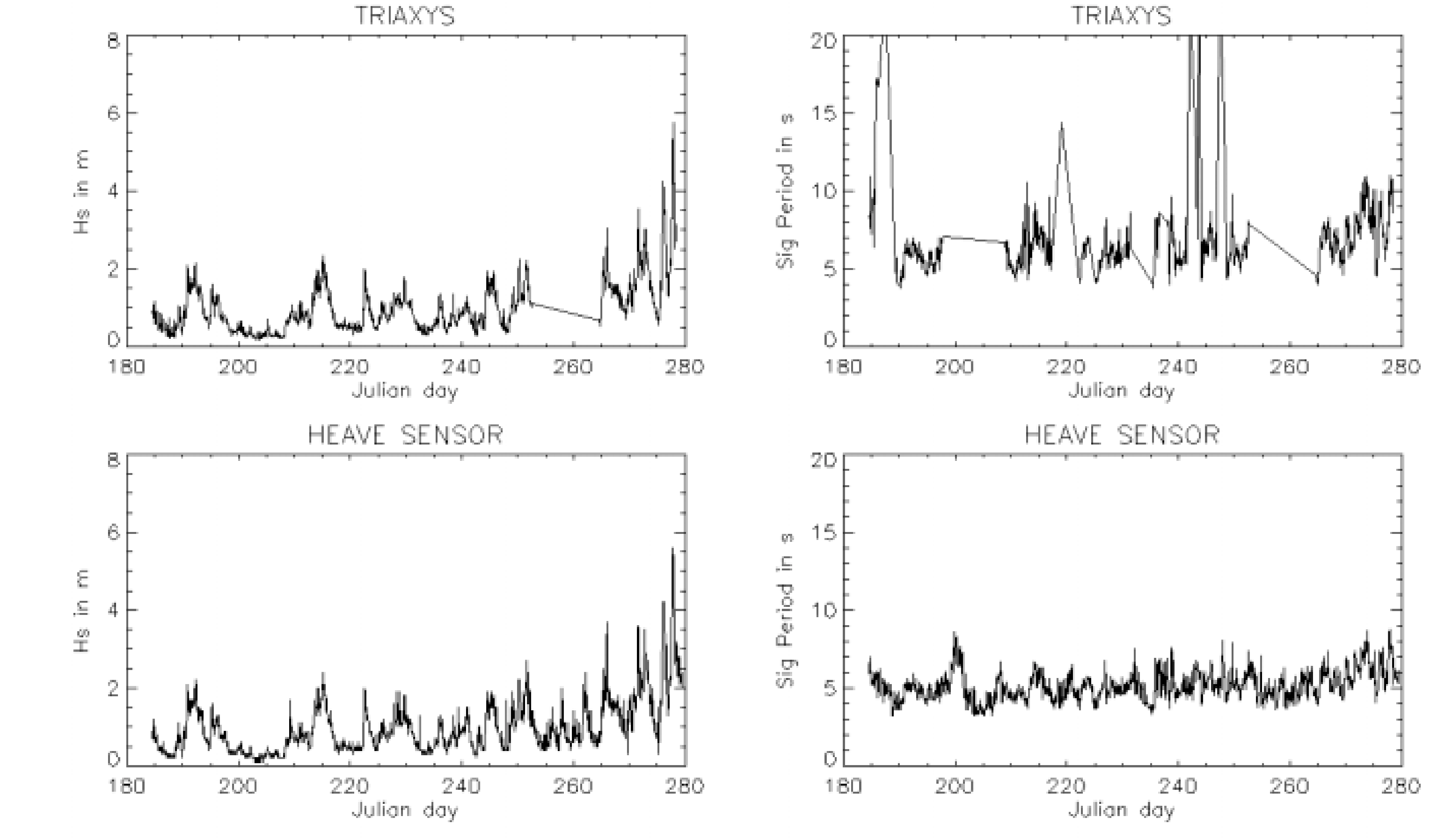


comparison of period from OOB/TRIAXYS wave sensor and on board heave sensor



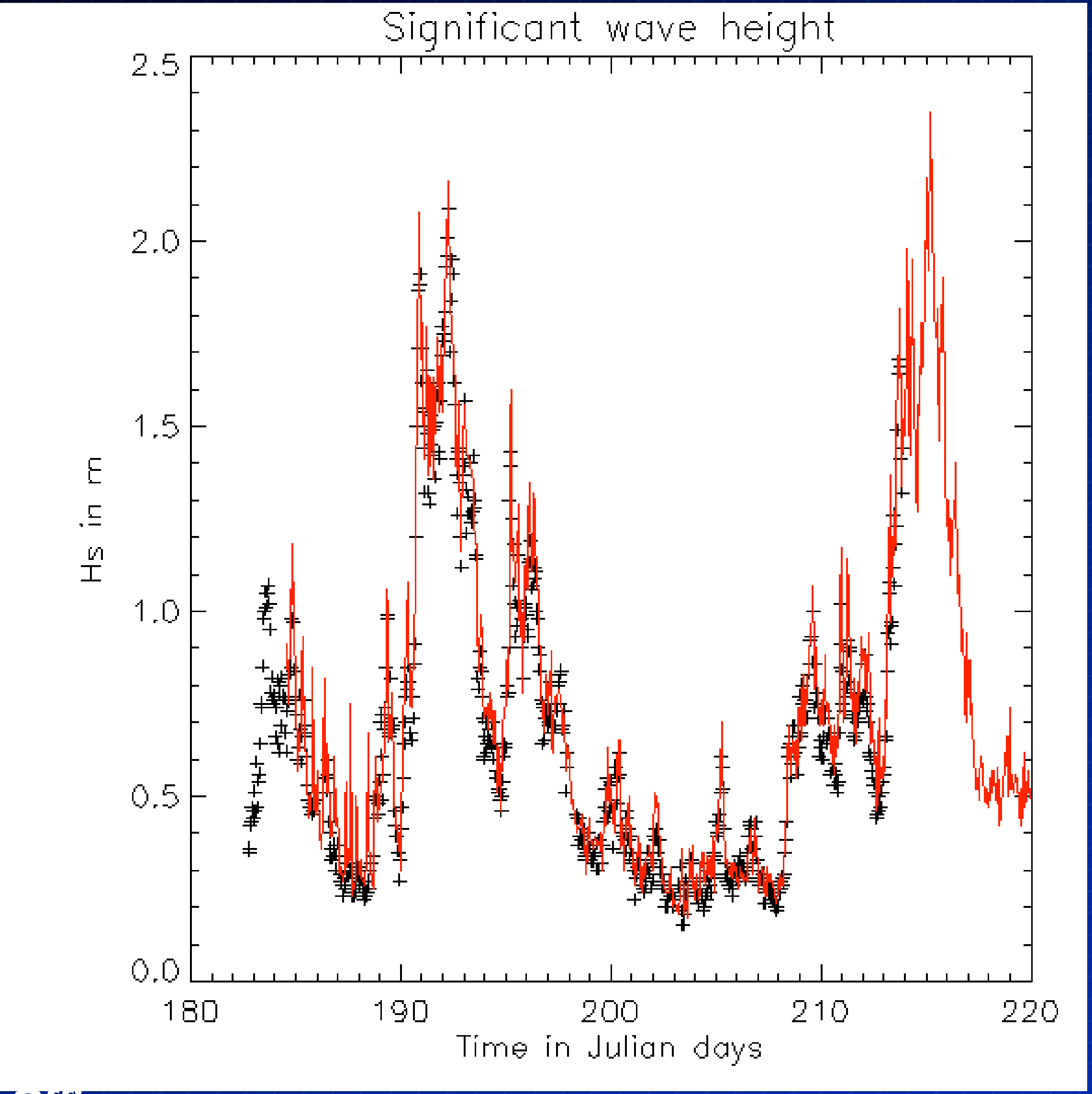
Note 1: Triaxys data has spurious spikes (period > 10s) which occur at times when the sig wave height is < 1.4 meters. This is due to a known software problem which the manufacturers claim has been solved.

comparison of wave period from OOB/TRIAXYS wave sensor and on board heave sensor



*** See note 1.**

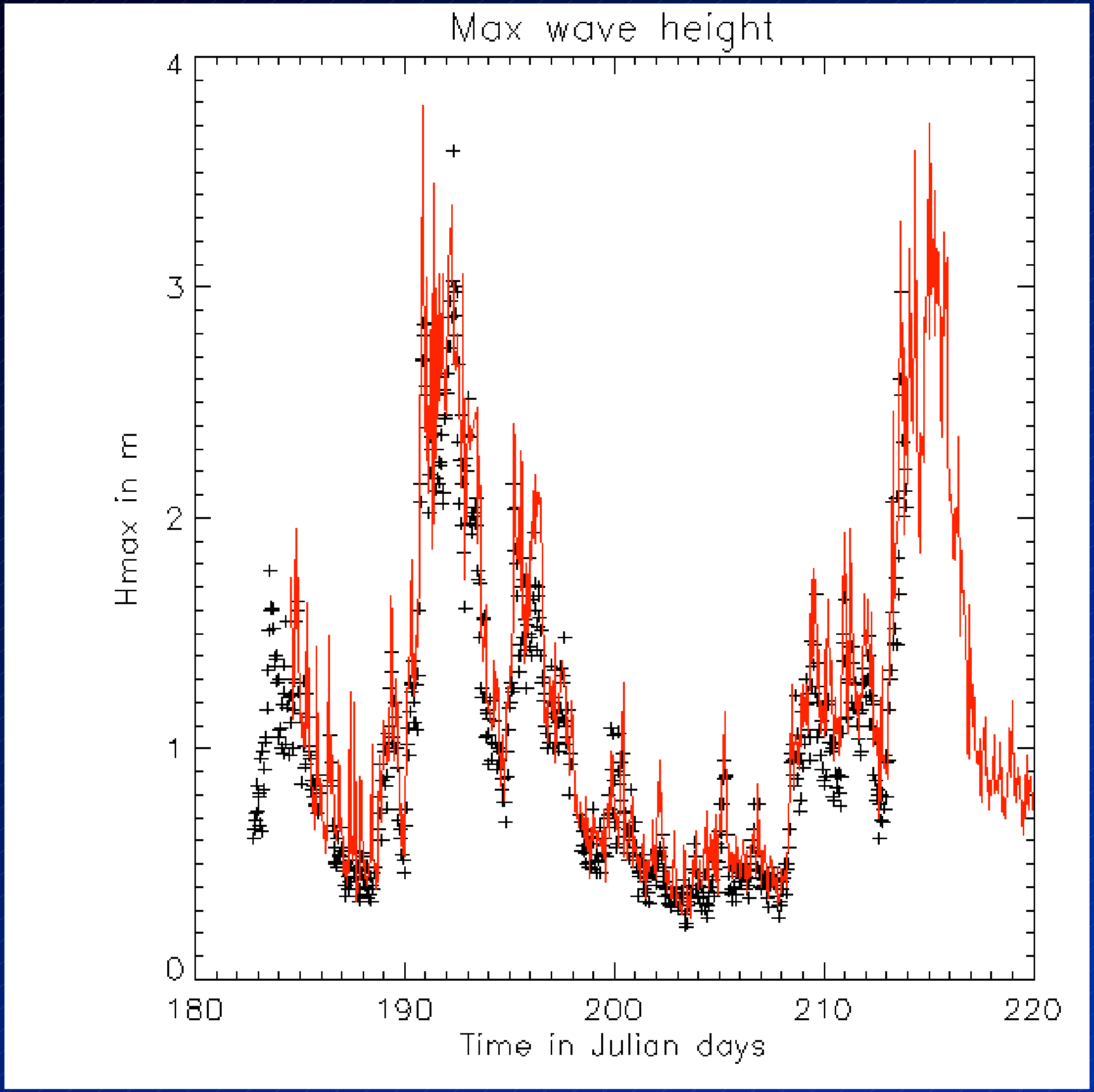
comparison of significant wave height from OOB/TRIAXYS wave sensor and nearby waverider



__TRIAXYS

+ Waverider

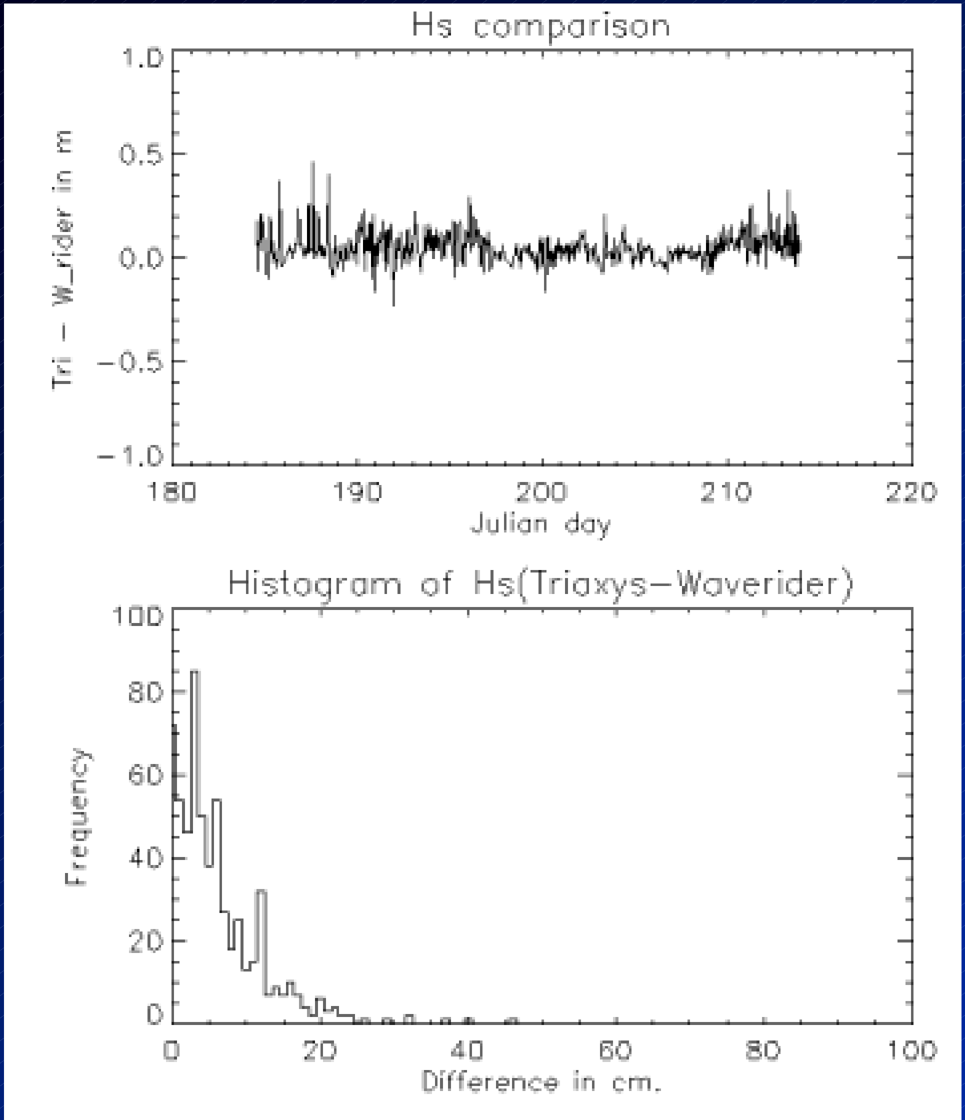
comparison of Maxwave height from OOB/TRIAXYS wave sensor and nearby waverider



__TRIAXYS

+ Waverider

comparison of significant wave height from OOB/TRIAXYS wave sensor and nearby waverider



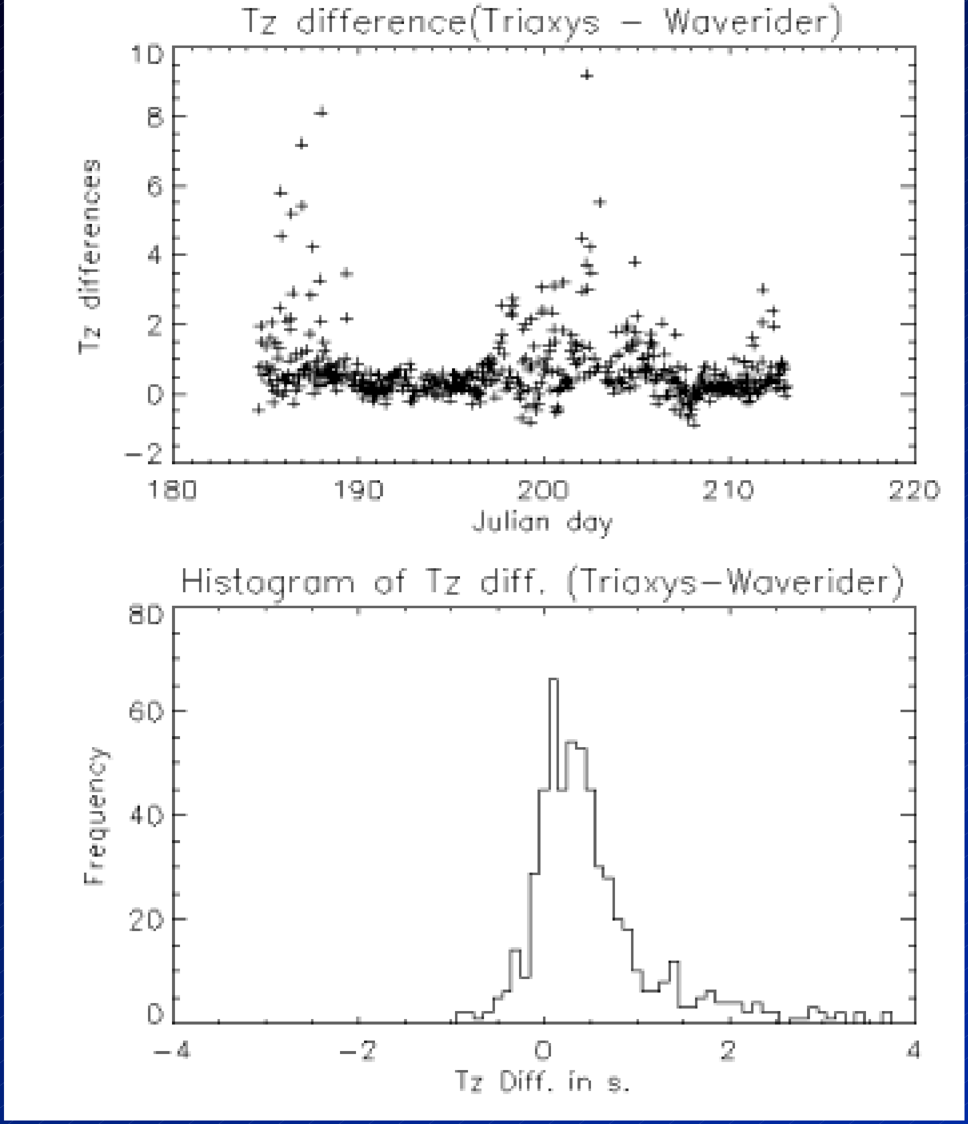
Av diff = 0.06m

Sd of diff = 0.06m

median diff= 0.05m

The Met.Office

comparison of wave period from OOB/TRIAXYS wave sensor and nearby waverider



Mean diff = 0.66sec

Sd of diff = 1.02 sec

median diff = 0.41sec

See note 1.

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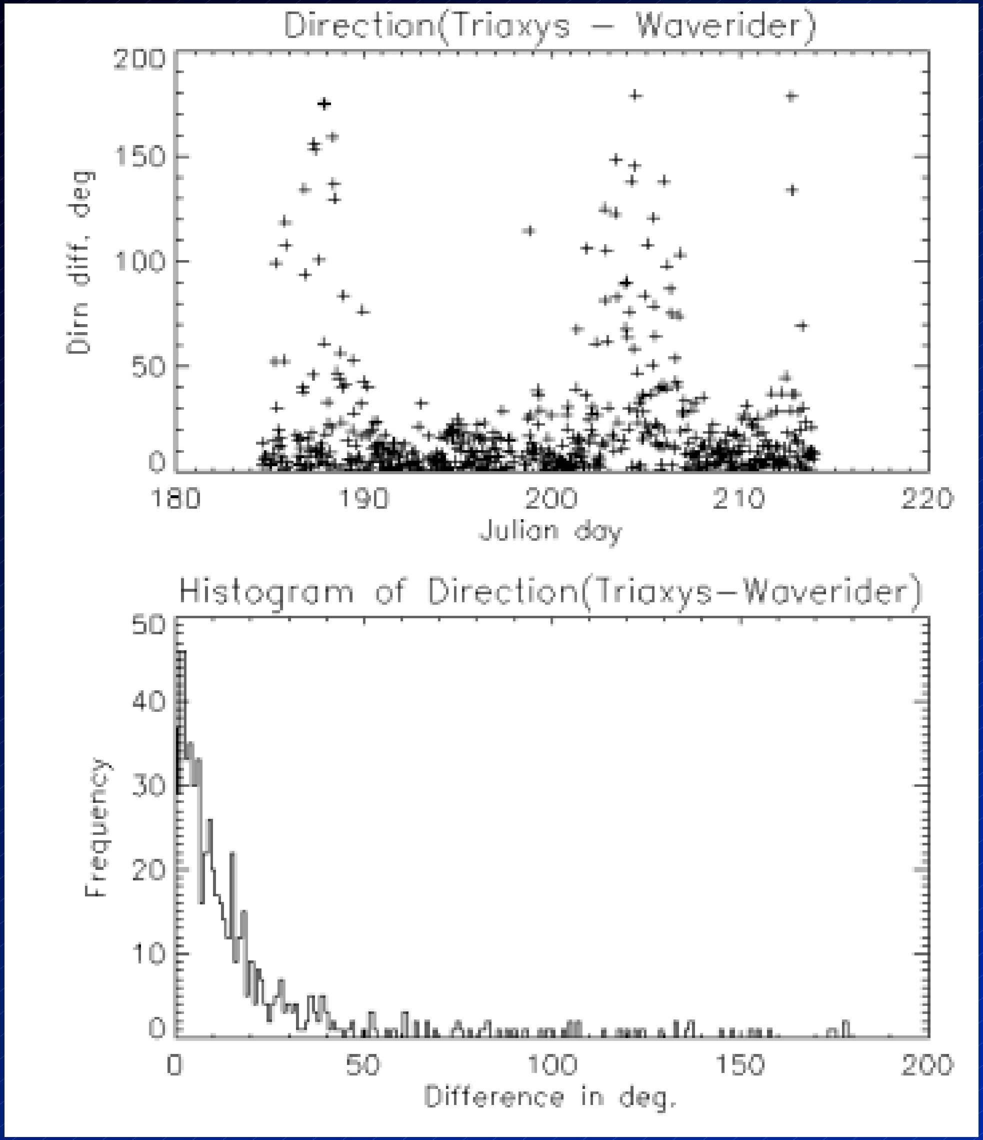
comparison of wave direction from OOB/TRIAXYS wave sensor and nearby waverider



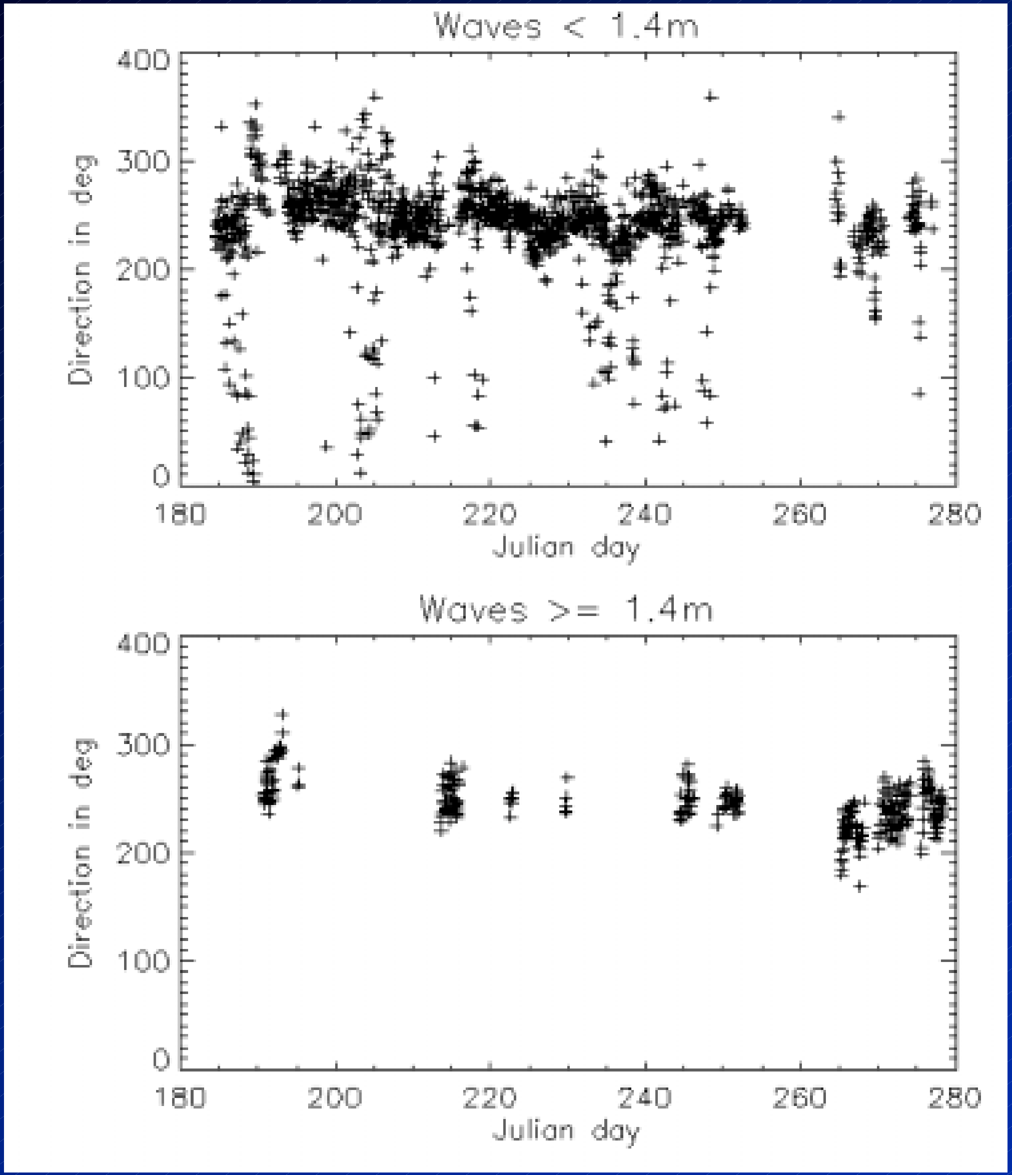
Mean diff = 19º

SD =30º

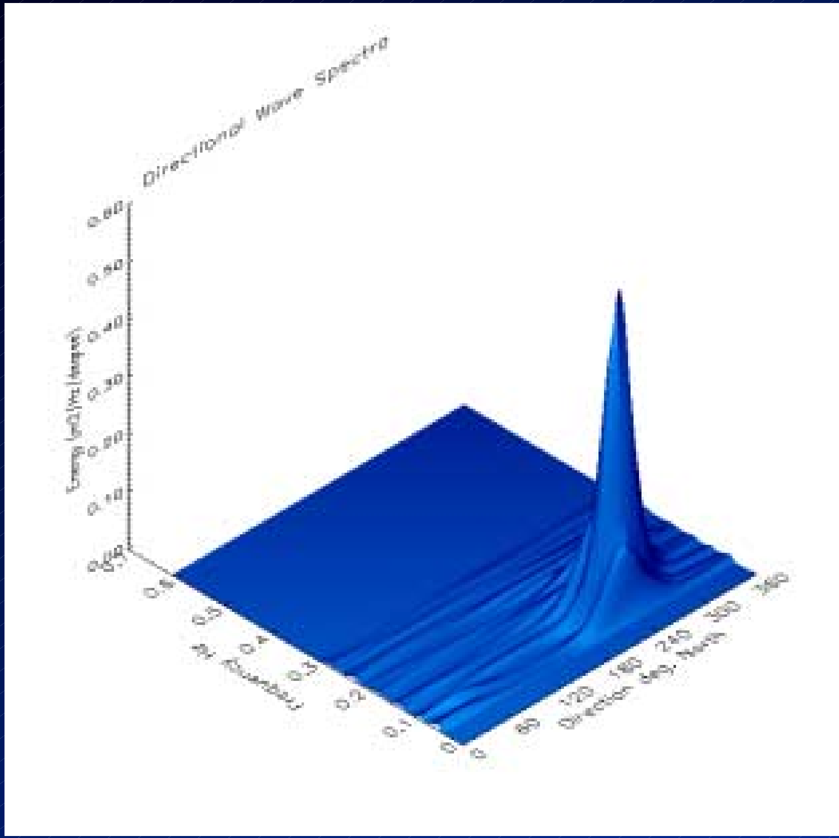
Median diff = 9.6º

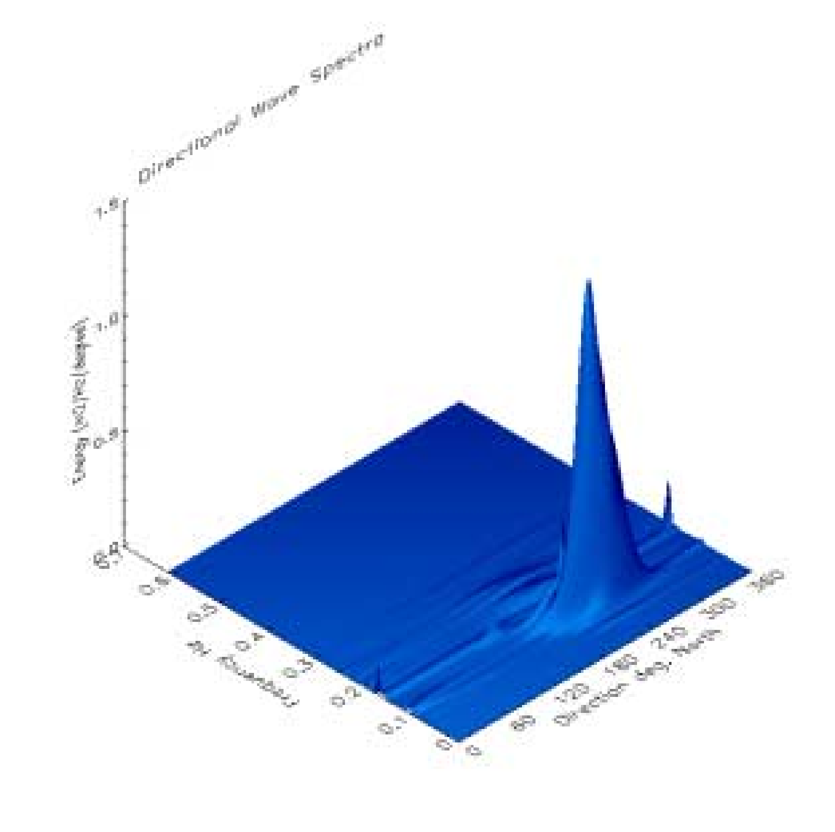
See note 1.

comparison of wave direction from OOB/TRIAXYS wave sensor and nearby waverider



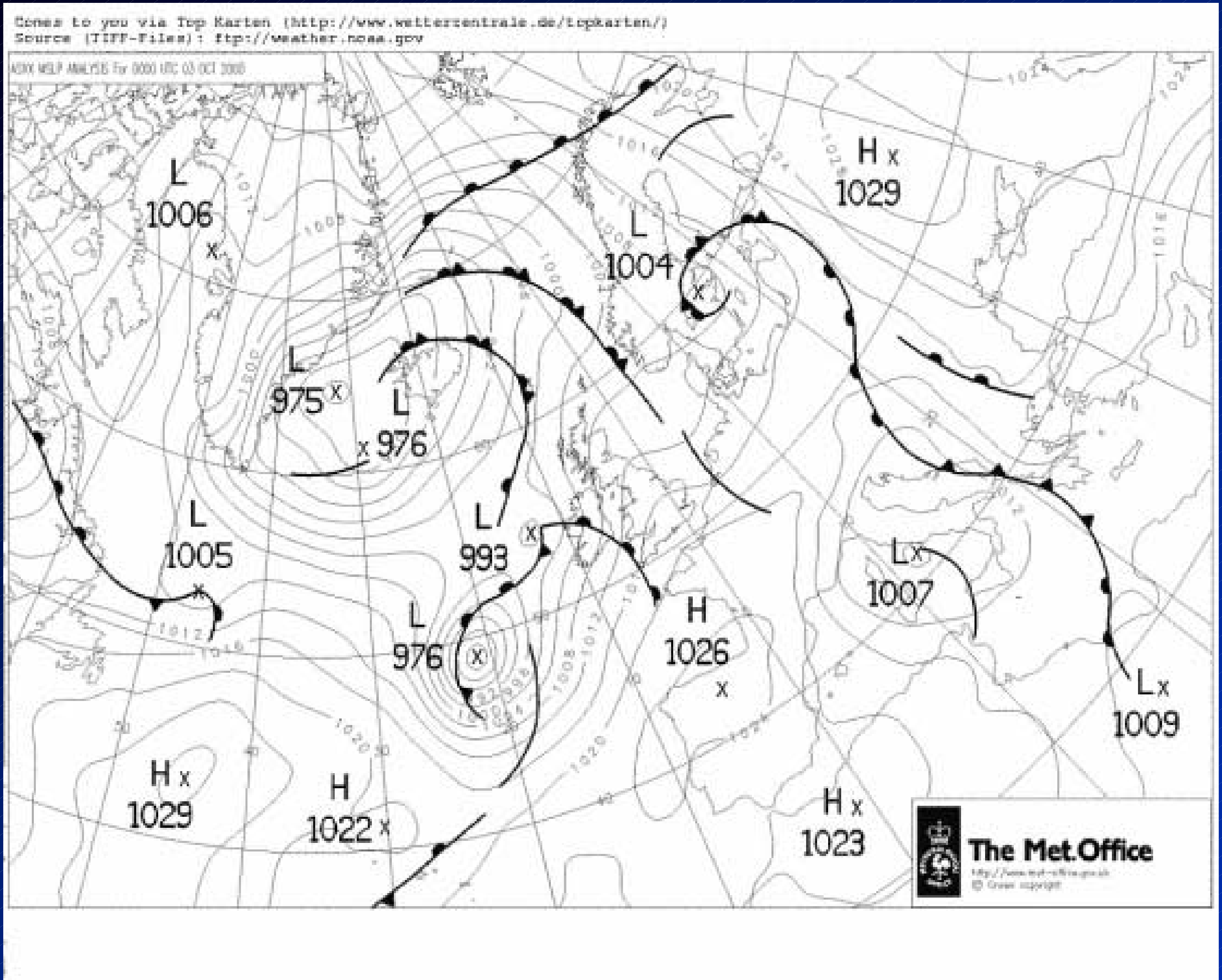
examples of spectral wave measurements from OOB/TRIAXYS sensor



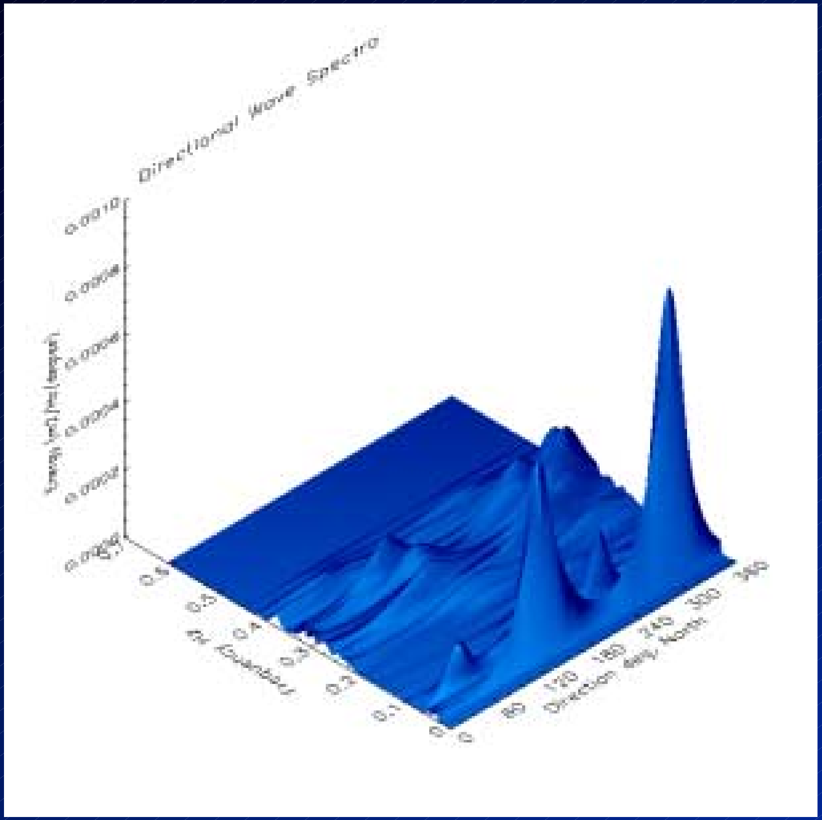


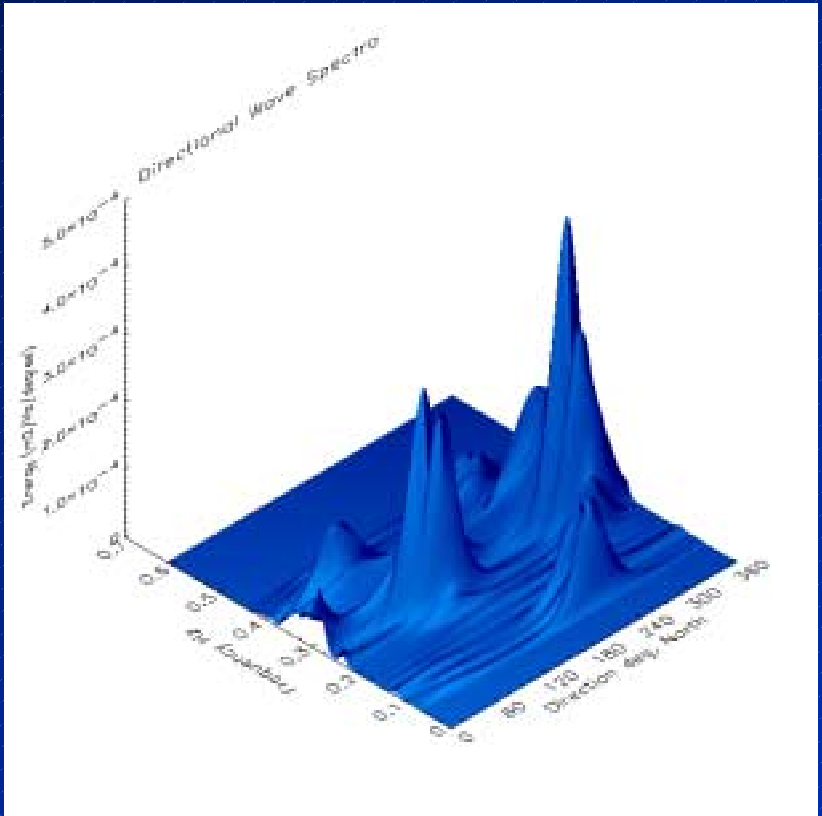
5.30pm and 11.30pm 3rd October 2000, Sig wave heights ~ 4.5 - 5.0 meters.

Corresponding synoptic chart



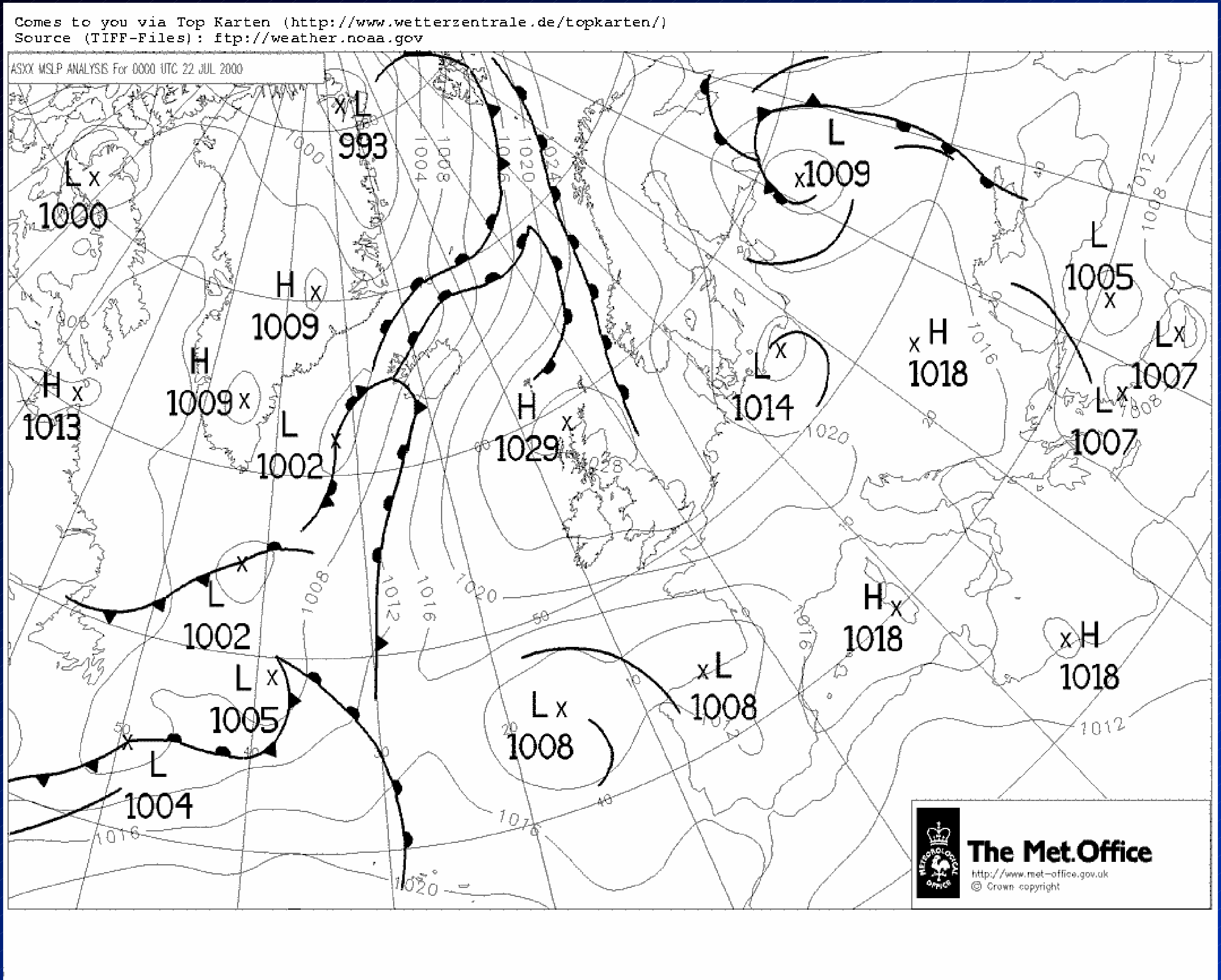
examples of spectral wave measurements from OOB/TRIAXYS sensor





3.30pm and 6.30pm, 22nd July 2000. Sig wave heights ~ 0.4 meters. Spectra contaminated by instrument noise - see note 1.

Corresponding synoptic chart



Summary.

- Results demonstrate that the Met Office buoy hull is capable of being used to produce directional wave spectra.
- Comparison of the Triaxys sensor with the on board heave sensor and a nearby waverider sensor show that the dynamics of the buoy hull have not significantly affected the measurement of ocean wave spectra during this trial.
- Further work will involve evaluating updated firmware to test whether the firmware eliminates the problem described in note 1 such that the unit performs well under all conditions.

Neptune™ - METOCEAN 's Deep-Diving Profiling Floats

Presented at the DBCP Workshop
Victoria, BC, October 2000

Summary

- Introduction
- Neptune Argo Floats
- Neptune Argo Sensors
- Argo Float Cycle
- First METOCEAN Deployment
- Velocity versus Depth Data
- Temperature Profile Data
- Conclusions

Introduction

- ARGO Requirements
- Technology Match
- Design Capability
- Manufacturing Capability
- Strong Teaming Effort

NEPTUNE™ Argo Floats

- Two Models -- LS and SC
- Design life of 150 profiles over 4 to 5 years with lithium battery pack
- Sea-Bird SBE-41CP or FSI Excell™ CTD Sensors
- ARGOS or ORBCOMM Telemetry
- Air Deployment Option (C-130 aircraft)

NEPTUNE™ Argo Floats and Sensors

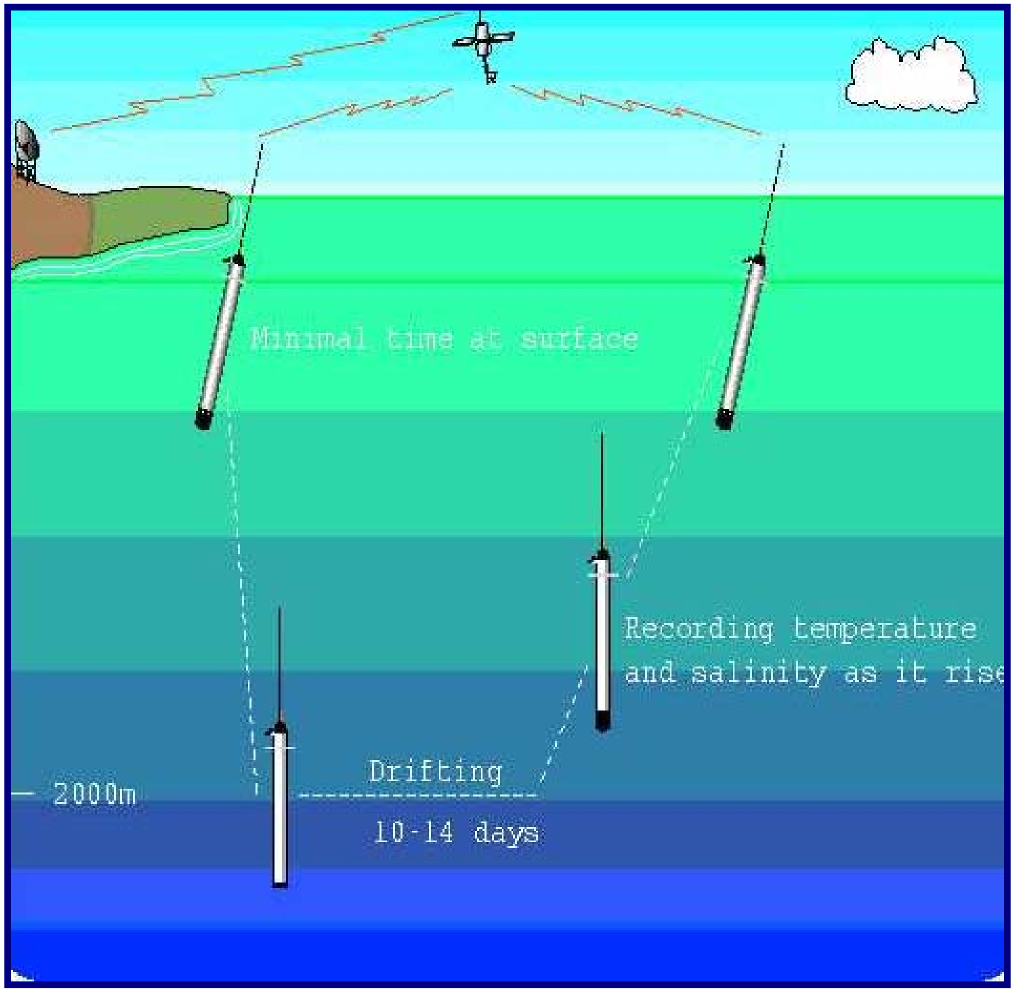
NEPTUNE™ Model LS

- Buoyancy engine designed by IFREMER
- Demonstrated long-term reliability based on MARVOR and PROVOR floats
- Robust buoyancy design allows profiles to 2000 meters in all oceans
- Weight: 34kg
  Length: 170 cm
  Diameter: 17.3 cm

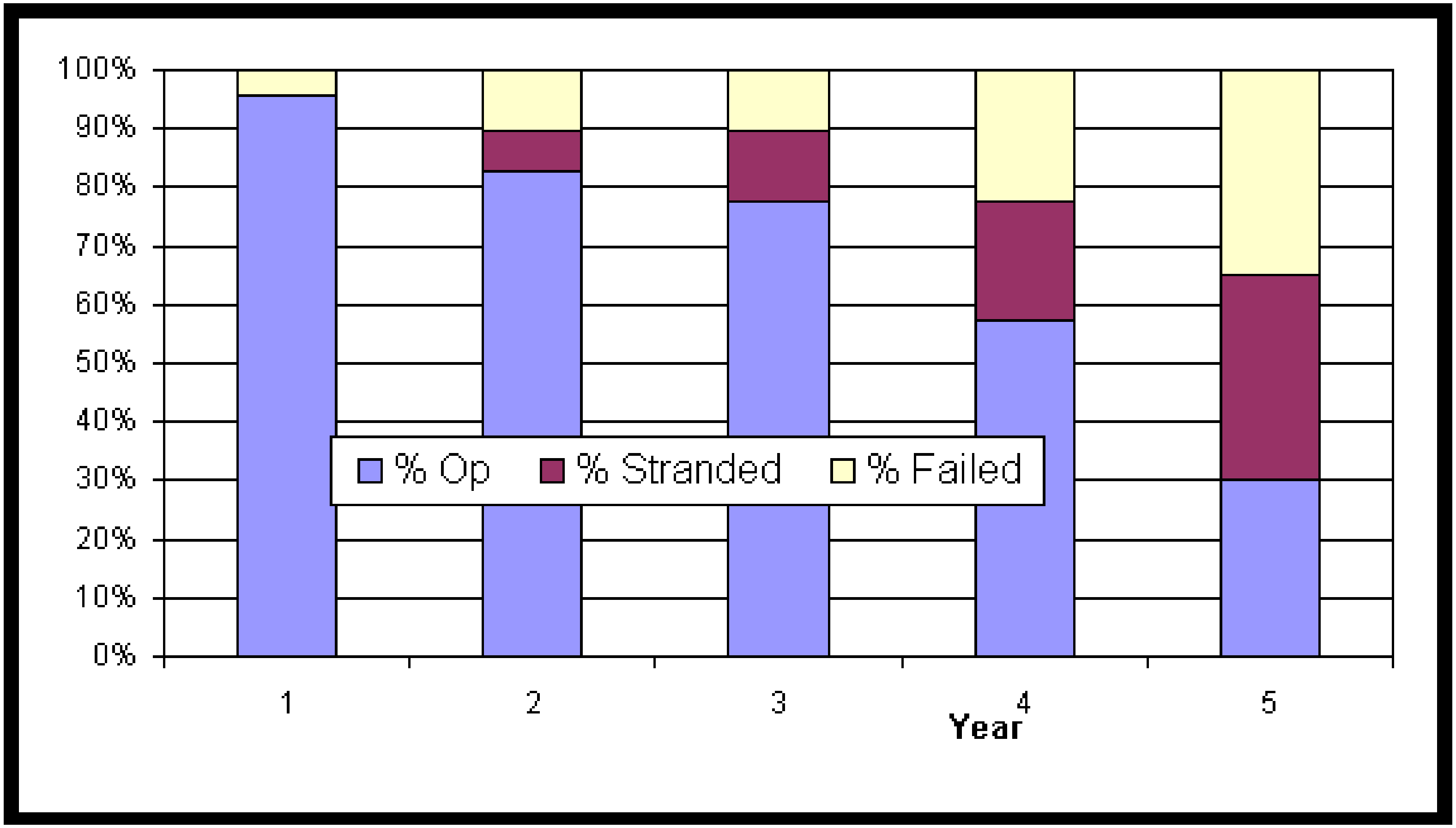
NEPTUNE™ Model SC

- Buoyancy engine design by SIO
- Piston driven engine
- Smaller buoyancy engine limits profiles to 1,500 meters in tropical oceans
- Weight: 30 kg
  Length: 110 cm
  Diameter: 16.5 cm

Argo Float Cycle

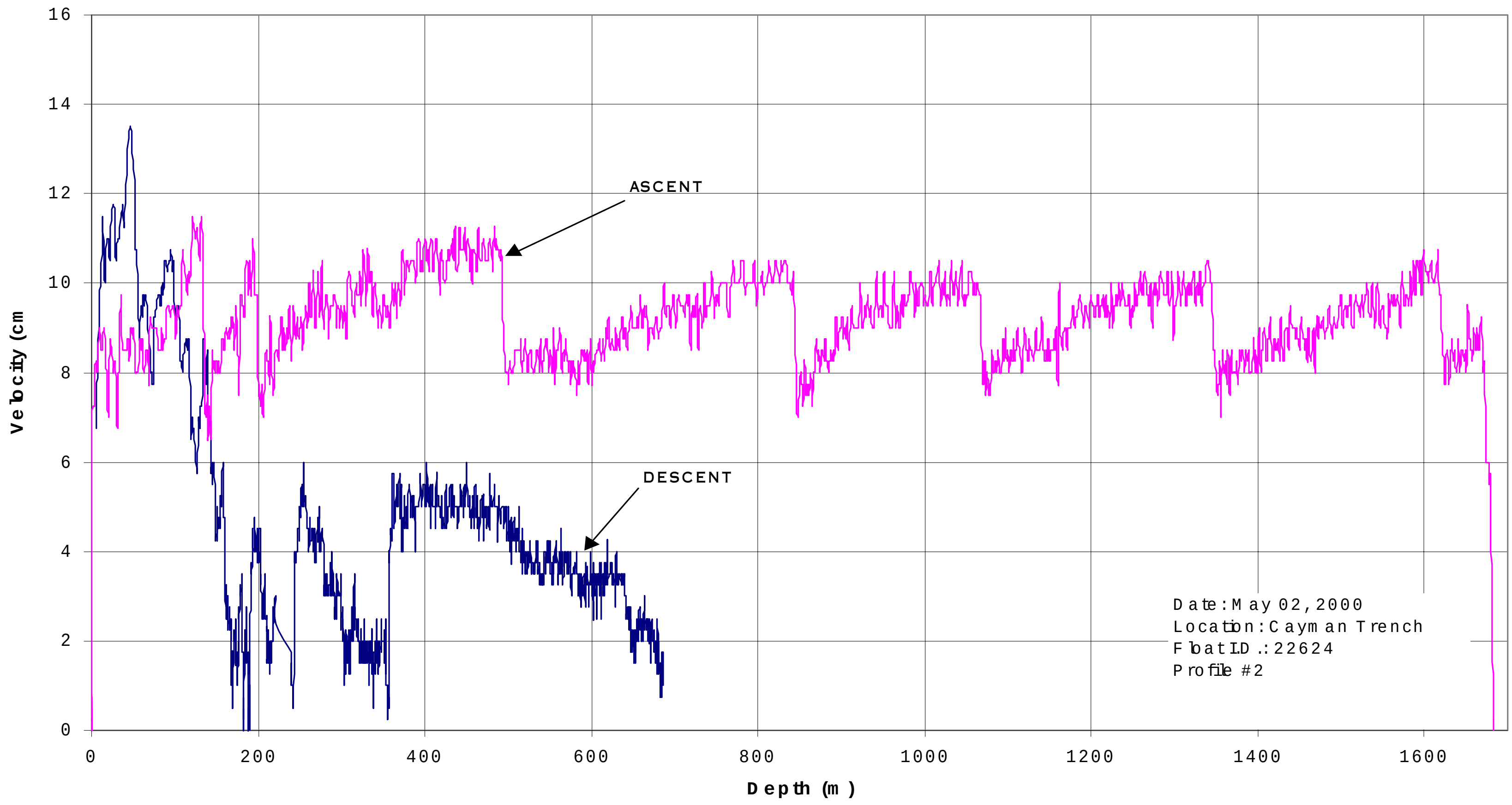


Provor Buoy Buoyancy Engine Reliability

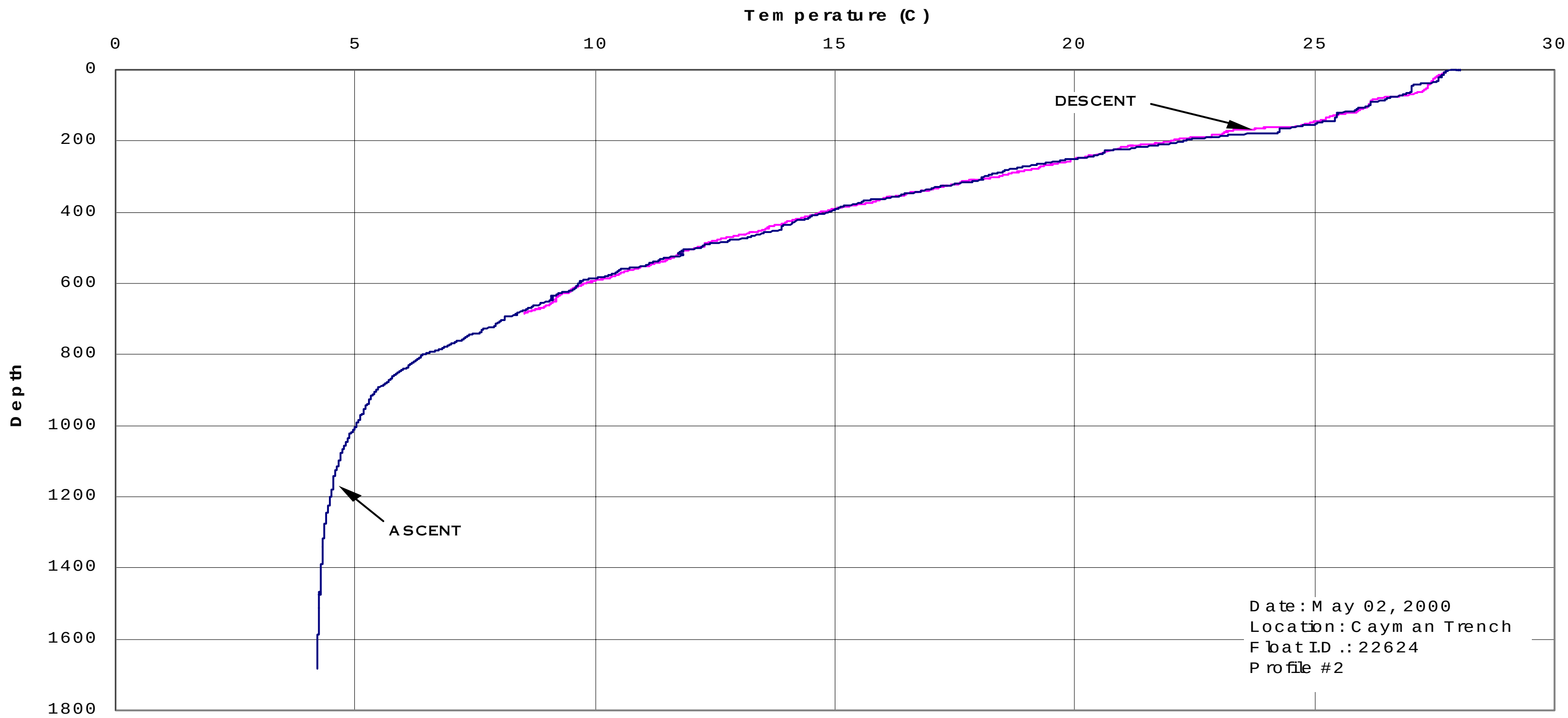


First Deployment of NEPTUNE™ LS Float

NEPTUNE™ LS Velocity vs Depth



NEPTUNE™ LS Temperature Profile



Conclusions

- Major Engineering Effort
- Development of Orbcomm Telemetry Continues
- Long-Term Testing Underway
- Neptune Floats now in Production - Available in early 2001

Project Argo, moving towards the implementation phase

By Howard Freeland
Institute of Ocean Sciences
Sidney, B.C., Canada

Argo is a large international project that aims to supply global surveys of the climatic state and the internal dynamics of the top 2000 metres of the global ocean, every 10 days. This talk will provide a summary of the current status of profiling floats intended for use in Argo, the objectives of Argo and the progress taken so far towards implementation. As of writing the national and international entities contributing to Argo are, Australia, Canada, the E.U., France, Germany, Japan, Korea, UK, Unesco and USA. Though there are strong indications that other countries will join us shortly. All countries have agreed that the data will be made available on the GTS and on the world wide web in near-real-time and agree that no data should be delayed by more than 12 hours. Deployment of the float array in the global ocean will be a significant challenge but exprimental deployments from aircraft have been extremely successful and the entire project appears to be quite tractable.

**SPECIFIC CONTRIBUTIONS TO THE OBSERVING SYSTEM:
SEA SURFACE TEMPERATURES**

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Abstract - Sea surface temperature (SST) observations have been made from in situ (ship and buoy) and satellites. SST analyses used for climate purposes must be constant in time and not influenced by the changes that have occurred in the type and number of SST observations. In particular, biases due to in situ instrument changes and satellite aerosol and cloud contamination must be corrected. The largest uncertainties in global analyses occur near the sea-ice margins where SST observations are sparse and where the accuracy of the analyzed ice concentration is not well known. High resolution SST analyses require the use of satellite as well as in situ SST data. For the high resolution analyses, the development of accurate algorithms to convert between skin SSTs measured by satellite and bulk SSTs measured by ships and buoys is critical. To improve these analyses additional satellite data are needed. This includes microwave satellite data which are unaffected by clouds and geostationary satellite data which can resolve the diurnal cycle.

Introduction

Sea surface temperatures (SST) are an important indicator of the state of the earth climate system as well as a key variable in the coupling between the atmosphere and the ocean. Accurate knowledge of SST is essential for climate monitoring, prediction and research. It is also a key surface boundary condition for numerical weather prediction and for other atmospheric simulations using atmospheric general circulation models. SST also is important in gas exchange between the ocean and atmosphere, including the air-sea flux of carbon. Although global SST analyses are prepared daily, weekly, and monthly it has recently become clear that unacceptable uncertainty exists, in various forms, in our present analyses. Regional uncertainties can be large enough to affect statistical forecasts of seasonal regional weather anomalies and estimates of carbon flux. The uncertainties in ocean basin scale anomalies also appear to be large enough to affect climate change detection. In particular, decadal trend uncertainties are sufficient to affect interpretation of the historical record and to limit the use of existing SST analyses to validate climate change model results. The purpose of this paper is to summarize the present state of SST data and SST analyses. In addition, we will

recommend some steps for enhancement of the in situ observing system for SST and the way that satellite and in situ SST information are processed that will substantially improve the quality of our SST analyses.
It is important to recall that seasonal average climate-scale SST RMS variability, over the past 50 years, is less than 1^{o}C everywhere in the world ocean except along the NW coast of South America, and is less than 0.5^{o}C over most of the world ocean (see Figure 2a of Harrison and Larkin, 1998). In addition, the global-average SST trend over the past 50 years is in the range of 0.2-0.4^{o}C (Diaz et al, 1999). We will show below that our present SST analysis skill is marginal to resolve variability at these levels. Thus, present levels of uncertainty introduce important limitations on our ability to do climate research and climate change detection and to provide climate services that depend on accurate SST information.

SST Data

The longest data set of SST observations is based on observations made from ships. These observations include measurements of SST alone as well as temperature profiles with depth. However, the observations of SST alone dominate the data sets and account for more than 90% of the observations. Although, the earliest observations were taken in the first half of the 19th century, sufficient observations to produce a global SST analysis were not available until about 1870. From 1870 to present, the number of observations generally increased except for noticeable dips during the First and Second World Wars. In addition to the changes in the number of observations, the method of measuring surface marine observations changed over the period from temperatures measured from uninsulated buckets to temperatures measured from insulated buckets and engine intakes. These instrument changes resulted in biases in the data set. Folland and Parker (1995) have developed corrections for these biases and incorporated them into UK Meteorological Office SST analyses. Although, as discussed in Kent et al. (1993), selected SST observations can be very accurate, typical RMS errors from ships are larger than 1^{o}C and may have daytime biases of a few tenths of a degree C (Kent et al., 1999).

SST observations from drifting and moored buoys began to be plentiful in the late 1970s. These observations are typically made by thermistor or hull contact sensor and usually relayed in real-time by satellites. Biases in the SSTs from buoys can occur in some designs, e.g., significant diurnal heating of the hull may occur under low wind conditions with some hull configurations. Although the accuracy of the buoy SST observations varies, the accuracies are usually better than 0.5^{o}C, which is better than ships. In addition, typical depths of the observations are roughly 0.5 m rather than the1 m and deeper depths from ships. The distribution of ship and buoy in situ SST observations (see Fig. 1) shows that the deployment of the buoys has partially been designed to fill in some areas with few ship observations. This process has been most successful in the tropical Pacific and Southern Hemisphere.

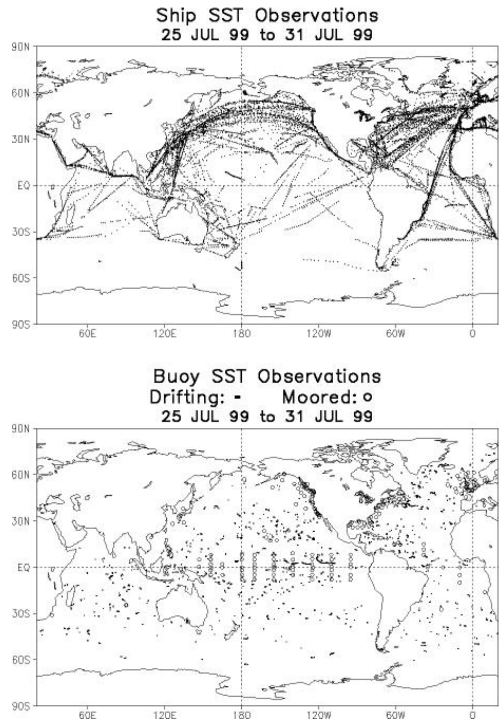

Fig. 1: Distribution of SST in situ observations from ships (top panel) and buoys (lower panel) for the week of 25-31 July 1999.

In late 1981, accurate SST retrievals became available from the Advanced Very High Resolution Radiometer (AVHRR) instrument, which has been carried on many NOAA polar orbiting satellites. These retrievals improved the data coverage over that due to in situ observations alone. The satellite retrievals allowed better resolution of small-scale features such as Gulf Stream eddies. In addition, especially in the Southern Hemisphere, SSTs could now be observed on a regular basis in many locations. These data are produced operationally by NOAA's Environmental Satellite, Data and Information Service (NESDIS) and also, during the last few years, by the US Navy.

Because the AVHRR cannot retrieve SSTs in cloud-covered regions, the most important problem in retrieving SST is to eliminate clouds. The cloud clearing algorithms are different during the day and the night because the AVHRR visible channels can only be used during the day. After clouds have been eliminated, the SST algorithm is derived to minimize the effects of atmospheric water vapor. The satellite SST retrieval algorithms are "tuned" by regression against quality-controlled buoy data using the multichannel SST technique of McClain et al. (1985). This procedure converts the satellite measurement of the "skin" SST (roughly a micron in depth) to a buoy "bulk" SST (roughly 0.5m). The tuning is done when a new satellite becomes operational or when verification with the buoy data shows increasing errors. The AVHRR instrument has three infrared (IR) channels. However, because of noise from sun glint, only two channels can be used during the day.

Thus, the algorithm is usually tuned separately during the day and the night and typically uses two channels during the day and three at night (Walton, et al., 1998). The algorithms are computed globally and are not a function of position or time.

If the retrievals are partially contaminated by clouds, the retrievals have a negative bias. Negative biases can also be caused by aerosols, especially stratospheric aerosols from large volcanic eruptions (e.g., see Reynolds, 1993). Although these biases are the most frequent, biases of either sign can also occur due to instrumental problems (e.g., the onboard black body calibration). In addition, bias errors can occur from the use of bad in situ data, which impact the satellite-tuning algorithm, and from extreme atmospheric conditions (e.g., high water vapor content) which may require a different satellite algorithm. The ratio of the number of daytime to nighttime satellite retrievals is now roughly one to one. However, the ratio was roughly five to one prior to 1988. From 1989 to present the nighttime satellite algorithm was gradually modified to increase the number of nighttime observations while the daytime observations remained roughly constant. A delayed-mode processing of satellite data done for the Pathfinder project (Podesta et al., 1997) could correct these differences and should be a better product for climate. However, because some Pathfinder SST biases remain, in situ data remain critical not only for satellite calibration and validation but also for final bias corrections.

Future improvements in the SST observing system will primarily be due to new satellite data. A significant change occurred during 1999 when SSTs from a second polar orbiting NOAA satellite were operationally processed for the first time. In addition, data from other satellites including microwave satellites, which can see through clouds, and geostationary satellites, which can resolve the diurnal cycle, are now becoming available. This will make it easier to do high resolution SST analyses as discussed later.

Climate Scale SST Analyses

For this discussion, SST analyses have been divided into two groups: climate and high resolution. The climate scale analysis typically has temporal resolutions from weekly to monthly and spatial resolutions from 1^{o} to 5^{o}. These analyses use in situ SST data and may or may not use satellite SST data when available. As mentioned below, sea-ice concentrations may also be used to augment the SST data at high latitudes. These analyses are often used on seasonal and interannual scales for monitoring and prediction of El Niño events and on decadal and centennial scales for climate trend detection. In addition, the SSTs are used as the ocean boundary condition for atmospheric general circulation models. For these purposes it is important that analysis methods be constant with time and not influenced by temporal changes in SST data. The problem of the changes in SST data is particularly difficult because not only did the number of in situ data generally increase with time but also additional data sources were added when observations from buoys and satellites became available.

To better understand the problems of climate scale SSTs, different SST analyses have been compared. Two studies will be discussed here. Hurrell and Trenberth (1999) compared four analyses: the National Centers for Environmental Prediction (NCEP) optimum interpolation analysis, henceforth OI, of Reynolds and Smith (1994); the NCEP empirical orthogonal functions analysis, henceforth EOF, of Smith et al. (1996); the UK Meteorological Global Sea-ice SST analysis, version 2.3b, henceforth (GISST) of Rayner et al, (1996); and the Lamont-Doherty Earth Observatory analyses of Kaplan et al. (1998) henceforth LDEO. A description of the data and analysis methods can be found in Hurrell and Trenberth (1999). The second study was presented at a Global Climate Observing System (GCOS) Workshop on Global Sea Surface Temperature Data Sets which was held at the Lamont-Doherty Earth Observatory, 2-4 November 1998 (WMO, 1999) and is updated here. This workshop study focused on the period 1982 to 1997 and added four additional analyses: the UK Meteorological Office Historical SST analysis, version 6, of Parker et al. (1994), henceforth MOHSST; the Japan Meteorological Agency, (T. Manabe, 1999, personal communication), henceforth JMA; the Naval Research Laboratory (J. Cummings, 1999, personal communication) henceforth NRL; and the Australian Bureau of Meteorology Research Centre (N. Smith, 1999, personal communication), henceforth BMRC. The resolution, period, and type of SST data used for each analysis are summarized in Table 1.

Table 1. SST Analyses with analysis periods and resolution. All analyses used in situ (ship and buoy) data. Analyses using sea-ice data converted to SSTs are indicated by Ayes@ in the ice column. Analyses using satellite data are indicated by Ayes@ if used or Acorrected@ if used with additional bias corrections. Months are noted under the Aperiod@ column if the analysis did not start in January.

Acronym	Period	Resolution	Satellite Data	Ice Data
BMRC	Jul-93 to present	1°	Corrected	Yes
GISST	1871 to present	1°	Corrected	Yes
JMA	1982 to present	2°	No	No
LDEO	1856 to present	5°	No	No
MOHSST	1856 to present	5°	No	No
EOF	1950 to 1998	2°	No	No
OI	Nov-81 to present	1°	Corrected	Yes
NRL	1995 to present	1/4°	Yes	Yes

Sea-ice information is used to generate additional SST data to augment other SST data in four of the analyses. The generation methods vary along with the accuracy of the sea-ice information. In the OI, BMRC and NRL analyses, an SST value representing the freezing point is added at locations where a specified sea-ice concentration is exceeded. The GISST method of generating SST from the sea-ice concentration, I, is more complicated and probably more realistic. In this method, a relation between SST and I is defined by a quadratic equation: $\mathbf{SST = a\,I^2 + b\,I + c}$, where a, b, and c are constants. The constants are determined by climatological collocated match ups between SST and sea-ice concentration with the constraint that SST = -1.8°C or 0°C when I = 1 over the ocean or fresh water lakes, respectively. In addition to uncertainties in these methods, the analyzed value of ice concentration as defined in different analyses is not accurately known especially in summer. The climatological sea-ice concentrations are shown for July in Fig. 2 for two analyses. The first, combined from Nomura (1995) and Grumbine (1996), the Nomura/Grumbine analysis, is an objective analysis of microwave satellite observations (SMMR and SSM/I). The second, the National Ice Center analysis (Knight, 1984), is a subjective analysis of in situ and satellite microwave and infrared observations. The concentrations of the Nomura/Grumbine analysis are much lower because the microwave satellite instrument interprets melt water on top of the sea ice as open water.

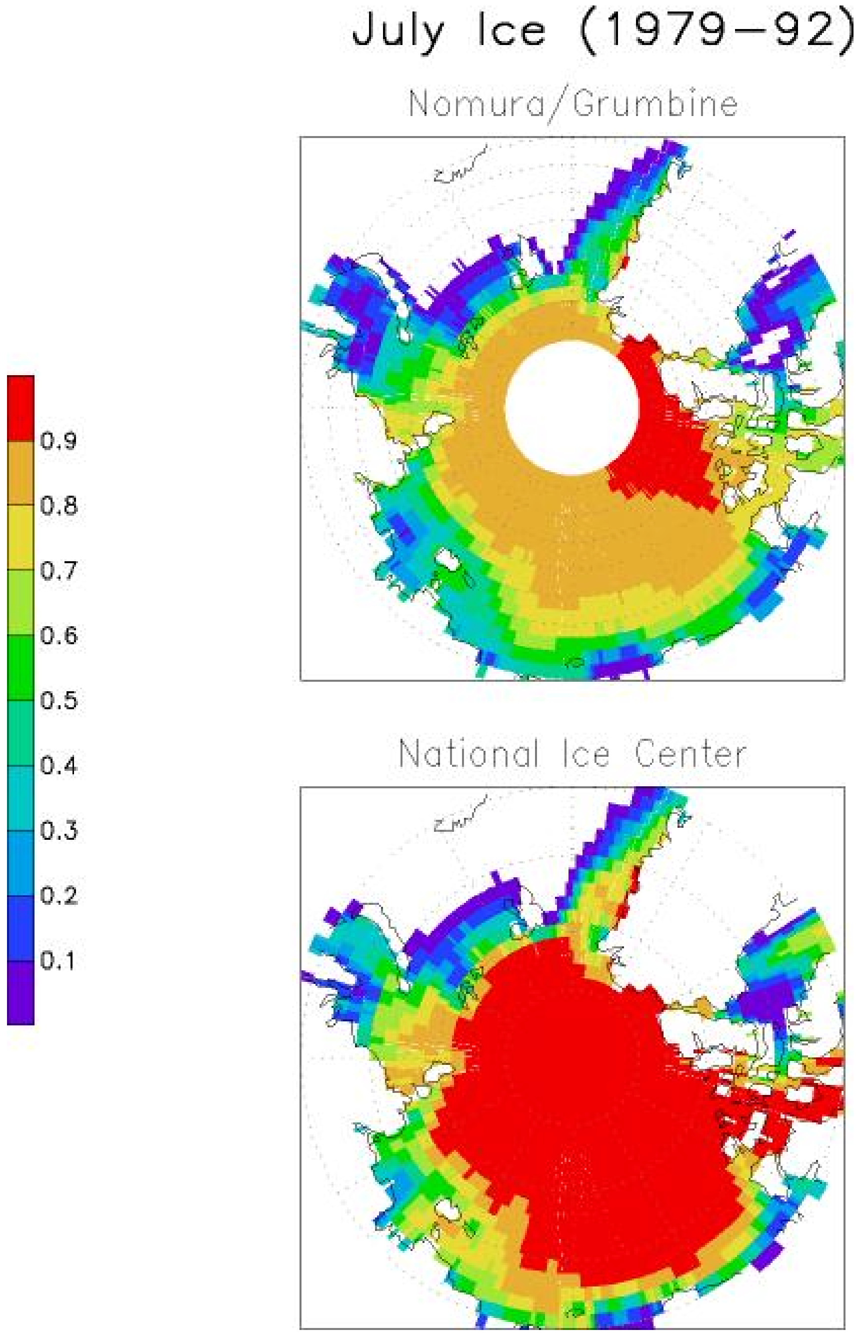

Fig. 2: Climatological sea ice concentrations for the Arctic for July for the period 1979 to 1992. The upper panel shows the analysis from Nomura and Grumbine; the missing data near the pole occurs because of lack of satellite observations. The lower panel shows the analysis from the National Ice Center (see text). The range of ice concentration is 0 (0%) to 1 (100%).

Both Hurrell and Trenberth (1999) and the workshop comparisons showed that differences among analyses were smaller within the tropics than the extratropics. This can be seen in the zonal averages shown for the four analyses with ice information in Fig. 3. The figure shows that Northern Hemisphere middle latitude differences are smaller than middle and high latitudes differences in the Southern Hemisphere. However, the differences above 60°N are the largest due to uncertainties near and within the Arctic sea ice. The workshop comparisons found that the monthly RMS differences among analyses were in the range 0.2°C to 0.5°C between roughly 40°S and 60°N except in coastal areas. They were larger outside this latitude belt. In particular, in situ only analyses had differences greater than 1°C south of 40°S. Hurrell and Trenberth (1999) showed that monthly lag one autocorrelations appeared to be depressed in the GISST analysis during 1982-1997 compared to the other analyses. In addition they found differences in the regional trends between the GISST and LDEO. LDEO used MOHSST, version 5, and GISST used MOHSST, version 6, as in situ input data. Thus, the differences may be due to changes in MOHSST or differences in the analysis methods.

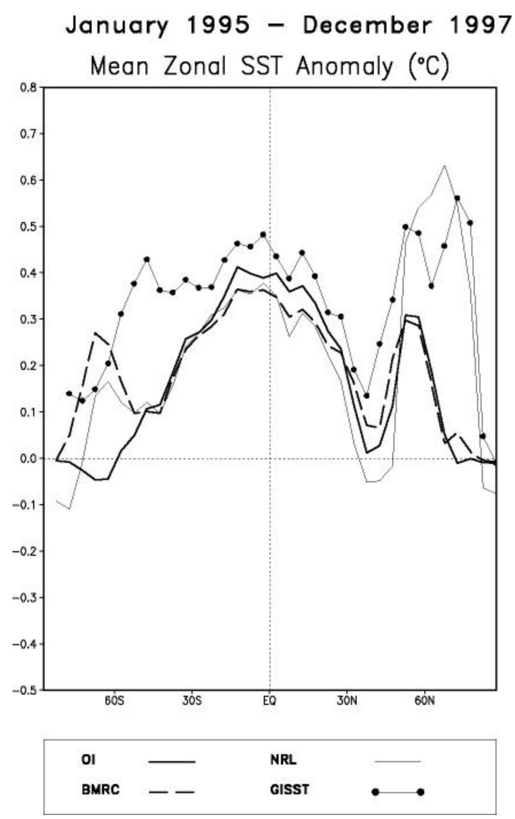

Fig. 3: Mean zonally averaged SST anomalies from four analyses for the period January 1995 to December 1997. All analyses used in situ and satellite SST plus SSTs generated from sea ice concentrations.

To illustrate the problems of a real-time satellite bias correction, the anomaly time series for the monthly OI and MOHSST SST anomalies, computed from 60°S to 60°N for the period 1982-1997, are shown in Fig. 4. This region was selected to minimize the impact of sea ice. Because the global coverage of the in situ data is not defined everywhere, the analyses were computed only over regions where MOHSST had values. The result shows that the MOHSST tends to be slightly more positive, roughly 0.1°C, than the OI analysis from 1990 onwards. The OI analysis has a real-time bias correction of the satellite data. To show the importance of this correction, a special version of the OI analysis was computed without the real-time bias correction of the satellite and also shown in the figure, labeled OI_NO. The differences between the two OI versions are much larger than the differences between the MOHSST and bias corrected OI analysis. In particular, impacts of the large negative satellite biases from the volcanic aerosols from El Chichón (1982-83) and Mount Pinatubo (1991-92) are clearly evident (e.g., see Reynolds, 1993). Further study has shown that the average difference between the OI and MOHSST analyses during the 1990s is due to two effects: a residual under correction of the satellite biases in the OI and differences in the nonlinear in situ data screening procedures used in the OI and MOHSST.

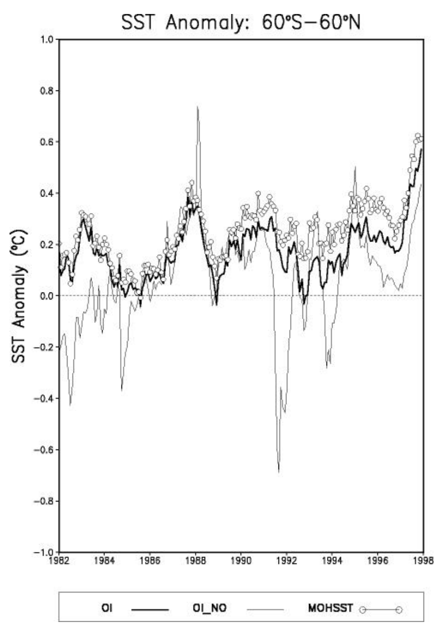

Fig. 4: Averaged (60°S to 60°N) SST anomalies from the OI and MOHSST analyses. The times series labeled A**OI_NO**@ is from a special version of the OI analysis without the real-time bias correction of the satellite data (see text). The averages are computed over common areas where the MOHSST analysis is defined.

The comparisons have shown that analyses using satellite data without careful bias correction should not be used for climate studies because of large potential biases in satellite retrievals. Satellite data can improve the coverage and spatial resolution of SST analyses and should be used with bias corrections. However, there were also large-scale differences among the in situ analyses of this magnitude, which could persist for several months.

These differences are most likely due to the nonlinear data procedures used to eliminate bad data rather than differences in the in situ data sets themselves. The largest differences among analyses with sea-ice data, occurred near the sea-ice margins. The differences were due both to uncertainties in the ice analyses as well as uncertainties in the method of converting from ice to SST.

Requirements for In Situ Observations for Climate

To be able to construct accurate SST analyses for climate, sufficiently accurate in situ and satellite SST data are needed. The in situ observations are needed to correct the satellite data and to provide SST in regions where there are no satellite data. We seek to estimate the minimum in situ coverage that is adequate to produce weekly a global SST analysis on a 5^o grid with errors below 0.5^oC. One of the steps in this process is to make assumptions about the required satellite coverage. If the satellite data density is adequate, in situ data will only be needed to correct the satellite data. In this case, the in situ data will be needed on a 10^o grid, because we assume that the satellite will give the large-scale SST gradients acceptably. If the satellite data density is not adequate, we assume the in situ data will be needed on a 5^o grid, so that they can on their own determine the SST field adequately.

First consider the properties of the most wide spread in situ sources of SST observations, surface moored and drifting buoys and ships. Reynolds and Smith (1994) estimated that the globally averaged in situ SST RMS errors were 0.5^oC for buoys and 1.3^oC for ships for their weekly OI analysis. The satellite errors in bias-free conditions were found to be 0.5^oC for daytime and 0.3^oC for nighttime. (The daytime satellite errors are larger because the diurnal cycle is not represented in a weekly analysis.) These error estimates included not only instrument errors but also include representativeness errors due to the difference between a point and a gridded value. With these estimates, 1 buoy observation or 6 ship observations are required at each grid point per week. One buoy observation is needed because the 0.5^oC error matches the 0.5^oC RMS analysis error. (Of course errors at an individual point will be larger). The requirement of 6 ship observations is based on the assumption that the observations are random so that the ship errors can be reduced to 0.5^oC by averaging (the reduction is given by dividing 1.3 by the square root of the number observations averaged). In fact, a surface drifting buoy typically will remain within a 5^o square for at least a week and give many more observations in that week than a merchant ship moving at 8 m/s.

To decide where the number of satellite observations is adequate on a 5^o grid, we assume that there must be at least 3 observations per week in a 1^o grid box (this is the requirement used in the NCEP OI analysis) and that at least 20% of the 1^o grid values contained within a 5^o grid have this minimum number of observations. These requirements were more stringent than the in situ requirements because satellite observations are made using one instrument and the errors may be correlated. If these requirements were met, satellite data were considered adequate for that week for that 5^o region.

Figure 5 shows the daytime (upper panel) and nighttime (lower panel) number of weeks where the satellite data were adequate for a recent 52 week period (December 1998-November 1999).
The satellite data density is considered acceptable in a grid box for the year if there are at least 40 weeks with adequate satellite data. Five rectangular regions are indicated on these figures, using a 10^o grid, to identify regions where the number of weeks of satellite data was below 40. This was done for both day and night with the exception that the day distribution was ignored poleward of 40^oN and 40^oS. (The daytime satellite field is impacted north of 40^oN and south of 40^oS by the limited amount of daylight in winter.) The difference between the two fields between 40^oS and 40^oN is due to the fact that different daytime and nighttime cloud clearing algorithms are used. For example, aerosols are often recognized as clouds by the daytime algorithm and as cloud-free by the

nighttime algorithm. This results in a reduced number of observations in the day and biased observations at night. The impact of this difference in the number of retrievals is illustrated in the figure by the boxed region in the northern tropical Atlantic, which is often affected by tropospheric aerosols in the Northern Hemisphere summer.

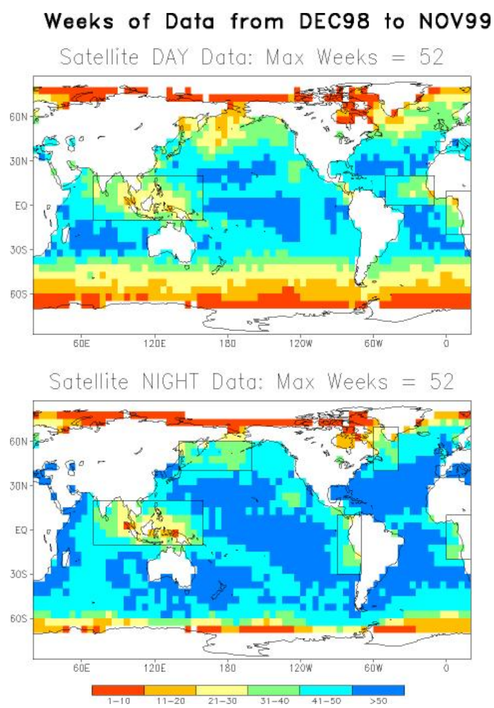

Fig. 5: Number of weeks with an adequate satellite observations (see text) on a 5° grid (daytime, top panel; nighttime, bottom panel). The period is December 1998 through November 1999.

Based on our previous assumptions and these results concerning the satellite distribution, we require that the in situ observations are adequate (1 buoy or 6 ship observations) on a 5° grid within the boxes defined in Fig. 5 and on a 10° grid outside the boxes. The results are shown in Fig. 6 for the same period used for the satellite data. Boxes with more than 40 weeks are considered to be well covered while boxes between 20-40 require more in situ data. Boxes with fewer than 20 weeks show regions with critical requirements for in situ data. Note that boxes that had adequate coverage on a 10° grid often drop into lower categories on a 5° grid.

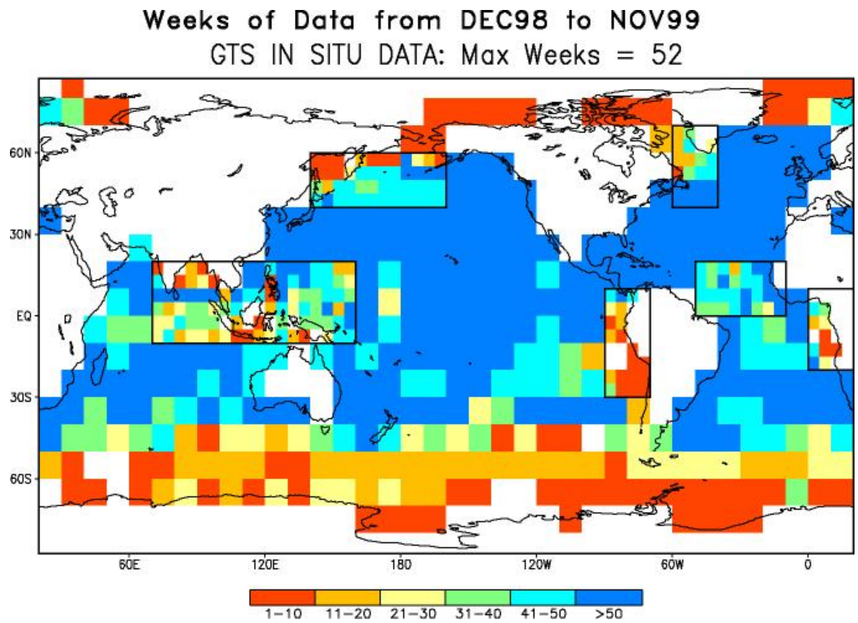

Fig. 6: Number of weeks with an adequate in situ observations (see text) on a 5 ^{o} and 10 ^{o} grid. The 5^{o} grid is required when the satellite observations (see Fig. 5) are not adequate. The period is December 1998 through November 1999.

Table 2. Number of additional buoys needed per year. The 5° and 10° boxes were defined from the satellite data (see Fig. 5). The periods were computed from January to December for all years except the final year of 1999 which was December 1998 to November 1999.

Period	Number for 5°	Number for 10°	Number for BOTH
1990	140	123	263
1991	152	131	283
1992	143	109	252
1993	141	114	255
1994	138	109	247
1995	127	84	211
1996	127	64	191
1997	123	67	190
1998	125	78	203
1999	121	79	200

These results are now extended into earlier years using the same 5^{o} and 10^{o} box definitions. It should be noted that the buoy requirements could also be met by ships that make more accurate observations (e.g., for example ships using hull contact sensors, Kent, et al. 1993). Although a delayed reporting time increases the number of in situ observations and thus decreases the number of new buoys needed by roughly 15-25%, GTS observations were used in the table to simulate a real-time requirement. To do this figures like Fig. 6 were generated for each year and the number of ocean 5^{o} or 10^{o} squares, as appropriate, were counted which had fewer than 40 weeks of adequate data between 60^{o}S and 70^{o}N. The number of squares required was assumed be equal to the number of buoys required during the year. These results are shown in Table 2. The table shows that the number of additional buoys required tends to decrease with time throughout the period.

Table 2 shows a minimum requirement for in situ data. This requirement for more buoy observations could be reduced if microwave SST retrievals were operationally available. In that case there would be no need for in situ observations on a 5^o grid. However, it is more likely that the actual number of buoys needed would be 2 or even 3 times the number shown in Table 2. This is because buoys could have systematic errors that were ignored in the original 0.5^{o}C error assumption. To compensate for any systematic error, additional buoys would be needed to allow more buoy-to-buoy intercomparisons. Pre-deployment calibration of the SST sensor on each buoy and an in situ data system that would permit use of the calibration information in real time would improve the buoy data set.

High Resolution SST Analyses

High resolution SST analyses have spatial scales of 1^o or higher and temporal scales of 24 hours or less. They have all of the potential problems that were discussed for climate SST analyses. However, high resolution analyses pose a special challenge because the data density (satellite and in situ) is reduced per analysis grid element (space and time). Inevitably, high resolution SST analyses will have larger uncertainties than climate analyses, given the same satellite and in situ data streams. We have identified some of the issues that will affect the production of high resolution SST analyses in the near future.

In regions with light winds and strong net heat fluxes into the ocean, diurnal SST signals of several degrees C can occur. This signal may be very close to the surface and may not reach typical in situ observation depths. This problem is further complicated by satellite SSTs which measure a skin temperature which is typically 0.3^{o}C colder than the layer immediately below the skin (see Webster et al., 1996 for details.). This is illustrated in Fig. 7 (WMO, 1999, figure IV.A.1). The figure shows two temperature profiles with depth: profile A for nighttime and for daytime with moderate to strong winds, profile B for daytime with light winds.

T(1) represents the skin SST measured by the satellite. T(2) corresponds to SSTs at depths typically sampled by buoys, while T(3) corresponds to SSTs at depths typically sampled by ships. However, the depth of the temperature maximum in Profile B could be shallower and not sampled by T(2). The tuning of the MCSST algorithm is based on assumed correlations of the skin, T(1), and the bulk SST, T(2). This assumption begins to break down during the daytime when a diurnal signal is present in the SSTs as shown in profile B. An example of the skin and bulk difference can be seen in Fig. 8 which shows skin and bulk SSTs at a buoy deployed in light winds of the western tropical Pacific (Weller and Anderson, 1996). The upper panel shows the diurnal average; the lower panel shows a sample of the day to day variability. The differences caused by the potential decoupling of skin and bulk SSTs are minimized by smoothing and by increasing the error statistics of day satellite SSTs relative to night. However, for high resolution SSTs, the vertical structure of the depth of the different observations must be properly resolved.

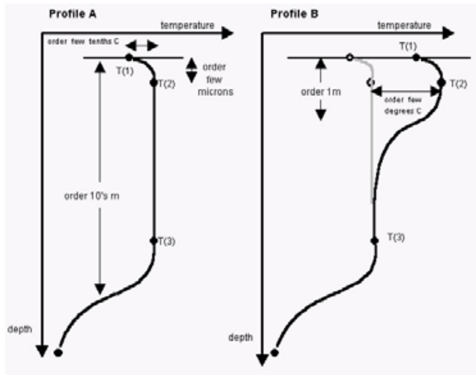

Fig.7: Schematic profiles: (A) for nighttime and for daytime with moderate to strong winds, (B) for daytime with light winds.

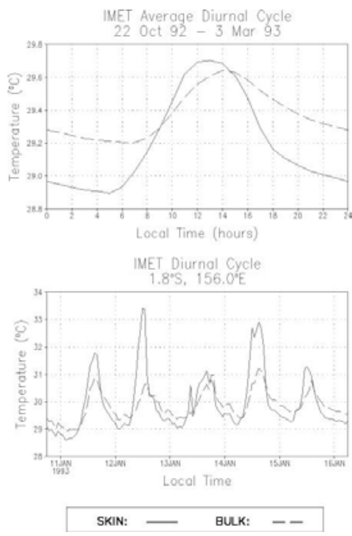

Fig. 8: Skin and Bulk SSTs (see text) from a buoy at 1.8^{o}S and 156^{o}E. The top panel shows the average diurnal cycle for the period October 22, 1992 to March 3, 1993. The bottom panel shows the variability in the diurnal cycle. In the bottom panel the labels on the x-axis are centered on local midnight.

The satellite data used in the SST analyses listed in Table 1 are derived from the AVHRR instrument. Although there were two polar orbiting satellites for most of the 1982-99 period, data were operationally processed from only one satellite until late spring 1999. Because of swath width limits one satellite cannot see the entire globe twice a day. This problem is made worse by clouds, which further degrade the coverage. Thus, only analyses with a dynamical component may be able to properly interpolate the analysis in space and time.

This data coverage problem will become less critical when more satellite data become available. Accurate SSTs from a microwave instrument, e.g., Tropical Rainfall Measuring Mission (TRMM), would produce SSTs which are unaffected by cloud cover (but are still affected by liquid water). In addition, SSTs from US Geosynchronous Operational Environmental Satellites (GOES) satellites are now available (Wu, 1999). The GOES instrument is similar to the AVHRR and can resolve the diurnal cycle in cloud free areas. However, further research is needed to improve the retrievals as discussed by Wick (1999). In addition, future GOES SST retrievals will be degraded because of instrument changes, which make the correction for atmospheric water vapor more difficult.

Some improvements in the in situ data must also be made. Most of the open ocean buoys do not report SSTs at six-hour intervals to save on satellite transmission costs. For example, the TAO network of moored buoys in the tropical Pacific (McPhaden, 1995) would be ideal for determining the diurnal cycle if all the data collected by the buoys were available in real-time. Metadata information on the characteristics of both ship and buoy SSTs are also needed to better define error characteristics so that better use can be made of the in situ data. In addition, more ship and buoy data are required south of 45^{o}S where there are currently insufficient in situ data to completely correct any satellite biases.

Conclusions

For both climate and high resolution SST analyses, satellite data are essential, but must be used with care. These data can greatly improve the coverage and spatial resolution of SST analyses. However, because of large potential errors in satellite retrievals, corrections using in situ information are essential. Thus, maintenance of an appropriate in situ observing system to support the ongoing correction of satellite SST is essential. For at least the next few years a combined satellite/in situ observing system must be deployed and sustained. It is also important to note that the present in situ observing system is not, on its own, adequate to produce climate SST analyses. Also noteworthy is that different organizations process in situ information differently, with substantial effects on the final SST analysis fields. A careful intercomparison of the in situ data processing methods is needed to develop more uniform procedures. Because of large uncertainties in present ice analyses and the methods of converting from ice to SST, in situ observations of both SSTs and sea ice concentrations are urgently needed near the ice.

The present in situ SST observing system must be enhanced if it is to be possible to produce climate SST analyses of the accuracy specified at the beginning of this paper, even using the relatively optimistic assumptions described here.

Regions have been identified where the existing in situ SST observing system must be enhanced. Both the satellite and in situ data streams must be monitored continuously to ensure that the minimal in situ observing system is maintained as conditions change in the future. In addition, SST analysis procedures need to make careful use of both data streams in order to give SST analyses of the desired accuracy.

For high resolution SST analyses, use of accurate satellite data from multiple sensors including microwave and geostationary instruments are critical. In addition, dynamic models are needed to interpolate in both and space and time in regions where SST data are missing. These models must include resolution of vertical scales so that the differences in the SST measurements from ships, buoys and satellites can be assimilated at the depths where the observations are made.

Intercomparisons of different SST products have shown important differences. It is important that

SST intercomparisons continue so that analysis and data differences can be better quantified and methods can be developed to minimize these differences. Because analyses continue to change, a continued reevaluation of the differences is required. An international GCOS working group has been established by the Atmospheric Observation Panel for Climate (AOPC) and the Ocean Observations Panel for Climate (OOPC) to evaluate SST products for climate. A parallel effort may be needed to compare high resolution SSTs analyses.

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The potential of data buoys in support to numerical weather prediction : the EUCOS initiative

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BACKGROUND

The EUMETNET Composite Observing System (EUCOS) is an initiative of The Network of European Meteorological Services (EUMETNET). EUCOS is the ground-based segment of the meteorological observing system optimised to support short-term (12 to 72h) Global Numerical Weather Prediction (GNWP) over Europe. It is the weather forecast using global numerical models and recognised as an application of common interest for all Members. It deserves a co-ordinated, cost efficient effort for making the necessary data available to forecast Centres. EUCOS represents the part of the in situ observing systems operated by Members to serve the needs of GNWP.

Data considered under EUCOS are primarily profile, surface and level measurements of temperature, wind, humidity and precipitation. The main task assigned to the Programme is to study scenarios to evolve towards a configuration which could be considered as more cost-effective to increase the quality of GNWP over Europe.

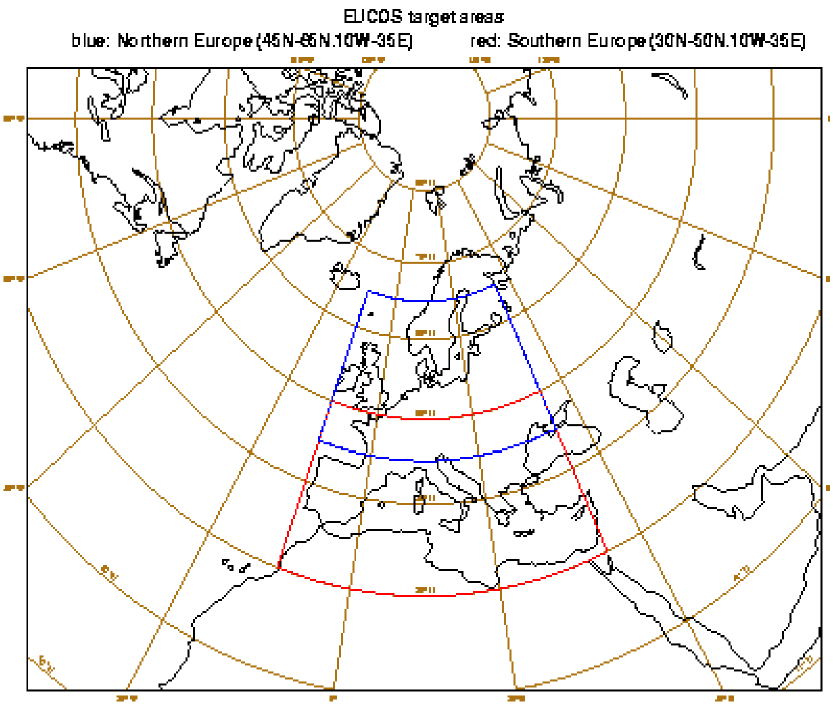
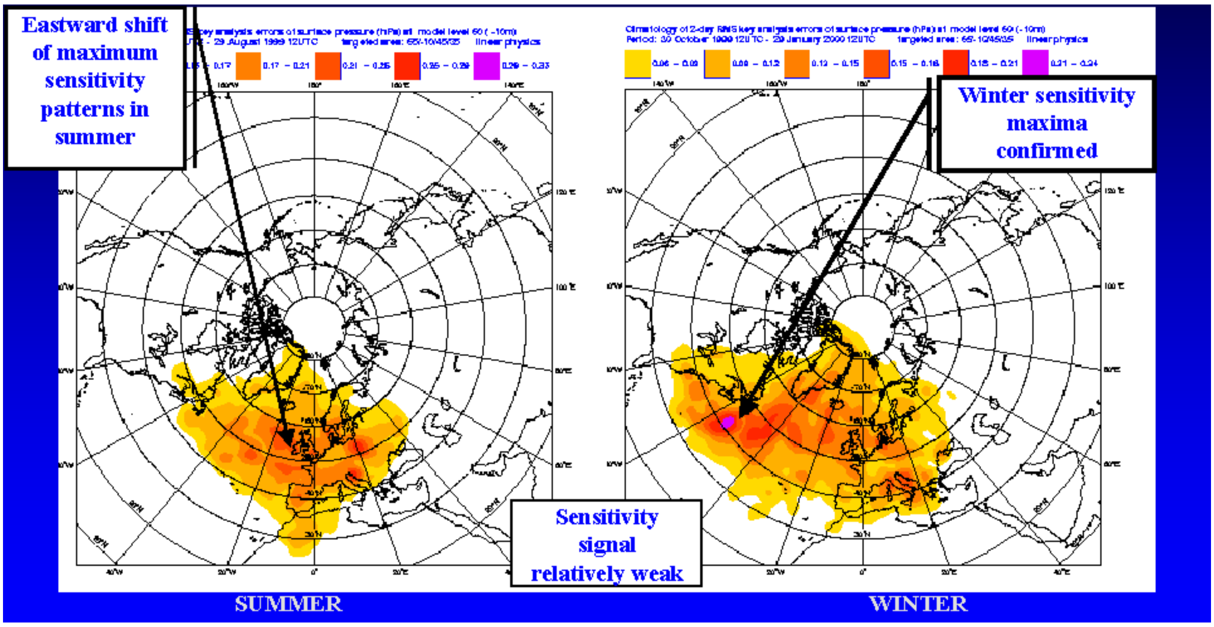


Figure 1 : Control regions for the sensitivity of 48h forecast to observing system evolutions. North Europe (45-65°N) and South Europe (30-50°N).

The EUCOS programme has been requested to study how to increase the observation effort over the Atlantic while maintaining the global cost of the system at constant level. It therefore



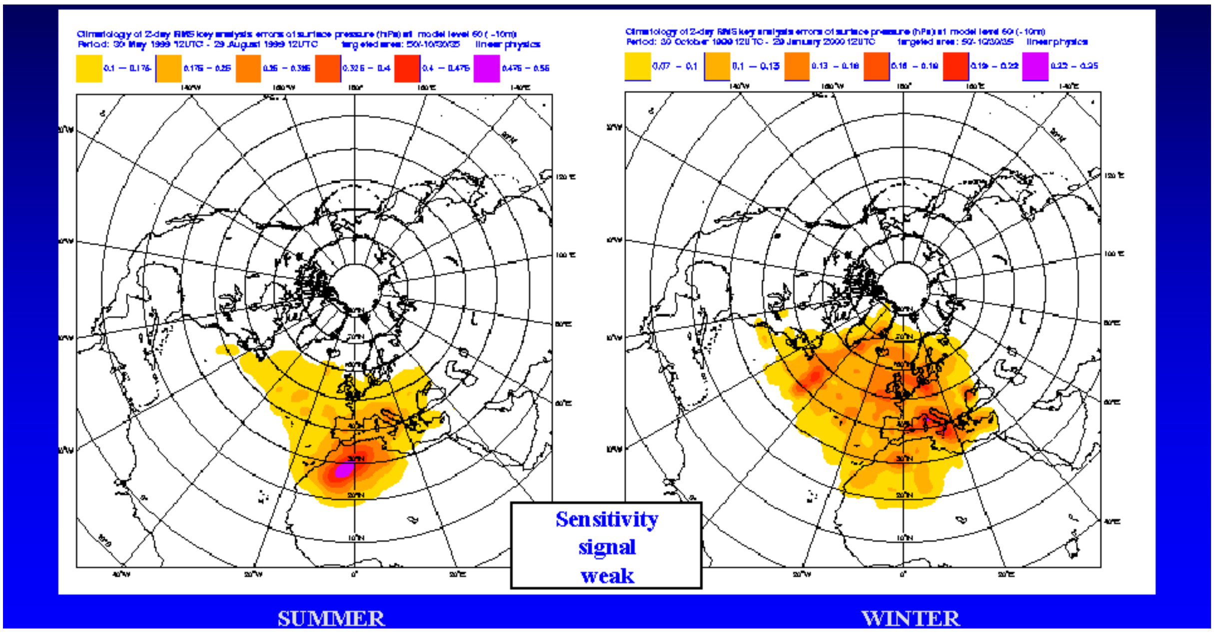


Figure 2 (top) and Figure 3 (bottom) : sensitivity maps for surface pressure for the forecast over Northern Europe (top) and Southern Europe (bottom).

included a study to identify the sensitive areas of the Atlantic region where to gather additional data (Marseille, Bouttier, 2000) and an observing system experiment to check impact (Cardinali, 2000) of a network evolution over the EUMETNET Members territories.

Results of these studies have enabled the EUMETNET Council to agree on design principles for the future EUCOS system. We consider here what is relevant to the deployment of data buoys over sensitive areas.

RESULTS

The climatology of sensitive area has been developed to define the regions where a change in the observing system may infer changes in the forecast 48h later over Northern or Southern Europe. (Figure 1). It has enabled to define where to gather additional profile data over the North Atlantic and the Mediterranean basin. It confirms results from the FASTEX experiment (1997), highlighting the variability of those areas, according to the control region (north / south) and the season (winter / summer).

Although the maximum sensitivity layer is between 700 and 400 hPa, calling primarily for additional profiles, the sensitivity close to the surface is sometimes weak but not negligible. From the figures 2 and 3 we may derive requirements for additional pressure data in support to the 48h forecast over Europe. From these figures we note that the whole Atlantic Ocean north of 40°N deserves pressure measurements, with special attention to the Gulf-Stream area in winter. On the opposite, the summer forecast over southern Europe appear less sensitive to pressure data over the Atlantic but lacks of information over Africa.

This is in line with results of the *Second CGC/WMO workshop on the impact of various observing system on NWP* (2000), where it has been recognised that the radiosondes are still the most important for NWP in the northern hemisphere, giving a gain on 1 day forecast skill, while the data buoys have generally a neutral impact on NWP. Therefore, if we can make strong recommendation to gather more profiles, there is no similar evidence for surface pressure data.

Nevertheless, the climatology derives only averages over some periods. Specific cases, within the study period, like the December 1999 storms over Western Europe, have been considered, where emphasis has been put by forecasters on the lack of surface pressure data in the areas where the phenomena developed. As a consequence, the recommendation for surface pressure data is to at least maintain the present level and to take advantage of the identification of sensitive areas for deployment, despite the weakness of the signal.

PERSPECTIVE FOR NETWORK DESIGN

EUCOS is now in a situation to issue some technical and functional requirements towards data buoys operators like EGOS and to VOS managers. One of them is the development of new observation strategies. Positive impact on 48h forecast will come only if effort is made for the data to be acquired at the right time and at the right place. Such observation targeting practices are fully accounted in the future EUCOS developments, primarily for profiles from ASAP ships, but also for surface systems. A very simple season-driven data buoy deployment targeting may be derived from the maps of figures 2 and 3.

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EUMETNET web : www.eumetnet.eu.org

World Ocean Surface Circulation

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During the past 15 years of the World Climate Research Program, direct measurements of ocean circulation were done with SVP drifters on a global scale. With these data a global ocean circulation chart has been derived and Ekman and Sverdrup circulation theories were tested. With the drifter observed surface currents, absolute sea level fields were derived for the Pacific. Direct measurements of eddy energy were compared to that derived from satellite altimeter data, which established the most effective algorithms for converting sea level slope to time-dependent geostrophic currents. Continued observations of the surface circulation are required to understand the complex advection-diffusion balance of thermal energy that governs the evolution of SST on interannual to decadal time scales. Surface current observations (and wind stress) are required for converting satellite observations to near surface circulation. The "Global Drifter Program" should maintain a primary objective the global surface current, SST and atmospheric pressure observations. Wind observations should be considered for a subset of drifters. A time-space evolving global surface velocity field in near real time can then be derived from a combination of satellite sea-level slope, wind and drifter observations. An increase of 300 drifting buoys to a net total of 1200 is recommended for the global array, with new deployments in the North Pacific and North Atlantic Oceans.

SEA SURFACE TEMPERATURE MEASUREMENT from ODAS Buoys

Presented at the

Data Buoy Cooperation Panel Meeting
Victoria, B.C., Canada

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October 2000

ABSTRACT

A Global Climate Observing System (GCOS) report published in November 1999 (Report Of The OOPC/AOPC Workshop On Global Sea Surface Temperature Data Sets GCOS #57;GOOS#79; WMO/TD #978) recommended a level of acceptable accuracy for the measurement of Sea Surface Temperature (SST) from the oceans. Following this, a Canadian Buoy Technical Meeting was convened by Environment Canada in February 2000 in Victoria, to examine if and how SST could be measured more accurately in the Canadian ODAS (Offshore Data Acquisition System) buoy network within the confines of it's existing budget.

At this meeting in Victoria, it was noted that while the accuracy and long term precision of the present measurement of SST from the Canadian ODAS buoys are sufficient for operational marine meteorological purposes, they are insufficient for climate change research. Since the buoy network provides an opportunity for long term SST measurements, it could provide a valuable data set if precision were improved.

Recent research has been carried out on a Canadian 3m buoy in sheltered coastal waters to compare SST measured with the standard temperature bolt in the hull, with measurements using a Seabird temperature sensor designed to be very stable (0.002°C) and sensitive (0.0001°C). The paper presents the results from this research and outlines the approach that is being taken in Canada to improve the accuracy of the SST measurements from the ODAS buoy network for climate requirements.

Existing Accuracies

For the US National Data Buoy Center (NDBC) ODAS buoys, the stated SST accuracy is ±1°C. For the Canadian ODAS buoys it is ±1°C for the ZENO payload and ±0.5°C for the Watchman payload. In practice the accuracies are better than this, approaching ±0.2°C. However, for long-term climate research the requirement is for SST precision to be ±0.05°C or better (GCOS, 1999). Table A below summarises these various accuracies.

Table A: Existing SST Accuracies and GCOS Requirements

Item	Accuracy	Comment
GCOS Requirement	0.1°C (means ±0.05°C?)	Ref GCOS 1999
NDBC Buoys	Stated as ± 1.0°C	
Environment Canada Design Specifications	ZENO Payload ± 1.0°C Watchman Payload ± 0.5°C	
Environment Canada Expected System Accuracy	± 0.4°C (±0.15°C from thermistor; ± 0.15°C from Watchman 12 bit A/D)	Axys 1996
Environment Canada Measured Accuracy	0.20°C (offset 0.13°C, r.m.s. scatter 0.02 C in monthly mean data)	This paper
Environment Canada New SST sensor	± 0.05°C	Axys 2000

The present accuracy uncertainty from buoy SST measurement is limited not only by the precision of the SST sensor itself, but also by the possible heat transfer from the upper surface of the buoy either through the hull or by heating of the air inside the buoy.

A further source of variability in SST measurement comes from the definition of sea surface and the location and depth of the sensor in the water column.

Definition of Sea Surface Temperature

If we are to measure SST from buoys to within 0.1°C then we need to be clear as to what we are measuring. The two profiles (shown below in Figure 1) indicate the variability experienced under two typical oceanographic conditions. From these profiles we can consider that the SST measurement from the Canadian ODAS buoys is defined as the bulk temperature just below the skin, T(2). T(1) is defined as the surface skin temperature which is the temperature that physically controls the surface fluxes and T(3) as the bulk mixed layer temperature which would be the temperature measured by Voluntary Observing Ships using hull contact or engine room intake sensors. Generally T(2) is well defined and is the typical measurement taken by SST buckets, drifting and moored buoys. However in light wind conditions during times of high insolation the value of T(2) may rise by a few degrees over a time scale of hours.

A more detailed discussion of this topic is contained in GCOS 1999.

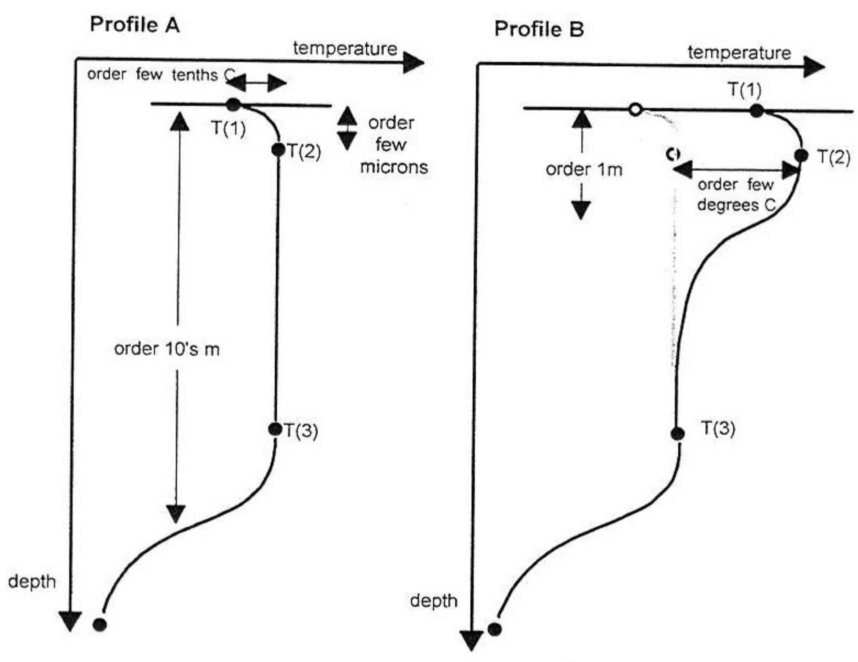

Figure 1. Schematic profiles for A) nighttime and daytime moderate to strong winds and B) daytime light wind conditions.

The Present Situation

The present temperature sensor used to measure SST in the Canadian ODAS buoys is a thermistor potted inside a bolt that is then mounted onto a nut welded against the inside of the floor of the buoy (see Figure 6). The temperature sensors (which include a thermistor and resistors) are calibrated only to check the correct functioning of the resistors. There is no attempt to correlate the resistor values with actual temperatures or to minimize the variability between sensors. Since the design accuracy is specified at ±0.5°C and the interchangeability of the sensor is ±0.27°C there has been no need for the sensors to be traceable. However with the emphasis on accuracy for climate change purposes, the sensors have recently been given serial numbers and can be tracked back to a particular buoy or time period. However, for the bulk of the historical data there is no reference linking a sensor to a particular buoy for a particular time period.

Experimental Determination of SST Accuracies

In November 1998 a 3-m Canadian ODAS buoy was deployed in sheltered waters in Saanich Inlet, near the Institute of Ocean Sciences, Sidney, British Columbia. The buoy was outfitted with an oceanographic sensor package in addition to the standard meteorological sensors. One of the additional instruments was a Seabird salinometer (temperature and conductivity sensor), which measured temperature at a depth of 37 cm in the “moon-pool” cut through the buoy’s hull to accommodate the oceanographic package. The Seabird temperature sensor is designed to be very stable (0.002°C) and sensitive (0.0001°C), as required for oceanographic measurements, and can therefore provide a reference against which to calibrate the standard sensor on this particular buoy (WMO# 46134).

Expected differences between the two measurements will result from poor instrument calibration, and instrument drift, as well as from real differences in the measurements made at different locations on the buoy. Any relative calibration and drift errors are assumed to be in the standard buoy sensor. Calm conditions allow stratification (rapid variation of temperature with depth in the water near the surface below T(2), as in Profile B above) that can cause apparent temperature differences between the two sensors. The standard sensor is mounted at a deeper depth, about 0.78 m, against the inside of the bottom of the buoy’s hull. Larger temperature differences at these two depths would be expected under strong solar heating or heavy rain. In addition, motion of water past the buoy can bring water from different depths to the two sites.

Results

Figure 2 shows a scatter plot of the temperature difference between the two sensors (Seabird - buoy) for one month of operation (August 1999), against the Seabird temperature. The plot indicates that the buoy sensor is about 0.1°C high over the whole range of temperatures measured in this month. RMS scatter in the difference is about 0.2°C, with occasional differences up to nearly 2°C (buoy high) and 1°C (buoy low).

Figure 3, a time sequence for this month, shows that the large differences tend to occur in groups, on days which are relatively calm (wind speed below 2 m/s). Figure 4 shows the difference as a scatter plot against wind speed for December and August 1999. All differences are below about 0.3°C for wind speeds above 4 m/s.

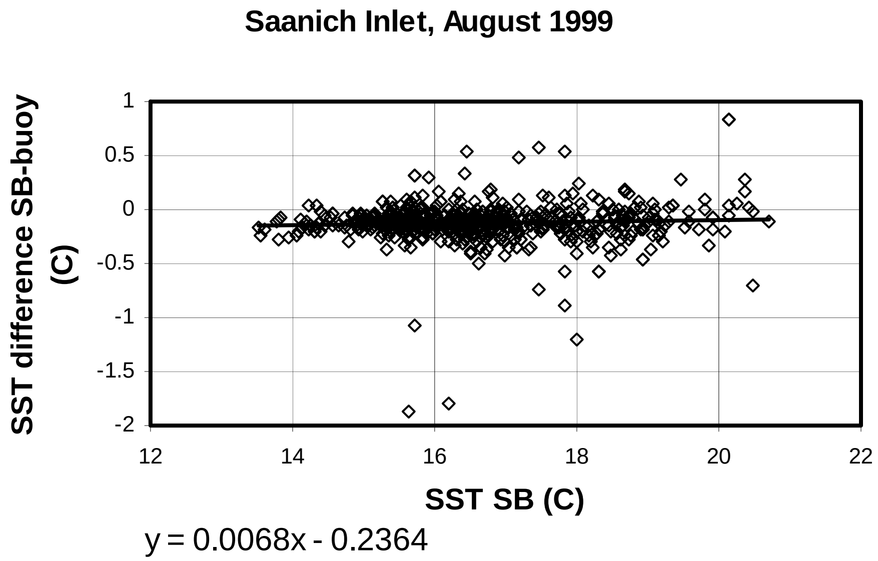

Figure 2 Scatter plot of the temperature difference between the two sensors for one month of operation (August 1999), against the Seabird temperature.

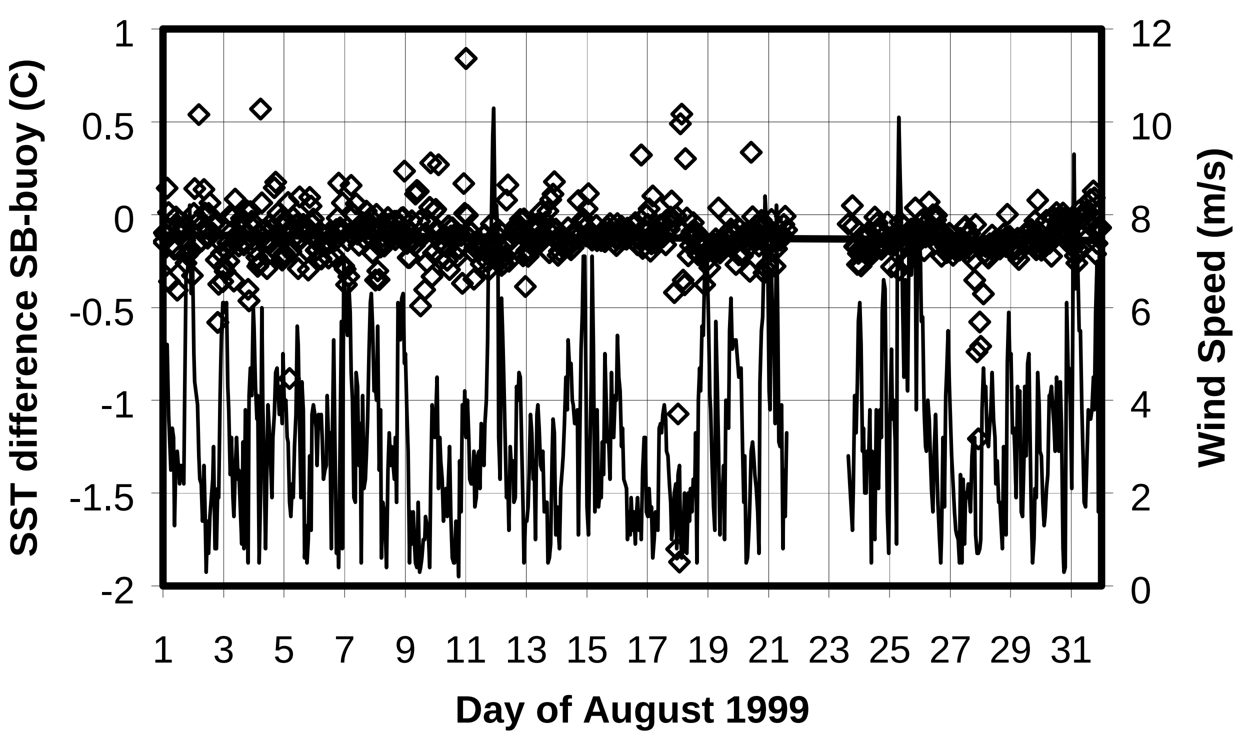

Figure 3 Time sequence of SST difference and wind speed for August 1999, showing that the large differences tend to occur in groups at times of low wind speed.

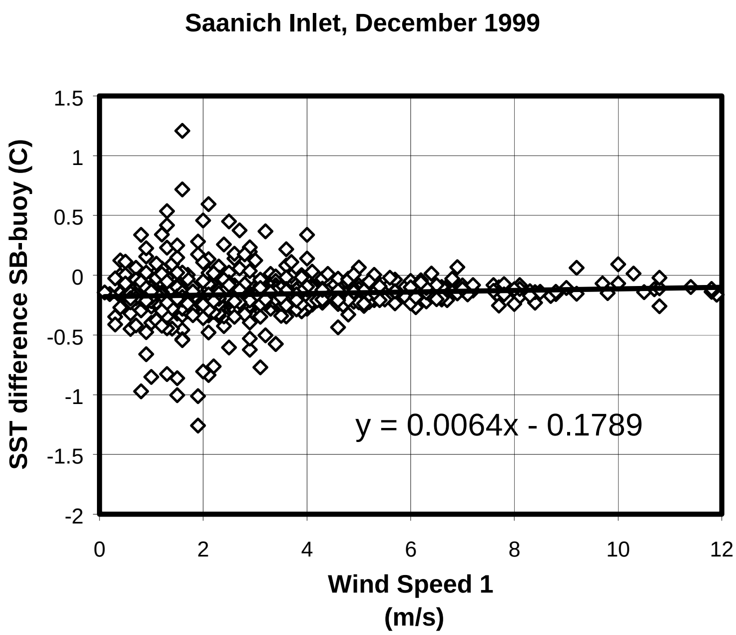

Figure 4 Scatter Plot against wind speed of data for December and August

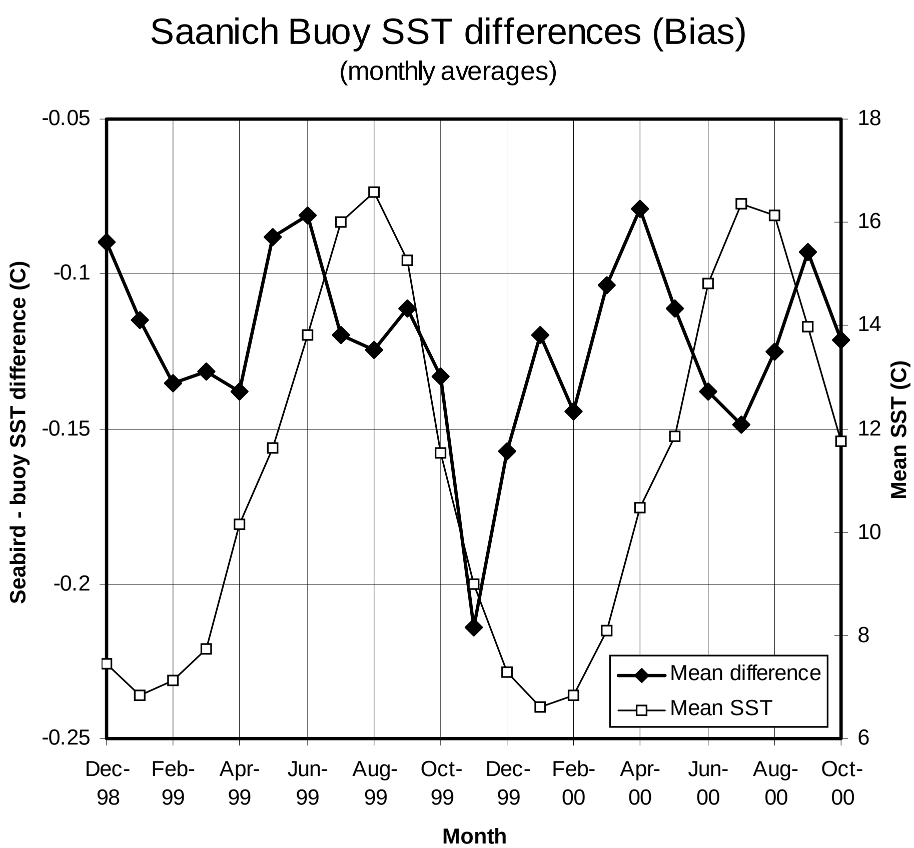

Figure 5 Seasonal Temperature Cycle of Monthly Means

This pattern is confirmed in data for other months. In most months, the largest differences tend to be "buoy high," suggesting internal buoy heating as a possible cause. The deeper sensor would otherwise tend to be cooler.

Figure 5 shows the seasonal temperature cycle of monthly means (white squares, right scale) cycling from a winter minimum just below 7°C to a summer maximum just over 16°C. The monthly mean difference between the two sensors (black diamonds, left scale) varies in the range –0.08 to -0.22°C, with an average difference of -0.125°C (buoy high) and an r.m.s. scatter of about 0.02°C. The time record shows no long-term drift (less than 0.02°C per year).

Future Activities

The present measurement methodology of SST is sufficient for marine meteorological purposes but lacks the accuracy and long-term precision to be reliable for climate change research. A summary of the factors that have been identified as having the potential to adversely affect SST measurement from the ODAS buoys are:

- Lack of precision and long-term stability of the SST sensor;
- Susceptibility of the sensor to be affected by the internal temperature of the buoy
- Possible lack of good thermal contact between sensor and bottom of hull
- Effect of bio-fouling

These four items are addressed in the long-term SST research program that is continuing on the 3M ODAS buoy in the Saanich Inlet from which the results of the determination of the existing accuracies given in the previous section of this paper were determined.

The key components of the research are:
a) development of a temperature sensor that can provide ± 0.05°C accuracy, as well having long-term stability and the ability to calibrate and identify each sensor.
b) the insulation of the temperature sensor
c) the packing of each SST bolt with thermal conducting grease to ensure a reliable thermal contact between the bolt and the hull
d) the painting of the buoy with antifouling paint to reduce the impact of growth on SST temperature fluctuations

a) Development of the new Sensor

The proposed new sensor uses a highly accurate precision thermistor coupled to a thermistor linearizing circuit that converts the non-linear response of the thermistor to a linearized digital output. A sensor with 0.05°C precision can be achieved by using a super stable thermistor, then generating a characterization curve at three temperature points, and then programming this curve into the calibration table of the linearizing circuit.

Figure 6 shows the thermistor potted into the new bolt design. The linearizing circuit and a small custom circuit board is in the enlarged head of the machined bolt. Locating the linearizing circuit near the thermistor decreases errors introduced by the resistance of the sensor leads.

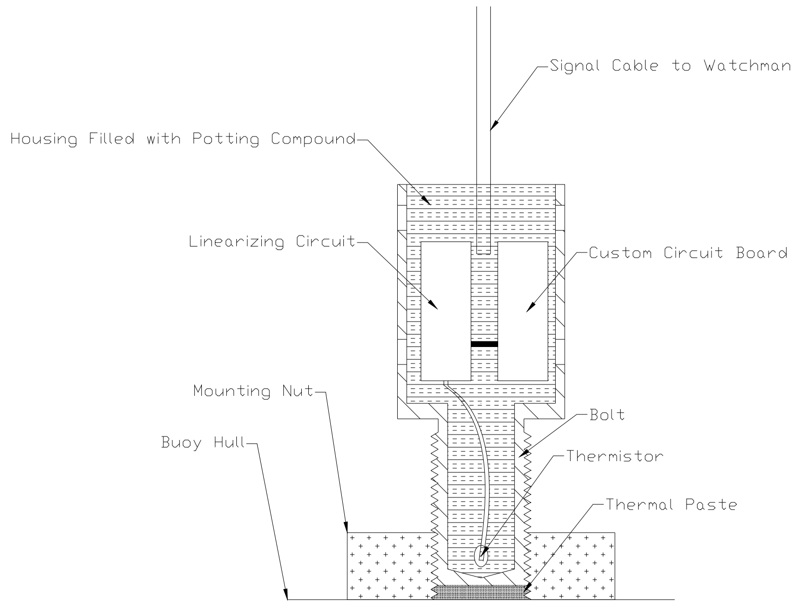

Figure 6

The new sensor will be available in 2001 and the first results of this research will be available for the next DBCP meeting in Perth in 2001.

b) Insulation of the temperature sensor
There is concern and some evidence (see experimental results) that the air temperature inside the buoy may affect the temperature of the temperature bolt. To determine if this is the case a second temperature bolt will be fitted in the experimental buoy. The second bolt will be insulated with a foam-filled inverted cup. The difference between the measurements from the two SST sensors will indicate the extent of this potential source of inaccuracy. In addition to this second temperature sensing bolt, a third uninsulated bolt may be installed to verify the effects of ambient air temperature on the sensors.

c) Thermal Grease
The thermistor is potted inside a bolt that is screwed into a nut that is welded onto the floor of the buoy. Even if the bolt is fully tightened down, it is possible that there is an air gap between the bottom of the bolt and the floor of the buoy. To avoid the possibility of an air gap existing, some thermal conducting grease is put in the nut.

d) BioFouling
The impact of biofouling on the precision of SST measurement is unknown. It is apparent that when a buoy is heavily biofouled the free movement of water past the buoy is affected. The water in contact with the hull may be either warmer or colder than the surrounding water. In the experimental buoy, we are experimenting with anti biofouling paint and its effectiveness in reducing the amount of biofouling.

In our implementation plan, in accordance with recommended GCOS/GOOS principles, both the new and existing SST measurement systems will be run in parallel for a period of 1-2 years in order to identify and quantify any potential inhomogeneities associated with the introduction of the new sensor

Acknowledgements:
The authors would like to acknowledge the assistance and enthusiasm of Ron McLaren, the Head, Marine Operations, Pacific and Yukon Region, Meteorological Service of Canada, Vancouver B.C. Without Ron's enthusiasm and help this project would not be possible.

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New Argos User Interface on the Web

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Abstract

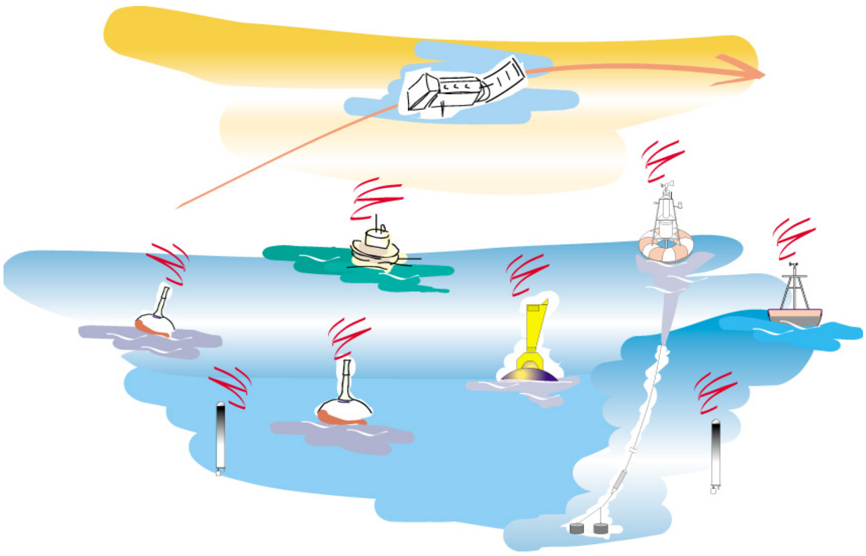
New data processing and management systems are being phased in at Argos centers. These will in particular provide:

- *a more open system that will let users access and modify platform processing, program characteristics on line, etc…*
- *selective access to results through simple queies via an improved user interface*

An overview of the project and of the new user interface, through a "guided tour" of selected screens, is given.

Data buoys and Argos

The world's oceans contain over 3000 drifting buoys, moored buoys, floats and other platforms monitored by the Argos satellite-based location and data collection system. In preparation the new international programs such as CLIVAR and GOOS, Argos is undergoing fundamental changes to better meet the needs of its main users: oceanographers and meteorologists. New features include two-way communication, increased data transmission capacity and the fully customized access to data and results that will be described below. Designed for and with its scientific users, Argos will remains the world's only satellite-based system dedicated to monitoring and protecting the environment.



Ocean platforms using Argos

New Argos User Interface as part of the enhancement of Argos processing capacities

Major user requirements that will be addressed include:

3 easier management of international programs deploying large numbers of platforms
3 more effective validation and sharing of results for program participants
3 improved location accuracy, via more and better-quality Doppler locations
3 data processing tailored to specific applications.

The main changes are being introduced in three phases, as follows:

- 1999-2000: building foundations for the future Argos system. This includes a new data processing structure implemented around an Oracle database management system; building a new web-based interface for users to access results over the Internet and send downlink messages to platforms.
- 2001: upgrading add-on services such as automatic data distribution, equipment monitoring (MBM, SMM). There will also be a new sensor monitoring service to inform users of events, such as a sensor recording an abnormally high increase in temperature.
- 2001-2002: serving the specific needs of different applications by implementing customized data processing and access. An existing example of such adaptation is the GTS subsystem now in use to validate and send Argos data straight onto the Global Telecommunication System.

Overview of some screens

The New User Interface is designed to:

- Minimize red tape between you and Argos,
- Provide you with a more open system that lets you access and modify platform processing, program characteristics and tailor your results,
- Let you send messages to your platforms (Argos Downlink).

Main menu: the access to key functions of the system

After keying your username and password, the following menu appears:

3 Fill in a New System Use Agreement

This let you apply to the Argos system. Forms are filled on-line. You can also list and review the status of your previous System Use Agreements.

3 Prepare platforms and programs for operation

Lets you tune you manage your programs, your platforms, check or modify the processing of data sent by your platforms.

3 Access your results

Provides you selective access to your data and allows you to define the formats, select the distribution media, customize your queries...

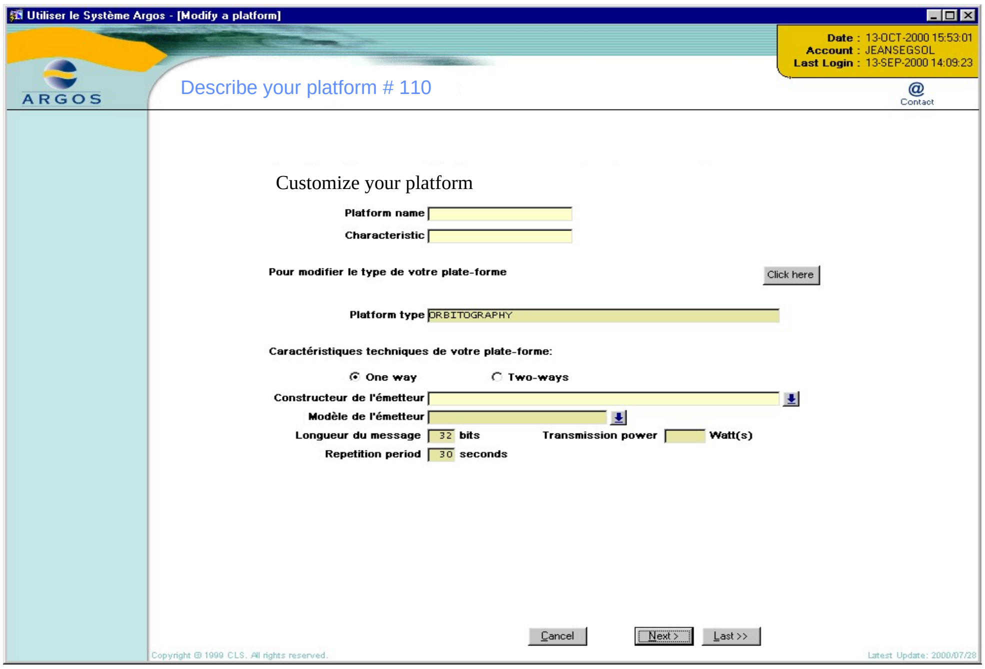
3 Send Downlink Messages

Dedicated to the Argos Downlink capability. Let's you input the messages you want to send to your platforms, inform you about the status and the results of the transmission. To facilitate your operations, you'll be able to store Downlink Messages specific to your platform.

Prepare your platforms for operation

Within the menu Prepare platforms and programs for operation you will be able to customize your buoys in the Argos system, change service and data processing – e.g. location settings, calibration curves ….

The screen below let you customize your platforms



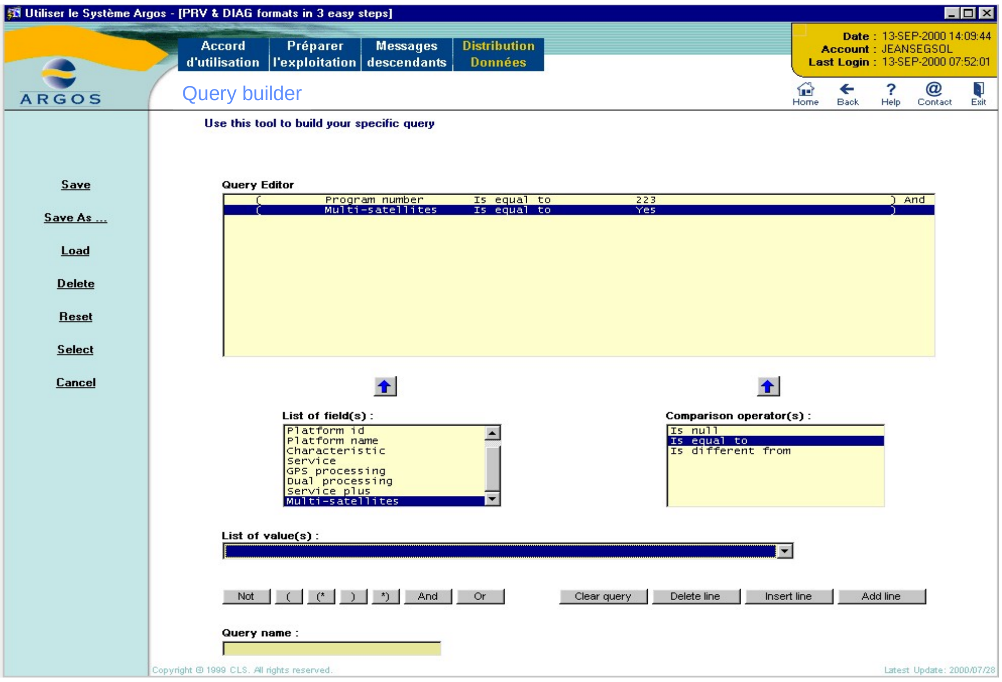
You can:

3 Give the platform a reference name, indicate a characteristic,

3 Indicate the type – i.e. drifter, moored buoy, profiler float…

3 Input manufacturer, model, transmission parameters…

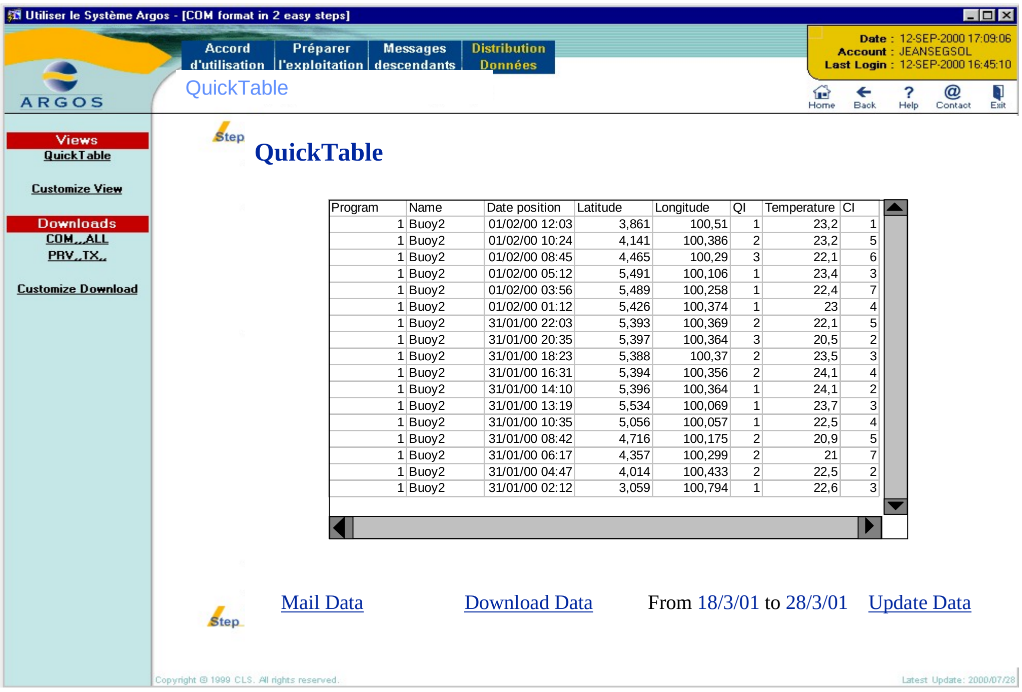
Query builder : the enhanced tool for selecting platforms or any piece of data



All fields of information available in the database, and in particular the ones you filled in to customize your platform can be used to make queries. For example you will be able to sort out your platforms or your results, by characteristic, platform type, manufacturer or by transmitter type etc…

Access your results: general screen with a QuickTable example

The frame on the left contains View and Download predefined commands related to your different needs. A simple click on the selected item will bring to the screen or to a file the desired data.

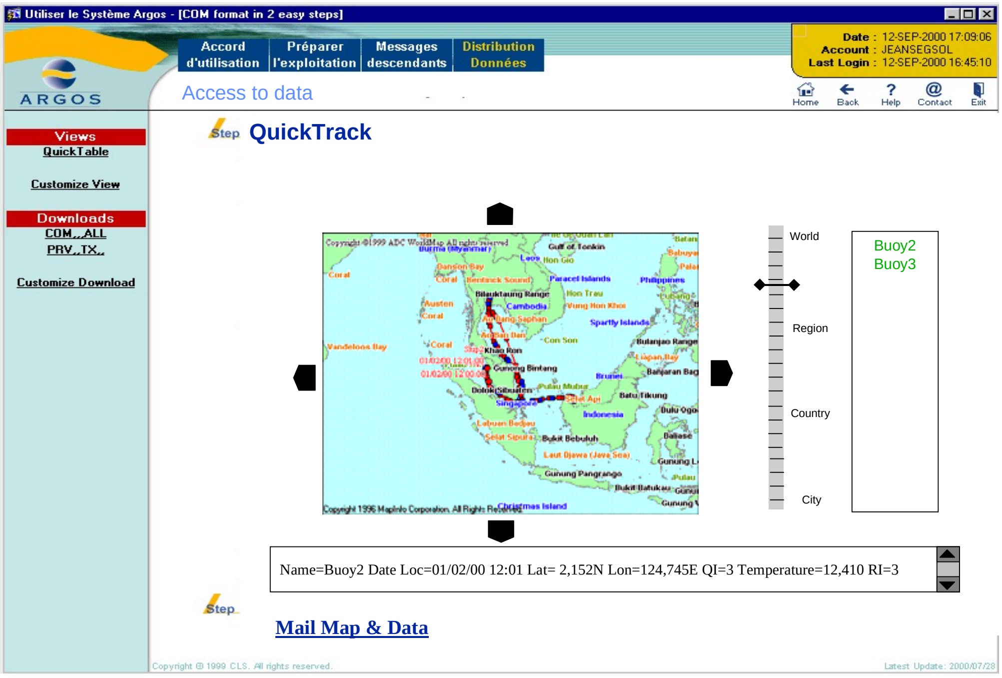


Program	Name	Date position	Latitude	Longitude	QI	Temperature	CI
1	Buoy2	01/02/00 12:03	3,861	100,51	1	23,2	1
1	Buoy2	01/02/00 10:24	4,141	100,386	2	23,2	5
1	Buoy2	01/02/00 08:45	4,465	100,29	3	22,1	6
1	Buoy2	01/02/00 05:12	5,491	100,106	1	23,4	3
1	Buoy2	01/02/00 03:56	5,489	100,258	1	22,4	7
1	Buoy2	01/02/00 01:12	5,426	100,374	1	23	4
1	Buoy2	31/01/00 22:03	5,393	100,369	2	22,1	5
1	Buoy2	31/01/00 20:35	5,397	100,364	3	20,5	2
1	Buoy2	31/01/00 18:23	5,388	100,37	2	23,5	3
1	Buoy2	31/01/00 16:31	5,394	100,356	2	24,1	4
1	Buoy2	31/01/00 14:10	5,396	100,364	1	24,1	2
1	Buoy2	31/01/00 13:19	5,534	100,069	1	23,7	3
1	Buoy2	31/01/00 10:35	5,056	100,057	1	22,5	4
1	Buoy2	31/01/00 08:42	4,716	100,175	2	20,9	5
1	Buoy2	31/01/00 06:17	4,357	100,299	2	21	7
1	Buoy2	31/01/00 04:47	4,014	100,433	2	22,5	2
1	Buoy2	31/01/00 02:12	3,059	100,794	1	22,6	3

Views display the selected results on the screen either in tables or maps. Downloads let you retrieve same data in files.

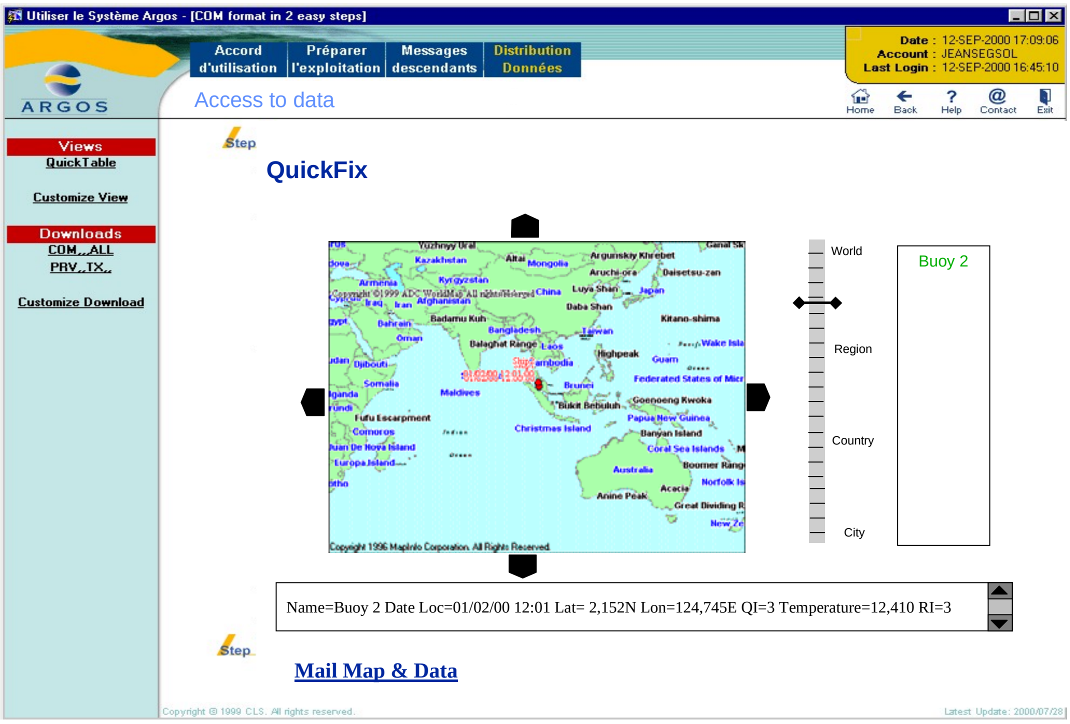
QuickFix,

Gives you the latest position of all your platforms on a map.



QuickTrack,

Displays the tracks of your platforms on maps.



Conclusion

The new user interface on the web provides a powerful user-friendly tool which enables you to:

- customize your application,
- define and modify data processing,
- build your own set of views and downloading commands to view and retrieve the Argos results.

This interface will be completed at the beginning of Y2001 and will then undergo a thorough test & tuning period for a couple of months. It is foreseen that it will be open to the web in June 2001.

As always, we'll look forward your comments and feedback to enhance this new tool and also to develop new capabilities you may require to facilitate your management of buoy data.

Inter comparison of sea surface meteorological data from two different buoys and with ship observations

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Abstract

The systematic and automated measurements from moored buoys under National Data Buoy Programme (NDBP) have largely enhanced the oceanographic database around the Indian seas. Under the Programme, array of 12 buoys were installed both in shallow and deep waters of Indian seas. The buoys mainly measure wave spectrum, current speed and direction, atmospheric pressure, wind speed and direction, surface water and air temperature. Few of the shallow water buoys have additional sensors to measure water quality sensors like chlorophyll-a, hydrocarbon, dissolved oxygen, optisensor and radioactivity.

An inter-comparison study has been carried out for the met-ocean data acquired by two distinctive type data buoys in deep waters of Bay of Bengal where they had been closely located. Further these data was compared with the in-situ measurements from ORV Sagar Kanya, which stationed near to the buoys site. The inter-comparison experiments carried out during the BOBMEX are very useful in assessing the confidence of measurements. In general, there is good agreement between the data measured onboard ship and met-ocean data buoy.

1. Introduction

The present observations were made during the Bay Of Bengal Monsoon Experiment (BOBMEX) with the main objective of collecting new observations over Bay of Bengal, using multiple platforms like moored buoys and research ships. The observations were carried out for about 45 days during the summer monsoon month of 1999 (16 Jul – 31 Aug) to cover all aspects of the intra-seasonal variability.

2. Observational strategy

Two distinct type of data buoys were used in this experiment; one SEAWATCH (SW), a vertically stabilized spar type buoy and WAVESCAN (WS), discuss wave follower type buoy. At the DS4 buoy site (13.0^{o}N & 86.9^{o}E) in the Bay of Bengal, a SW buoy was attached to the existing WS buoy for the inter comparison of observations. The Department of Ocean Development (DOD) research vessels *ORV Sagar Kanya* (SK) remained stationary near to the DS4 buoys site during the observational campaign. The location of the buoys (DS4) and the ships (SK) relative position where the time series measurements were carried out during the BOBMEX are shown in Figure 1.

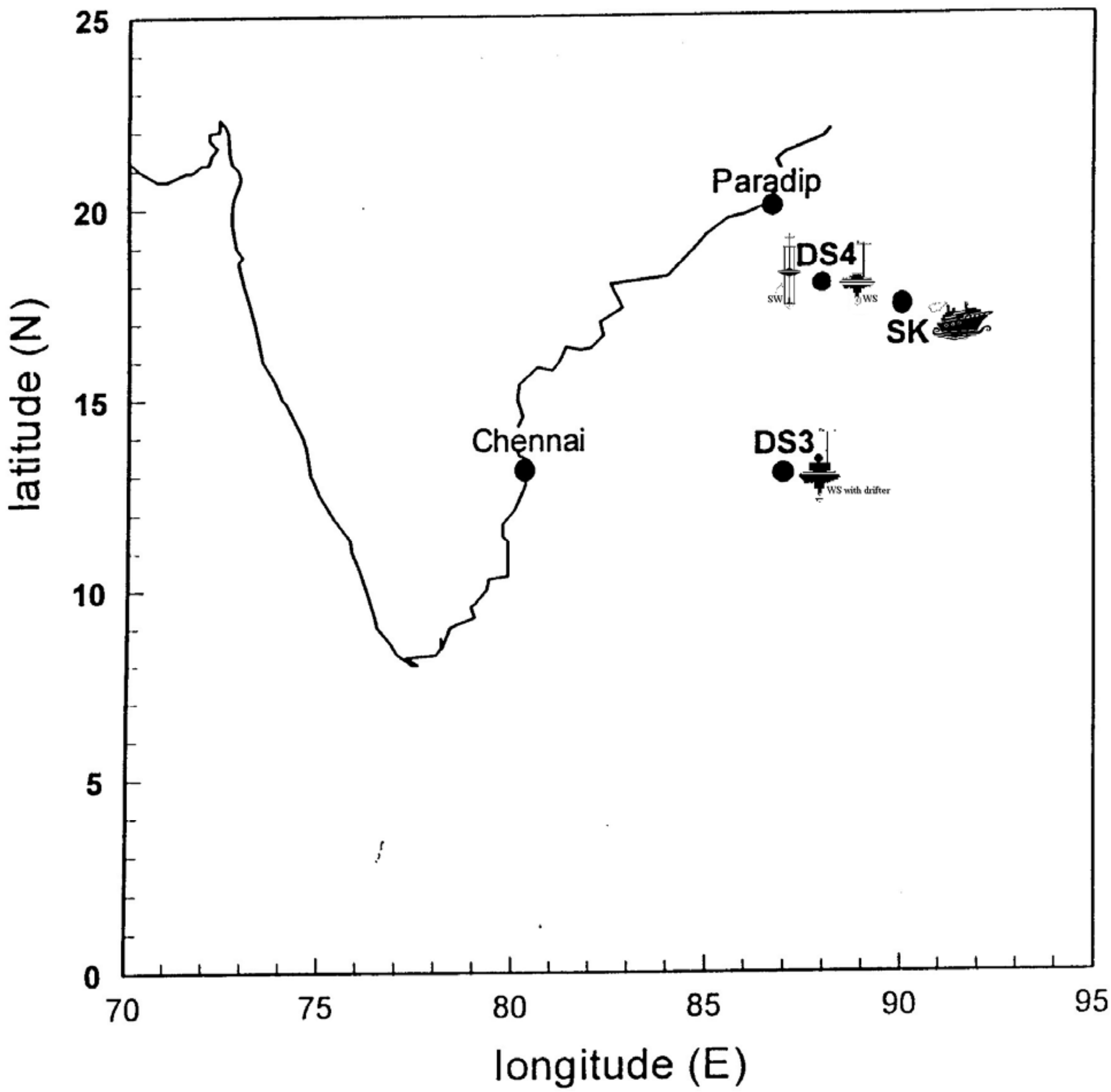

Figure 1: The buoys (DS4 & DS3) and ships (SK) position in central Bay of Bengal

The meteorological sensors in the buoy are mounted at 3 m height above the sea surface and the oceanographic sensors at 3 m below the water surface. Sampling interval for buoy observations was set for 3 hourly intervals.

3. Sensor details

Both the buoys were equipped with same meteorological and oceanographic sensors measuring wind speed & direction, atmospheric pressure, air temperature, wave spectrum. The details of the sensors used for this inter-comparison study are given in Table 1.

Table 1 Sensor details

Parameters	Platform	Sensor Type/Make	Sensor height	Accuracy	Sampling Interval	Averaging time (min)
Air temp	SK	Hg in glass, Metkit	~ 14 m	± 0.2°C	30 min	2
	WS	Platinum resistance, Omega	3 m	± 0.1°C	3 hourly	10
	SW	Platinum resistance, Omega	3 m	± 0.1°C	3 hourly	10
Air pressure	SK	Pressure gauge	~ 12 m	± 0.1 hPa	30 min	1
	Drifter	Capacitor film	4 m	± 0.2 hPa	~ 3 hourly	-
	WS	Capacitor film, Vaisala	3 m	± 0.1 hPa	3 hourly	1 sample
	SW	Capacitor film, Vaisala	3 m	± 0.1 hPa	3 hourly	1 sample
Wind	SK	Cup anemometer	~ 14 m	± 0.1 m/s	30 min	10
	WS	Cup anemometer, Lambrecht	3 m	± 1.5% FS, ± 3.6°	3 hourly	10
	SW	Cup anemometer, Lambrecht	3 m	± 1.5% FS, ± 3.6°	3 hourly	10
Wave	SW	MRU-6, SEATEX	Sea level	± 10 cm	3 hourly	34
	WS	MRU-6, SEATEX	Sea level	± 10 cm	3 hourly	34

4. Observations

a. Air Pressure

Figure 2(a) show the comparison of air pressure observations between SW and WS buoys. There is good agreement between both the buoy observations with the correlation coefficient of 0.96 (Table 2). The air pressure observations also show the semi-diurnal fluctuations due to atmospheric tides, which is common over tropics.

The observations between the buoy and ship show reasonably good agreement with a correlation coefficient 0.91 (Table 2 and Figure 3(a)). The difference in air-pressure may be possibly due to the distance between the two platforms, and the difference in height of observations.

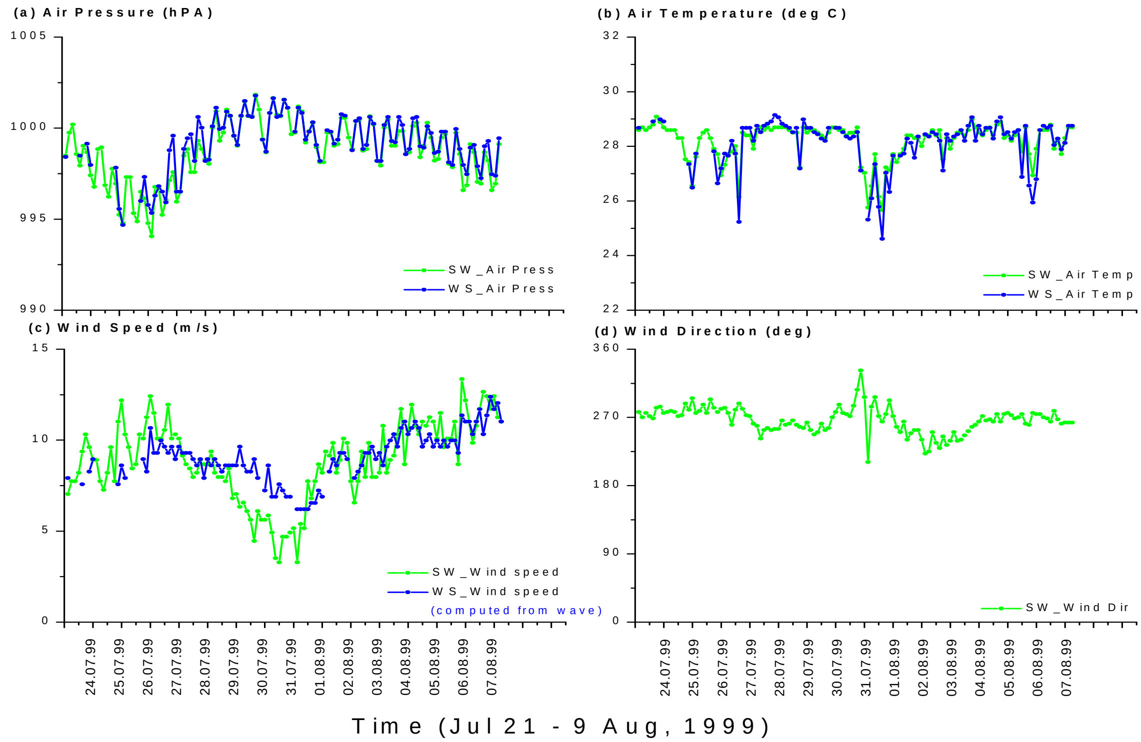

Figure 2: The observations of (a) air pressure, (b) air temperature, (c) wind speed and wind direction between SW and WS buoys.

b. Wind

The Buoys measure winds at 3 m height while that of ships observation were taken at 22.8 m. For the comparability of the wind observations reporting have been corrected to 10 m (U_{10}) from sea surface (z m) using the logarithmic profile calculation

$$U_{10} = u_z\left(\frac{10}{z}\right)^{\frac{1}{7}}$$

Direct comparison of wind observations between the buoys could not be made since the wind speed sensor failed in WS buoy. Figure 2(c) shows the calculated wind derived from the wave spectrum (high frequency component) of WS buoy and with the SW wind. It shows reasonably good agreement in the trend when the wind speed is greater than 5 m/s.

Wind speeds from the ship and buoy are consistent with each other. The mean differences in magnitude are about 1.64 m/s, which may be attributed to the turbulent nature of the flow. Though the ships observations seem to be over estimating the winds, the correlation is reasonably good (Figure 3(c) and Table 3). The wind direction observed by the buoy is predominantly westerly but the manual observations from the ship differ in direction resulting to comparatively low correlation coefficient (0.10). The resolution of wind direction is ± 2 deg for the buoy whereas it is ~ ± 10 deg for manual observations onboard also biased with the individuals making observation.

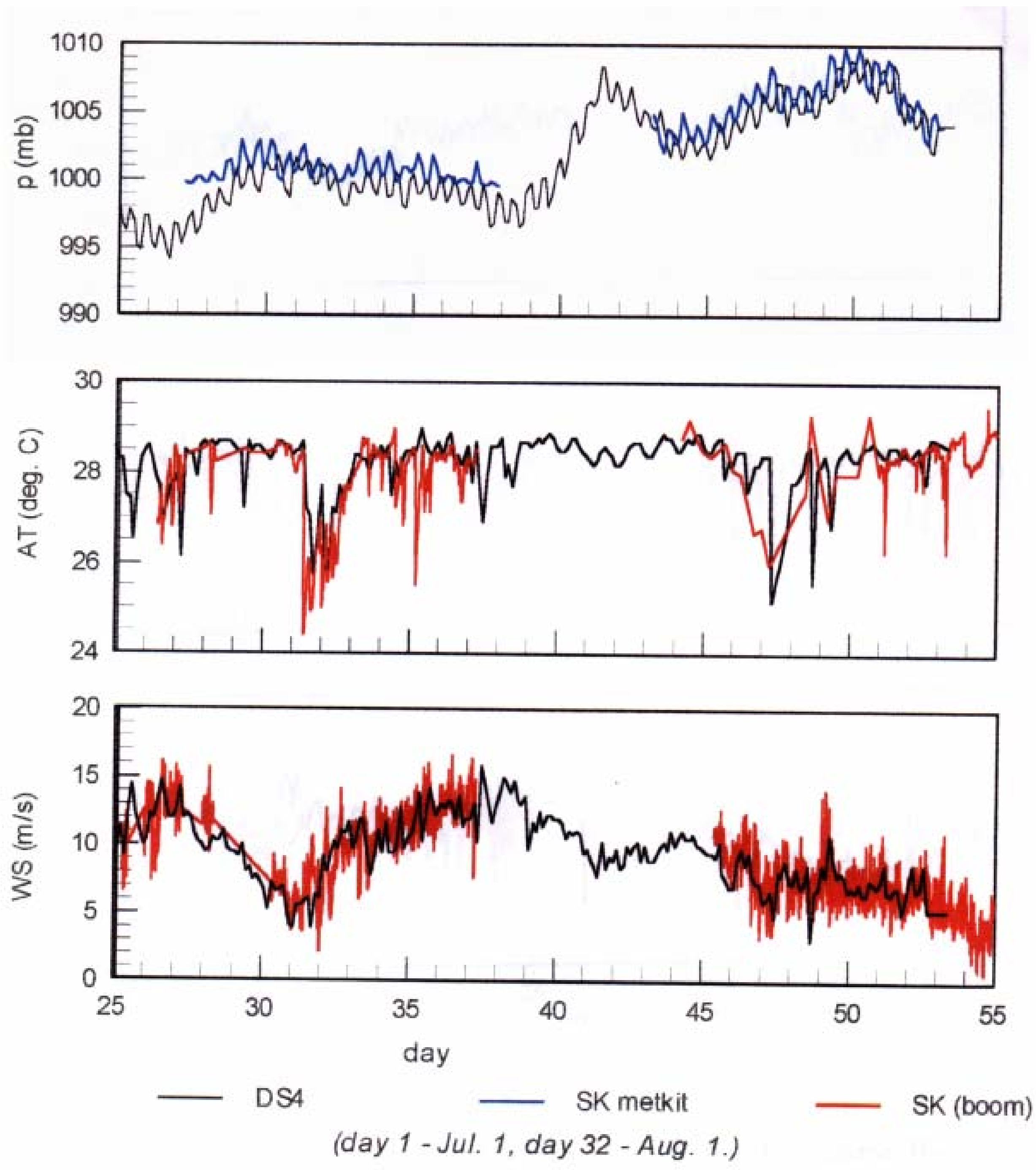

Figure 4: The met observations of (a) air pressure (b) air temperature and (c) wind speed at DS4 position by buoy and ship

c. Air Temperature

Air temperature measurements between the buoys show good correlation of 0.95 while that between the buoy and ship is 0.58, the difference could be due to the difference in space of observations.

d. Wave

The wave measurements between the two distinctive buoys (SW and the WS) have shown remarkable agreement. Figure 4 shows the significant wave height, significant wave period, swell height and the mean wave direction measured from both type of buoys. For all the parameters, the differences observed are within the sensor accuracy. The statistical analysis of buoy observations (Table 2) shows good agreement between SW and WS buoys.

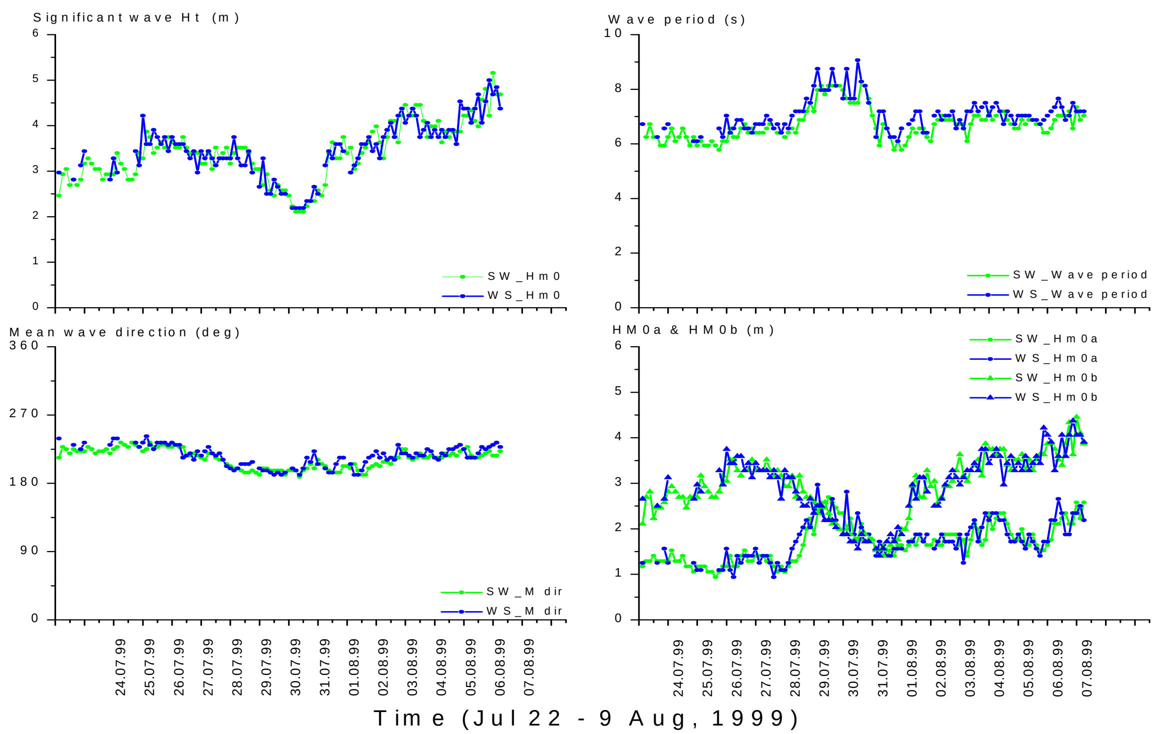

Figure 5: The observations of (a) significant wave height, (b) wave period, (c) mean wave direction and (c) spectral components of wave height (Hm0a and Hm0b) between SW and WS buoys.

Table 2: Statistical analysis of the parameters between SW and WS

Parameter	Correlation coefficient	Mean difference	Bias	Standard Deviation
Air temperature	0.95	0.23	0.07	0.26
Air Pressure	0.96	0.35	-0.30	0.43
Significant Wave Height	0.87	0.25	-0.01	0.19
Average wave period	0.81	0.35	-0.28	0.30
Mean wave direction	0.81	6.8	-4.32	5.40
Mean Swell Height	0.83	0.21	0.03	0.16

Table 3: Statistical analysis of the parameters between SK Vs WS

Parameter	Correlation coefficient	Mean difference	Bias	Standard Deviation
Air Temperature	0.58	0.60	-0.07	0.52
Air Pressure	0.91	1.10	-1.07	0.58
Sea surface temp.	0.10	0.15	0.09	0.19
Wind speed	0.77	1.64	-0.48	1.49
Wind direction	0.10	20.16	10.88	16.74

6. Air Pressure observation from WS and the drifter mounted over it

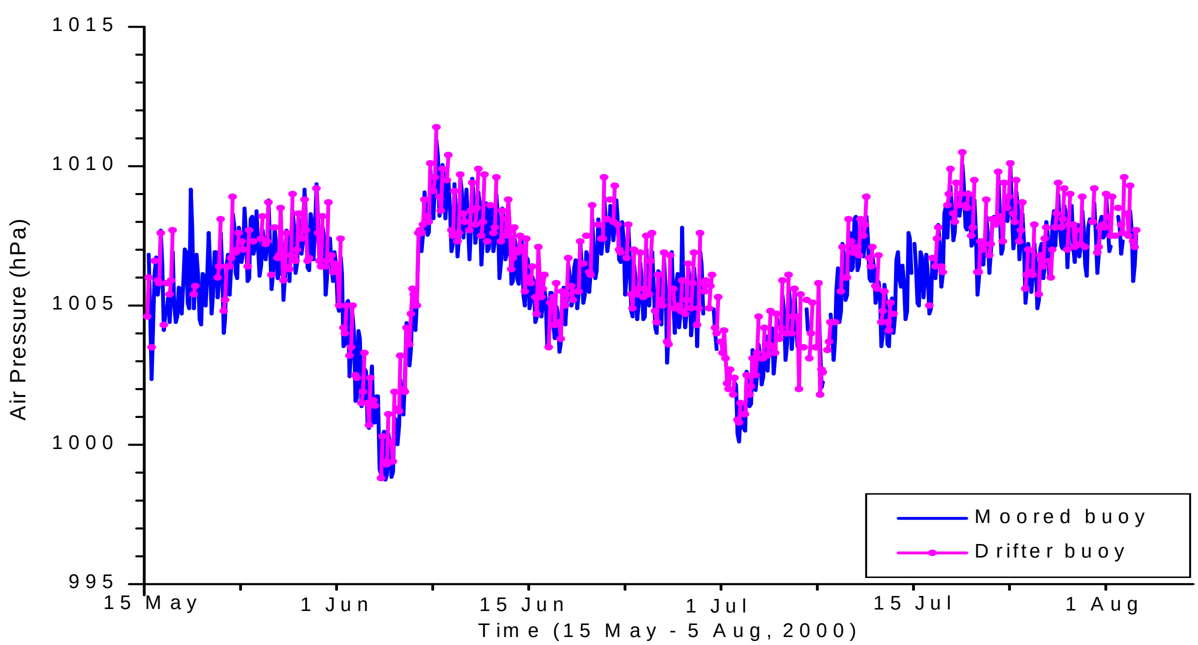

Figure 3: Air pressure observations from moored WS buoy and the drifter buoy mounted on it at DS3 location

A SVP-B drifter was mounted over the WS buoy at DS3 buoy location (Figure 1). Figure 5 shows the comparison of the air pressure observations between the SW and drifter buoy for over two months between May and August 2000. Both the buoys show good correlation between observations though the observations do not closely match in time; i.e., the WS buoy observations are made at regular three hourly intervals but the drifter observations are made at ~ 3 hourly intervals which coincides with the satellite pass.

7. Conclusion

The results show that there is good agreement of surface meteorological and oceanographic data measured by the two distinctive buoys (SW and WS) and the differences are only within the sensors accuracies. There is also reasonably good agreement between the buoys and ships observations except for wind speed and direction. The random errors between ship and buoy wind observations could be attributed to their relative position (~100 km apart) and turbulent nature of the wind during the monsoon season.

USE Of GPS DRIFTERS FOR MEASUREMENT OF NEAR SURFACE CURRENTS IN A WIDE STRAIT

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We have recently undertaken a program of measurements and numerical modeling of the strong currents in Juan de Fuca Strait. There have been several oceanographic studies and models of this wide strait, but our understanding of the near surface circulation and its variability is poor because previous current measurement programs have under-sampled the near surface region. While satellite tracked surface drifters, like those developed for the World Ocean Circulation Experiment (WOCE), are suitable for the measurement of open ocean currents, the accuracy and frequency of the position fixes provided by satellite-based location system are insufficient to resolve the short space and time scale of the flow in the coastal zone. The Global Positioning System (GPS) has improved both the frequency and accuracy of drifter positioning, and its wide spread use has made it feasible to incorporate this technology into the field proven WOCE surface drifter. In the last two years, we have modified, tested and successfully used WOCE – GPS drifters from three different manufactures. An indispensable component of our drifter program is a ship-based, real time tracking system. The tracking system comprises a commercially available uplink receiver to acquire the direct data transmissions from the drifters, together with a software program which we developed in-house to process the data messages so that we may monitor the drifter positions and their onboard sensor data in real time. With the use of the real time tracking we are able to recover and re-seed the drifters when they leave the experimental area, and we have been able to adjust our sampling strategy based on the observed surface circulation patterns. We have conducted drifter experiments in all seasons with as many as 12 drifters deployed at one time in the strait and obtained many days of drifter tracks. The GPS drifters have performed well in severe wind conditions and provided continuous and precise data through out their deployments. The drifter tracks have confirmed the estuarine surface outflow current and provided detailed observations of large scale, surface flow reversal during the passage of major winter storms.

A buoy network for a region of complex mesoscale weather

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1. Early History

Meteorological information from fixed locations in the Pacific began in 1946 with the establishment of Ocean Station ‘Dog’ at 50°N 145°W. The name of this station was changed to ‘Able’ in 1947, to ‘Peter’ in 1948 then to its final name of ‘Papa’ in 1956. The Canadian government was responsible for this ocean station from 1950 until it was closed in 1981. The last of the vessels that patrolled ocean station Papa were the purpose build weatherships, *CCGS Vancouver* and *CCGS Quadra*.

There were several other Pacific Ocean weather stations, besides station Papa, but most of them were in effect for only short periods of time (Figure 1). These stations include November (30°N 140°W), Oboe (40°N 140°W), Queen (48°N 168°W), Sugar (48°N 162°E), ‘T’ (29°N 135°W), Uncle (28°N 145°W) and Victor (34°N 164°W). The names (except for ‘November’, which originally had the name ‘Nan’) were based on the British forces phonetic alphabet, which was in use until 1952.

Prior to the ending of Ocean Station Papa the United States government began deploying buoys over the eastern Pacific. A buoy, with the numerical designator of 46004, was anchored in 1976 at 51.0°N 135.8W - about 300 miles east of the ship Papa station. The Canadian government took over responsibility for this buoy in 1985 and it was given the common name of ‘Middle Nomad’.

2. Development of the buoy network

The initial Canadian plan for the development of the buoy network was to install an offshore ‘picket line’ of buoys across the Canadian offshore waters. This picket line was established between 1985 and 1987 using the 6 metre ‘Nomad’ type buoys. The first of buoy within this picket line was the middle nomad buoy (46004). The south nomad buoy (46036) became the second when it was anchored at 48.3°N 134.0°W in May 1986. The north nomad buoy (46184) at 54°N 139°W completed the outer line in September 1987. These buoys were to give an early indication of the location and strength of incoming lows and frontal systems.

The Nanakwa Shoal buoy was added in May 1986 in order to support the preparation of a marine forecast for Douglas Channel. Douglas Channel is the main passageway used by vessels going to and from the Alcan aluminum smelter at Kitimat.

The second picket line of buoys was established in 1988 and 1989 over the outer coastal waters, just west of the Queen Charlotte Islands and Vancouver Island. The hulls used for these, and all subsequent coastal buoy locations, were the 3 metre discus buoys. The attached map (Figure 2) shows the locations of the entire buoy network. In the years 1990 to 1993 a third picket line was established across the inner coastal waters and two buoys were added to fill in the gaps near the southern Queen Charlotte Islands and off the northwest corner of Vancouver Island.

3. Mesoscale wind and wave variations

The full network of buoys has allowed the marine forecasters at the Pacific Weather Centre in Vancouver to recognize the local winds and waves that occur across the British Columbia (BC) coastal waters and to include these variations within the marine forecasts. The complex topography of the coast and a number of interesting features within the bathymetry of the water areas are responsible for many of these variations. Some of these local effects are described below.

i. Statistics of the average number of days with gale force winds in December across the BC coast show conditions (Figure 3) that appear to be fairly uniform, but a number of significant variations may be seen upon closer inspection. Over the offshore waters the northern Nomad buoy has more gales than does the southern Nomad buoy (12.8 compared to 10.7). This variation reflects the fact that most lows track into the northern Gulf of Alaska. This means that locations farther away from the Gulf of Alaska normally experience lighter winds. A peak of gale frequency near northern Vancouver Island is primarily due to enhancement of the winds from topographical forcing. Significantly lower values of winds over the inner south coast waters of the Strait of Georgia result from a weakening of approaching weather systems as they cross the northern Mainland coast and Vancouver Island.

ii. When individual storms are studied several local variations become apparent. With the approach of a front from the northwest the winds become southeasterly in direction and increase in strength (Figure 4). Depending on the exact orientation of these winds one buoy will have stronger or weaker winds as the local topography steers and modifies the flow pattern. With a more easterly flow, for instance, the winds are lighter to the west of the Queen Charlotte Islands (at West Moresby buoy, 46208) but are stronger where they are enhanced by channelled flow from mainland inlets, such as at Central and West Dixon Entrance buoys. When the winds are more from the south the Central Dixon Entrance buoy is sheltered from the land and has much reduced sea height development due to limited fetch distances.

iii. When a ridge of high pressure builds off the coast the winds shift into the west or northwest (Figure 5). When this occurs after the passage of a front the winds shift from southeast into the west and the seas go through significant changes. The seas that developed by the southeast winds die away and are replaced by wind waves from the west. Through the inner waters the northwest winds are not as strong as those west of the Charlottes and no westerly swells are added from the vast expanse of the Pacific. In this situation the seas at the North Hecate buoy (46183) generally drop to less than one metre, while the seas west of the Charlottes, at either the West Dixon Entrance buoy (46205) or the West Moresby buoy (46208) may remain well above 2 metres. The South Hecate buoy (46185) frequently will have higher seas due to the addition of swells that come from the west or southwest.

iv. One other variation within the wave field occurs because of the coastal bathymetry. Westerly swell which reaches the West Dixon Entrance buoy (46205) will be much reduced by the time they reach the Central Dixon Entrance buoy (46145) because of the shoaling effects caused by passage over Learmouth Bank (Figure 6). The bathymetry of Queen Charlotte Sound may also have had an influence on the extreme seas that have been recorded at South Hecate buoy (46185). In December 1991 an extreme wave height of 30.4 metres was recorded at the South Hecate buoy. It is thought that the seas may have been enhanced by focusing of the wave energy around a small raised hill on the seabed just south of the buoy. It is interesting to note that while the 6 metre Nomad buoys are used in the offshore water areas, the highest seas have been recorded by the 3 metre discuss buoys over the shallower coastal waters. The East Delwood buoy (46207) also recorded an extreme wave just near 30.8 metres in December 1993.

v. Most coastal buoys display a seasonal pattern of wave heights which reflect the wind changes that occur through the year (Figure 7). The lowest average sea height occurs in the late summer when the weather systems are at their weakest. The seas rise through the autumn months and peak in December; then fall in January before rising again in February. The lower sea heights in January are likely due to a change in pattern of winds rather than a weakening of the dynamics of the weather systems. In late December and January a ridge frequently develops over the BC interior that produces very strong outflow winds through the mainland inlets but much lighter winds away from the inlets. The periods of outflow conditions reduce the frequency of strong weather systems that approach the coast and as a result lower substantially the average wave heights.

vi. The three buoys off the west coast of Vancouver Island represent three different wind wave regimes (Figure 8). The highest winds are recorded at the middle one of the three, the South Brooks buoy (46132). The coastal topographical enhancement of the winds is greatest at this buoy, for both northwest and southeast winds. The highest seas have been recorded at the northern one, the East Delwood buoy (46207).

The southern most one, La Pérouse Bank buoy (46206) records significantly lower winds and waves than either of the other two. These lighter winds are due to the fact that a lee trough develops along the southern shore of Vancouver Island when winds between 500 –2000m blow from the north or northeast across the Island. The lee trough begins to open as these low level winds turns into the north and widens out from the coast as the flow becomes more northeasterly. At some point when the flow approaches an easterly direction the trough collapses and southeast winds begin to form along the island. The lower seas at 46206 are due to the greater distance from the main track of lows that moves up into the northern Gulf of Alaska and also because of the lee trough development. Because of this lee trough the higher seas that develop with northwest winds remain offshore, often just west of buoy 46206, and move instead toward the Washington and Oregon coast.

vii. The wind and wave regime over the inner waters of the Strait of Georgia is distinctly different from the other regions of the BC coast. The winds through the inner waters go through a variety of interesting cycles that are strongly influenced by the local topography. The waves that develop in the strait are fetch limited. The highest seas at Sentry Shoal buoy (46131), the northern-most buoy in the strait occurs with southeast winds, while the southern-most buoy, Halibut Bank (46146), builds its highest seas with northwest winds. Due to the fact that the maximum fetch distance for either buoy is about 70 nautical miles the highest seas that have been recorded have been near 5 metres. No ocean swell ever enters the Strait of Georgia.

4. Conclusions

The deployment of buoys across the BC coast and its offshore waters has resulted in a buoy network, which has enabled the recognition of many mesoscale variations of winds and waves. The hourly data received from the buoys allow the marine forecasters at the Pacific Weather Centre to write forecasts that reflect the complexity of the mesoscale weather environment of the BC coastal waters. The marine forecasters and the mariners who ply the coastal waters have come to rely on the data from the buoys. It is hard to imagine the time when the data from the ocean station ‘Papa’ was one of the only pieces of information from the northeastern Pacific Ocean.

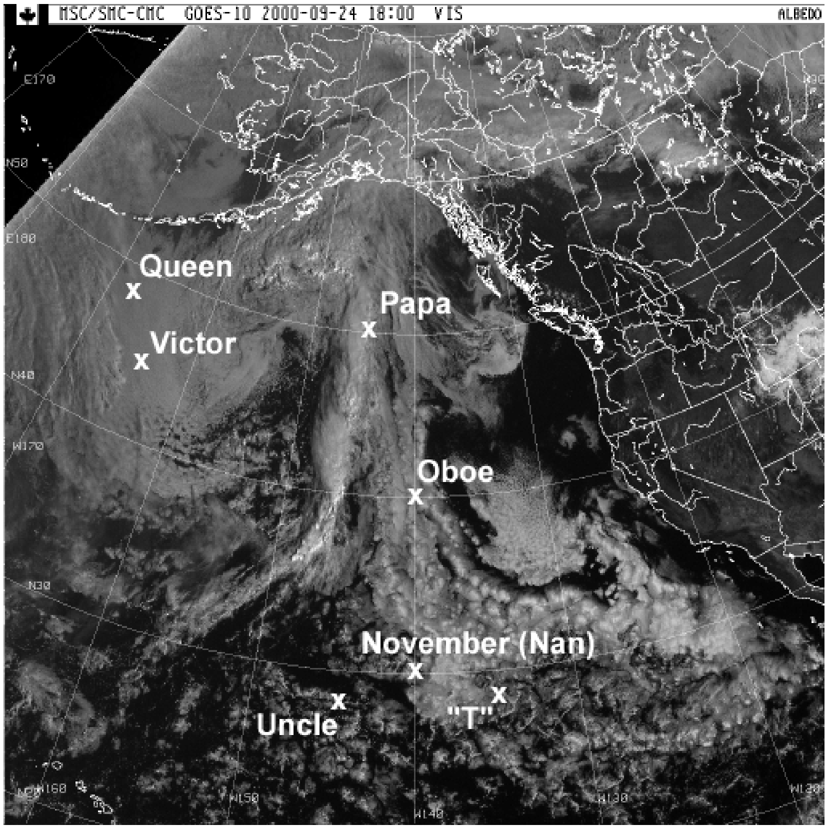

Figure 1. Locations of past Pacific Weather stations

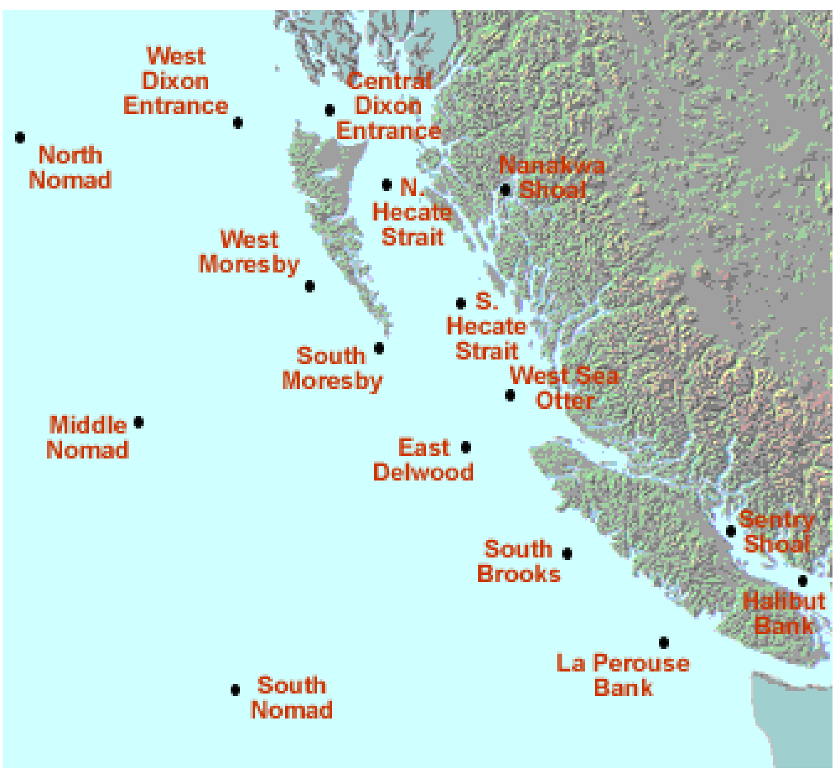

Figure 2. Map showing all buoys with common names

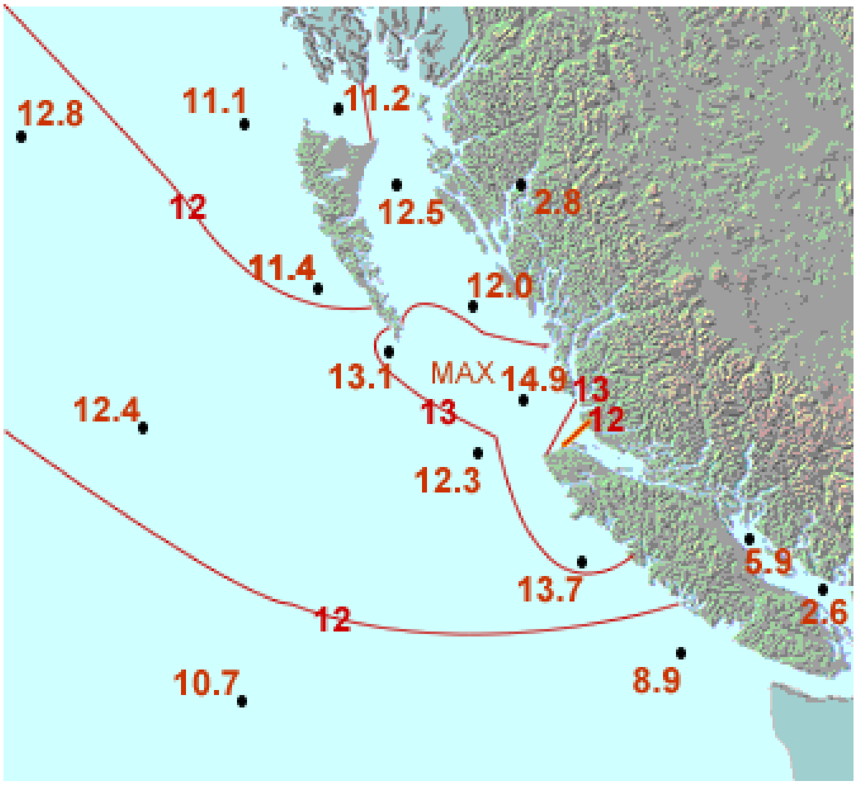

Figure 3. Average number of days with gale force winds in December

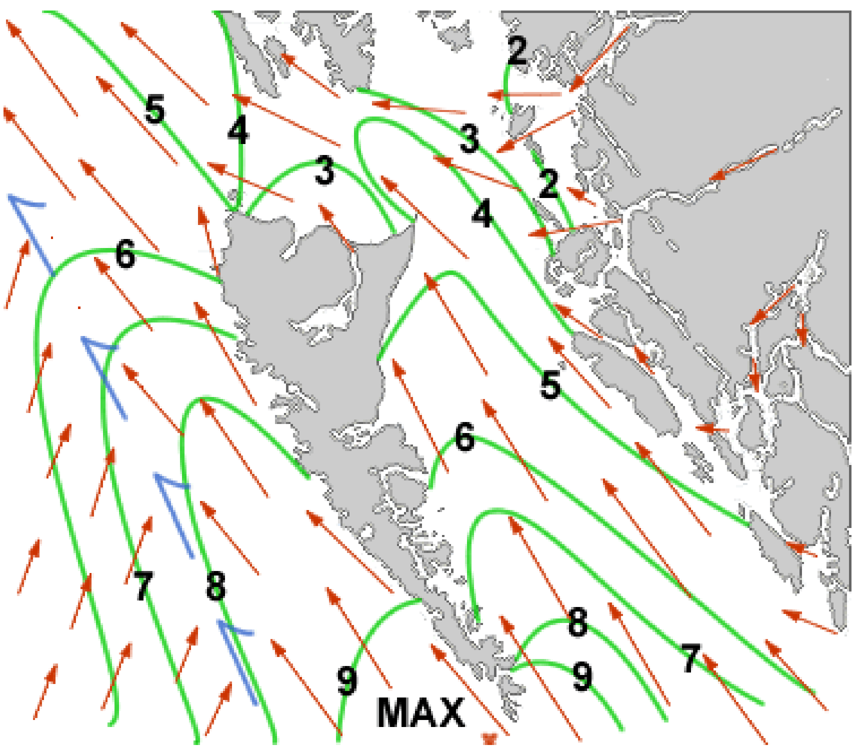

Figure 4. Map of local winds and waves with an approaching front

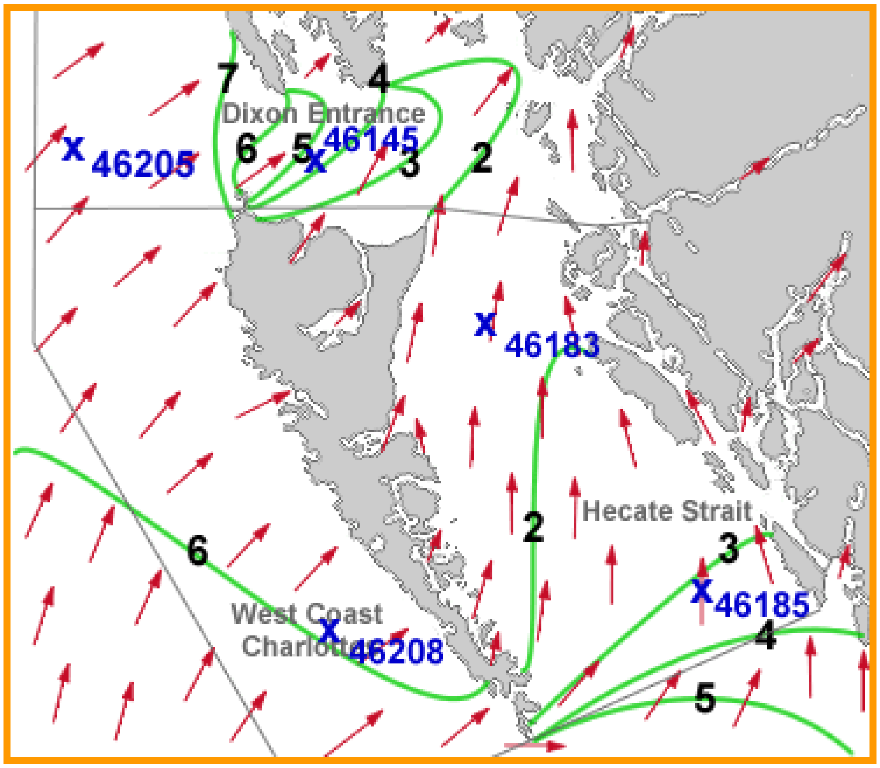

Figure 5. Map of local winds and waves following a frontal passage

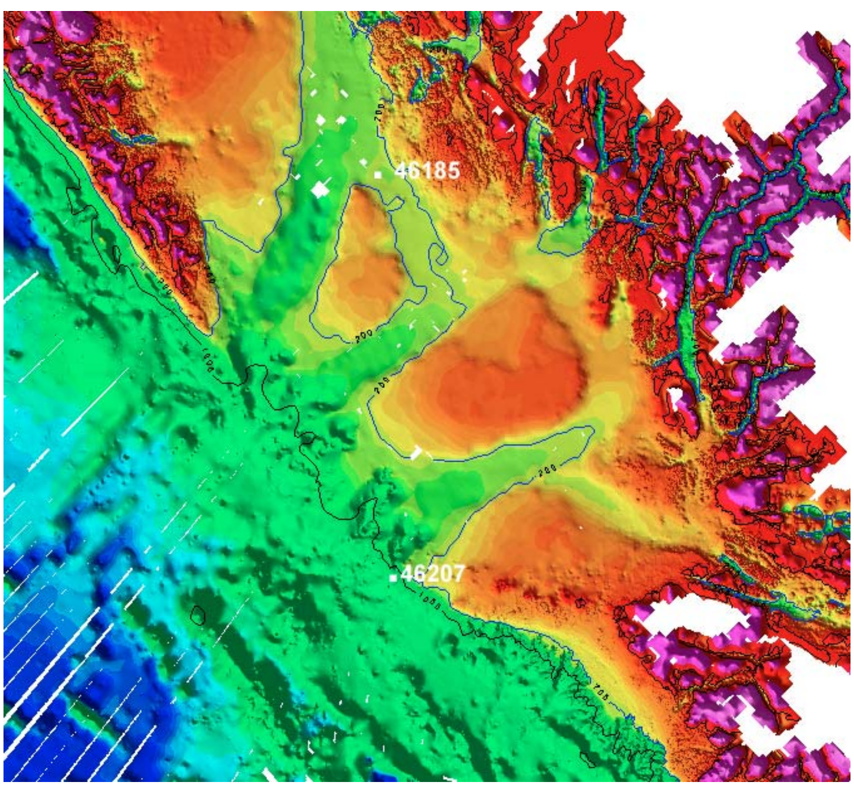

Figure 6. Map of Queen Charlotte Sound with extreme waves and bathymetry

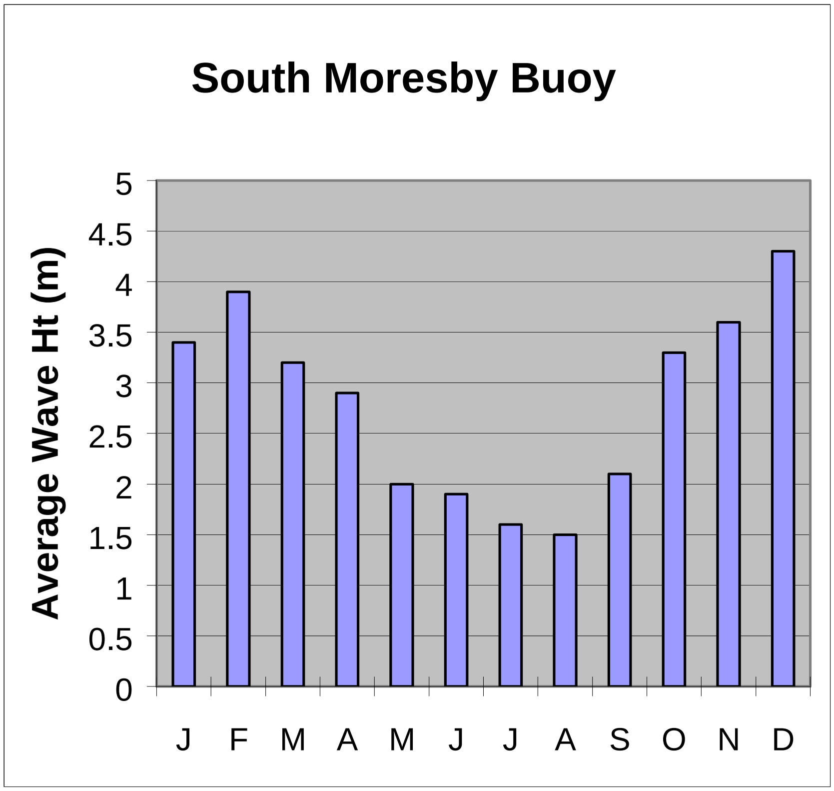

Figure 7. Graph of average wave heights at South Moresby buoy (46147)

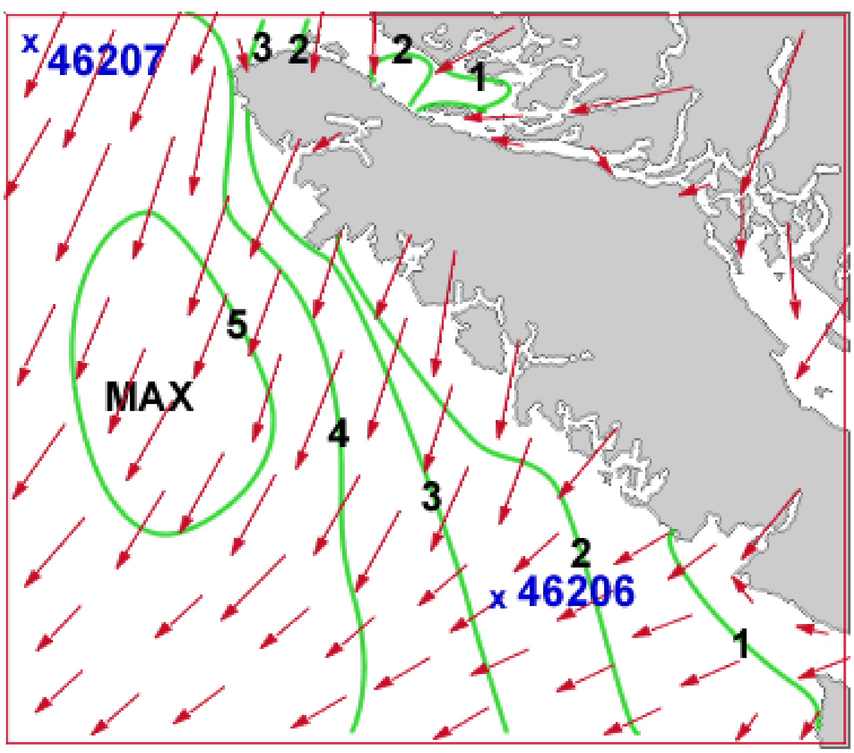

Figure 8. Illustration of northeast outflow winds

Physical and biological monitoring with the western Canadian ODAS marine buoy network

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Sensors are being added to some of the 17 meteorological ODAS buoys along and off the west coast of Canada to provide time series of physical and biological information. Sensors have been installed on two 3-meter discus buoys so far, starting in 1997. Measurements include salinity, insolation (PAR), water colour and fluorescence. Instruments are designed to provide time series of surface water properties that can be linked to water colour images from satellites such as Seawifs. Images show coastal physical and biological patterns in space and time for fisheries management and climate-related studies. In addition 50 and 200 kHz acoustic sounder systems have been installed to give depth profiles of zooplankton and fish. This paper shows examples of the data and discusses implications of the program.

1. Introduction

The array of 17 ODAS buoys along and off the west coast of Canada provide basic weather and ocean data for the federal Environment (EC) and Fisheries and Oceans (FOC) departments. The buoys provide adequate power, data handling and hourly real time data relay for additional sensors. It is therefore extremely cost-effective to add instruments to provide time series of physical and biological parameters for fisheries management, climate studies and for calibration and validation of satellite image data. Related requirements for monitoring the newly-announced Marine Protected Areas on the west coast of Canada are also being evaluated. A system for real-time display of the data on the web is under development at http://www-sci.pac.dfo-mpo.gc.ca/ecobuoys.

The first 3 EC/DFO ODAS buoys were installed on the west coast of Canada in 1987, and the array was finally brought up to its full number of 16 in 1993, with an additional experimental buoy (46134) being added in 1998. Three of the buoys are deployed offshore, 6 are in exposed locations near shore, and 8 are in sheltered waters (Figure 1). The buoys are well located for monitoring coastal water properties as well as weather for which they were originally designed. The standard buoys measure wind speed and direction, wave height and spectrum, surface water and air temperature and atmospheric pressure, data which are useful for interpreting the biological data, or when planning a service call to the buoy.

As well as their intended use in weather forecasting, the data from these buoys have been used to validate COADS wind data (Cherniawsky and Crawford, 1996) and wind and wave measurements from the Topex/Poseidon satellite (Gower, 1996), and to detect the long term sea surface temperature trends associated with El-Nino and climate change (Gower and Mclaren, 1999, Gower et al, these proceedings). First results from these biological sensors were reported by Gower et al., 1999. The need for biological time series is made especially urgent by the launch in August 1997 of the Seawifs satellite, and in December 1999 of the Terra satellite carrying MODIS. Both MODIS and Seawifs are designed to image coastal patterns of near surface phytoplankton. Similar and more sophisticated satellite sensors are planned for launch in the near future.

2. Biological Sensor Installations

A minimally modified test buoy with externally mounted sensors, was deployed on Constance Bank near Victoria on September 24, 1997. An irradiance PAR sensor was installed on the top of the buoy, and a similar underwater PAR sensor was deployed at 2.5 m depth under the centre of the buoy, looking up. A 7-channel radiometer covering the Seawifs satellite spectral bands plus in-situ chlorophyll fluorescence at 685 nm was mounted under the buoy, looking down. Water was pumped to two fluorometers, mounted on the buoy, to one from a depth of 0.5 m and to the other from 2.5 m. Problems with the buoy electronics prevented data acquisition until December 17 after which measurements continued until April 18 1998, when the buoy was recovered. On May 13 1998, this same buoy was re-deployed on a standard ODAS location on Halibut Bank (46146), where it is still providing limited data.

Problems were quickly encountered with cleaning the optical sensors with this type of installation. Their fixed locations under the buoy required use of divers or of a vessel large enough to lift the buoy out of the water. In addition, the use of separate fluorometers to measure at two depths, made it hard to separate spurious differences due to fouling, from real differences due to near-surface stratification. Also, a measurement depth deeper than 2.5 meters is required to sample below the summer pycnocline, but this was limited by the draft of the buoy.

In 1998 an improved sensor package was constructed, designed to be mounted in a well or “moon-pool” cut vertically through the hull of the buoy (Fig. 2). The underwater PAR sensor and a deep-water inlet were suspended 8 meters below this package at the end of a weighted line. In addition, water was pumped sequentially from the two depths through both fluorometers and a salinometer with small anti-fouling modules in the line. This package was deployed on November 28, 1998 in a new buoy at a location in Saanich Inlet near the Institute of Ocean Sciences, and given the code 46134. The location is accessible and sheltered, and in an area known for its high spring and summer productivity.

3. Examples of buoy data

A. Solar Irradiance (PAR)

This looks to be the simplest and cheapest parameter to measure from a buoy, of those so far attempted. The sensors are mounted in air, and at both the Halibut Bank and the Saanich Inlet locations they appears to remain clean over long periods. The data are important as showing both the energy supply for photosynthesis and the heat input to the ocean. Aerosol optical depth can also be deduced on relatively cloud-free days. Measurements on the buoy are recorded at 1 hour intervals, and are the averages from three 1-minute sampling periods spaced through the preceding hour

An example of a PAR time series is shown in Fig 4. This shows the daily average PAR computed from the 24 hourly readings available per day. The time series covers nearly two years. The strong annual cycle is due to changes in both day length and the sun's maximum elevation above the horizon. In this plot, hourly values were averaged for the 538 days out of the 653 total having more than 21 measurements. This type of data is required for deducing primary productivity from the chlorophyll concentrations imaged by satellites, and for modelling water temperatures. Very few measurements are available, with none over water. It has been proposed to install above water PAR sensors on all buoys in Figure 1, but funding is not yet available.

B. Salinity

The Seabird "Microcat" salinometer has operated for nearly two years with only minor effects from fouling. Figure 5 shows comparisons with samples measured in the laboratory both as a scatter plot and as a time series. Outlying points may be due to local variability in water properties. The more clustered points in Figure 5b then show almost no drift over the first year (<.02 ppt) (measurements started in Dec 1998) and some evidence of a drift of about 0.05 ppt during the second year. This slow rate of fouling would allow collection of good quality data from any of the buoys in Figure 1, given the annual servicing schedule of the buoys. Fouling of the pumps and of the one-way check valves might be a more serious limitation.

C. Chlorophyll concentration from fluorometry

The two fluorometers on buoy 46134 provided consistent data over most of 1999 and 2000. Fouling was monitored by noting the difference between the outputs of the two fluorometers, and was countered by cleaning (bottle-brushing) of fluorometers either in the field or in the laboratory. Data correction was also applied by interpolating the zero level of each fluorometer between apparently times of cleaning.

Fig. 6 shows the full time series of fluorometer measurements (daily averages) converted to chlorophyll pigment concentrations using calibration data from bottle samples. The plot shows concentrations deduced from measured fluorescence at the surface (heavy line) and at 8 m depth (lighter line). The time of the spring bloom in Saanich Inlet can be seen to start on about March 24 (day 83) in 1999, and on about March 11 (day 71, or 436 from the start of 1999) in 2000. This time series provides new information on the dynamics of plankton growth. For the first time, it is based on (hourly) sampling sufficiently rapid to monitor growth and bloom events, compared to previous sampling at weekly or monthly intervals.

In both years it can be seen that indicated concentrations are lower at the surface. This is as would be expected in a nutrient-depleted surface layer, but is also a property of the photo-inhibition, which affects the fluorescence signal from phytoplankton in the surface water. Figure 7 shows part of the chlorophyll pigment time series for April 1999 (heavy line) showing the dips in the fluorescence measured in surface water at times of high solar irradiance, PAR, also measured on the buoy (light line). The dotted line shows the (more variable) signal from water at 8 m depth, which is unaffected by photo-inhibition. It can be seen from Figure 7 that chlorophyll levels are lower in the surface layer, as indicated by fluorescence measured at night. Effect of photo-inhibition on the daily averages (Figure 6) will increase as the days lengthen in summer. Inhibition will clearly reduce the fluorescence signal available for measurement by the MODIS and MERIS satellite sensors, sometimes to very low values.

D. Acoustic profiles

An acoustic profiler operating at 200 KHz was added to the buoy in September 1999 to provide profiles of backscatter signal intensity for monitoring the density of zooplankton and fish. Profiles are recorded once per minute from the surface to the bottom at 65 meters depth with 0.5 m resolution. The transducer has a beam 9 degrees wide and is mounted near the edge of the buoy (about 1.2 meters off centre) looking 15 degrees off nadir, away from the mooring chain, which hangs from the centre of the buoy. Data are recorded on the buoy, and need to be down-loaded about once every 3 weeks.

Images of measured echo signal (Figure 8) show the diurnal cycle of zooplankton vertical migration in which they descend from the surface layers at dawn, and spend the day in near-darkness hiding from predators. In deeper water in Saanich Inlet zooplankton form a scattering layer at about 120 m during the day. At the shallower buoy location , they presumably spend the day on or near the bottom at shallower than the preferred depth. At dusk, they return to the water column. The bottom 2 meters of the water column are hidden from the sounder by the strong bottom return.

The sounder has operated continuously for more than a year. The record shows the seasonal cycle of scatterer distribution in the water column, and a variety of transient effects such as returns from fish schools, scattering layers and rising and sinking objects. In August 2000 a 50 KHz sounder was added to allow discrimination of larger targets such as fish.

4. Conclusions

The project is making steady progress towards the goal of an operational Marine Ecosystem Observatory at a variety of locations on and off the British Columbia coast. The effects of fouling are being studied and techniques for dealing with it are being refined. In-water optical measurements being made on the buoys, but not presented here, are most affected, though at an accessible site like Saanich Inlet the sensors can be cleaned often enough to give good data. Sensor manufacturers are developing countermeasures, such as wipers and protective shutters, which we hope to evaluate.

The improved form of sensor installation is being extended in early 2001 to the buoy on Halibut bank in Georgia Strait, and funds are being requested for instrumenting buoys off the west coast of Vancouver Island and in Hecate Strait, and one of the Nomad buoys further offshore. In addition, it is planned to install other sensors to measure optical transmission and nutrients. In December 1998, the first of two new Marine Protected Areas on the west coast were announced. A suitably instrumented buoy may well have a role for marking and monitoring such areas.

5. References

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6. Acknowledgements

This work was originally supported under the PERD program, and is presently supported by DFO under the Climate Program. We acknowledge the help and enthusiasm of many organizations and individuals who share our interest in monitoring and protecting coastal waters, especially the Data Buoy group of Environment Canada, the Hovercraft and Dive Unit of the Canadian Coast Guard, and many colleagues at IOS, especially Ann Gargett, Angelica Pena, John Wallace, and Lizette Beauchemin.

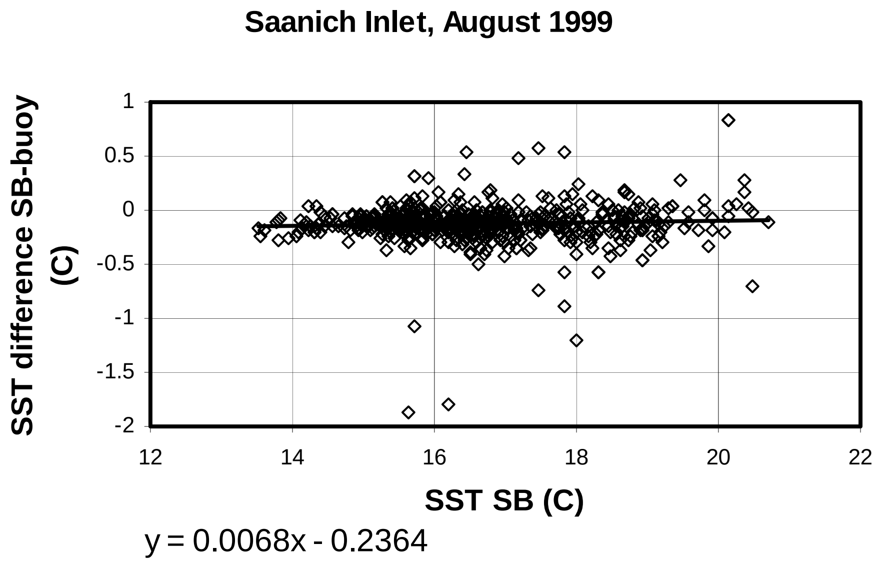


Figure 1 Scatter plot of the temperature difference between the two sensors for one month of operation (August 1999), against the Seabird temperature.

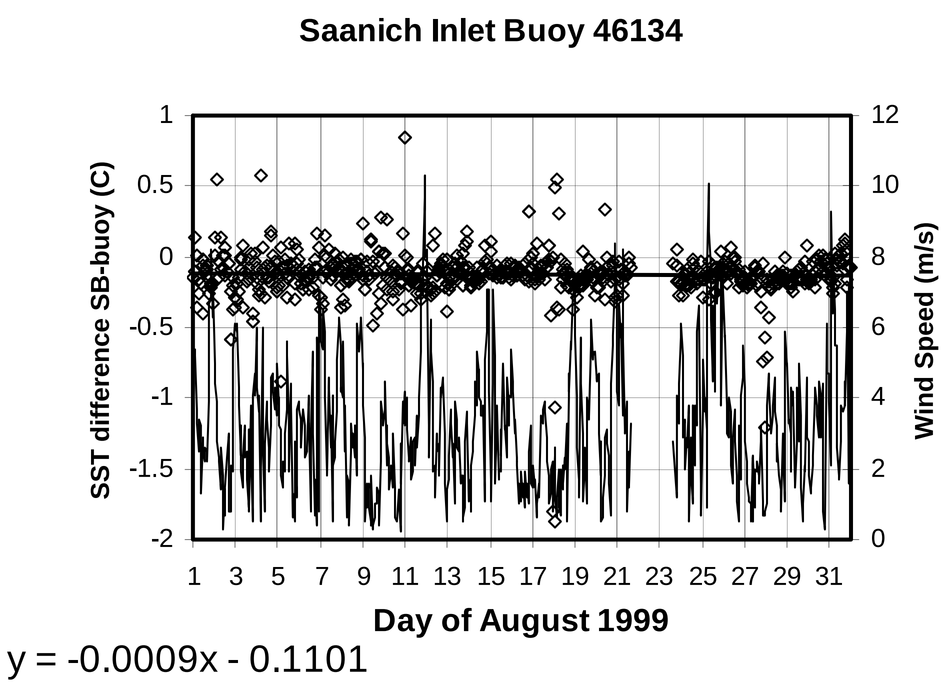


Figure 2 Time sequence of SST difference and wind speed for August 1999, showing that the large differences tend to occur in groups at times of low wind speed.

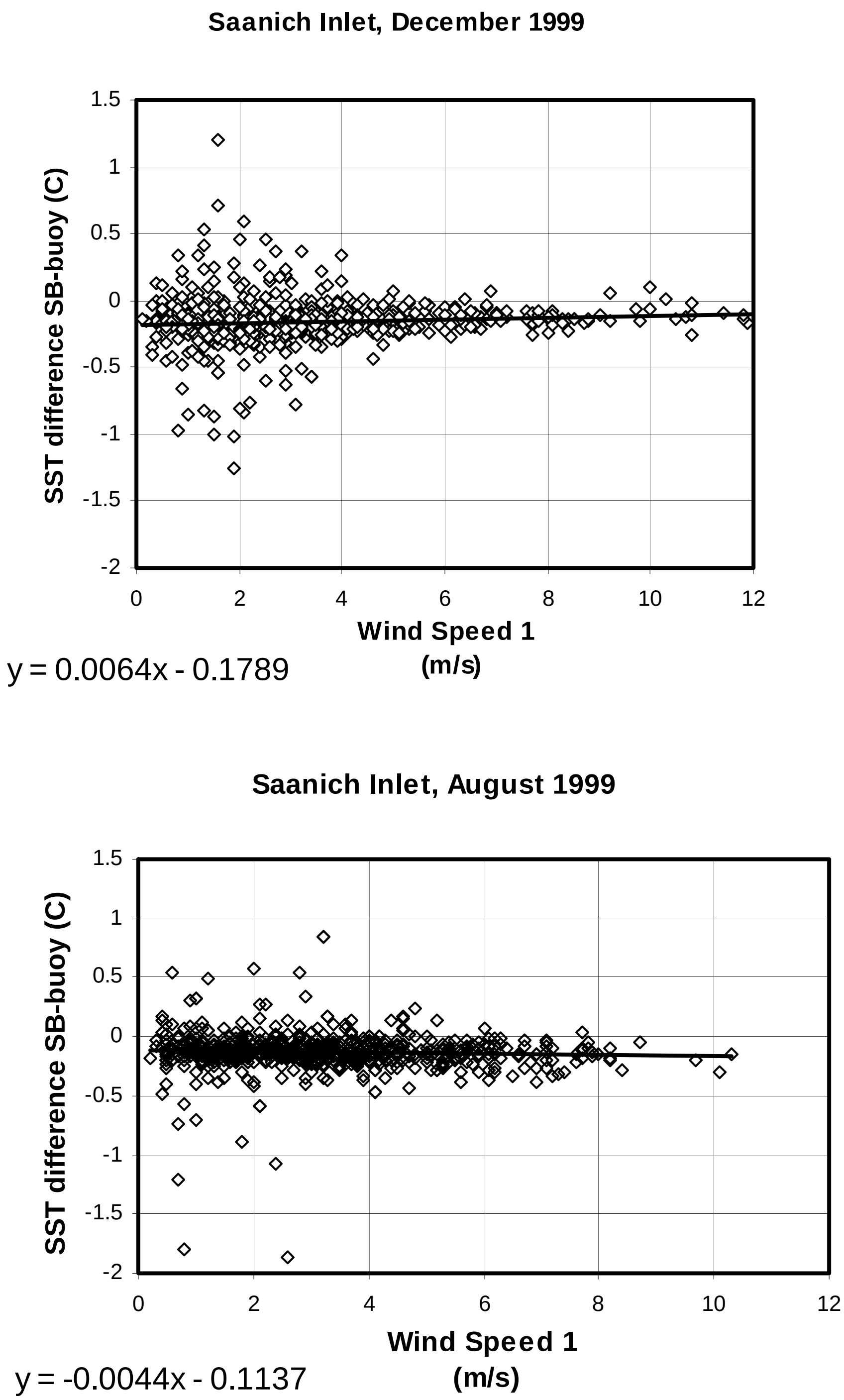


Figure 3 Scatter plots of the temperature difference against wind speed for December 1999 and August 1999. SStT differences are below about 0.3 C for wind speeds above 4 m/s.

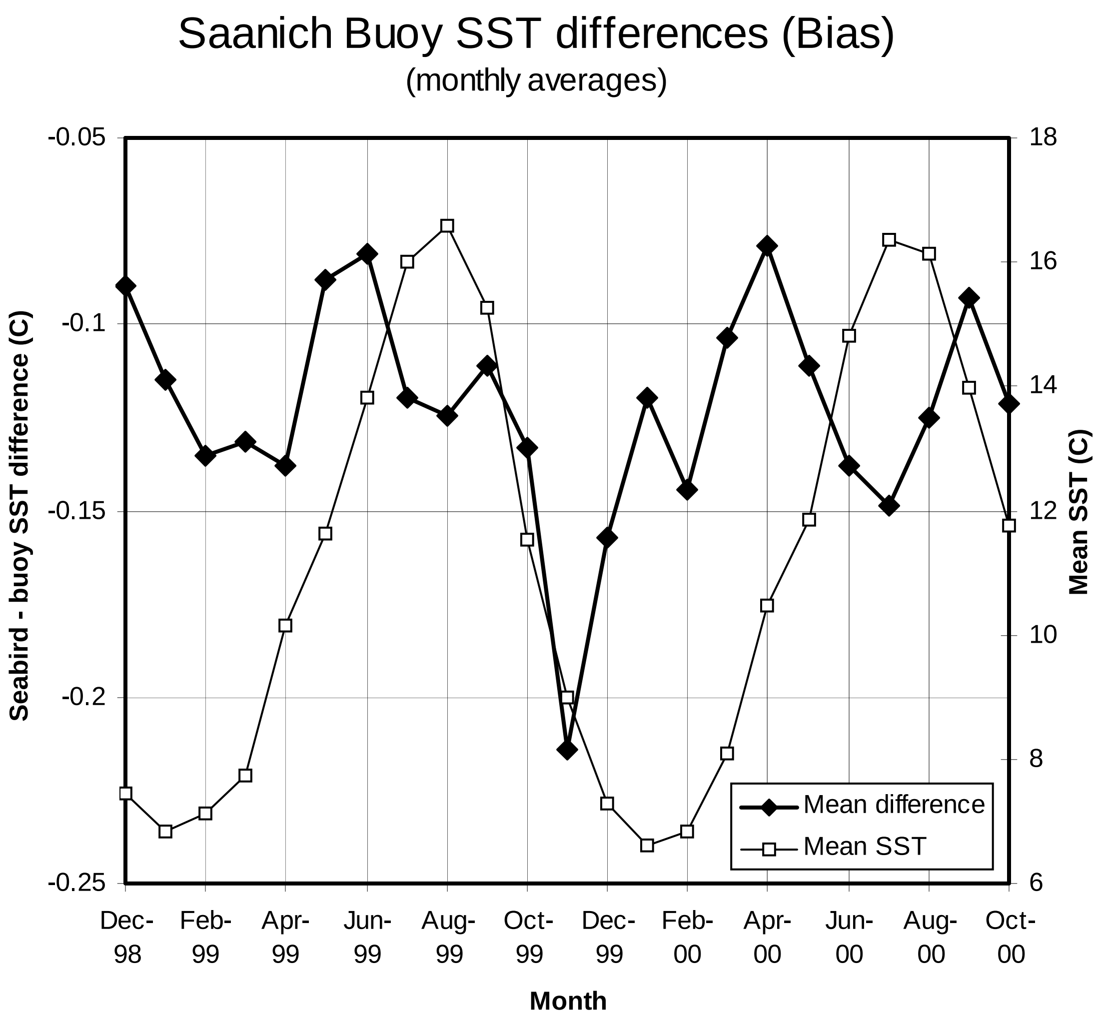


Figure 4 Monthly mean difference between the two sensors (black diamonds, left scale), and seasonal cycle of monthly mean SST (white squares, right scale).

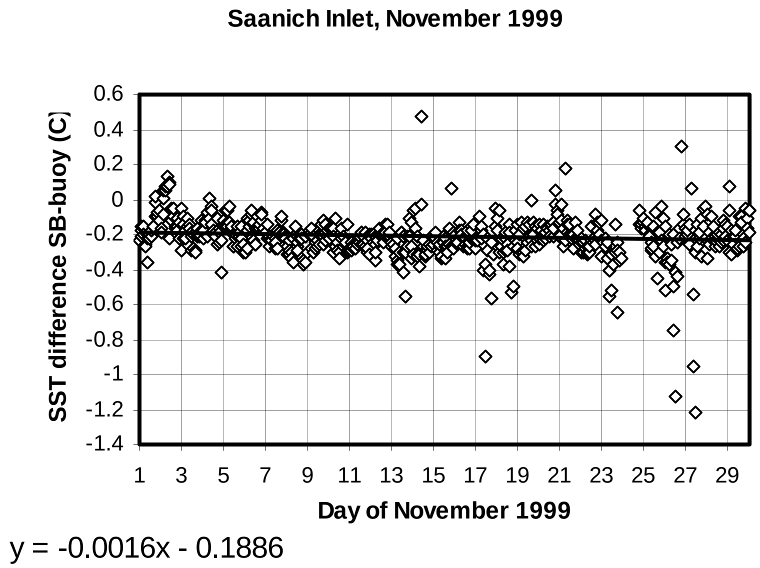


Figure 5. The temperature difference in the month (November 1999) showing the largest difference in Figure 4.

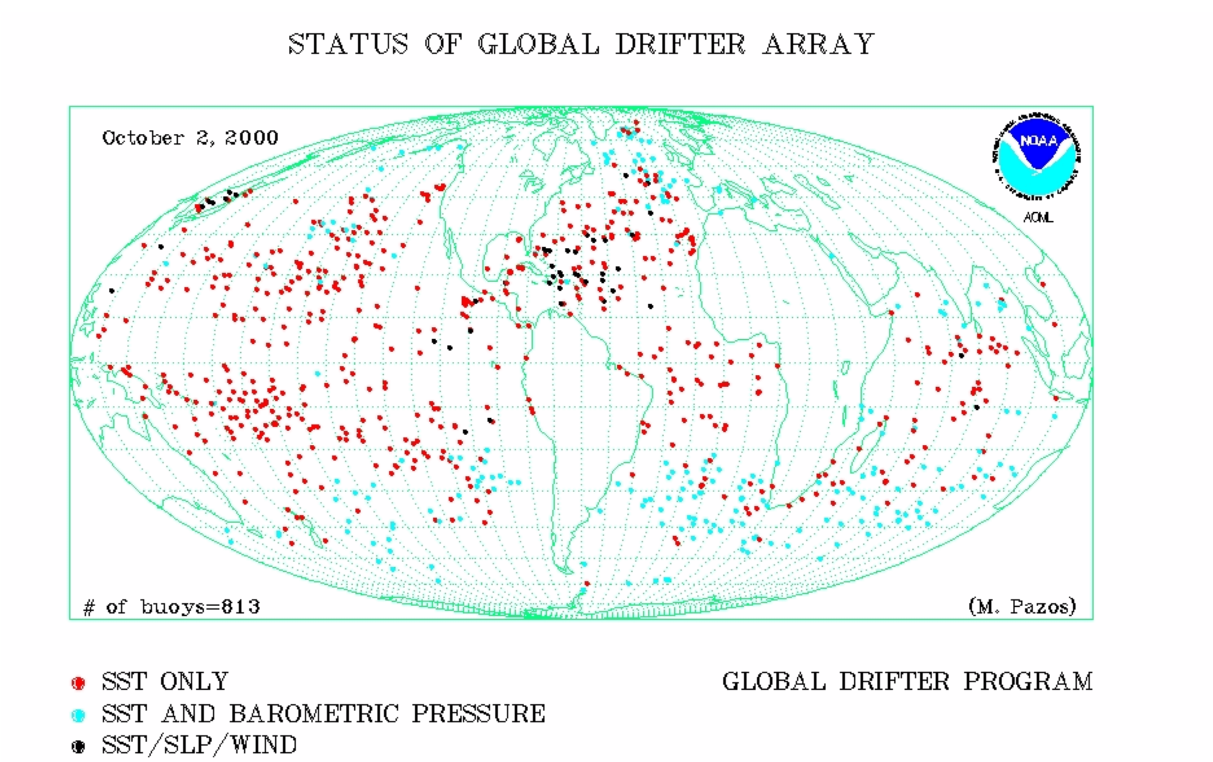
Status of the Global Drifter Array and Hurricane Array Deployments
DBCP-16, Victoria, B.C. October 2000

Craig Engler
NOAA/AOML

Introduction

The Global Drifter Program (GDP) is a branch of the Global Ocean Observing System (GOOS) Center at NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML). The GDP mission is to maintain a global array of ARGOS tracked Lagrangian Drifters to meet the need for an accurate and globally dense set of in-situ observations of sea-surface temperature (SST) and surface circulation. This data supports short-term (seasonal-to-interannual) climate predictions as well as climate research and monitoring.

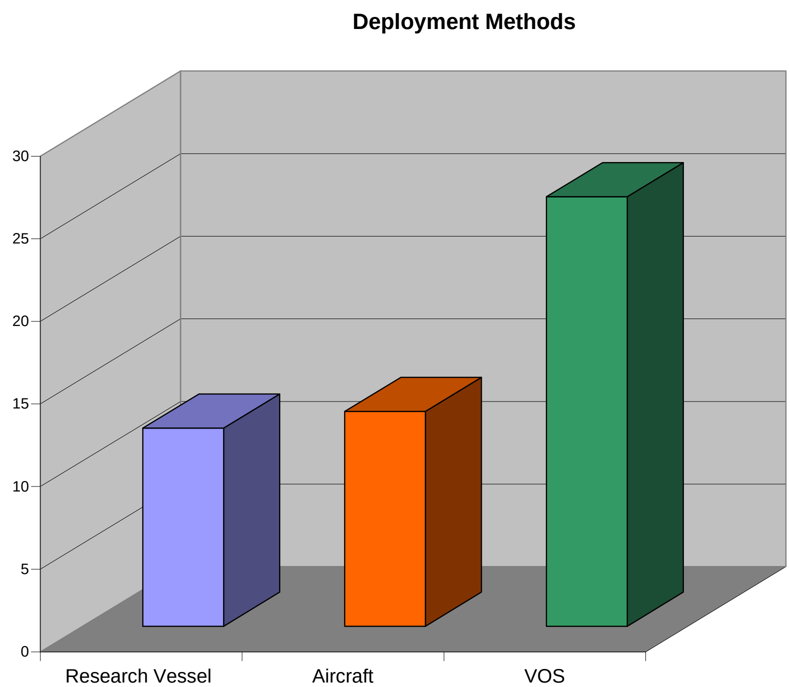
A total of 433 GDP buoys were deployed in the Tropical and Southern Oceans between October 1999 and September 2000. A number of the buoys deployed in the southern oceans were SVP buoys upgraded with Barometers. In addition to the SVP and SVP Barometer drifters the GDP has deployed an array of Hurricane Observation Wind drifters in the Tropical Atlantic for the 2000 Hurricane season. The deployments of these buoys were made by Naval Aircraft, Voluntary Observation Ships and Research Vessels.



Summary of Deployments by Ocean Basins

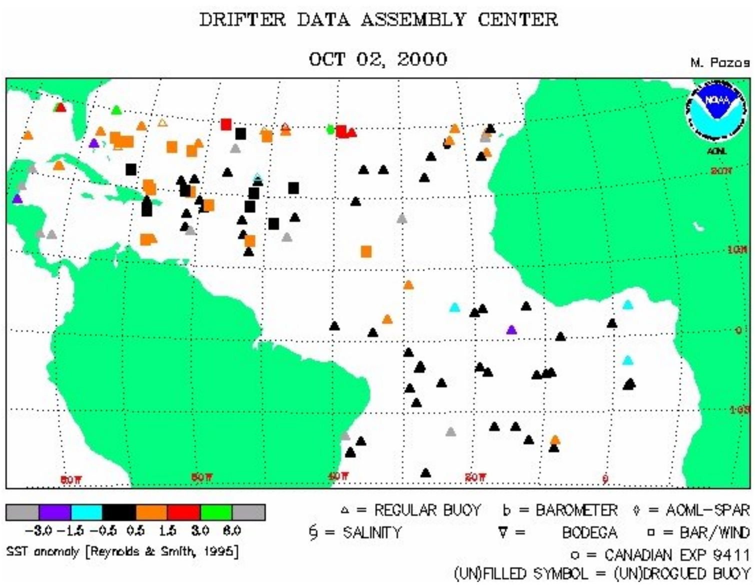
Tropical Indian Ocean (20 S – 20 N)

51 Buoys were cooperatively deployed in the Tropical Indian Ocean in the past year. 42 were standard SVP buoys, 9 were standard buoys equipped with a barometer upgraded by funds from Meteo-France and the Australian Bureau of Meteorology. 24% were deployed by Dutch and French Research Vessels, 25 % by Aircraft and 51% by Voluntary Observation Ship. We acknowledge the support of United States Naval Oceanographic Office, Meteo-France, the Australian Bureau of Meteorology, the South African Weather Bureau and researchers from the University of Cape Town.



Tropical Atlantic Ocean (20 S – 30 N)

From October1999 to September 2000 a total of 77 SVP buoys have been deployed in the Tropical Atlantic region. 68 % of these buoys have been deployed by Research vessels from the ICCM (Instituto Canario De Ciencias Marinas), Centre IRD de Brest and HBOI (Harbor Branch Oceanographic Institute Ft. Pierce Florida). The remaining 32% by VOS (Voluntary Observation Ship).



Hurricane Array

To support hurricane predictions for the 1999 Hurricane Season, nine GDP & two Meteo-France wind drifters were deployed in the tropical Atlantic. Eight of these drifters were air deployed in July1999 by the U.S. Naval Oceanographic Office and 3 were deployed by a Meteo-France recruited Ship of Opportunity. The GDP extends our thanks to NAVOCEANO and Meteo-France for their assistance.

To support hurricane predictions for the 2000 Hurricane Season, nine GDP wind drifters were air deployed in the Tropical Atlantic in May 2000. These wind drifters are funded by NOAA / Office of Global Programs for the value of the data gathered by the wind drifters. The nine Hurricane Wind Buoys from this season's deployment are transmitting and have been placed on the GTS. Two additional NAVOCEANO Wind Buoys were deployed by VOS in early September.

Tropical Pacific Ocean (20 S – 20 N)

Under the ENSO program 132 standard buoys and 5 Barometer buoys were deployed in tropical waters west of the Date Line. 31% were deployed by NOAA Research Vessels servicing the Tropical Atmosphere Ocean (TAO) Array and by Research vessels from Noumea Institut de Recherche pour le Developpement (I.R.D.). 69% were by Voluntary Observation Ships many with Scripps VOS program Ship riders.

Under the CORC program in cooperation with Peter Niiler/Chris Martin of Scripps Institute of Oceanography SIO) 97 drifters were deployed in the eastern tropical Pacific waters. Deployments were made 54 % by Research Vessel from CICSE and 46% by Voluntary Observation Ships.

Southern Ocean Basins

Southern Indian Ocean (60 S – 20 S)

18 buoys were deployed in the Southern Indian Ocean. 56% with Barometer Upgrades funded by the Australian Bureau of Meteorology and Meteo-France. Research Vessel and Voluntary Observation Ships deployed the buoys. We acknowledge the support of Meteo-France, the Australian Bureau of Meteorology, the South African Weather Bureau and researchers from the University of Cape Town.

Southern Atlantic Ocean (60 S – 20 S)

14 SVP drifters in the South Atlantic deployed by Research Vessel and Voluntary Observation Ship. 71% of the buoys were barometer. The GDP acknowledges the assistance of the South African Weather Bureau (SAWB), the Brazilian Navy, and ARGENTINA INIDEP (Instituto Nacional de Investigacion y Desarrollo Pesquero) in the deployment efforts.

Southern Pacific (60 S – 20 S)

36 buoys were deployed in the South Pacific. 56% were standard buoys and 44% barometer buoys. We acknowledge the assistance of the Meteorological Service of New Zealand, Noumea I.R.D., and University of Washington Ship riders, Scripps Institute of Oceanography ship riders in the deployment of the buoys. Voluntary Observation Ships and the United States Coast Guard. An 11% failure rate was observed in the lower latitudes and is being investigated.

2000 Problems

Problem Areas continue to be the Southern Oceans. Due to the limited VOS and commercial shipping traffic in the lower hemisphere. Holes continue to exist in the

Southern Pacific. The Naval Oceanographic Commission is assisting by deploying in January. A United States Coast Guard Icebreaker en-route to Antarctica will also deploy drifters. Future Assistance is requested to maintain the array throughout the seasons.

2000-2001 Plans

Plans are for the deployment of 419 Drifters in the period between October 2000 and September 2001.

Tropical Oceans

AREA	Deployment Number
Tropical Pacific	205
Tropical Atlantic	78
Tropical Indian	50

*** 20 buoys have been upgraded with Barometers by Meteo-France and Australian Bureau of Meteorology**

Southern Oceans

AREA	Deployment Number
Pacific	35
Atlantic	20
Indian	22

*** 39% will be upgraded with Barometers**

9 WOTAN (Tropical Atlantic) drifters will be deployed in the Hurricane formation Region at the beginning of the 2001 Hurricane Season.

Drifter Data Assembly Center Report

By

Mayra Pazos

NOAA/AOML

The Drifter Data Assembly Center (DAC) is part of the Global Ocean Observing System (GOOS) Center operated at NOAA/AOML. The primary goal of the DAC is to collect and provide uniform quality control of sea surface temperature (SST) and surface velocity measurements and make them available to the oceanographic community in an effort to improve ocean monitoring and climate prediction. These measurements are obtained in collaboration with other national and international partners.

This presentation will focus on new products that expand the use of our drifter program data. One new product provides hurricane forecasters with meteorological and surface oceanographic data in the hurricane development sector of the Atlantic Ocean. In an effort to provide the pertinent data for hurricane and prediction, each year Surface Velocity Program drifters equipped with barometer and wind sensors are deployed.

This year's hurricane array is composed of nine drifters provided by AOML and deployed northeast of Brazil by the Navy, in May 2000. Eight additional drifters were provided by the Navy and deployed east of the Bahamas in August 2000. Daily drifter tracks, and data files are available through the DAC WEB page. Other processed historical drifter data can be downloaded from the WEB, including drifter trajectories and monthly and seasonal SST and surface velocity fields.

At the beginning of October 2000, there were 813 buoys transmitting from all programs from which AOML Drifter Data Assembly Center receives and processes data (Figure a). The Evolution of the Global Drifter Array since 1988 is shown in Figure b.

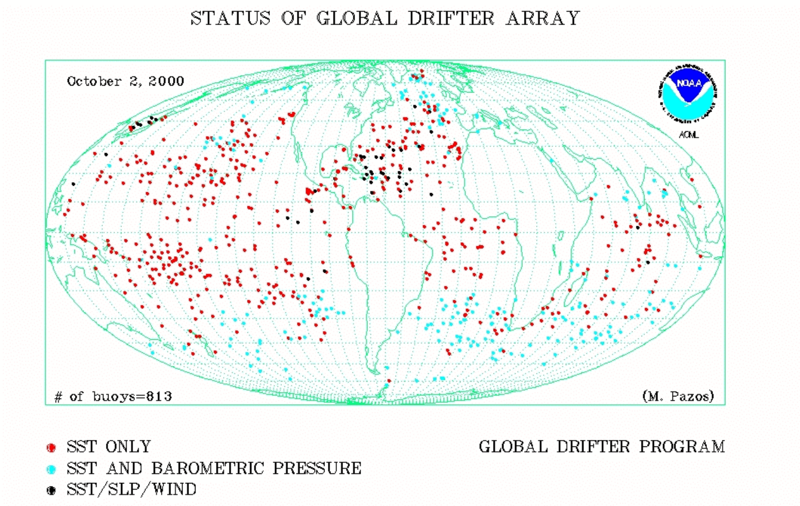


Figure a

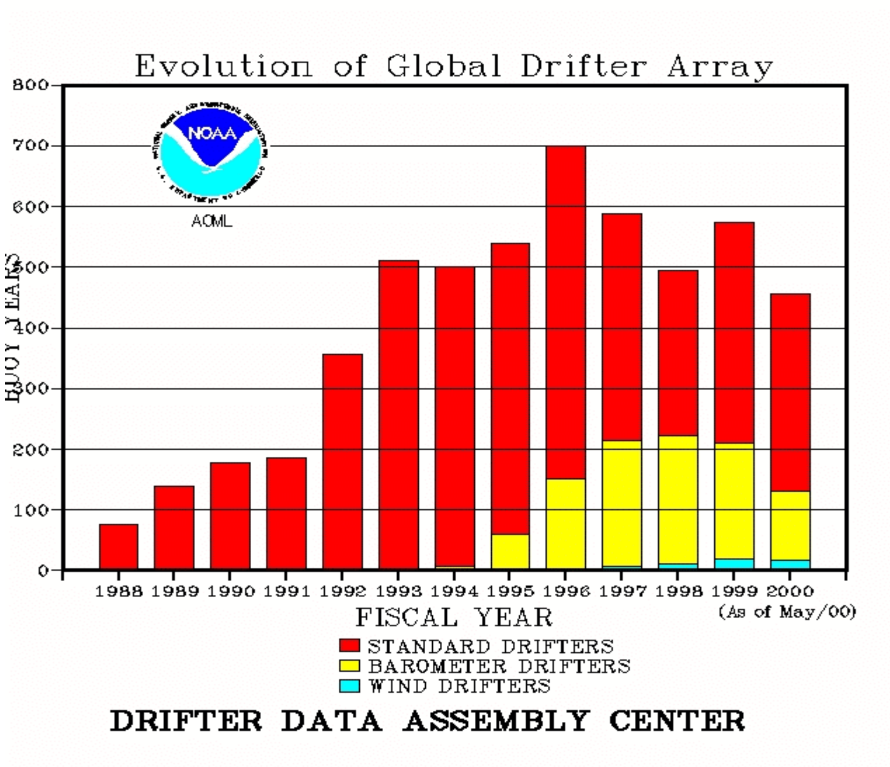


Figure b

DAC's New Products on the WEB

www.aoml.noaa.gov/phod/dac/dacdata.html

- Interpolated Drifter Data.
- Hurricane array drifter trajectories, with hurricane tracks and data files, updated daily.
- Seasonal mean velocity plots, variance around the mean velocity and number of point contour maps by basin.
- Seasonal Mean velocity world data files.
- Altimeter and GTS near real time data.

Variations in Surface Air Temperature Over the Arctic Ocean

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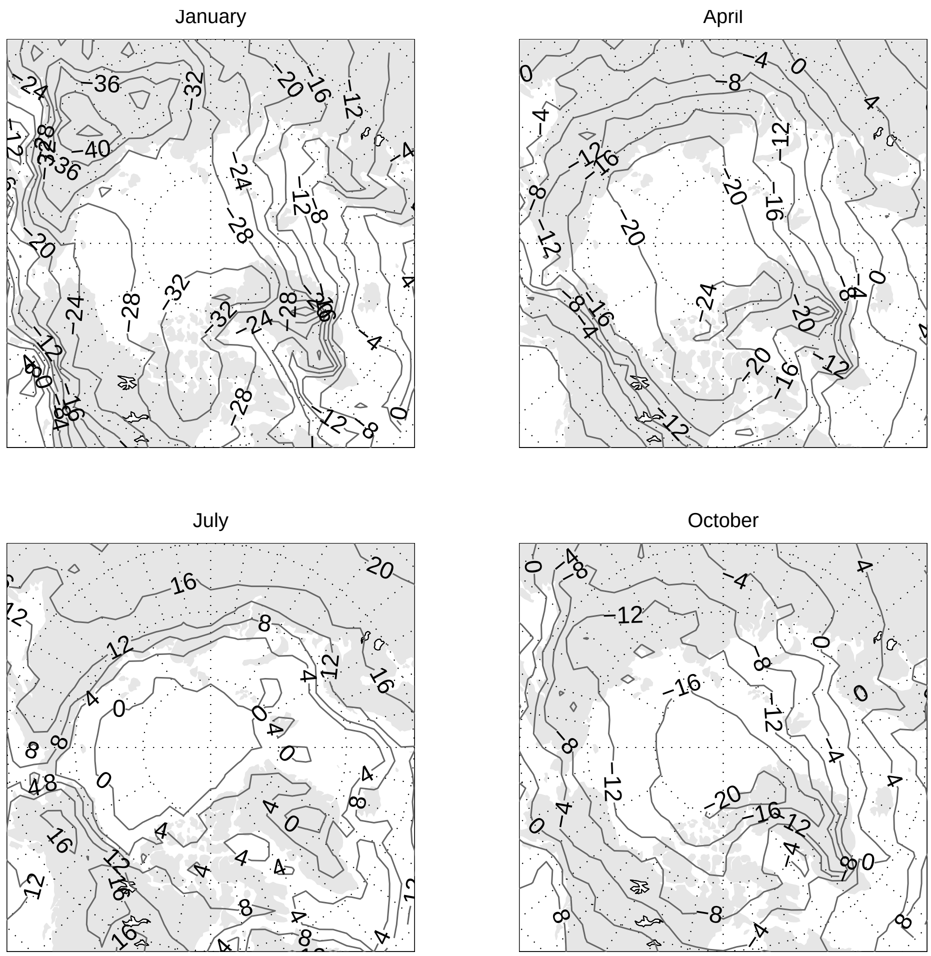

Figure 1. Mid-season monthly mean maps of surface air temperature.

1. INTRODUCTION

Until recently the Arctic Ocean has lacked a systematic, accurate dataset on surface air temperature (SAT) at 2-m height. These data are especially important in the Arctic because most simulations by global climate models with enhanced greenhouse forcing predict that any warming in the global climate will be amplified at the poles. This implies that any change in the climate may first be detected at the poles. In addition, although the winter heat balance of multiyear ice is strongly dominated by the radiation balance, the ice growth in open water and leads is more strongly dominated by the sensible and latent heat fluxes, which depend strongly on the SAT. These SAT fields are essential for studies of climate change and for validation and forcing of numerical models.

In this study, we will describe a new SAT analysis from the International Arctic Buoy Programme (IABP), and the NASA EOS program Polar Exchange at the Sea Surface (POLES) called the IABP/POLES SAT analysis. Using this dataset, we will show the seasonal SAT climatology, show the trends in SAT and finally, we will relate these changes to the Arctic Oscillation.

2. DATA

The data used in this study are (1) data from drifting buoys, obtained from the IABP; (2) North Pole (NP) drifting station data from the Arctic and Antarctic Research Institute in Russia; and (3) meteorological data from land stations, obtained from the National Center for Atmospheric Research (NCAR).

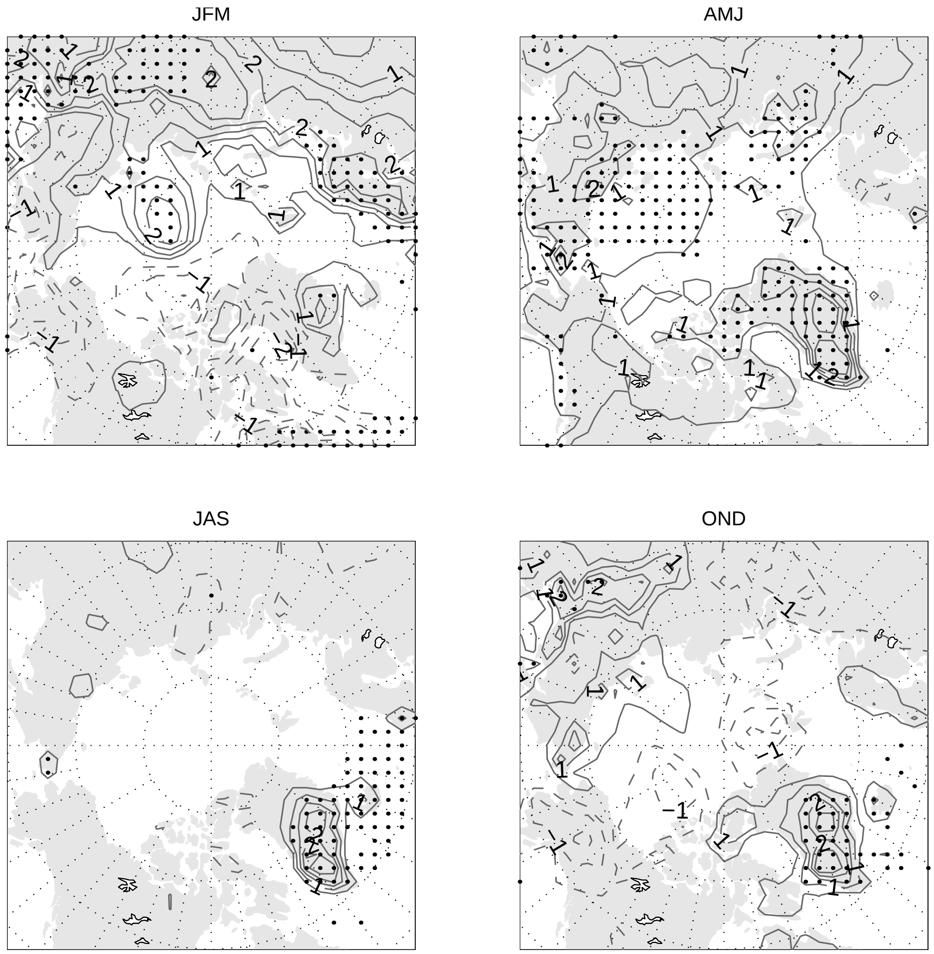

Figure 2. Trend maps of surface air temperature.

The data from NP drifting stations are considered the most accurate SAT dataset for the Arctic Ocean. Using the SAT statistics from these stations we were able to filter the buoy data and discard bad observations. The three data sets are then combined using the objective analysis procedure, optimal interpolation. Twelve-hourly SAT fields have been analyzed from 1979 to present. These data can be obtained from the IABP web server: http://IABP.apl.washington.edu. For further details regarding these data, please refer to Rigor et al. (2000).

3. SEASONAL CLIMATOLOGY AND TRENDS

Figure 1 shows the monthly mean fields (1979-1997) derived from this analysis for January, the coldest month in the Arctic; July, the warmest month; April, and October, the transition months. In January, the coldest region over the ocean is north of the Canadian Archipelago, while over land the coldest region is over Siberia. During summer the SAT over the ocean is held to an isothermal value of -0.2°C, the melting point of sea ice.

Figure 2 shows the seasonal trends, which were evaluated by least squares fits of the annual and season temperatures for each grid cell. The seasons were defined as January-March (winter), April-June (spring), July-September (summer), and October-December (autumn). The significance of each trend was calculated using a Student t-test for accepting the hypothesis that there is no trend. Trends significant at the 95% level are marked with black dots.

Over the Arctic Ocean, the annual trends (not shown) exhibit a warming of about 1.0°C/decade in the eastern Arctic, primarily in the area north of the Laptev and East Siberian seas, whereas the western Arctic shows no trend, or even a slight cooling in a small portion of the Canadian Beaufort Sea.

During winter, the trends show a significant warming of up to 2°C/decade in Europe and 1-2°C/decade over Eurasia, extending north over the Laptev Sea; however, a cooling trend of 1°C/decade is shown over the Beaufort Sea and eastern Siberia extending into Alaska. During spring, a warming trend of 2°C/decade can be seen over most of the Arctic. This trend is significant in the eastern Arctic Ocean. Summer shows no trends over the Arctic Ocean, but the trends on the coasts of Greeenland and in the North Atlantic are significant. During fall, the trends show a significant warming of 2°C/decade over the coasts of Greenland, and near Iceland, but a cooling of 1°C/decade over the Beaufort Sea and Alaska.

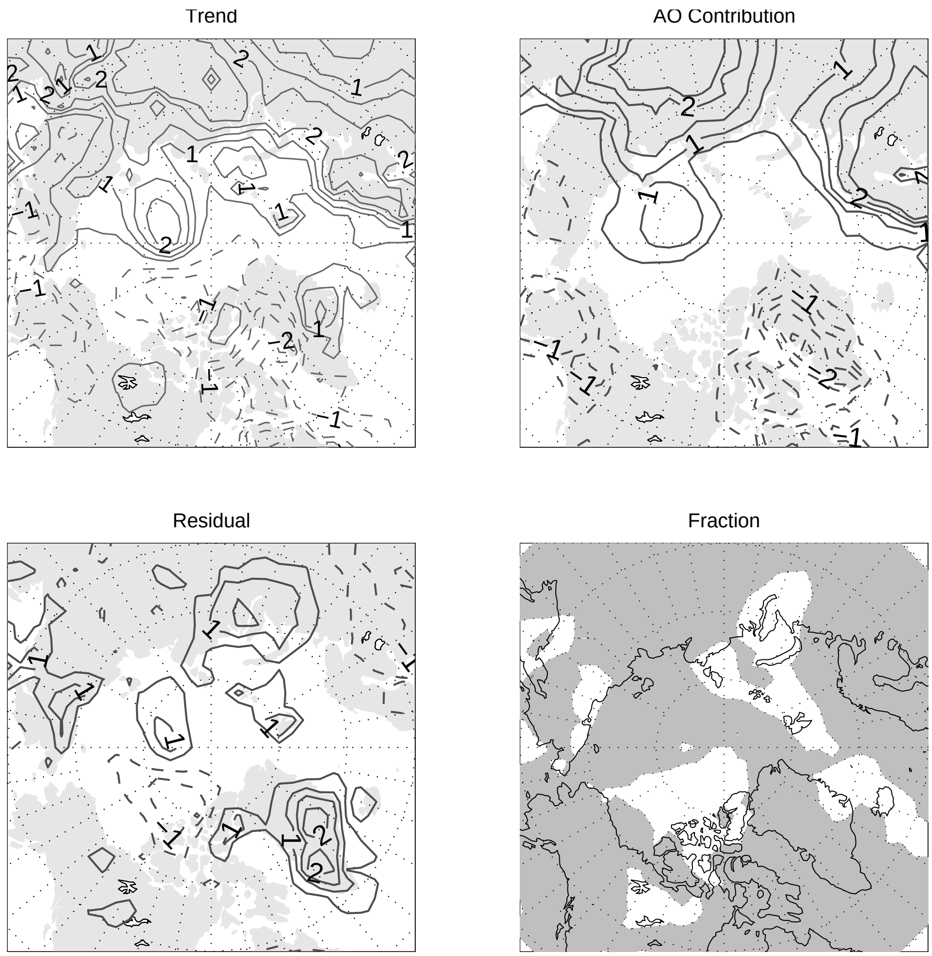

Figure 3. Contribution of the Arctic oscillation to winter (JFM) SAT trend.

The ice and snow masses in the polar regions interact with the global climate system in a myriad of complex ways. During most seasons, SAT trends can be studied by simple statistical methods, but during summer, because these masses hold the SAT to the melting point of sea ice, detection of changes in SAT must rely on other, less direct indicators such as the length of the melt season (not shown, please see Rigor et al. 2000). The melt season is defined as that period when the SAT is near or above the melting point of ice.

On average, melt (not shown) begins over Siberia, Alaska, Northern Canada, and the North Atlantic on the first of May. By the first of June, melt has advanced to the edge of the marginal seas, into the Canadian Archipelago, and into the Greenland and Barents seas. The advance of the melt isotherm stalls at the coast and margin of the Arctic Ocean for a few weeks, slowed by the large mass of snow and ice over the ocean. Once the entire mass of ice is brought near to the melt point, melt then advances rapidly over the Arctic Ocean, reaching the pole on 19 June, 2 weeks later. The last area to reach the melt point is the Lincoln Sea, adjacent to Northern Greenland, which begins to melt on 21 June, 2 days after the pole.

The onset of freeze (not shown) occurs at the pole on 16 August, and the freeze isotherm advances more slowly than the melt isotherm. Freeze returns to the marginal seas a month later than at the pole, on 21 September. Near the North Pole, the length of the melt season is about 58 days, while in the marginal seas, the melt season is about 100 days.

5. AO SIGNATURE

The Arctic Oscillation (AO) (Thompson and Wallace 1998) is the first principal component of Northern Hemisphere sea level pressure. Using the East Anglian SAT data set, Thompson and Wallace (1998) show that the AO accounts for more than half of the winter (November- April) warming over the Eurasia land areas. Following Thompson and Wallace (1998), we estimate the contribution of the AO to trends in SAT over the Arctic Ocean. Figure 3a shows the SAT trends in winter (January-March), and Figure 3b shows the contribution of the AO to the SAT trends. The contribution of the AO is estimated by regressing the monthly SAT on the AO index and then multiplying by the trend in the AO (1.186 standard deviations/decade from 1979-1997). It should be noted that the regression may also produce a negative relationship, but for which the AO may still explain a significant portion of the variance in the SAT trend. As such, we take the absolute value of the regression. The residual SAT trends not explained by AO-related contributions are shown in Figure 3c, and the fraction of the SAT trend explained by the AO is shown in Figure 3d. The areas where the AO explains more than 50% of the SAT trend are shaded in gray. Over the Arctic Ocean, the AO evidently accounts for 74% of the warming over the eastern Arctic Ocean, but the AO does not explain the trends over eastern Siberia nor over the Canadian Archipelago.

6. CONCLUSIONS

The period 1979-1997 is one of the greatest warming periods during the past 150 years in the global climate record and is the warmest period on record (Jones et al. 1998). Over the globe, Jones et al. (1998) found this warming to be 0.16°C/decade and that this warming was greatest during winter and spring.

Over the Arctic land areas, warming trends in the SAT of 1°C/decade and 2°C/decade (1978-1997) were found by Jones et al. and by this study (1979-1997) during winter and spring, respectively. A cooling trend of 2°C/decade was also found over eastern Siberia. This trend is significant at the 95% level. The warming trend during spring spans most of the Arctic region and is significant at the 95% level over most of the eastern Arctic.

The winter and spring warming over the eastern hemisphere land masses extends out over the eastern Arctic Ocean, where the trends are 1°C/decade and 2°C/decade, respectively. The spring warming trend over the eastern Arctic Ocean is significant at > 95% level. The western Arctic Ocean and Alaska show no trend or even a cooling trend of 1°C/decade during winter.

On average, we find that melt begins in the marginal seas by the first week of June and advances rapidly over the Arctic Ocean to reach the pole by 19 June, 2 weeks later. The onset of freeze occurs at the pole on 16 August, and the freeze isotherm advances more slowly than the melt isotherm. Freeze returns to the marginal seas a month later than at the pole, on 21 September. Near the North Pole we estimate the length of the melt season is about 58 days, while at the margin of the Arctic Ocean the melt season is about 100 days.

The spring warming is associated with a lengthening of the melt season by 0.9 days/decade over the entire Arctic Ocean. The eastern Arctic Ocean shows an increasing trend of 2.6 days/decade; however, the western Arctic Ocean shows a slight decreasing trend of -0.4 days/decade in the length of the melt season.

These trends are related to the changes in circulation noted by Walsh et al. (1996), Maslanik et al. (1996), and Thompson and Wallace (1998). The location of the cyclonic anomaly favors stronger and more frequent warm, southerly advection in the east Arctic, and the production of new, thin ice in along the flaw leads of the Russian Marginal Seas, and in the eastern Arctic Ocean due to divergence of ice to the right of the wind forcing. Both of these processes increase the heat flux from the ocean during winter.

The AO accounts for more than half of the SAT trends over Alaska, Eurasia, and the eastern Arctic Ocean but less than half over the western Arctic Ocean.

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