Training Manual on Best Practices for Instruments and Methods of Ocean Observation

19-21 November 2012
Chennai, India

by

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This Training Manual on 'Best Practices for Instruments and Methods of Ocean Observation' is prepared on the occasion of the Regional Workshop on 'Best Practices for Instruments and Methods of Ocean Observation' organized from 19 - 21 November 2012 in Chennai India. The Regional Workshop has been organized by the World Meteorological Organization (WMO) and its constituent the Data Buoy Cooperation Panel (DBCP); the National Institute of Ocean Technology (NIOT); the Bay of Bengal Large Marine Ecosystem (BOBLME) Project; and the Bay of Bengal Programme Inter-Governmental Organisation (BOBP-IGO).

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For bibliographic purpose this document should be cited as:

Anon 2012. Training Manual on Best Practices for Instruments and Methods of Ocean Observation.
Regional Workshop on 'Best Practices for Instruments and Methods of Ocean Observation'.
19 – 21 November 2012, Chennai, India. WMO/DBCP; NIOT; BOBLME Project;
and BOBP-IGO, Chennai, India. pp 200.

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Printed at L S Graphics, Chennai, Tamil Nadu, India

Content

Introduction

Climate change and environmental issues have become one of the most critical issues for the global community. At no point of time in the past history of mankind, these issues have been discussed and debated as intensely as they are now. The World Meteorological Organization (WMO) of the United Nations in its annual day celebrations on 23 March 2012 highlighted that weather, climate and water services are of growing importance for the sustainable socio-economic development of present and future generations. It further said that advancing knowledge about weather, climate and water is crucial to agriculture and food security, disaster risk reduction, water management, health and many other sectors and will play a crucial role in shaping the global development agenda beyond 2015.

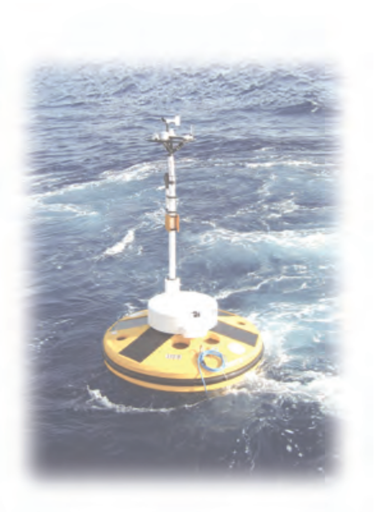
The Regional Workshop on the 'Best Practices for Instruments and Methods of Ocean Observation' is an outcome of the increasing focus of the global community on climate and environmental issues and the commitment of the concerned UN agencies and other inter-governmental bodies to monitor climate variability through the application of science and knowledge of climate information and prediction. Advocating the need for improved knowledge management in the area of climate science, Mr Michel Jarraud, Secretary General, WMO in his Foreword to the publication, 'Climate ExChange' released on the occasion of the First Extraordinary Session of the World Meteorological Congress in Geneva (29 – 31 October 2012) has rightly said "better climate services through improved quality, accuracy, timeliness, location specificity and user friendliness of the information will facilitate key social benefits. These include a reduction in the loss of life and property associated with climate change-related natural hazards, enhanced productivity in sectors reliant on climate and a more efficient management of institutions dependent on weather and climate".

This Regional Workshop has been possible through the joint initiative of various Organizations, in particularly the Data Buoy Cooperation Panel, the National Institute of Ocean Technology, the Bay of Bengal Programme inter-Governmental Organisation and the Bay of Bengal Large Marine Ecosystem Project. The larger objectives of the Workshop are aimed at:

- Demonstrating the crucial role of ocean observations for understanding and predicting weather, ocean and climate;
- Building capacity within regional institutes and individuals to apply new Ocean Observing System (OOS) Data for enhanced predictive capability for meteorological purposes, fisheries management and predicting extreme events;
- Learning practical implementation aspects for deployment and operation of data buoys at sea and collection, collation and processing of buoy data;
- Familiarizing with the advances in instruments and tools for collection of data and developments in Information and Communication Technology (ICT) for facilitating better understanding of the ocean/weather/climate events and
- Enhancing regional coordination and co-operation between all parties concerned.

This Regional Workshop has been possible with the support of the Secretary General of WMO, the Executive Secretary of IOC and the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the funding support received from the Data Buoy Cooperation Panel and the Bay of Bengal Large Marine Ecosystem Project. The National Institute of Ocean Technology and the Bay of Bengal Programme inter-Governmental Organisation have together shouldered the responsibilities for organization of the Workshop with the very proactive support received from the Ministry of Earth Sciences and the Ministry of Agriculture (Department of Animal Husbandry, Dairying and Fisheries), Government of India. The National Institute of Oceanography, Indian Meteorological Department, Indian Institute of Tropical Meteorology and the Indian National Centre for Ocean Information Services have cooperated in various ways, including their participation in the Workshop. The cooperation received from the participating countries in nominating their representatives to the Regional Workshop is duly acknowledged and it is hoped that their representatives will benefit from participation and extend the skills learnt to their work place. Finally, the cooperation and involvement of the industry in making this Regional Workshop productive and successful has been immense and without their support this task would not have been possible. Their valuable contributions have enabled documenting the best practices used for instruments and ocean observation and will be immensely useful for the practitioners of meteorology and ocean observing community, both in the region and elsewhere.

* * *



Regional Workshop on Best Practices for Instruments and Methods of Ocean Observation

19-21 November 2012, Chennai, India

PROSPECTUS

1.0 Background and Rationale

The Joint WMO-IOC Data Buoy Cooperation Panel (DBCP) is an official body of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and of the World Meteorological Organization (WMO). The work of the Panel supports the Observations Programme Area, overseen by the joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM). During the twenty-seventh Session of DBCP (DBCP-27) in Geneva, Switzerland from 26-30 September 2011, the Panel drawing on the success of the NIOT/BOBP-IGO Regional Workshop on 'Establishing a Cooperative Mechanism for Protection of Met Ocean Data and Tsunami Buoys in Northern Indian Ocean Region' held in Chennai, India from 6-7 May 2011 recognized the value of continued efforts in holding in-region activities. The Panel felt that such regional initiatives will further involve countries to utilise available data from buoys; permit research activities in a coordinated and systematic way and understand the importance of scientific instruments calibration, validation, data collection, etc. The Panel also reaffirmed its desire to actively encourage the participation of developing nations in the Panel's activities, as a means for these nations to assist the Panel in achieving and sustaining its objectives for a globally distributed data buoy network. The Panel therefore decided to continue its efforts to build and sustain utilisation of buoy data and to build-capacity in the Bay of Bengal region.

In this context, the National Institute of Ocean Technology (NIOT), Chennai under Ministry of Earth Sciences-Government of India, in association with the Bay of Bengal Programme Inter Governmental Organisation (BOBP- IGO), Chennai, the Joint WMO-IOC Data Buoy Cooperation Panel and the Bay of Bengal Large Marine Ecosystem (BOBLME) Project have planned to organize a Regional Workshop on Best Practices for Instruments and Methods of Ocean Observation in Chennai India, from 19 to 21 November, 2012. This Workshop would be one of the first efforts in bringing together the researchers, oceanographers and engineers from the Bay of Bengal region to interact with R&D Managers of reputed manufacturers involved in development of instruments related to Ocean Observation systems (OOS).

2.0 The Regional Workshop

The Regional Workshop is being jointly organized by the capacity building teams of the DBCP, the NIOT, the BOBLME Project and the BOBP-IGO.

WMO (*http://www.wmo.int*)**:** Established in 1950, the WMO is a specialized agency of the United Nations and has a membership of 189 Member States and Territories.WMO promotes cooperation in the establishment of networks for making meteorological, climatological, hydrological and geophysical observations, as well as the exchange, processing and

standardization of related data, and assists technology transfer, training and research. It also furthers the application of meteorology to public weather services, agriculture, aviation, shipping, the environment, water issues and the mitigation of the impacts of natural disasters. In collaboration with other UN agencies and the National Meteorological and Hydrological Services, WMO supports the implementation of a number of environmental conventions and is instrumental in providing advice and assessments to governments on related matters.

The Data Buoy Cooperation Panel *(DBCP- http://www.jcommops.org/dbcp)*: The DBCP is an official joint body of the WMO and the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO). It consists of the data buoy component of the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the Global Ocean Observing System (GOOS). The DBCP coordinates the use of autonomous data buoys to observe atmospheric and oceanographic conditions over ocean areas; increase the quantity, quality and timeliness of atmospheric and oceanographic data in ocean areas; and improve global forecasts of weather and ocean conditions, plus also contributes to climate study and oceanographic research.

NIOT *(http://www.niot.res.in)*: Considering the importance of the oceans, the Ministry of Earth Sciences (formerly known as the Department of Ocean Development), established the NIOT in 1993 as an autonomous society to develop reliable indigenous technology to solve the various engineering problems associated with harvesting of non-living and living resources in the Indian Exclusive Economic Zone (EEZ), which is about two-thirds of the land area of India. Of the many technology groups and programmes/projects that the NIOT runs, the OOS is an important

Operational Programme. This Programme is mandated with the important task of developing technologies for OOS and their operation and maintenance.

BOBLME Project *(http://www.boblme.org)*: The Project is implemented and executed by the Food and Agriculture Organization of the United Nations (FAO) and funded by the Global Environment Facility (GEF), Norway, the Swedish International Development Cooperation Agency, the participating Governments (Bangladesh, India, Indonesia, Malaysia, Maldives, Myanmar, Sri Lanka and Thailand) and the National Oceanic and Atmospheric Administration of the United States. The Project aims to improve the lives of the coastal populations through better regional management of the Bay of Bengal (BoB) environment and its fisheries. It addresses fisheries resources management, coastal habitat conservation, ecosystem health and pollution, as well as large-scale processes in the BoB. Under the large-scale processes area of work, the Project aims at sharing information with other regional and global environmental monitoring programmes for improved understanding of the BOBLME ecological functions and processes, including *inter alia* improved understanding of the large-scale oceanographic and ecological processes controlling BOBLME's living resources.

BOBP-IGO (*http://www.bobpigo.org*)**:** The BOBP-IGO is mandated to enhance cooperation among member-countries, other countries and organizations in the region and provide technical and management advisory services for sustainable coastal fisheries development and management in the Bay of Bengal region. The BOBP was initially established in 1979 as a field Project of the Food and Agriculture Organization of the United Nation. In April 2003, the BOBP became an IGO. The Headquarters of the Organisation are located in Chennai and presently Bangladesh, India, Maldives and Sri Lanka are members of the IGO. The Organisation works very closely with the governments as also the fishers and their associations in the BoB region.

Objectives

The Workshop is aimed at capacity building of scientist, researchers, engineers and managers on best practices for calibration and testing instruments for ocean observation systems.

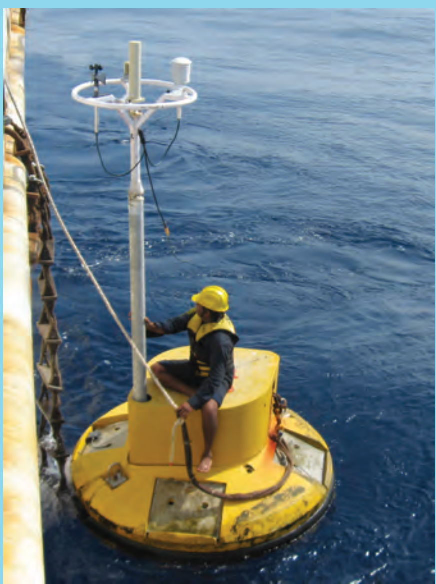
The Workshop will act as a platform and will unveil insight to new meteorological and oceanographic observational systems, moorings, sub-sea cables, batteries, telemetry and brings together scientists, engineers, technicians and key manufacturers of marine instruments and prospective vendors who utilise/work on ocean observational systems. This Workshop will also provide an opportunity to understand the design and development issues faced by the user community. Experts from relevant industry will be invited to provide solutions on technical issues and interact with the participants.

The Workshop will offer an exceptional opportunity for participants both to learn new skills and to make significant and ongoing contributions to their own programmes.

Further the Workshop will also concentrate on present and future trends in OOS, methods and standards that are followed worldwide and the calibration techniques offered by OEM's. The expected outcome of this Workshop will generate awareness on new OOS and shall bring up new ventures and business solutions.

This Workshop is also likely to contribute to the recent initiatives of the Ministry of Earth Sciences, Government of India on the establishment of a National Centre for Atmospheric Technology (NCAT), which would lead to technological developments for an end-to-end, integrated and inter-operable network of Indian atmospheric observations, data communications, management and delivery systems, supported by comprehensive user-oriented software utilities for various applications. The NCAT is expected to emerge as a world class institution with calibration and testing instruments of global standards as a WMO Regional Instrumentation Centre.

New Users: This Workshop will attract participants from the countries surrounding the Bay of Bengal - Bangladesh, India, Indonesia, Malaysia, Maldives,



MET-OCEAN & TSUNAMI BUOY LOCATIONS

Myanmar, Sri Lanka, Thailand apart from DBCP and BOBLME representatives.

Some of the major outcomes of the Regional Workshop would be:

- Best practices adopted globally in handling meteorological and oceanographic equipment;
- Common practices, training on calibration and troubleshooting techniques;
- New observation systems and data loggers;
- Hands on experience on various sensors, observational systems; and
- Information sharing and networking among the countries within and also outside the region;

Date and Venue

The Regional Workshop will be organized from 19 – 21 November 2012 at the NIOT Campus, Velachery – Tambaram Main Road, Narayanapuram, Pallikaranai, Chennai – 600 100,Tamil Nadu, India (Tel: +91- 44- 66783300, Fax: +91- 44- 22460275; Email: workshop2012@niot.res.in; Website: www.niot.res.in).

Format of the Workshop

The Regional Workshop shall include 06 technical sessions, training on calibration and troubleshooting and visit to stalls set up by leading industries displaying their new products. The participants will have a hands on experience, on problems faced in handling sensors, etc. Copies of the technical presentations shall be distributed to the participants of the Regional Workshop.

Conduct of the Workshop

The National Workshop will be conducted in English.

Participation

The Workshop participants shall include representatives from the (i) Ministries/ Departments of Oceanography, Meteorology, Fisheries and Research Institutions working on oceanography or marine sciences.

Coordination of Workshop

The BOBP-IGO will coordinate the Regional Workshop arrangements with assistance from Dr R Venkatesan, Head-Ocean Observation Systems, NIOT.

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Regional Workshop on Best Practices for Instruments and Methods of Ocean Observation

19 - 21 November 2012, Chennai, India

Programme

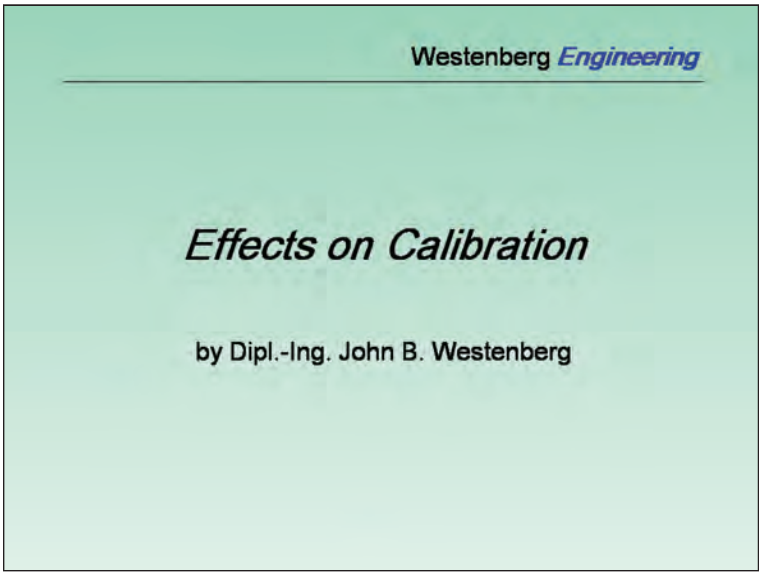
19/11/2012	**Day 1**	
Time (hrs)	**Event**	
08:30 - 09:15	Registration	
09:15 - 10:15	Opening of the Workshop	
10:15 - 10:45	Group Photo and High Tea	
Session 1		
Introductory Presentations		
Time (hrs)	**Institution/Country**	
10:45 - 11:45	Presentations by MoES, NIOT, INCOIS, IITM and NIO, India	
11:45 - 13:00	Country Presentations – Bangladesh, Indonesia, Kenya, Korea, Malaysia, Myanmar Oman, Pakistan, Sri Lanka and Thailand	
13:00 - 14:00	Lunch	
14:00 - 14:15	Introductory talk on WMO Integrated Global Observing System (WIGOS) programme by Dr Etienne Charpentier, WMO, Switzerland	
Session 2		
Theme: Meteorological and Coastal Observation		
Time (hrs)	**Title**	**Presenter**
14:15 - 15:00	Fluid dynamics, wind tunnels and calibration of anemometers	M/s. Westernberg Engineering, Germany
15:00 - 15:45	Humidity measurement and calibration	M/s. Rotronic South East Asia Pte Ltd, Singapore
15:45 - 16:00	Refreshments	
16:00 - 16:45	Hydrolab, your partner for water quality monitoring	M/s. OTT Hydromet, USA
16:45 - 17:30	Ensuring quality in operating CODAR SeaSonde Coastal Networks	M/s. CODAR Ocean Sensors Ltd., USA
17:30 - 18:00	Visit to NIOT facilities	
20/11/2012	**Day 2**	
08:45	Arrival at NIOT	
Session 3		
Theme: Ocean Observation		
Time (hrs)	**Title**	**Presenter**
09:00 - 09:30	Sensing conductivity, temperature, pressure and dissolved oxygen using Sea-Bird Electronics' sensors and instrumentation	M/s. Sea-Bird Electronics, Inc., USA
09:30 - 10:00	Optical and nutrient measurements for long-term biogeochemical monitoring using WET Labs and Satlantic Instrumentation	M/s. WET labs, USA

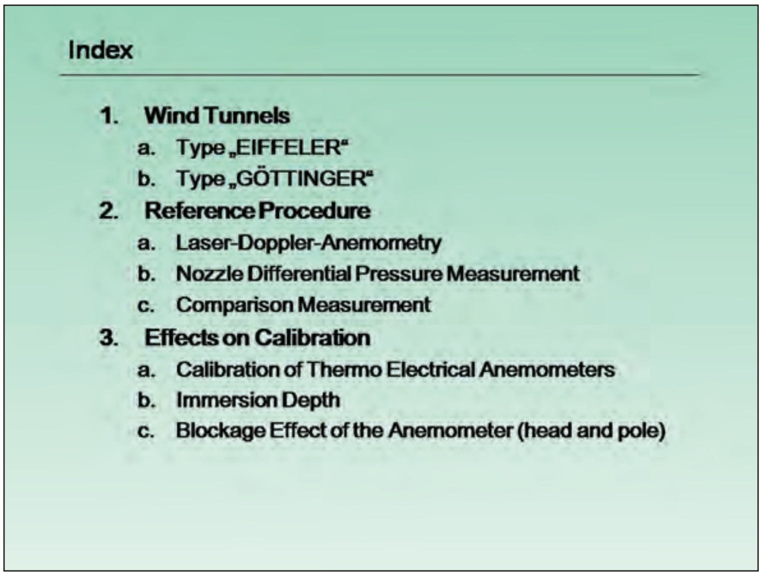
10:00 - 11:00	• Underwater positioning solution using acoustic and inertial technologies • Acoustic releases application	M/s. IXBLUE, France
11:00 - 11:15	Refreshments	
11:15 - 12:00	Multi-parameter observations from coastal waters to the deep sea: focus on quality control and sensor stability	M/s. Xlyem Inc./Sontek/YSI Inc. /AADI, USA
	Session 4	
Theme: Satellite Communication		
Time (hrs)	**Title**	**Presenter**
12:00 - 12:15	Over view of INSAT communication for data collection	Mr Tata Sudhakar
12:15 - 12:30	Status of satellite communications for data transmission	M/s. Elektronik Lab, India
12:30 - 13:00	Operational ocean *in situ* data collection by satellite	M/s. CLS/Argos, France
13:00 - 14:00	Lunch	
	Session 5	
Theme: Ocean Data Collection-I		
Time (hrs)	**Title**	**Presenter**
14:00 - 14:40	Minos X profiler with Xchange sensors	M/s. AML Oceanographic, Canada
14:40 - 15:20	Automated flowing pCO2 measuring system	M/s. General Oceanics Inc., USA
15:20 - 15:35	Refreshments	
15:35 - 16:00	Echo sounder	M/s. Cadden, France
16:00 - 18:30	Hands on demo on the instruments by industry experts and display of equipment by Kongsberg Maritime Ltd., Norway and other industries: Venue- Varuna Hall & Stalls	
21/11/2012	**Day 3**	
08:45	Arrival at NIOT	
	Session 6	
Theme: Ocean Data Collection-II		
Time (hrs)	**Title**	**Presenter**
09:00 - 09:45	Sub-sea monitoring applications and advance acoustic telemetry techniques	M/s. Sonardyne, Singapore
09:45 - 10:30	Moored buoys	M/s. Fugro Oceanor AS, Norway
10:30 - 11:00	ADCP technology	M/s. Teledyne RD Instruments, USA
11:00 - 11:15	Refreshments	
Panel Discussion		
11:15 - 12:15	Panel Discussion	
12:15 - 13:00	Closing of the Workshop	
13:00 - 14:00	Lunch	
14:00 - 17:30	Group discussion and interaction with industry	

Meteorological and Coastal Observation

Fluid dynamics, wind tunnels and calibration of anemometers

Westenberg Engineering consists of the engineering office 'Westenberg Engineering' and the manufacturing company 'Westenberg Wind Tunnels'. The Company Westernberg Engineering was founded by Mr. John B. Westenberg, Graduate Engineer in 1992. For organizational reasons, the Company Westenberg Wind Tunnels was founded in addition to this in 2008. The Company Westenberg Engineering deals with engineering tasks and, additionally, it offers services dealing with the subject of fluids and fluid measuring techniques. For these services the Company can also make use of its own calibration laboratory accredited by the German Calibration Service. Based on its long-standing experience, the Company designs and manufactures wind tunnels and offers services dealing with fluid dynamics.

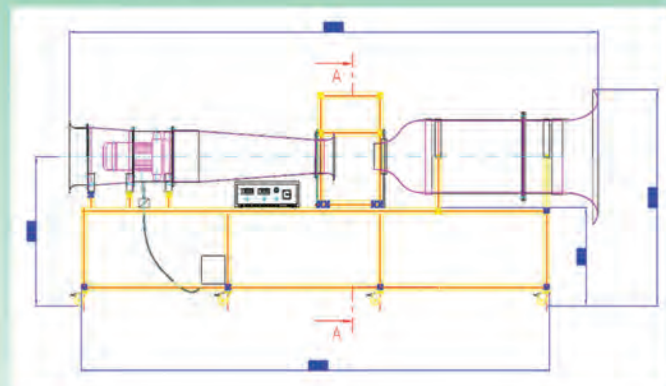




Wind Tunnels

- A wind tunnel is a test bed which is used for the calibration of anemometers.
- A wind tunnel generates a constant air flow with an uniform velocity distribution over the cross section and should have a degree of turbulence lower than 1%.
- We differentiate between wind tunnels with air recirculation and without air recirculation.

Wind Tunnels



Wind Tunnels

Characteristics of a wind tunnel type "EIFFELER"

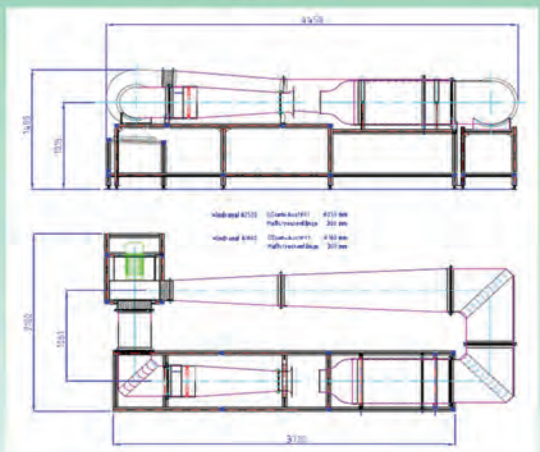
- It is a wind tunnel without air recirculation
- The air flow is ingested from the calm ambient air
- There is a negative pressure in the test chamber
- Air flow quality is influenced by pressure fluctuations and surges in the ambient air
- No corners which can cause turbulence

Wind Tunnels

Characteristics of a wind tunnel type "EIFFELER"

- Because of low friction losses and the ingestion of the calm ambient air there is a low increase of temperature in the test chamber
- Compared to a wind tunnel type "GÖTTINGER" the energy demand is higher
- Lower manufacturing effort than a wind tunnel type "GÖTTINGER"
- No twist effects caused by the fan

Wind Tunnels



Wind Tunnels

Characteristics of a wind tunnel type "GÖTTINGER"

- It is a wind tunnel with air recirculation
- There is an open measuring section (with ambient pressure) instead of a measuring chamber (with negative pressure)
- Because of higher friction losses there is a higher increase of temperature in the wind tunnel and in the measuring section
- According to the application a cooling system is helpful
- Quiet during operation

Reference Procedure

- Reference Procedure
  - Laser-Doppler-Anemometry
  - Nozzle Differential Pressure Measurement System
  - Comparison Measurement

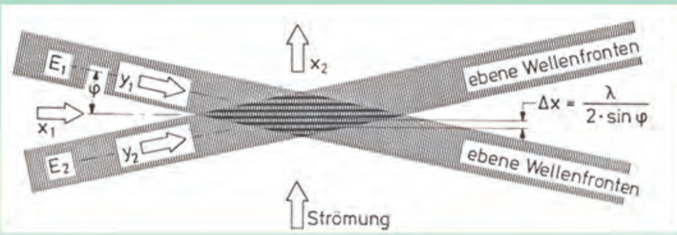
Reference Procedure

Characteristics of the LDA measurement system

- Very high accuracy in a wide velocity range (0,2 % from the value)
- For measuring velocity of gases and fluids
- Independent of the air density
- Contact less
- Measuring of temporal velocity fluctuations

Reference Procedure

Functional principle of the LDA measurement system



Reference Procedure

Characteristics of the Nozzle Differential Pressure Measurement System

- Dependent on the air density
- High accuracy, dependent on
  - the accuracy of the absolute pressure transmitter
  - the accuracy of the differential pressure transmitter and
  - the accuracy of the temperature transmitter
- No blockage effect
- Building of a nozzle factor
- Applicable from 1 m/s up
- Several differential pressure modules are necessary

Reference Procedure

Formula for the Nozzle Differential Pressure Measurement System

$$\Delta p_{stat} + \frac{\rho}{2}\left(\frac{\dot{V}}{A_1}\right)^2 = \frac{\rho}{2}\left(\frac{\dot{V}}{A_2}\right)^2 \Rightarrow \frac{2\Delta p_{stat}}{\rho} = \dot{V}^2\left(\frac{1}{A_2{}^2} - \frac{1}{A_1{}^2}\right)$$

$$v_2 \cdot A_2 = \sqrt{\frac{\frac{2\cdot\Delta p_{stat}}{\rho}}{\frac{1}{A_2{}^2} - \frac{1}{A_1{}^2}}} \Rightarrow v_2 = \sqrt{\frac{\frac{2\cdot\Delta p_{stat}}{\rho}}{1-\left(\frac{A_2}{A_1}\right)^2}}$$

Reference Procedure

Characteristics of the Comparison Measurement

- Low cost
- Most inexact measurement
- Only probes of the same type are compared
- The reference has no higher accuracy than the probe

Effects on Calibration

Calibration of Thermo Electrical Anemometers

- The thermo electrical anemometer does not measure the air velocity but the mass flow
- The mass flow contains the air density
- The air density contains the barometric pressure and the air temperature
- A compensation of the changes of the air density is essential, otherwise a measurement error is the effect

Effects on Calibration

Formula air density

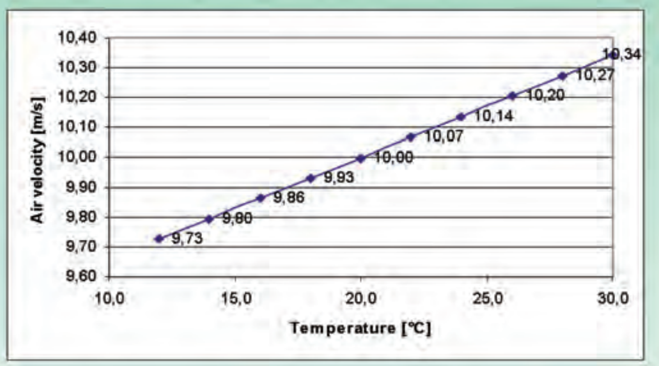
$$\rho = \frac{p_{atmos}}{R \cdot T}$$

Formula air velocity

$$v = \frac{\dot{m} \cdot R \cdot T}{A \cdot p_{atmos}}$$

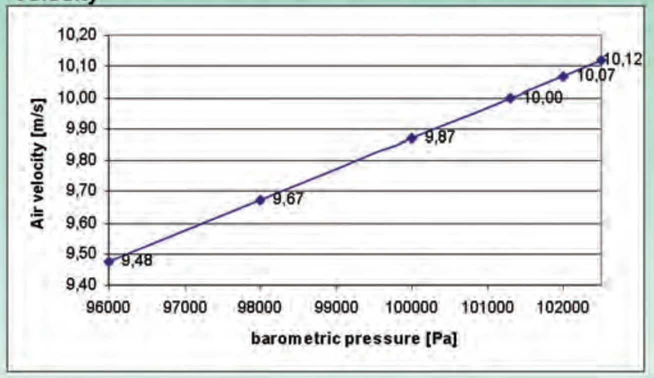
Effects on Calibration

Influence of changing temperature on air velocity



Effects on Calibration

Influence of changing barometric pressure on air velocity



Effects on Calibration

Influence of Immersion Depth

- If you place a probe in a wind tunnel the test bed resistance raises and the volume flow decreases.
  Therefore: The anemometer should indicate a lower value.
- However the deeper the anemometer is in the air flow, the higher is the value displayed.
  So, what happens?

Effects on Calibration

Influence of Immersion Depth

- During the calibration the anemometer is placed in the measurement section. The vane and a part of the pole extend into the cross section of the nozzle.
- The air flows through the vane and around the pole, not only radial around the pole but also axial.
- The axial air flow leads to the head of the anemometer and accelerates the vane. The display indicates the value + the value of the influence of the pole

Effects on Calibration

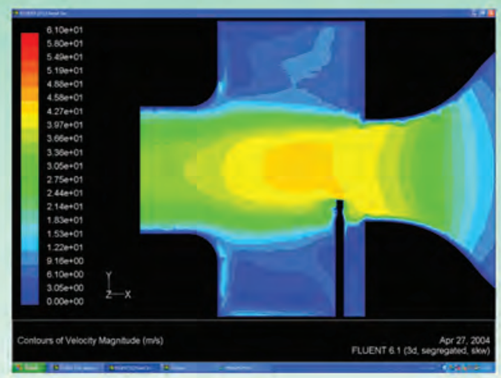
Influence of Immersion Depth

The influence is dependent on:

- The geometry of the anemometer
- The body structure of the pole
- The nozzle cross section

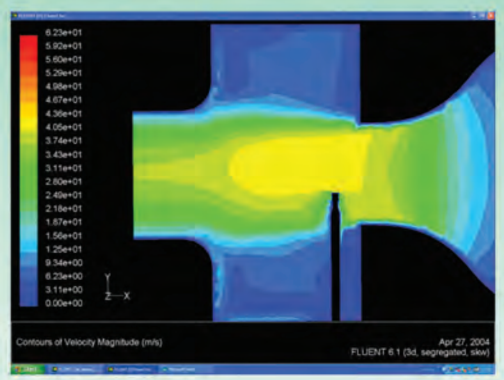
Effects on Calibration

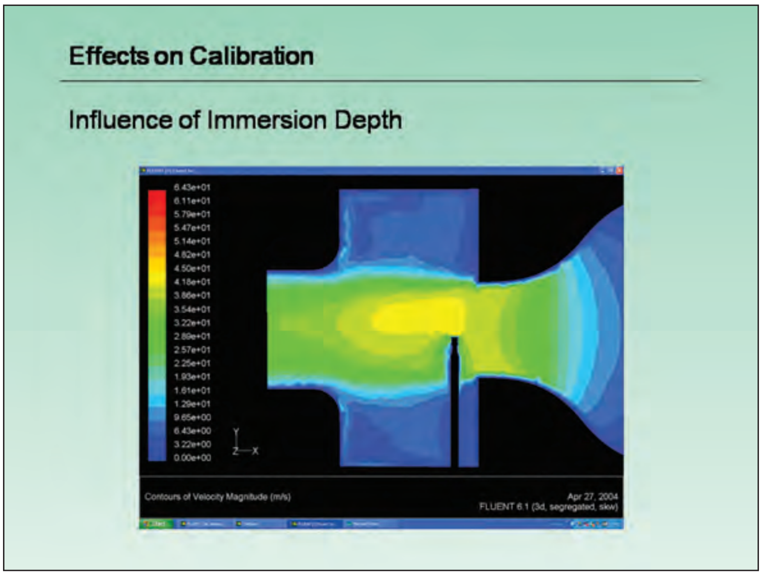
Influence of Immersion Depth



Effects on Calibration

Influence of Immersion Depth




Effects on Calibration
Influence of Immersion Depth
Contours of Velocity Magnitude (m/s)
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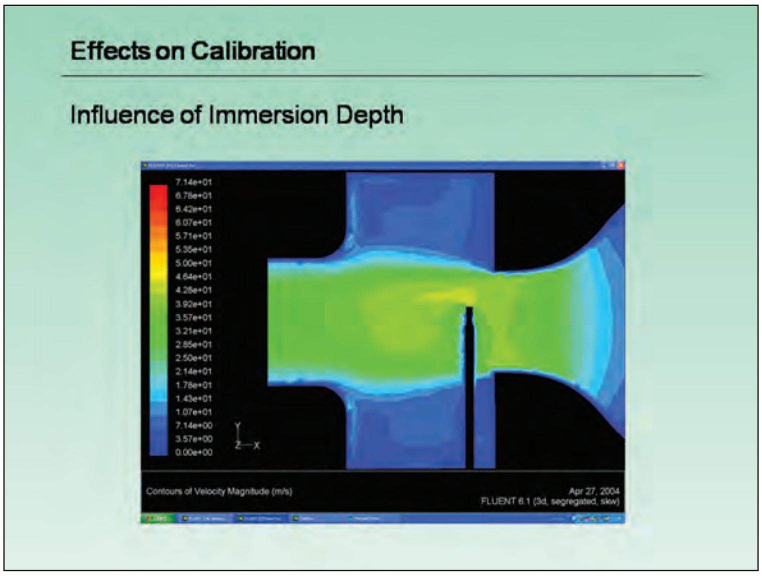
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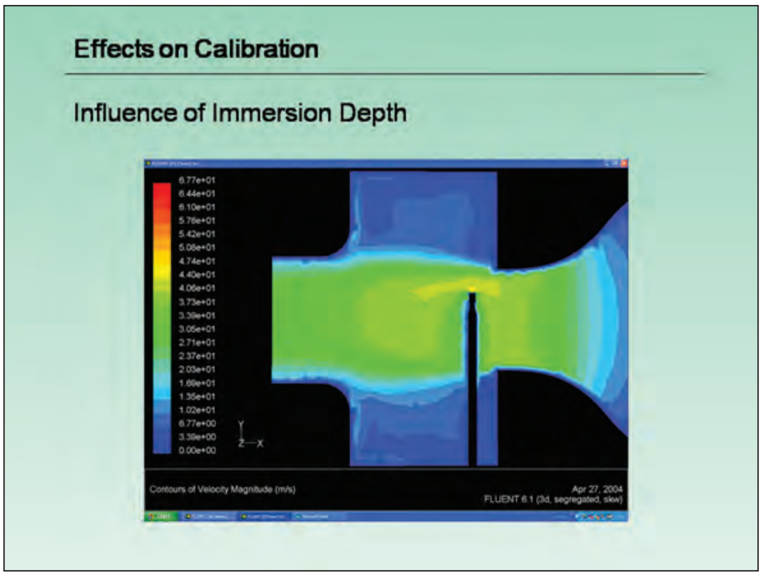
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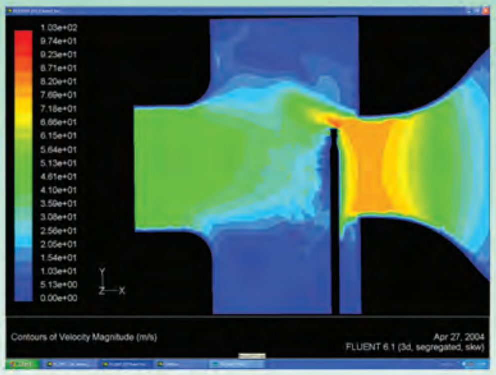


Effects on Calibration

Influence of Immersion Depth

How can this influence be minimized?

- Every calibration lab should use the same calibration procedure
- Every calibration lab should use the same nozzle cross section
- Every calibration lab should use the same place for fixing the air probes in the measurement section

Effects on Calibration

The Blockage Effect

- This effect is influenced by the immersion depth and the size of the anemometer
- Basically: the bigger the head and the pole of an anemometer is the higher is the blockage effect in the flow field.
- This effect influences the wind tunnel as well as the calibration

Effects on Calibration

The Blockage Effect

What happens in the wind tunnel?

- The pressure accumulates against the flow direction. An influence on the result of the reference is possible.
- The test bed resistance in the wind tunnel raises up and the volume flow decreases
- In a closed measuring section the air velocity raises around the probe. The value at the display increases.
- In an open measuring section the air flow enlarges around the probe. The value at the display decreases.

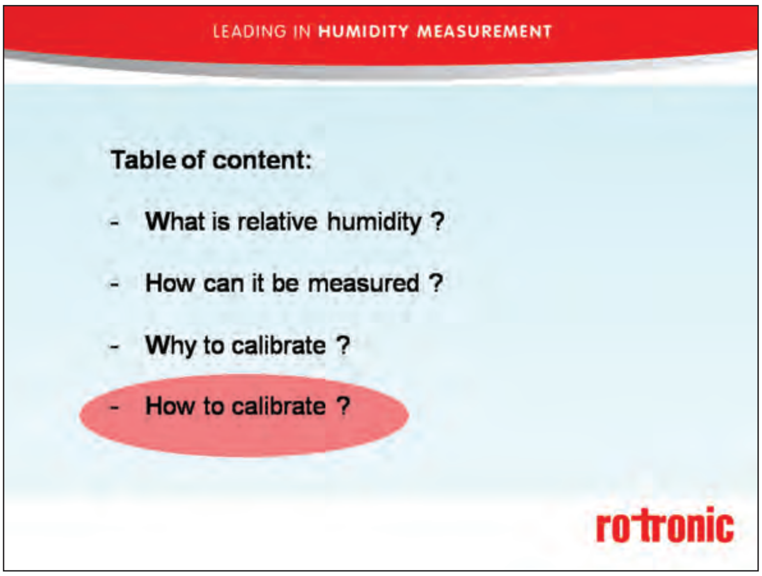
The End

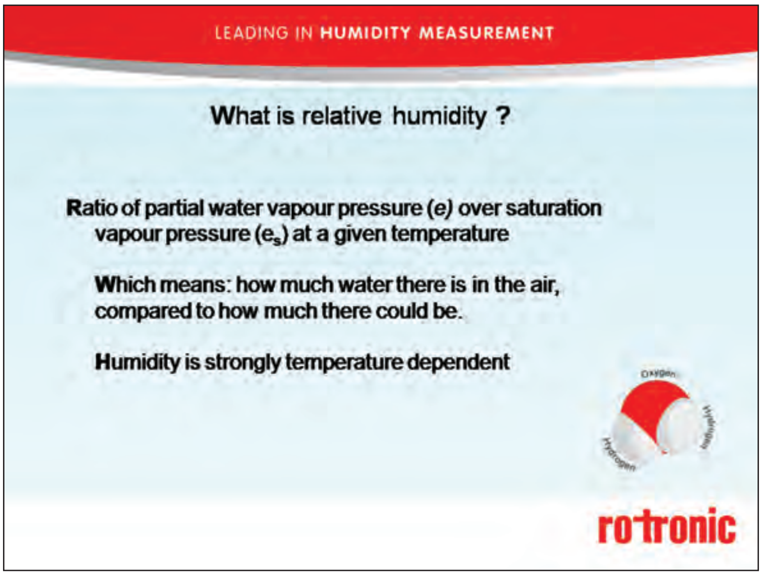
Thank you for paying attention!

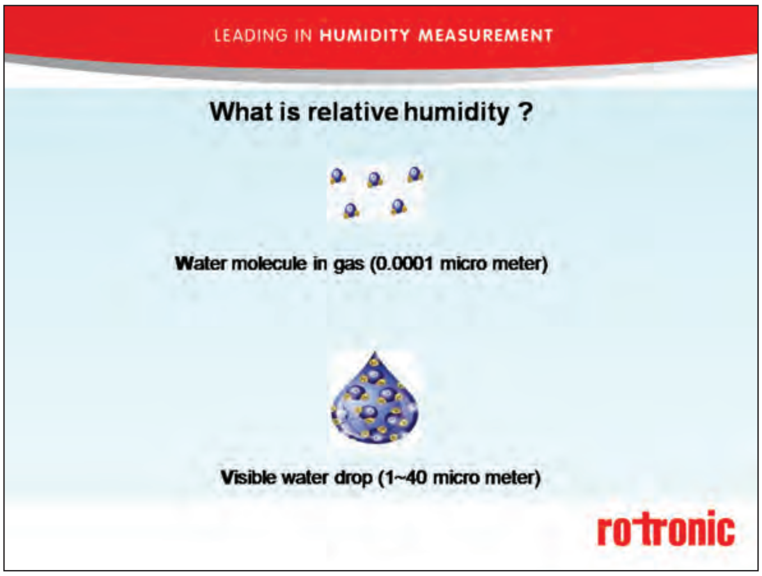
* * *

Humidity measurement and calibration

Rotronic was founded in 1965. It is privately owned and is managed by the Schroff family. The Company is positioned as an internationally aligned trading and manufacturing company, and offers the most varied solutions for dealers and industrial customers. Its lines of business include products for measuring humidity and temperature, everything to do with IT accessories and networking technology, solutions in the areas of 19" equipment and uninterrupted power supply for safety systems and all types of devices. The Company realises about 60 percent of its turnover abroad. In humidity and temperature measurement, the Company is one of the strongest players worldwide. The 9 subsidiaries are located in the main global markets, such as the USA, China, Singapore, the UK, France, Italy and Germany. The newest branch office was opened in Milan in 2010.




LEADING IN HUMIDITY MEASUREMENT
What is relative humidity ?
Ratio of partial water vapour pressure (*e*) over saturation vapour pressure (e_s) at a given temperature
Which means: how much water there is in the air, compared to how much there could be.
Humidity is strongly temperature dependent
rotronic


LEADING IN HUMIDITY MEASUREMENT
What is relative humidity ?
Water molecule in gas (0.0001 micro meter)
Visible water drop (1~40 micro meter)
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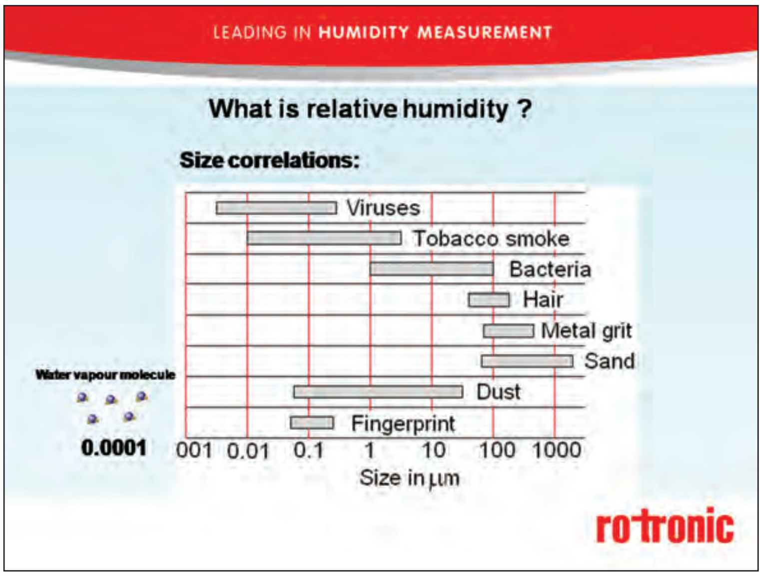
LEADING IN HUMIDITY MEASUREMENT
What is relative humidity ?
Size correlations:
Viruses
Tobacco smoke
Bacteria
Hair
Metal grit
Sand
Dust
Fingerprint
Water vapour molecule
0.0001
001 0.01 0.1 1 10 100 1000
Size in µm
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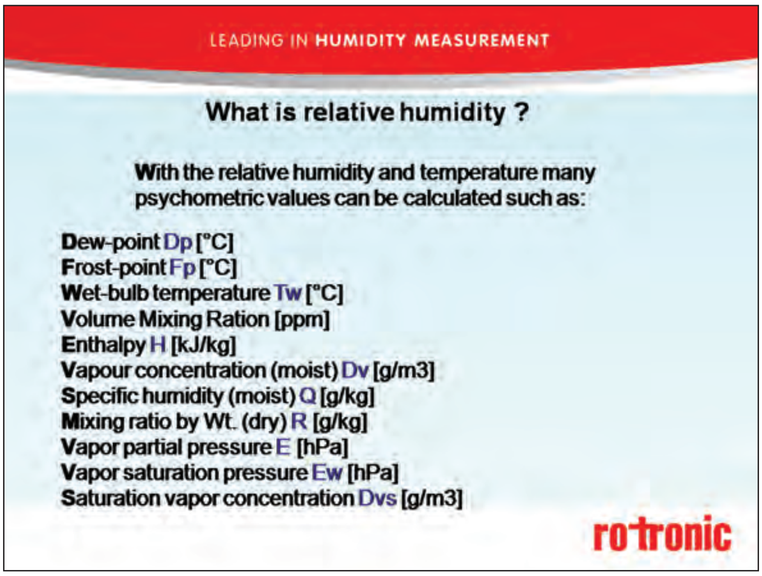
LEADING IN HUMIDITY MEASUREMENT
What is relative humidity ?
Examples everybody realizes everyday:
WARM MOIST AIR
COLD GLASS
CONDENSATION
rotronic


LEADING IN HUMIDITY MEASUREMENT
What is relative humidity ?
With the relative humidity and temperature many psychometric values can be calculated such as:
Dew-point Dp [°C]
Frost-point Fp [°C]
Wet-bulb temperature Tw [°C]
Volume Mixing Ration [ppm]
Enthalpy H [kJ/kg]
Vapour concentration (moist) Dv [g/m3]
Specific humidity (moist) Q [g/kg]
Mixing ratio by Wt. (dry) R [g/kg]
Vapor partial pressure E [hPa]
Vapor saturation pressure Ew [hPa]
Saturation vapor concentration Dvs [g/m3]
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LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
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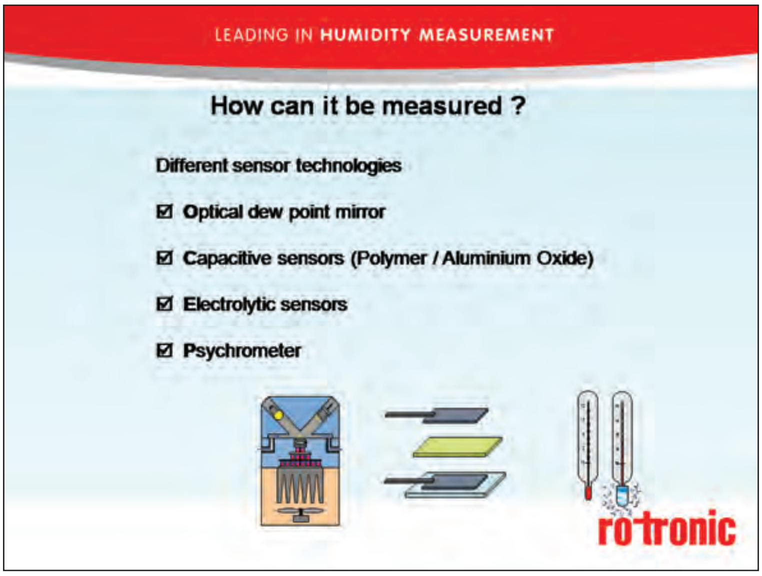
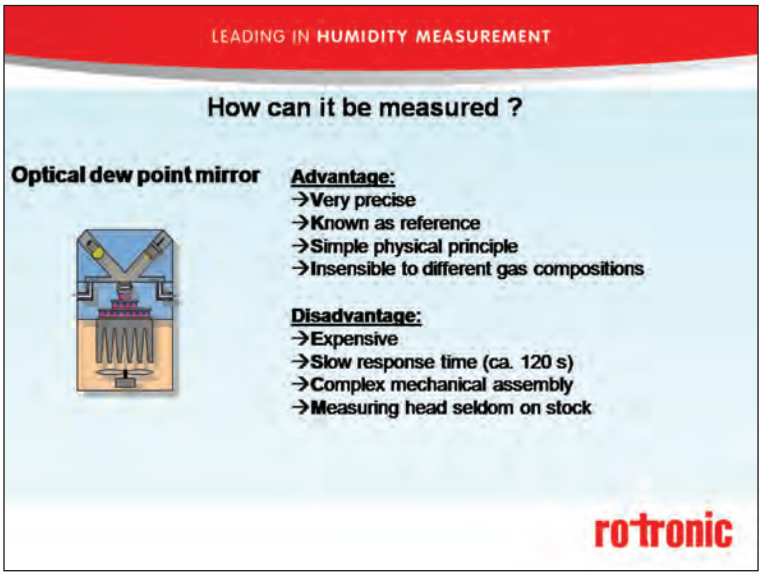
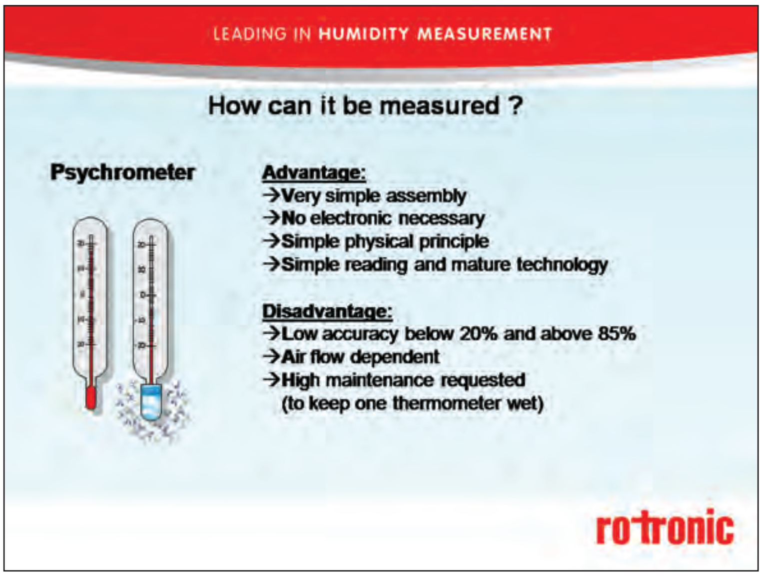

LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Different sensor technologies
☑ Optical dew point mirror
☑ Capacitive sensors (Polymer / Aluminium Oxide)
☑ Electrolytic sensors
☑ Psychrometer
rotronic


LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Optical dew point mirror
Advantage:
→Very precise
→Known as reference
→Simple physical principle
→Insensible to different gas compositions
Disadvantage:
→Expensive
→Slow response time (ca. 120 s)
→Complex mechanical assembly
→Measuring head seldom on stock
rotronic


LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Psychrometer
Advantage:
→Very simple assembly
→No electronic necessary
→Simple physical principle
→Simple reading and mature technology
Disadvantage:
→Low accuracy below 20% and above 85%
→Air flow dependent
→High maintenance requested
(to keep one thermometer wet)
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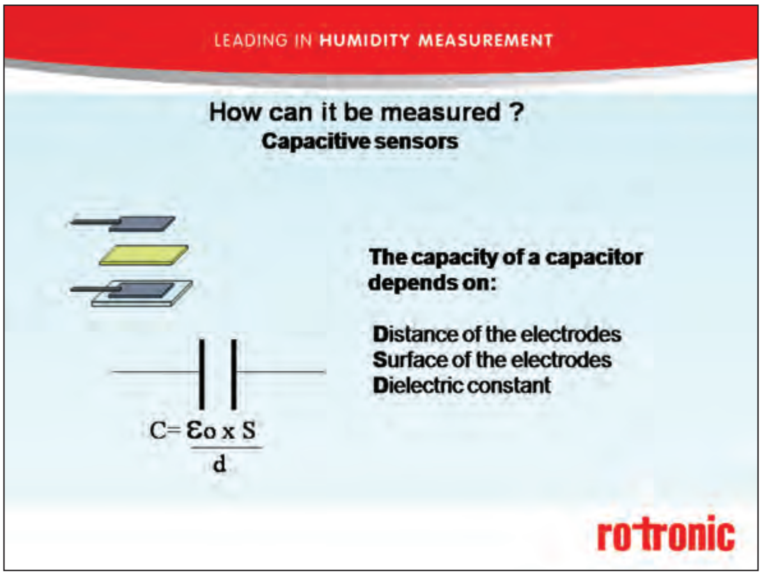
LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Capacitive sensors
The capacity of a capacitor depends on:
Distance of the electrodes
Surface of the electrodes
Dielectric constant
C= Ɛo x S / d
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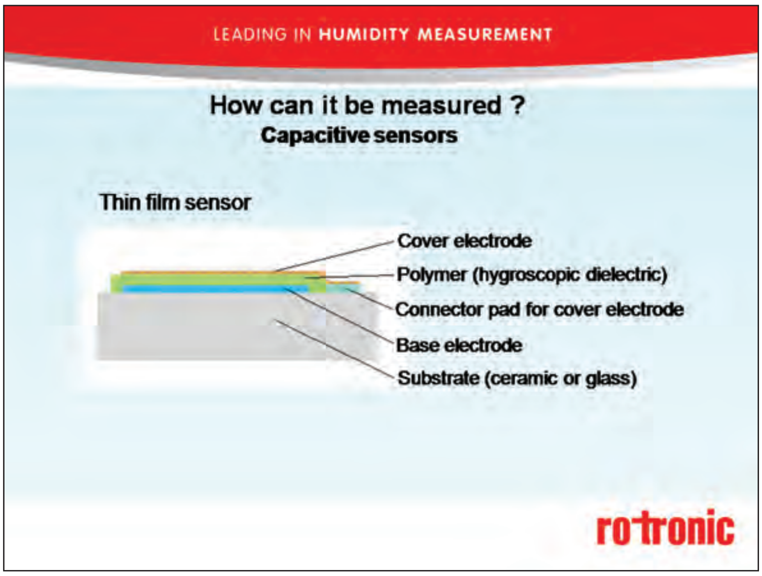
LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Capacitive sensors
Thin film sensor
Cover electrode
Polymer (hygroscopic dielectric)
Connector pad for cover electrode
Base electrode
Substrate (ceramic or glass)
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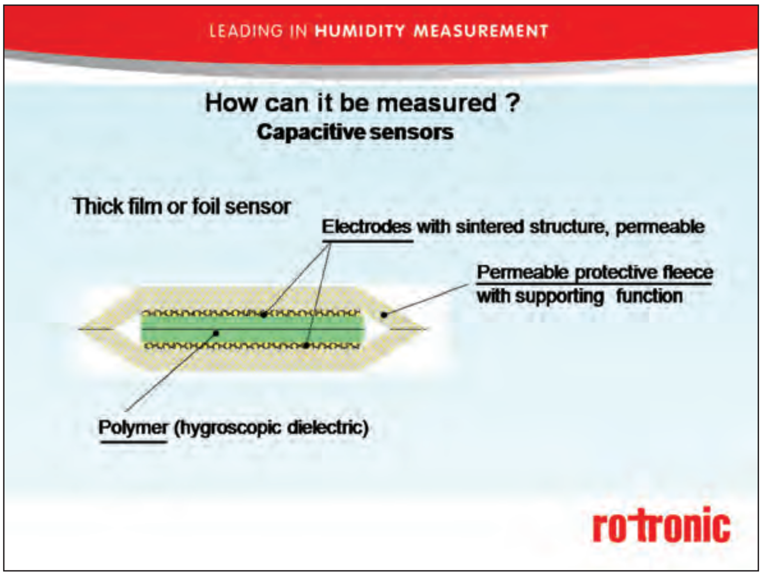
LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Capacitive sensors
Thick film or foil sensor
Electrodes with sintered structure, permeable
Permeable protective fleece with supporting function
Polymer (hygroscopic dielectric)
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LEADING IN **HUMIDITY MEASUREMENT**

How can it be measured ?

Capacitive sensors

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LEADING IN **HUMIDITY MEASUREMENT**

How can it be measured ?

Capacitive sensors

How it works:

The polymer (dielectric) between the electrodes is hygroscopic, that means it tends to equilibrate with it's environment. This independent of prevailing pressure.

Thus it either absorbs or releases water molecules, which in turn changes the capacity of the capacitor. This capacity can then be measured.

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LEADING IN **HUMIDITY MEASUREMENT**

How can it be measured ?

Capacitive sensors

To be avoided:

→ Do not touch the sensors with fingers

→ Avoid dust accretion

→ Position the probes correctly and use the right filters

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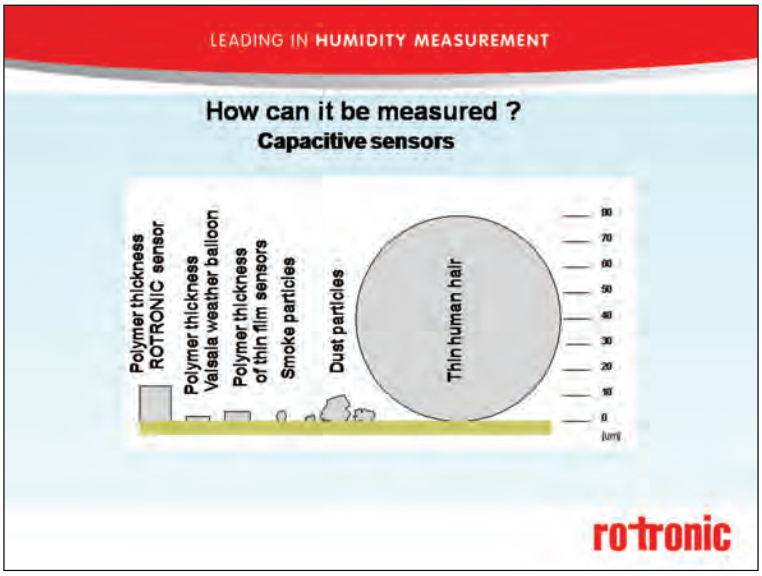
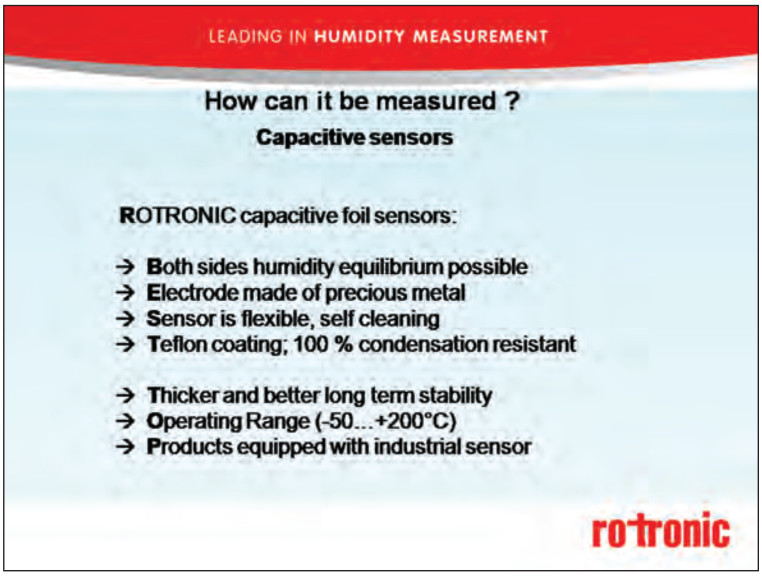

LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Capacitive sensors
Polymer thickness ROTRONIC sensor
Polymer thickness Vaisala weather balloon
Polymer thickness of thin film sensors
Smoke particles
Dust particles
Thin human hair
80
70
60
50
40
30
20
10
0
[um]
rotronic


LEADING IN HUMIDITY MEASUREMENT
How can it be measured ?
Capacitive sensors
ROTRONIC capacitive foil sensors:
→ Both sides humidity equilibrium possible
→ Electrode made of precious metal
→ Sensor is flexible, self cleaning
→ Teflon coating; 100 % condensation resistant
→ Thicker and better long term stability
→ Operating Range (-50...+200°C)
→ Products equipped with industrial sensor
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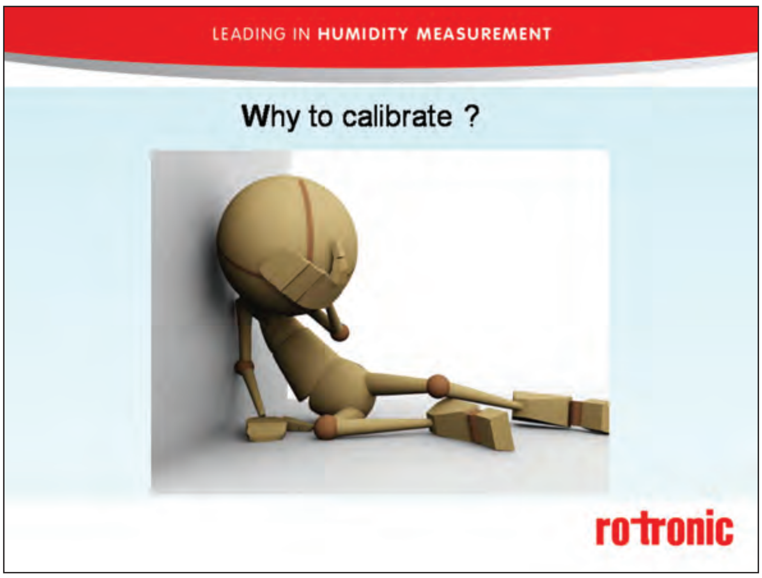
LEADING IN HUMIDITY MEASUREMENT
Why to calibrate ?
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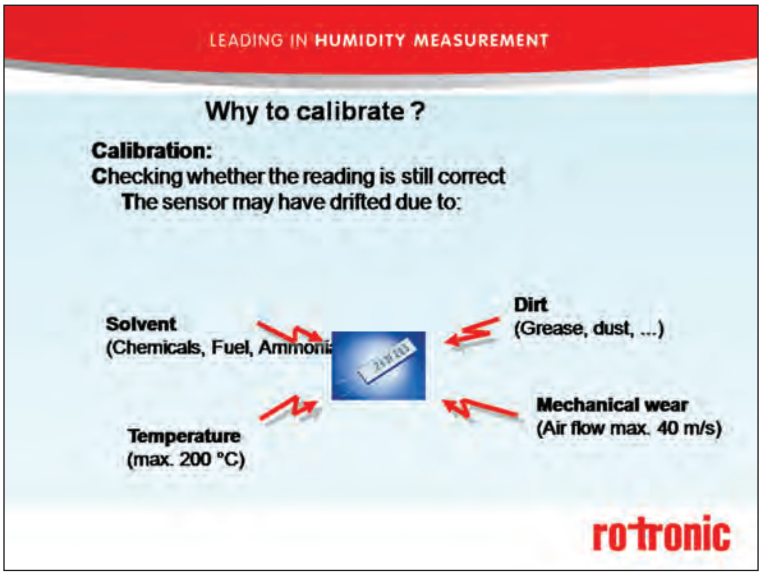
LEADING IN HUMIDITY MEASUREMENT
Why to calibrate ?
Calibration:
Checking whether the reading is still correct
The sensor may have drifted due to:
Solvent
(Chemicals, Fuel, Ammoni
Dirt
(Grease, dust, ...)
Temperature
(max. 200 °C)
Mechanical wear
(Air flow max. 40 m/s)
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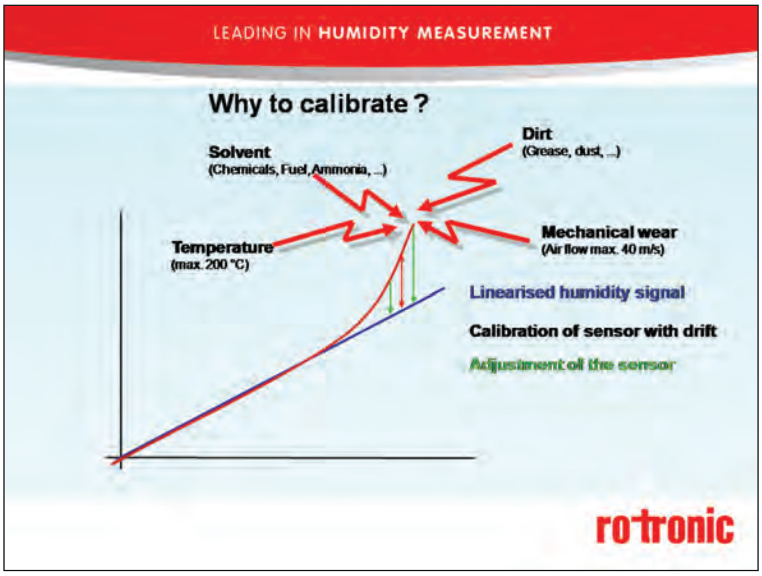
LEADING IN HUMIDITY MEASUREMENT
Why to calibrate ?
Solvent
(Chemicals, Fuel, Ammonia, ...)
Dirt
(Grease, dust, ...)
Temperature
(max. 200 °C)
Mechanical wear
(Air flow max. 40 m/s)
Linearised humidity signal
Calibration of sensor with drift
Adjustment of the sensor
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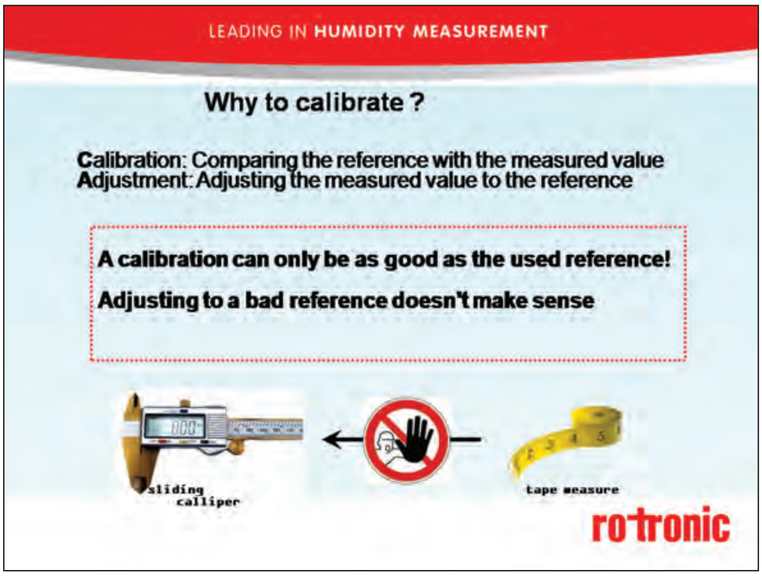
LEADING IN HUMIDITY MEASUREMENT
Why to calibrate ?
Calibration: Comparing the reference with the measured value
Adjustment: Adjusting the measured value to the reference
A calibration can only be as good as the used reference!
Adjusting to a bad reference doesn't make sense
sliding calliper
tape measure
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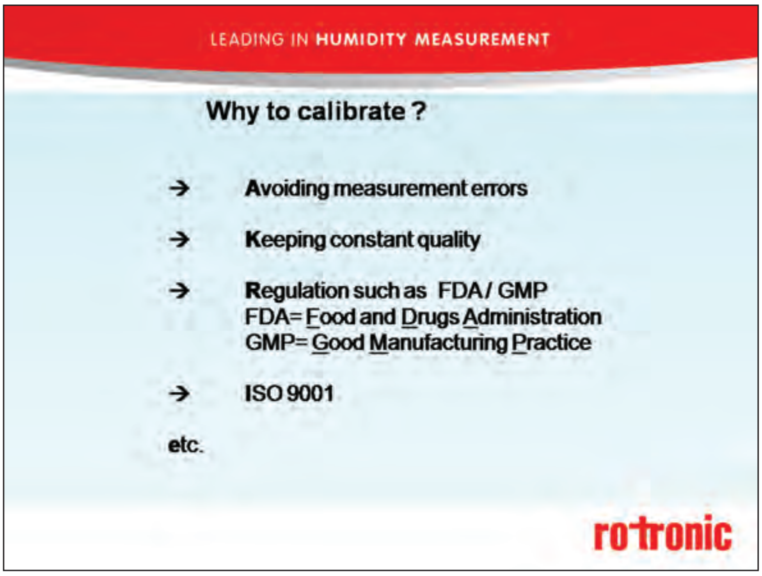
LEADING IN HUMIDITY MEASUREMENT
Why to calibrate ?
→ Avoiding measurement errors
→ Keeping constant quality
→ Regulation such as FDA / GMP
FDA= Food and Drugs Administration
GMP= Good Manufacturing Practice
→ ISO 9001
etc.
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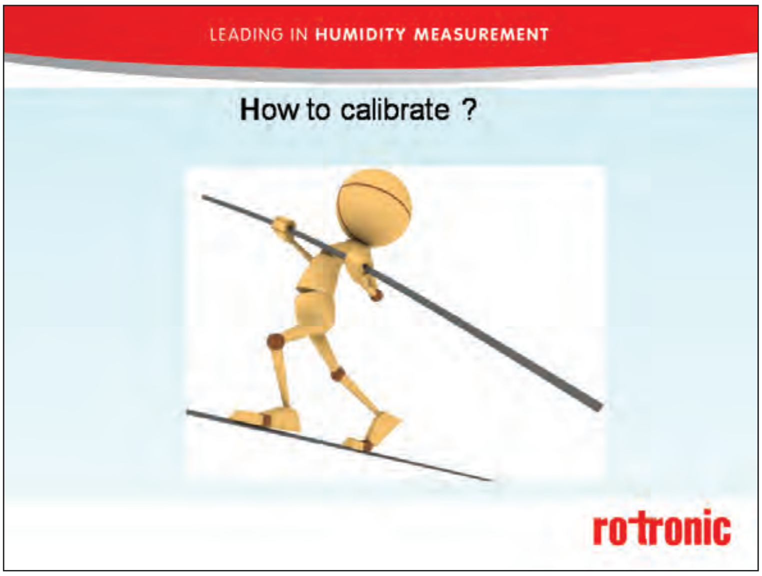
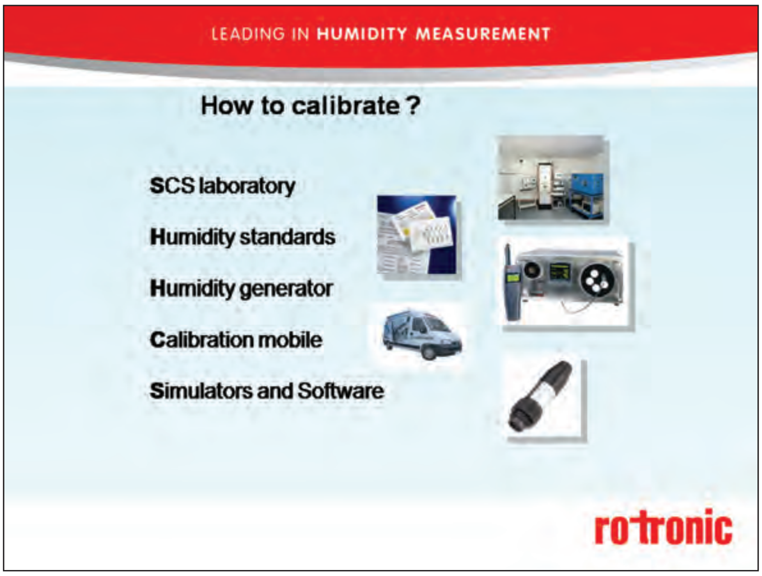

LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
rotronic


LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
SCS laboratory
Humidity standards
Humidity generator
Calibration mobile
Simulators and Software
rotronic

LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

Calibration interval

- → ROTRONIC recommends to calibrate the probes once a year
- → In harsh environment (e.g. chemical pollution, high temperature), a higher frequency is required.
- → According to internal regulations
- → In doubt start with a higher interval and reduce interval

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LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

SCS Laboratory

Uncertainty at 23°C ± 5°C

0,5 % rh ... < 20 % rh	→	± 0,2 % rh
20 % rh ... < 40 % rh	→	± 0,3 % rh
40 % rh ... < 65 % rh	→	± 0,4 % rh
65 % rh ... < 85 % rh	→	± 0,5 % rh
85 % rh ... 95 % rh	→	± 0,6 % rh

Capability on temperature ±0,1 °C

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LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

SCS Laboratory

Uncertainty at -10°C...0°C

10 % rh ... < 20 % rh	→	± 0,6 % rh
20 % rh ... < 40 % rh	→	± 0,9 % rh
40 % rh ... < 65 % rh	→	± 1.5 % rh
65 % rh ... < 95 % rh	→	± 2.1 % rh

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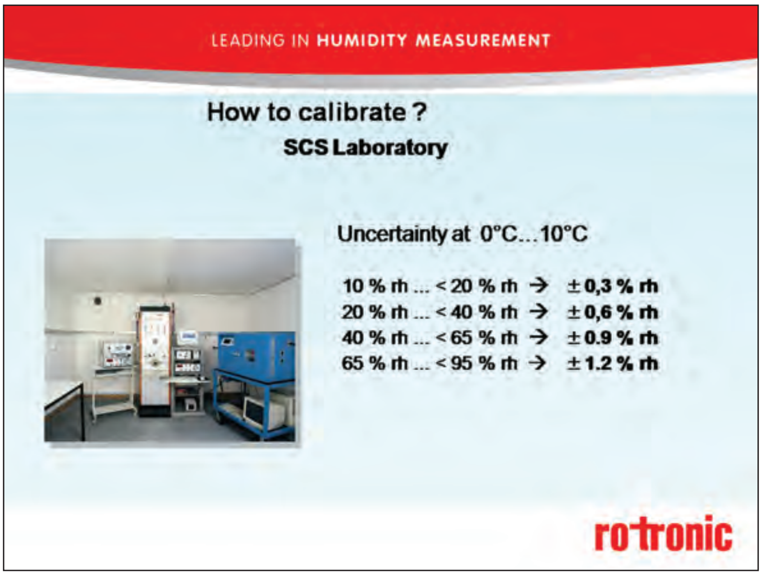
LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
SCS Laboratory
Uncertainty at 0°C...10°C
10 % rh ... < 20 % rh → ±0,3 % rh
20 % rh ... < 40 % rh → ±0,6 % rh
40 % rh ... < 65 % rh → ±0.9 % rh
65 % rh ... < 95 % rh → ±1.2 % rh
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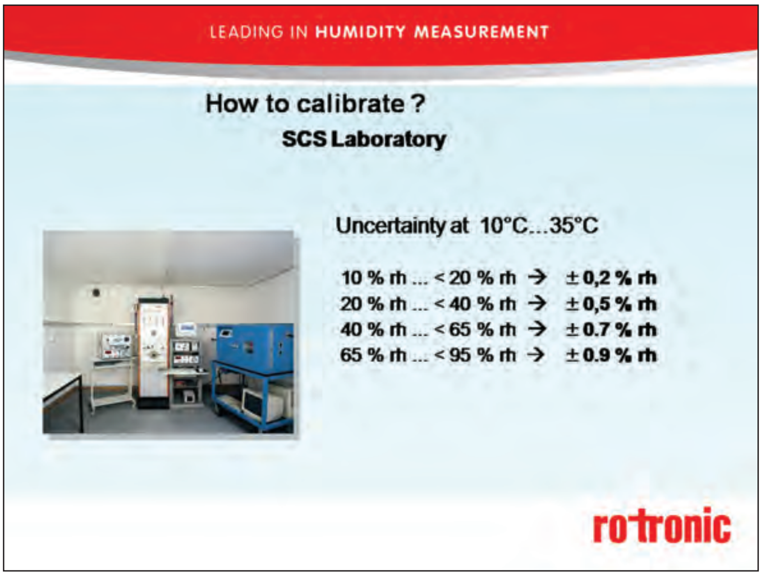
LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
SCS Laboratory
Uncertainty at 10°C...35°C
10 % rh ... < 20 % rh → ±0,2 % rh
20 % rh ... < 40 % rh → ±0,5 % rh
40 % rh ... < 65 % rh → ±0.7 % rh
65 % rh ... < 95 % rh → ±0.9 % rh
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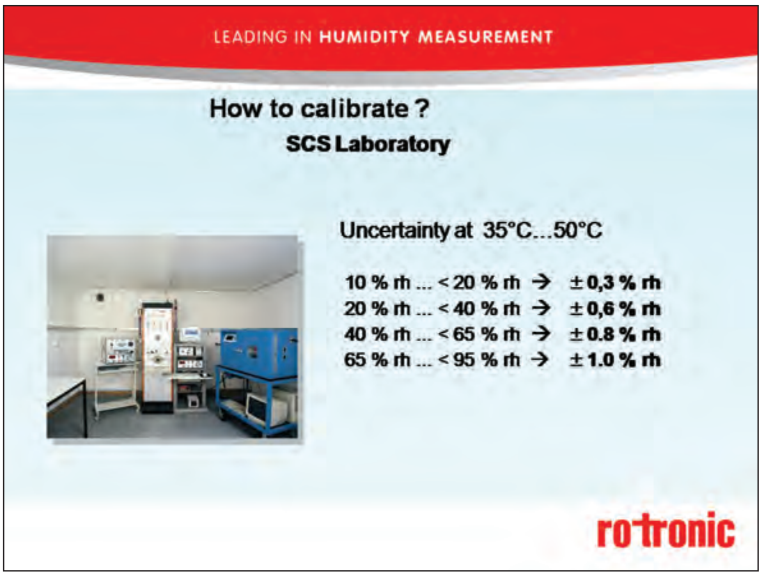
LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
SCS Laboratory
Uncertainty at 35°C...50°C
10 % rh ... < 20 % rh → ±0,3 % rh
20 % rh ... < 40 % rh → ±0,6 % rh
40 % rh ... < 65 % rh → ±0.8 % rh
65 % rh ... < 95 % rh → ±1.0 % rh
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LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

SCS Laboratory

Uncertainty at 50°C...70°C

10 % rh ... < 20 % rh	→	± 0,4 % rh
20 % rh ... < 40 % rh	→	± 0,6 % rh
40 % rh ... < 65 % rh	→	± 1.0 % rh
65 % rh ... < 95 % rh	→	± 1.6 % rh

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LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

SCS Laboratory

Temperature only in air:

-10 °C ... 0 °C	± 0,25 °C
0 °C ... 35 °C	± 0,15 °C
35 °C ... 50 °C	± 0,20 °C
50 °C ... 70 °C	± 0,25 °C

Temperature only in bath:

Resistive temperature device PT100:

25 °C ... 125 °C	± 0,03 °C

Probes with analogue output

- 25 °C ... 125 °C	± 0,05 °C

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LEADING IN **HUMIDITY MEASUREMENT**

How to calibrate ?

Humidity standards

→ Acclimate the calibration material

→ Mount the calibration device on the probe, and fill the humidity standard on the textile pad. Close it tight and wait for about 40-60 minutes.

→ Check the value on the reference instrument, multimeter etc..

→ Protocol the value, if desired adjust (Adjustment)

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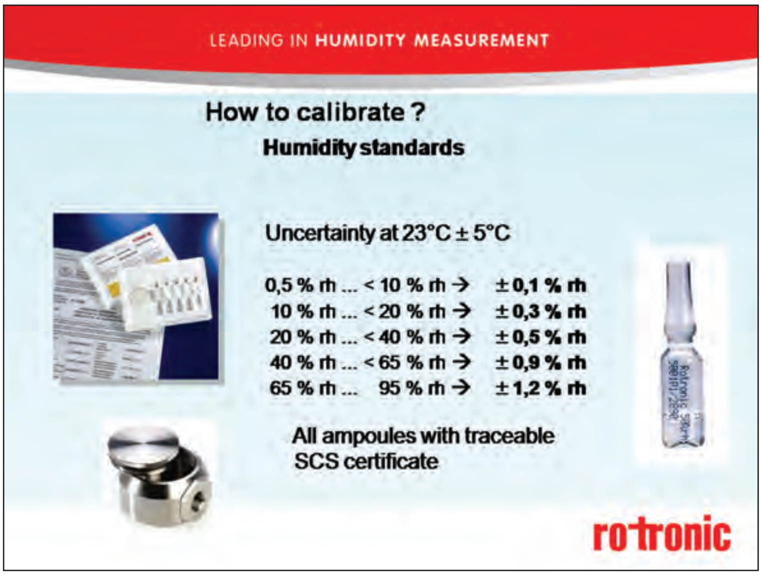
LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
Humidity standards
Uncertainty at 23°C ± 5°C
0,5 % rh ... < 10 % rh → ± 0,1 % rh
10 % rh ... < 20 % rh → ± 0,3 % rh
20 % rh ... < 40 % rh → ± 0,5 % rh
40 % rh ... < 65 % rh → ± 0,9 % rh
65 % rh ... 95 % rh → ± 1,2 % rh
All ampoules with traceable
SCS certificate
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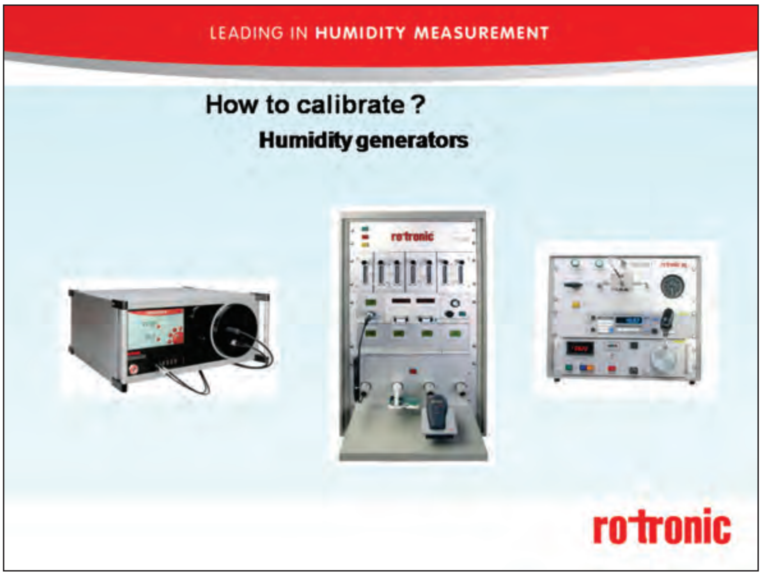

LEADING IN HUMIDITY MEASUREMENT
How to calibrate ?
Humidity generators
rotronic


LEADING IN HUMIDITY MEASUREMENT
Questions
rotronic

* * *

Hydrolab, your partner for water quality monitoring

OTT Hydromet helps water resources professionals generate reliable data throughout the entire cycle of water, from measuring precipitation to monitoring estuaries and ground water, and everything in between. Hydrolab multi-parameter water quality instruments are built using the industry's leading sensor technology. OTT products have been leading level, discharge and precipitation measurements for over 130 years.

OTT Hydromet/Hach Company had its presence in India for over 20 years now. Initially operated through distributors since 2007, HACH Hydromet and Hach's direct employees are also based in India.

Introduction

The methods used to perform water quality monitoring have changed dramatically over the last 10-15 years. In the past, water samples were typically collected and stored for shipment to a laboratory, where they were analyzed. Problems associated with this practice included ensuring that the samples were transported properly so as to not affect their chemical properties, and the time associated in getting the results back.

Today, many of these tests are now routinely performed *in-situ*. Advancements in electronics have made field instruments much more reliable and instruments easier to use. As a result, the data can now be obtained faster and more accurately than ever before. With the use of battery powered data loggers, water quality data can be collected continuously to establish trends or to determine when specific events occurred.

For more than 35 years, Hydrolab has designed and manufactured multiparameter sondes for water quality monitoring in the environment. At the heart of Hydrolab instruments is our superior sensor technology, which ensures that the important data you collect is solid, reliable, and dependable. In addition, our sensors are built to last, so your total cost of ownership is ultimately the lowest in the industry.

Hydrolab multiprobes are built around a common set of reliable sensors and electronic components. Packaged in a rugged, non-corrosive housing, our multiprobes also include user-friendly software, printer-ready data formats, and compatibility with third-party devices.

Hydrolab introduced the first multiparameter sonde in 1968, and set the standard for water quality multiprobes worldwide. Since then, our instruments have continued to perform reliably and accurately, even under the most adverse field conditions. Hydrolab's record of innovation has been consistently strong throughout its history, and since joining Hach Company, our rate of innovation has increased even further.

Some key dates in Hydrolab's history include:

1968	First four-electrode conductivity sensor
1969	First submersible pH sensor
1974	First solid-state RAM for data storage
1980	First submersible, unattended multiprobe with built-in data logger
1991	Introduced a two-year warranty
1992	First digital multiprobe for monitoring two-inch wells
2002	Joined Hach Company and relocated operations to Loveland, Colorado
2003	Introduced Self-Cleaning Turbidity and Hydras 3 LT operating software
2004	Introduced integrated Chlorophyll a and Rhodamine WT sensors

Introduced the DataSonde 4X for X-tended deployment

Introduced the first Blue-Green Algae sensor for a multiparameter sonde. Hydrolab's recent integration into Hach Hydromet has provided the brand with access to the industry's best research, engineering, manufacturing, service, and technical support resources. Our customers can expect continuous innovation from the new organization now and into the future.

Available Parameters (Sensors)

Temperature

Temperature is defined as a measure of the amount of heat present in water. Temperature measurement is essential to the measurement of dissolved oxygen, specific conductance, salinity, pH, alkalinity and most other water quality parameters. Temperature controls the metabolism of aquatic plants and animals and is largely responsible for biochemical reactions and many other processes.

Principles of operation

A Thermistor is a temperature dependent resistor. When temperature changes, the resistance of the thermistor changes in a predictable way.

Thermistors are inexpensive, easily-obtainable temperature sensors. They are easy to use and adaptable. Circuits with thermistors can have reasonable output voltages - not the millivolt outputs thermocouples have. Because of these qualities, thermistors are widely used for simple temperature measurements.

Features and benefits

- Provides critical compensation for Dissolved Oxygen, Conductivity, pH, and nutrient sensors
- Compliant with EPA170.1 and SM2550B

Product data

Range: -5 to 50^0 C ***Resolution:*** 0.01^0 C

Accuracy: +/- 0.10^0 C

pH

pH is the measure of hydrogen ion activity of a system. pH is a major factor affecting the availability of nutrients to plants and animals. It partially controls the concentration of many biochemically active substances dissolved in water and affects the efficiency of hemoglobin in the blood of vertebrates, as well as the toxicity of pollutants. It is measured by the amount of hydrogen ions passed through the permeable glass electrode and referenced to a known source. The greater the hydrogen ion concentration, the lower the pH on a scale of 0 to 14 units. Typically, pure the water the more neutral the pH (7). The Hydrolab pH sensor uses a glass bulb measuring electrode and refillable reference electrode.

There are two versions available:

- Standard reference: uses a separate measuring electrode and reference electrode, each in their own sonde port.
- Integrated reference: combines the measuring electrode and reference into one sonde port.

Principles of operation

pH measurement in natural aquatic environments is commonly done electrochemically by measuring the voltage between a pH-sensitive glass electrode and a reference electrode. Commercial pH meters convert voltage readings into pH units using calculations based on the Nernst equation and sometimes other assumptions about the environment and measurement system. Because of unavoidable differences between theoretical pH measurement systems and real-world pH measurements systems, pH is often said to be defined "operationally" based on an accepted electrochemical method such as Standard Method 4500-H+ or similar methods from other standards organizations.

Features and benefits

- A user-rebuildable reference electrode extends the life of the pH sensor while minimizing costs as the measuring electrode does not necessarily need replacement when the reference electrode is depleted.
- The choice of standard or integrated refillable reference allows flexibility in sonde configuration.

Product data

Range: 0 to 14 pH units ***Resolution:*** 0.01 pH units

Accuracy: ±0.2 pH units

Specific conductance

Conductivity is a measure of the ability of water to pass an electrical current. Compensation of this measurement to 25 °C constitutes specific conductance. Specific conductance indicates the amount of dissolved substances (salts). Specific conductance is the inverse of electrical resistivity, corrected to 25 °C.

The Hydrolab Conductivity sensor uses four graphite electrodes in an open cell design to provide extremely accurate and reliable data with virtually no maintenance.

Principles of operation

Conductance sensors measure the resistance of a small electrical current passed between the five pins of the sensor.

Features and benefits

- Design based on four graphite electrodes in an open cell design. It reduces measurement error due to environment – sediment falls to the bottom of the cell, and bubbles rise to the top. Measurements are reliable in any condition. Easily maintained between deployments by cleaning with a Q-tip or cotton swab.

Product data

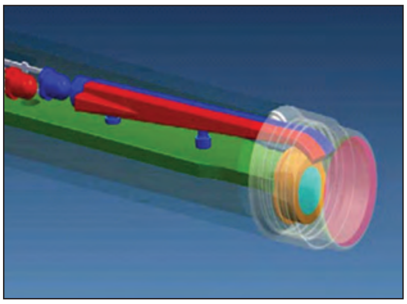
Range: 0-100 mS/cm ***Resolution:*** 0.001

Accuracy: ± (0.5% of reading + 0.001 mS/cm)

Dissolved Oxygen (Luminescence Dissolved Oxygen Sensor)

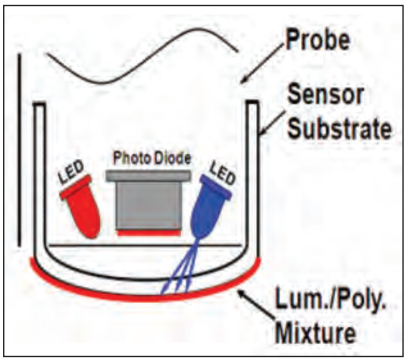
A measure of the amount of oxygen (O_2) dissolved in water. The concentration of DO is controlled by consumption by aerobic organisms, consumption by plants during darkness, production by plants during daylight, exposure (or lack of) by natural re-aeration (waterfalls and riffles) and water temperature, flow and depth. Low dissolved oxygen level (0 to 8 mg/L) is an indicator of high oxygen demand on the water caused by either high biological or chemical oxygen demand (BOD or COD).

Since 2002, Hach has established itself as the premier provider of luminescent dissolved oxygen (LDO) technology and only Hydrolab Series 5 sondes feature Hach LDO technology – designed, manufactured and supported by Hach in Loveland, Colorado. Now in its second generation, the Hach LDO sensor for Hydrolab sondes is better than ever.



Principles of operation

Luminescent oxygen concentration in a given water sample. Blue light from a LED is transmitted to a sensor cap coated with a luminescent material, which excites in the presences of oxygen molecules. As the luminescent material relaxes, it emits a red light. The time from when the blue light was sent and the red light is emitted is measured. The more oxygen that is present, the shorter the time it takes for the red light to be emitted.



This time is measured and correlated to the oxygen concentration. Between the flashes of blue light a red LED is flashed on the sensor cap and used as an internal reference to help validate each measurement. The sonde can display the oxygen as a concentration or as percent saturation.

Features and benefits

- No membranes so concerns about air bubbles, 24-hour membrane relaxation and the art of maintenance are a thing of the past.
- Calibrations that last without drift means that deployments will last longer, reducing frequency of trips to the field for maintenance, saving your time and money.
- Does not consume oxygen so passive fouling will not affect DO readings.
- Designed, manufactured and supported by Hach Hydromet, the experts in LDO technology.
- Fouling or other debris does not affect the Hach LDO sensor, unless the growth is an organism that locally consumes or produces oxygen.

Product data

Range:

0 - 60* mg/L

* Exceeds Maximum Natural Concentrations

Accuracy:

+/- 0.1 mg/L at <8 mg/L

+/- 0.2 mg/L at >8 mg/L

+/- 10% reading >20 mg/L

Resolution:

0.01 mg/L

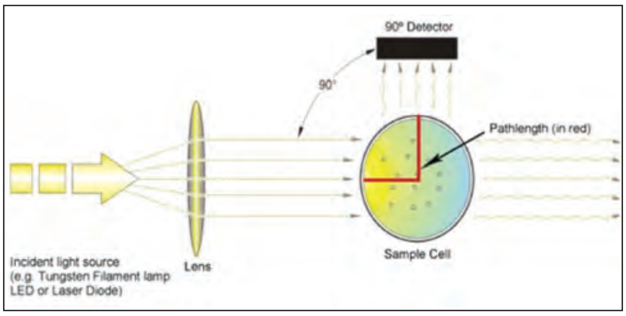
Turbidity Sensor (by Turner Designs)

In simple word – Turbidity is a measure of the degree that water loses its transparency due to the presence of dispersed suspended solids like silt, clay, organic matter and other particles.

Moreover, by definition, turbidity obstructs light, thus reducing the growth of marine plants, eggs and larvae, which are usually found in the lower levels of an aquatic system. Turbidity change may indicate a new pollution source (organic or inorganic) in natural waters *i.e.* bacteria, nutrients, pesticides, metals.

Hydrolab Series 5 sondes use a self-cleaning turbidity sensor that measures from 0 to 3000 NTU and includes a user-programmable cleaning system to remove fouling or debris that could potentially affect readings.

Principles of operation



Turbidity sensor of Hydrolab is ISO 7027 compliant. A "nephlometer" fires out a light from an LED at 880 nm and a photodiode collects the backscatter (right angle) from particles in the water; no particles, no backscatter

Features and benefits

- User-programmable, self-cleaning system can perform up to 10 cleaning cycles before each reading and the sensor's fixed parking position ensures consistent data collection after each cycle.
- Superior corrosion resistance in saline environments with a plastic sensor housing and titanium wiper shaft, rated to depths of 200m.
- 0-3000 NTU range allows turbidity tracking with exceptional linearity, even during rain storms or other events that cause abnormally high readings.
- Utilizes a small aperture technique to reduce false readings from particulates and other debris.
- Designed to be compliant with the ISO 7027 Turbidity Measurement Standard.
- Excellent performance in low-NTU environments due to enhanced noise cancelling techniques.

Product data

Range: 0-3000 NTU

Accuracy:

± 1% up to 100 NTU,

± 3% from 100-400 NTU

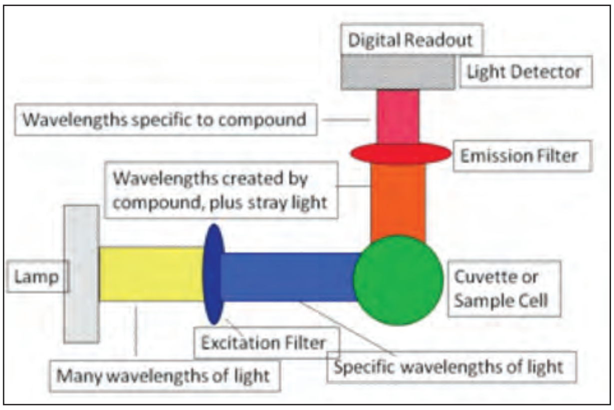
± 5% from 400-3000 NTU

Resolution*:*

0.1 NTU from 0-400 NTU;

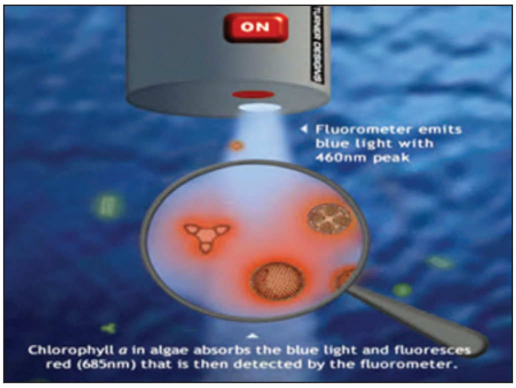
1 NTU for >400 NTU

Chlorophyll a Sensor (by Turner Designs)



Chlorophyll a is a measure of the amount of green, living material in water at any particular time..

In vivo analysis is the direct measurement of chlorophyll a in living algal cells, without extraction or chemical treatment. The obvious advantage of *in vivo* analysis is rapid, on-the-spot measurement eliminating the delays for extraction and laboratory measurement. For qualitative analysis, *in vivo* measurement alone may answer the analyst's questions. For quantitative determinations, the *in vivo* data are compared with other measurements, including fluorometric extractive data. For a more detailed discussion of *in vivo* chlorophyll methodology, refer to the Turner Designs' *in vivo* chlorophyll E-Support section of their web page or contact them.



Principles of operation

In all Hydrolab equipment chlorophyll is measured by emitting light at a known wavelength and measuring the amount of fluorescence produced by the living algae suspended in the water body or water sample. Chlorophyll a is measured in µg/L and can range from 0 to 500µg/L in natural environments.

Features and benefits

- Provides the most accurate measurement of Chlorophyll a because of electronic filtration of ambient light, efficient optical coupling and quality optical components.
- Excellent turbidity rejection due to small sample volume design and high quality optical filters.
- Available with solid Secondary Standards to provide a quick and simple method to verify the sensor's stability over time.
- The Secondary Standard can be adjusted to correlate to a known chlorophyll concentration.
- Three auto-selected gain ranges provide a wide measurement range of 0.03 to 500 µg/l for Chlorophyll.

Sensor housing:

- **Stainless steel:** Standard housing for typical fresh water applications.
- **Titanium option:** Corrosion-resistant housing for use in aggressive saline environments such as oceans, bays and estuaries.

Product data

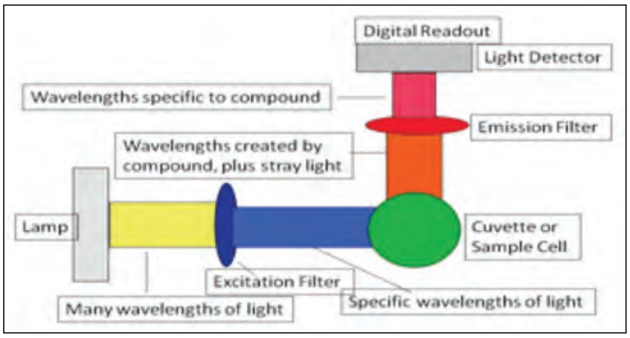
Minimum Detection Limit:
0.03 µg/l

Dynamic Range:
Low sensitivity: 0.03-500µg/L
Med. sensitivity: 0.03-50µg/L
High sensitivity: 0.03-5µg/L

Accuracy:
+/- 3% for signal level equivalents of
1 ppb rhodamine WT dye or higher
using a rhodamine sensor

Resolution:
0.01 µg/L

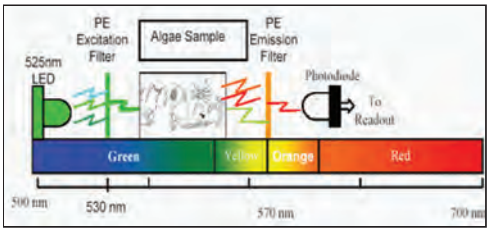
Blue-Green Algae Sensor (by Sensor Turner Designs)



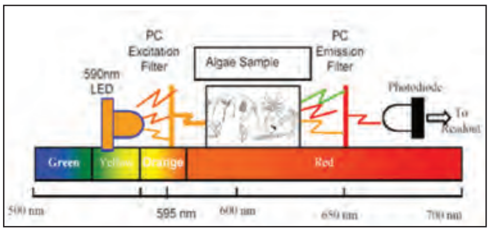
Cyanobacteria, a.k.a. blue-green algae, are common forms of photosynthetic bacteria present in most freshwater and marine systems. The real-time monitoring of cyanobacteria through fluorometry can serve as an early warning system for potentially hazardous conditions. In addition to potential toxin production, cyanobacteria blooms can also result in water with an unpleasant appearance, and in the case of drinking water, an unpleasant taste and odour. These problems adversely affect water quality and diminish the water's recreational utility. Also of concern are high cell concentrations causing an increase in filter run times in drinking water plants. Thus, monitoring the cyanobacteria population and distribution in lakes, reservoirs and coastal areas is extremely important for resource protection, public health and safety, and overall economics.

Principles of operation

Phycoerythrin (Marine)



Phycocyanin (Freshwater)



Features and benefits

- Available in two forms, one for detecting phycocyanin (fresh water), and one for detecting phycoerythrin (marine water).
- Available with solid Secondary Standards to provide a quick and simple method to verify the sensor's stability over time.
- The Secondary Standard can be adjusted to correlate to a known blue-green algae concentration.
- Three auto-selected gain ranges provide a wide measurement range of 100 to 2,000,000 cells/mL for either phycocyanin or phycoerythrin.
- Provides the most accurate measurement of phycocyanin or phycoerythrin because of electronic filtration of ambient light, efficient optical coupling and quality optical components.
- Incredibly fast response time through electronic filtration of ambient light.
- Excellent turbidity rejection due to small sample volume design and high quality optical filters.

Sensor housing:

- **Stainless steel:** Standard housing for typical fresh water applications.
- **Titanium option:** Corrosion-resistant housing for use in aggressive saline environments such as oceans, bays and estuaries.

Product data

Minimum Detection Limit:

100 cells/mL

Low sensitivity: 150-2,000,000 cells/mL

Med. sensitivity: 150-200,000 cells/mL

High sensitivity: 150-20,000 cells/mL

Accuracy:

+/- 3% for signal level equivalents of 1 ppb rhodamine WT dye or higher using a rhodamine sensor

Resolution: 20 cells/mL

Other Water Quality Sensors from Hydrolab

- Salinity, Total Dissolved Solids
- Resistivity
- Dissolved oxygen (DO) [mg/L; % sat]
- Redox potential (ORP)
- Total dissolved gas (TDG)
- Ammonium / Ammonia
- Chloride
- Nitrate
- Rhodamine WT (Florescence dye)
- Li-COR Ambient light (PAR)
- Absolute depth or vented water level))

Operation device

Hydrolab sonde DS5 and MS5 series can easily be connected to various devices such as Surveyor, Laptop and PDA to operate with a software package called Hydras 3LT. Calibration can be done using this device.

a) Surveyor is a simple and rugged handheld display that is designed specifically for use with Hydrolab DS5, DS5X, and MS5 Multiprobes for complete water quality sonde set-up and real time monitoring. With the internal batteries you only need to be sure the battery is charged. The internal battery voltage (IBV Volts on the display) should be 7.5 volts or better.

b) The Trimble® Recon® outdoor rugged handheld is used for complete Hydrolab water quality sonde or for real time monitoring.

c) Laptop connection is also feasible with RS232 serial port.

Maintenance and calibration of sensors

Datasondes and Minisondes can be configured in a multitude of ways but the Sonde itself will need to be cleaned and serviced on a regular basis usually monthly for either long-term deployments or regular use. All maintenance and most calibrations, except maybe depth, must be performed in a controlled environment (laboratory, office or even a motel room).

Most parameters, with the exception of Redox, are temperature compensated. Therefore, the temperature sensor, the Sonde, the calibration solution and even the air around them must all be at the same temperature for calibrations to be correct and accurate. For the Sonde to produce the best data possible calibrate on a regular basis where the air temperature is stable.

The outside of the Sonde and sensors must be cleaned of sediment and debris first before any maintenance can be started.

Required equipment and accessories:

- Clean counter top space in a laboratory.
- Distilled water, methanol, cotton swabs, paper towels and silicone grease.
- Lab stand and clamp (H013910) or lab chain clamp to hold the Sonde inverted and vertical.
- Basic Maintenance Kit including small Allen wrenches and screwdriver.
- Soft bristle scrub brush and green scrub pads and cleanser (Sparkleen works great for the sensors, Citrus Cleaner for the housing).
- O-rings for MS5 (H002811) or DS5/x (H000568), Silicon grease and silicon lubricant (Armor All) for impeller.
- 3 Volt Lithium clock battery for Series 4a (H002819) and 5 (2002) and 5x (H005258).

Maintenance

The Sonde and circulator should be maintained on a regular basis (at least monthly during daily use) or prior to and after any long-term deployment.

- It should be cleaned if the Sonde is covered with sediment, algae and other unknown material.
- Be sure to practice safe lab procedures and treat each piece of equipment carefully. Disinfect the equipment for any bacterial contamination with bleach, etc.
- Use the brush to gently brush away sediment algae, bugs and any other debris around the sensors. Remove the membrane tip from any Ion Selective Electrodes (NH4, Chloride & Nitrate) and replace with the small white screwin plug. User can use Sparkleen, Citrus Cleaner and or alcohol to thoroughly clean around the sensors.

- Clean and remove the debris that may be wrapped around it and under the bushing. In some areas pyrite or other iron-based materials can accumulate around the magnet of the circulator and in time can interfere with its function and even cause premature wearing of the surfaces.
- Every other year the O-rings should be replaced in the Sonde. Great care should be taken to open the Sonde. Carefully separate the Housing and the Storage cup ends until the MPL board and Backbone are totally exposed. Remove the two black, locking hooks on the 10 Pin connector and then disconnect the Connector and Ribbon Cable. A couple of small desiccant packs should fall out and may need to be replaced.
- O-rings should be checked for any wear spots, tears or deterioration and replacing the same if required.
- Internal lithium coin battery should be checked in the DS5 or MS5 to ensure it is still at or above 3 volts DC. If not replace with a new one. Replace the desiccant with new or recharged silica gel packets and carefully put the Sonde back together ready for use.

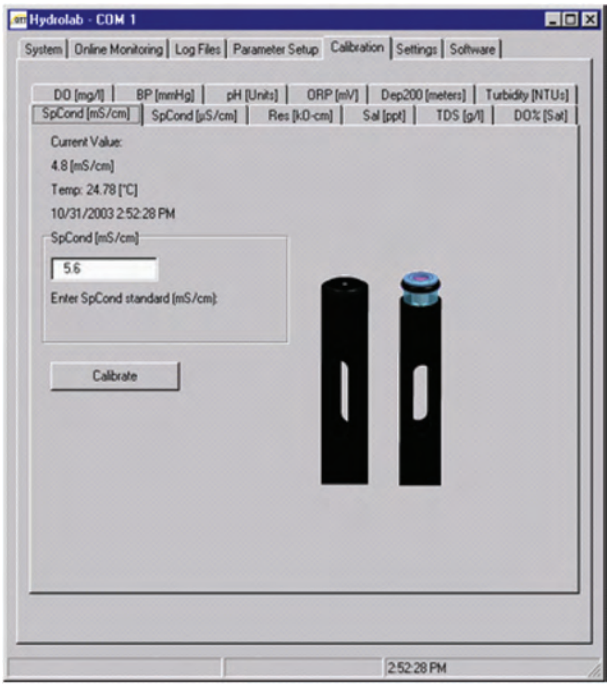
Calibration

Calibrating the sensors using Hydras 3 LT:

- Attach the power and data cable to the Sonde. Attach the 9-pin connector to a PC.
- Start Hydras 3 LT. Wait for the software to scan for connected Sondes. Highlight the multiprobe and press OPERATE SONDE.

Note: If the Sonde appears to be connected and the software does not recognize the Sonde connection, remove and replace the connector cable and press RE-SCAN FOR SONDE. Repeat until Hydras 3 LT recognizes the Sonde.

- Click on the Calibration Tab and click on the parameter to be calibrated.
- Enter the calibration values and click CALIBRATE.



Calibration preparation

The following is a general outline of the steps required to calibrate all the sensors.

- Select a calibration standard whose value is near the field samples.
- Clean and prepare the sensors.
- To ensure accuracy of calibration, discard used calibration standards appropriately. Do not reuse calibration standards.

Temperature sensor calibration

The temperature sensor is factory-set and does not require recalibration.

Specific conductance calibration

Note: TDS measurements are based on specific conductance and a user-defined scale factor. The factory default scale is 0.64 g/L / mS/cm.

This procedure calibrates TDS, raw conductivity, and salinity. Specific conductance requires a two-point calibration. Calibrate the sensor to zero and then to the slope buffer.

- Pour the specific conductance standard to within a centimeter of the top of the Calibration Cup.
- Make sure there are no bubbles in the measurement cell of the specific conductance sensor.
- Enter the Sp. Cond standard for mS/cm or µS/cm using Hydras 3 LT software or a Surveyor.

pH/ORP calibration

- Pour the pH or ORP standard to within a centimeter of the top of the cup.
- Enter the units for pH or ORP using Hydras 3 LT or a Surveyor.

Note: pH is a two-point or three-point calibration. A pH standard between 6.8 and 7.2 is treated as the "zero" and all other values are treated as the "slope". First calibrate "zero", then calibrate "slope".

After the sensors have been properly maintained, the sensors can be calibrated. Always allow sufficient time for thermal stabilization of the standards.

Luminescent Dissolved Oxygen (LDO) calibration

The LDO sensor compensates for the temperature of the water. To perform an accurate calibration it is important that the temperature of the water remain constant during the procedure. The easiest way to do this is to allow the water used for calibration to sit overnight in an open container until it equilibrates to room temperature. If the temperature changes by more than 0.5°C during calibration, dissolved oxygen measurements may be inaccurate and the sensor will need to be recalibrated when the temperature of the water stabilizes. For this reason, the calibration should also not be done in direct sunlight. Stand the sonde so the sensors are pointed upwards with the storage cup attached.

Add about one liter of room temperature de-ionized water (or clean tap water with a conductivity of less than 500 micro-Siemens per centimeter) to a clean one gallon jug. Shake the jug very vigorously for 40 seconds.

Establish a connection to the sonde using Hydras3 LT and click the button labeled 'Operate Sonde'. Wait for Hydras to initialize the sensors. Progress can be monitored on the bar at the bottom of the screen. Storage cup should be filled over the sensors to the bottom of the threads and place the storage cap upsidedown. Do not screw the cap on.

When the sonde is ready for 'Calibration' 'LDO (%Sat)' tab has to be selected . A picture of the LDO sensor should appear on the screen. Wait for the current value and temperature readings to stabilize. If the cap was stored wet this should happen very quickly. A dry cap may take several minutes to stabilize.

Enter the current absolute barometric pressure in mm/Hg in the box. Click 'Calibrate'.

A "Calibration Successful" message will be displayed.

Self Cleaning Turbidity Two Point Calibration

The Self Cleaning Turbidity sensor is almost completely maintenance free.

The Self Clean Turbidity sensor uses scattered light to report the concentration of suspended particles in water, so it is important to clean the instrument as thoroughly as possible prior to calibration.

Establish a connection to Hydras3 LT and click the 'Operate Sonde' button.

Zero Point Calibration – With the sensors pointed upwards, fill the storage cup approximately 75% with de-ionized water or <0.1 NTU StablCal and screw the storage cap on tightly. Slowly turn the sonde over so the sensors point downwards.

After clicking the 'Calibration' tab, in Hydras3 LT, select 'Turbidity [rev]' tab, a picture of same will appear. Verify the value in the box which should be '1' than click the 'Calibrate' button. The wiper should make one complete revolution completing the calibration successful. After that select the 'Turbidity [NTU]' tab, two boxes will appear on this page, in the box labeled 'Turbidity [Point]' enter '1'. In the box labeled 'Turbidity [NTU]' enter a value of 0.3 to 0.6 depending on the cleanliness of the sensors. Calibration Tab should be clicked when the readings at the top of the page are stable.

High-End Calibration: The high-end calibration point should be a value higher than the highest value anticipated at the deployment site. The standard factory high point is 100 NTU. Pour the de-ionized water out of the storage cup and dry the sensors again. Gently swirl or invert the bottle of 100NTU StablCal for two to three minutes to mix the suspension.

The sensor should be dipped twice by putting the calibration solution up to 25% and pouring out after shaking than to 75% of the storage cup. The end of the Self Cleaning Turbidity sensor should be fully submerged. Again, in Hydras3 LT, click on the 'Calibration' tab, then click on the 'Turbidity [rev]' tab. Verify that the value in the box is '1' and click the 'Calibrate' button. The wiper should make one complete revolution, removing any air bubbles from the optics.

Click the 'OK' button in the "Calibration Successful" window. Now again the same procedure will be followed by clicking on the 'Turbidity [NTU]' tab. In the box labeled 'Turbidity [Point]' the value should be '2'. In the box labeled 'Turbidity [NTU]' value should conform to '100'. When the readings are stable, clicking the 'Calibrate' tab and OK button in the calibration successful window will lead to calibration the sensor.

Chlorophyll a *in vivo* Calibration

There are two methods of calibration of Chlorophyll a sensor.

- Chlorophyll a *in vivo* calibration with secondary standard
- Chlorophyll a *in vivo* calibration without secondary standard

Chlorophyll a *in vivo* calibration with secondary standard

Since there is no primary standard available for chlorophyll a, the calibration process requires a sample value to be recorded and then an extraction performed to find the true value. When the true value of the sample is known, there are two methods of calibrating the sensor: with a solid standard, and without.

Establish a connection to the sonde with Hydras 3LT. Click the button labeled ’Operate Sonde’. When the sonde finishes its initialization, click the ‘Calibration’ tab, clicking the ‘Chlorophyll [ug/L]’ tab will result in appearance of a picture of the fluorometer as well as the current value, the date and time, the current temperature and the voltage reading of the sensor.

Begin with a clean and dry sonde. Attach the calibration cup and fill it to the threads with sample water that has been filtered of all phytoplankton using a 0.45 µm filter, or optionally de-ionized water. The reading should be allowed to stabilize for a minute. Type ‘0’ into the box and click ‘Calibrate’. A “Calibration Successful” message will appear. Empty the storage cup and rinse the sensors. Dry the sensors and attach the storage cup. Fill the cup to the threads with a fresh sample from the deployment site. Wait one minute for the readings to stabilize. If you are using a solid standard for calibration, record the current µg/L value.

Have an extraction performed on the sample to find the true concentration.

If you are using the solid standard, rinse and dry the sensors and place the standard over the top of the fluorometer. Use the small screwdriver provided to adjust the standard until the µg/mL reading displayed in the Hydras window is the same as what was recorded for the sample. When the current value matches the recorded value, the top of the solid standard can be tightened so that it ‘locks’ the standard to that value.

When the results of the extraction are known, the ‘chlorophyll a’ sensor is re-calibrated using this value.

If you are using the solid standard, perform the same zero calibration as before. Rinse and dry the sensors. Place the solid standard over the fluorometer and wait one minute for the readings to stabilize. Type the value of the extraction into the box and click ‘Calibrate’. A “Calibration Successful” message will appear.

If the solid standard is not adjusted, it can be used on this specific sensor for future calibrations or to check for drift. Record the extracted value and keep it with the standard.

The Chlorophyll a sensor is now calibrated.

Blue Green Algae Calibration

The Blue-Green Algae fluorometers use the same principles but different wavelengths of light to detect different chemicals in the sample.

There are two methods of calibration of blue-green algae.

- Blue-green algae calibration with secondary standard
- Blue-green algae calibration without secondary standard

Establish a connection to the sonde with Hydras 3LT. Click the button labeled ’Operate Sonde’. When the sonde finishes its initialization, click the ‘Calibration’ tab, then click the ‘Phycocyanin [cells/mL]’ tab or Phycoerythrin [cells/L] tab. You will see a picture of the fluorometer as well as the current cells/mL, the date and time, the current temperature and the voltage reading of the sensor. Begin with a clean and dry sonde. Attach the calibration cup and fill it to the threads with sample water that has been filtered of all blue-green algae, or optionally, clean fresh water. Wait for one minute for the readings to stabilize. Type ‘0’ into the box and click ‘Calibrate’. A “Calibration Successful” message will appear. At this point, record the voltage reading.

Empty the storage cup and rinse the sensors. Dry the sensors and attach the storage cup. Fill the cup to the threads with a fresh sample from the deployment site. Wait one minute for the readings to stabilize. Record the voltage reading.

Have an extraction performed on the sample to find the true concentration.

When the results of the extraction are known, the blue-green algae sensor is re-calibrated using this value.

The secondary calibration will be done under the 'Phycocyanin [volts]' tab or Phycoerythrin [volts] tab.

Type '0' into the box labeled 'Phycocyanin [cells/mL]' or Phycoerythrin [cells/mL]. Type the voltage from the original zero point calibration in the box labeled Phycocyanin [volts]' or Phycoerythrin [volts]. Click the 'Calibrate' button. A "Calibration Successful" message will appear.

Now type the extracted value into the box labeled 'Phycocyanin [cells/mL]' or Phycoerythrin [cells/mL]. Type the voltage recorded from the sample before it was extracted into the box labeled Phycocyanin [volts]' or Phycoerythrin [volts]. Click the 'Calibrate' button. A "Calibration Successful" message will appear.

These concentrations and voltages can be used for future calibrations of this specific Blue-green Algae sensor.

Deployment and sampling methods

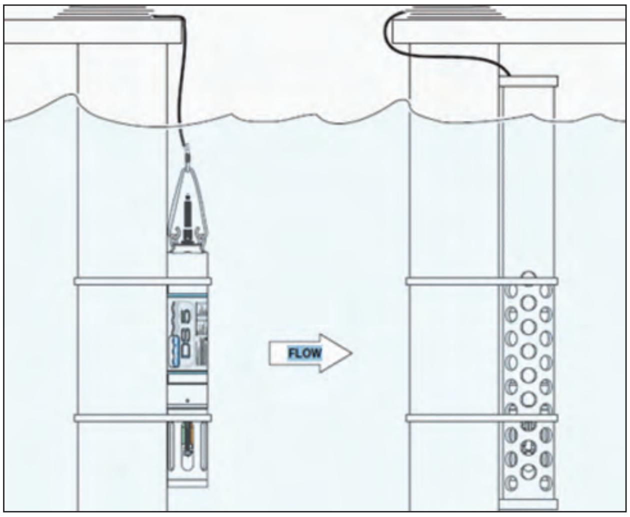
Deployment considerations:

- **Pressure extremes**
- **Temperature extremes**

Deployment in open waters

Long-term deployment in open waters

When using the multiprobe in open water, place the multiprobe where it will not get damaged. Following diagrams will help for how to deploy in open waters



Short-term deployment in open waters

Generally, short-term deployment implies hand-held operation.

Hydrolab copper anti-fouling solutions

Hydrolab devices come with specific anti fouling devices for marine application.

Instrument bio-fouling is a challenge consistently faced by water quality professionals in their effort to collect accurate data. Bio-fouling not only affects data, but also significantly increases instrument maintenance costs and time spent in the field.

Copper tape

Available in 2" and 3" widths, copper tape offers the flexibility and protection of individually wrapping each sensor. A guide outlining proper application procedures can be found above.

Copper sensor guard

Available for the DS5 and DS5X sondes as well as the DS4a, copper sensor guards are identical to standard sensor guards, only constructed out of a copper alloy. Copper sensors guards inhibit the growth of matter that would normally adhere to the sensor guard and potentially interfere with measurements.

Copper mesh

Copper mesh can be applied to either a standard or copper sensor guard and reduces the likelihood of matter entering and building up on sensors without creating a substrate for organisms to attach.

Case study

Hydrolab Series 5 with Hach LDO Helps Louisiana Department of Environmental Quality Assess Post-Katrina Situation

In the aftermath of hurricane Katrina, when the levies broke around New Orleans, the Louisiana Department of Environmental Quality (LADEQ) was pressed into service. The agency relied on its inventory of water quality monitoring instruments to track where water was, and what areas were contaminated.

The Department owns as many as 80 separate Hydrolab water quality monitoring instruments between all of its divisions and they have typically been able to use Hydrolab instruments for 8 to 10 years. The instruments in the Department's inventory include Minisonde 4a and Series 5 instruments with Hach LDO.

Under normal circumstances, this equipment is deployed as part of the State's ambient water quality monitoring network. This program is used for continuous monitoring to meet Clean Water Act requirements for monitoring surface water. Each year, monitoring stations are set up at approximately 130 sites state-wide.

After the levies were breached, the ambient network was put on hold and the program was adapted to handle post-hurricane impact assessment, with the Department's focus turned to the areas impacted by the flooding. The instruments were deployed in a massive effort to take readings at between 40 and 50 sites along the Gulf Coast impact zone. Some existing sites were used and new sites were established to characterize the direct and indirect effects the hurricane had, particularly to the Lake Pontchartrain area.

For the Series 5, in particular, Department staff for the Water Quality Surveys Section appreciate that the instruments can be quickly calibrated, and that they hold their calibration well. They prefer the Series 5 with Hach LDO because they can be quickly redeployed, and the lack of a membrane means they require less maintenance than instruments using a Clark cell. In addition, deployment in a challenging environment such as a flooded city could also pose fouling problems with older technology, while Hach LDO is not affected.

The data gathered was necessary to profile the situation and assess the effects on surface water bodies. All these sites were visited at least twice and some were decommissioned as the floodwater receded. Some sites are still active and have been visited a dozen times or more. In all, Department staffers have made up to 600 site visits and counting.

'Obviously, our workload went way up,' notes Chris Piehler of the Louisiana Department of Environmental Quality's Surveillance Division. 'And there has never been a storm where the after effects have been monitored this closely.'

Despite the impressive number of site visits, in uniquely challenging conditions, all Hydrolab instruments performed exactly as the LADEQ has come to expect - there have been no reports of any failures in the field. As a result of the quality of data provided by the Hydrolab sondes, plus the staff's efforts to ensure that data is accurate and verifiable when it is collected, there has been a very low rate of rejection of field data.

For more information about Hydrolab water quality measuring instruments, including the Hydrolab Series 5 with Hach LDO, visit the Hydrolab Water Quality Sensors page on www.ott.com,

For additional information, please contact us at the following email address

someshkumar@hach.com
pborah@hach.com

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Ensuring quality in operating CODAR SeaSonde Coastal Networks

In **CODAR** design has been improved upon over the last 20 years and is now replaced with the SeaSonde®. The SeaSonde is the only commercially available HF radar system with a proven track record and stands at the forefront of precision current measurement and ease of utility. Designed and built by CODAR Ocean Sensors, the SeaSondes have a small antenna footprint, low power output and 360 degree possible viewing angle which minimizes siting constraints and maximizes coverage area. They can be remotely controlled from a central computer in your office and set for scheduled automatic data transfers. The SeaSonde is ideal for fine scale monitoring in ports and small bays, as well as open ocean observation over larger distances up to 70 km. For extended coverage, the Long-Range SeaSonde can observe currents as far as 200 km offshore.

A. Site-Specific practices after installation that ensure quality

Unlike other simpler oceanographic sensors that operate in a much more uniform fashion after unpacking from the box, HF radar data quality depends in a complex manner on the land and ocean environment near the radar site. Two major factors can limit accuracy and must be calibrated carefully right up front. Normally, CODAR staff attend to these calibrations — supported by the client — and monitor for optimization over a several-week period after installation.

- **Antenna pattern measurement/calibration:** Most significant errors in current mapping are due to bearing angle errors or biases. The receive antenna in all HF radars is used to determine bearing. Its pattern must be known in order to estimate echo bearing accurately. Idealized "textbook" patterns are distorted by the local environment (including feedline layout) near each antenna element. These should be known and included as calibration in order to remove this source of error from current maps.

CODAR has developed an advanced but simple-to-implement, GUI-driven methodology for measuring antenna patterns and mitigating effects of distortion in current extraction. This presently involves use of a lightweight portable transponder. The latter can be transported on a boat that circles the antenna several hundred meters away (takes less than an hour), or by walking the transponder on land around the front of the receive antenna (if there is enough space to the sea); the first method is preferred. After measurement, the calibration processing (normally based on help from CODAR staff) refines this pattern and includes it in the configurations folder for real-time processing at that site.

Antenna patterns should be measured/remeasured:

- Just after site installation;
- Whenever the receive antenna and/or cabling is replaced;
- If there is a change in the local environment near the antenna;
- Approximately every two years; this guideline can be modified based on examining amplitude/phase diagnostics, discussed subsequently.

- **First/second-order boundary limit setups:** Current and wave information in HF radars comes from the first-order (Bragg) and second-order echo spectral regions. It is essential that the software be able to discriminate and separate these echo regions properly. However, these echo regions are very site specific; they depend on the prevailing current and wave climatologies at that location.

Therefore, CODAR staff work with the client to examine data from each new site after installation. Setting these echo spectral boundary limits correctly depends on the interplay of several parameters that are stored in the site's preferences folder. Normally, CODAR works with the client's data over a period of three months to ensure that these parameters are optimized. This span is necessary to ensure that a full range of site- specific current/wave conditions are encountered. Once these are set correctly for a given site, they need not be revisited again. Default settings are least likely to be correct at higher HF frequencies and where currents are strong.

B. Automatic algorithmic removal of spurious data

Many years of CODAR experience with HFSWR has revealed at least five types of spurious signals that can be and are mitigated by real-time software filtering algorithms:

- **Ship-type echo removal**: Ship echoes are large, and range over the same span of Doppler velocities as sea echoes. CODAR scientists have developed and used algorithms for 22 years that identify these echoes and remove them, so that they do not produce spurious current vectors or wave information. This is based on the unique properties of ship echoes: how long they persist in the range and Doppler cells; this type of interference has time scales of several minutes.
- **Ionospheric-type echo rejection**: At certain times of the day/night, strong echoes from overhead ionospheric layers at ranges between 90 - 250 km can produce spurious current vectors. Algorithms were developed to identify the presence of these echoes and remove them. Sometimes this can leave a gap at the ranges corresponding to the ionospheric echoes, but this is better than wild vectors. Often only one side of the Doppler spectrum (positive/negative) is affected, so that redundant information produces no gaps. There are preference parameters that can be adjusted to optimize performance. This type of interference can persist from one-half to two hours.
- **Impulse removal**: Lightning strokes are an example of this, persisting only 10 - 20 milliseconds but very intense. Unless excised, such impulses have the effect of raising the noise floor so that range is drastically reduced. CODAR excises such bursts from the time series before Doppler processing, a procedure in effect for nearly ten years. This improves the performance greatly, especially when storms or other impulse sources are close by.
- **Radio signal interference rejection**: Radio interference very often manifests itself in FMCW radars as vertical stripes in colored range/Doppler plots (*i.e.*, appearing at all ranges but in constant-Doppler bands). These have the unique property that they appear at both positive as well as "negative" ranges (the latter being an artifact of the normal in-phase/quadrature radar signal processing; however actual echoes occur only at positive ranges. CODAR developed algorithms several years ago to identify these and use their negative-range images to cancel the interference from positive ranges, nearly always cleaning up the spectra so that Bragg peaks, second-order echoes, and ships are seen clearly. Such radio signals can typically last up to a half an hour or longer.
- **Echoes from offshore wind turbines**: Occasionally HF radars are accidentally or purposefully sited so that they look out at farms of wind turbines that may be tens of kilometers offshore. These produce Doppler-echo spurs at those ranges that can fall in spectral space where Bragg, second-order, or ship echoes exist. These spurious echo sidebands are produced by the amplitude and phase modulation of the echoes from the blades that rotate at ~15 rpm. CODAR has analyzed and is testing processing methods that place these interfering sidebands outside of the span used for currents (including tsunamis), waves, and ships. When the blade sidebands occasionally do fall within our desired spectral signal space, algorithms will track and remove those offending Doppler cells, because their variation based on blade speed changes is slow enough to follow.

C. "SeaSondeReport" files collectable at radar sites

In order to facilitate the ability of clients and operators to collect relevant diagnostic information at radar sites (system and information logs) when problems are suspected, CODAR devised an easy-to-use script that an operator can execute. This immediately collects and assembles a zipped archive that can be emailed as an attachment to CODAR for troubleshooting. We call this attachment a "SeaSondeReport File". There are four levels available: High, Medium, Low, and Web, which grab the same information but for varying amount of time going backward from the present. Their sizes can span between 6 MB and 20 MB. This diagnostic information includes:

Computer information consisting of:

- Computer profile: kind, hardware, OS-X version, etc.
- Crash logs
- Latest system logs

SeaSonde information consisting of:

- Latest radial/elliptical velocity files, latest wave files, and latest spectra
- Radial 'Configurations' folder
- SeaDisplay site map
- Combine 'Configurations' folder
- Radial Site Status which contains the latest Radial Web Server information
- Radial Web Server Alert logs
- Diagnostic logs/files (described in next section)
- SeaSonde Software Version list
- Catalog listing of all files in the SeaSonde 'Data' folder
- Sentinel logs ('Sentinel' is the top-level manager algorithm)
- User-site log (notes logged by persons making changes at the site)

D. Diagnostics files to maintain system quality and/or troubleshoot

From the beginning of SeaSonde development/operation, CODAR has always maintained ASCII diagnostic files. Entries are written to these diagnostics files as frequently as every ten minutes. These constitute histories of the radar system "health". There are two types of files being constantly recorded: one relating to system/hardware performance and the other to the signal environment being observed. New files are started every week.

CODAR also provides graphic tools that allow the operator to display multiple simultaneous histories for any combination of these user-selectable diagnostics. This can be over hours, a day, week, month, several months, a year, etc. Such combined display histories are extremely valuable in:

- **Preventive maintenance**. Viewed on a regular basis (*e.g.*, weekly), they allow the identification of an abrupt or gradual component failure or onset of external signal interference. In most cases, the source of the problem can be narrowed down to a specific component or source of an offending external signal.
- **Troubleshooting.** When a client or operator encounters the onset of a major defect (for example output current maps show no vectors), the display of the diagnostic files usually reveals the cause. This can be done either by the client/operator or by CODAR staff at the request of the client.

Here is the information monitored and archived in these diagnostics files:

- "HDT" Files (hardware integrity/health). This file begins with comments that include all receiver, signal and processing metadata settings, followed by the following columns:
- Time of observation — expressed in computer log time (minutes)
- Receiver temperature
- AWG (advanced waveform generator) module temperature
- Transmit trip hex code (logs when transmitter shuts off, *e.g.*, due to temperature threshold being exceeded)
- AWG run time code (how long AWG has been running uninterrupted)
- Power supply voltage

- Nominal +5 Volt supply (actual voltage)
- Nominal -5 Volt supply (actual voltage)
- Nominal +12 Volt supply (actual voltage)
- Internal transmit chassis temperature
- Transmit power amplifier module temperature
- Forward power exiting transmitter toward antenna
- Reflected power coming back from antenna into transmitter
- Transmitter power supply nominal +5 Volt supply (actual voltage)
- GPS receiver mode
- GPS display mode
- Phase-lock loop unlock indicator
- High receiver temperature
- Receiver humidity (percent)
- Power supply current (amps)
- External Input A
- External Input B
- Computer uninterrupted run time (minutes)
- Actual date/time of the log entry

"RDT" Files (received signal characteristics/heath). This file begins with comments that include all receiver, signal, and processing metadata settings, followed by the following columns. These are calculated from every CSS cross spectral file and/or the short-term radial velocity file created from that CSS:

- Time from start reference, in seconds
- Normalized antenna channel amplitude balance from sea echo: Loop #1 to monopole
- Normalized antenna channel amplitude balance from sea echo: Loop #2 to monopole
- Antenna channel phase difference balance from sea echo: Loop #1 to monopole
- Antenna channel phase difference balance from sea echo: Loop #2 to monopole
- Phase balance difference set used for processing: Loop #1 to monopole
- Phase balance difference set used for processing: Loop #2 to monopole
- Measured noise floor in dBm: Antenna Channel #1
- Measured noise floor in dBm: Antenna Channel #2
- Measured noise floor in dBm: Antenna Channel #3
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #1
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #2
- Signal (max Bragg peak)-to-noise ratio, dB: Antenna Channel #3
- Range cell where SNR was maximum
- Number of Doppler cells at all ranges that produced radial velocities
- Percentage of calculated radial vectors that were dual angle
- The count or total number of radial vectors found for that CSS file
- The average number of radial vectors calculated per range cell
- The number of range cells that produced radial vectors
- The maximum range seen for radial current calculation, in km
- The maximum radial velocity seen at all ranges
- The average radial velocity seen at all ranges

- The average of bearings that produced radial velocities for all ranges
- The type of radial velocity file produced. These include the following categories: (i) Ideal-pattern short-time radials; (ii) Measured-pattern short-time radials; (iii) Ideal-pattern merged final radials; (iv) Measured- pattern merged final radials.
- The type of spectra used/available for radial processing: includes CSS, CSA, CSQ cross spectral files.
- The remaining columns contain the complete date and time information

The same type of "RDT" file is produced for bistatic/multi-static operations, where scalar elliptical velocities are calculated rather than scalar radial velocities. These files are called "EDT", and contain essentially the same information and format as that described above for the "RDT" case.

E. "RadialWebServer" to view summary of diagnostics, warnings, and data

The RadialWebServer is a unique creation done by CODAR about five years ago. It gives limited access to a SeaSonde Radial Site (remote radar) through a web browser like Safari, FireFox, or Explorer (not all browsers may be fully supported). Access is limited to viewing and downloading the site's status, configuration, spectra, diagnostic, wave and radial data. This can be done from a desktop computer (Mac or PC); from a laptop; from an iPad, or iPhone (as well as other smart phones equipped with a web browser). For example, on an iPad or iPhone, the user can expand a chart or graph to legible size in the normal way by using fingers on the touch-screen to expand the image, thereby enlarging it.

Among the items concisely reported and graphically displayed are:

- *Status - top level alerts*: This is a listing of any warnings of possible malfunctions or non-normal status indicators.
- *Site's more detailed status*: A listing of the essential information about the site, including location, antenna bearing, signal properties, time at the site, etc.
- *Radial display*: Plot the most recent or any radial velocity plot over the past year. This includes averages over a day; those done from ideal or measured antenna patterns, etc.
- *Wave display*: Plot a history of the wave information. Can be up to present, or over any past period.
- *Spectral display*: Shows the present or allow plotting any echo Doppler spectra within the last year at that site.
- *Diagnostic display*: Plot the hardware and data/signal diagnostic history of any parameters available from the diagnostic files.
- *Logs*: Allows viewer to look at any critical site logs, or create and download a SeaSondeReport file (described previously).
- *Settings*: Change the refresh interval and set up the "alert" email service.

Note: for security, one cannot use this browser to change or control any of the radar functions, signal, and processing parameters. That must be done from a laptop in a more password-protected procedure.

Detailed information on this RadialWebServer can be found in the following two documents available from the "www.codar.com" website:

- **RadialWebServer User's Guide**
- **RadialWebServer Installation & Administration Guide**

F. Warning messages sent to client/operator by email

The RadialSiteReporter tool monitors the status of the Radial Site and is an important companion of the RadialWebServer. The RadialWebServer uses the results of this tool for the site status, details and alerts. ***The RadialSiteReporter can also email changes in alerts. This tool is scheduled to run once a minute.*** email is done by using the command line tool 'sendmail'.

Each alert has four states: *newly tripped*, *still tripped*, *newly cleared*, and *still cleared*. email alerts happen only when at least one alert is newly tripped or cleared, upon which all the newly cleared alerts and all new and old tripped alerts are emailed out.

There are over 120 alert messages that can be sent out when a system or operating defect is encountered. Often several alert messages are triggered together, permitting a more detailed diagnosis of a problem,

The alert messages and more details on setting up this unique CODAR QA/QC service is found in the document: **RadialSiteReporter** on our website: www.codar.com.

G. Real-time uncertainties and error metrics in radial current files

CODAR for years has outputted uncertainties and other quality metrics, along with the estimated radial velocities, in files with names beginning "RDL". In our standard LLUV format (longitude/latitude/east current velocity/north current velocity), these uncertainties appear as columns to the right of the velocities. Uncertainties are standard deviations calculated from the data themselves. They include:

- *Spatial uncertainty/quality*: This is the standard deviation calculated at the short-term CSS output interval (typically 10 minutes at frequencies above 5 MHz) for all of the individual velocities that fell in a given range/bearing cell.
- *Temporal uncertainty/quality*: This is the standard deviation of the short- term radial velocities (*e.g.*, every 10 minutes) averaged over the user-chosen merging period (*e.g.*, over an hour).
- *Velocity maximum*: The maximum of all of the radial velocities used to compute the mean estimate for that range/bearing cell.
- *Velocity minimum*: The minimum of all of the radial velocities used to compute the mean estimate for that range/bearing cell. The difference between this and the previous number gives the "span" of velocities from which the mean is constituted, which is another metric of data quality (large spans are suspect).
- *Spatial count*: The number of vectors included in the average for the short-time radial estimate (*e.g.*, over 10 minutes) and its uncertainty.
- *Temporal count*: The number of vectors included in the average for the merged (*e.g.*, over an hour) radial estimate and its uncertainty.

All of the above metrics give useful information on radial velocity data quality. It is important to note that each of these metrics (as well as the radial velocity itself) is a statistical estimate. Therefore, absolute correlation of a given metric for that time and spatial cell with velocity quality does not always have a one-for-one correspondence.

For example, a large uncertainty does not always mean a bad radial vector; nor is an obvious outlier velocity always accompanied by a large uncertainty metric. Hence, using each uncertainty to threshold to eliminate outlier velocities is not recommended.

However, over a region of space and period of time, studies by Laws (supported by US IOOS) and others show a definite and irrefutable relationship to data quality (documentation is available). Therefore, these metrics are highly useful in assessing data quality and system health. They are also useful as data covariances in numerical models, because there they enter in space-time aggregate/average sense.

Exactly the same uncertainties and quality metrics are outputted – in the same format – for bistatic elliptical scalar velocities that are stored as "ELP"-titled files. These metrics all apply to the scalar elliptical velocity component, just as they apply to the radial velocity component for "RDL" files collected from backscatter radar geometries.

It is important to note that these uncertainties and metrics do not apply to the u/v components of either of these scalar velocities independently. However, the radial and elliptical uncertainties can be and are propagated through to calculate uncertainties for total vectors produced therefrom; documentation explaining this process are available in the CODAR library.

Although most people ignore these quality metrics that CODAR outputs, we recommend that users consider and use them on a wider basis in order to assess system and data QA/QC because — as mentioned above — they have been proven meaningful.

H. "RadialMetric" data output option

A useful way to diagnose possible problems or optimize performance is to process the same raw data sets offline, with a number of different parameter preference settings. A large number of either default or user-selected parameters control the processing and decision making. The final data products (*e.g.*, radial or total vector maps and ASCII files), therefore, have undergone quite a few irreversible steps; in other words, it is not possible to go back to raw data from the much more compact, final data products. Although the raw data can be reprocessed offline in order to evaluate any number of different parameter permutations, CODAR is too often labeled a "black box" where no one can understand or change any of the settings that might have produced different — or better — results. However, offline reprocessing of archived raw data is cumbersome and time consuming.

For this reason, with support from NOAA's US IOOS through a contract from Scripps Institution of Oceanography, CODAR has produced and makes available a new, optional ASCII format for radial vector file outputs. This output is called "**RadialMetric**". It is a file that complements and/or replaces the normal ASCII Radial Files created at the SeaSonde radar sites in real time. In this ASCII file are every possible intermediate data product for each range and Doppler cell from which radial vectors are created. In other words, no irreversible steps have been made, and the user can try any combination of different radial processing parameters by manipulating the data within this special RadialMetric file. For example, one can try different MUSIC direction-finding processing parameters; examine whether better quality can be obtained by employing signal-to-noise ratios (SNR) as a filter; average in a different manner over bearing and/or Doppler shift, etc.

This special file output can be requested in the processing control file called "AnalysisOptions.txt". There may be only a few users who are interested in reanalyzing or doing their own optimization studies at this level. The consequences are that these RadialMetric files are much larger (sometimes by a factor of five or more) than the normal Radial File outputs. This has impacts in archival/data transfer considerations. More details about this QA/QC and data optimization tool are found in the document **"RadialMetricDescription.pdf"** from our website www.codar.com.

I. Decomposing total vector maps to obtain/compare radials/ellipticals

CODAR offers a useful tool to assess data quality in synthesizing total vector maps. The philosophy of this tool and its utility is the following. Total vector maps are normally composed from at least two, and usually more, radial (backscatter) and elliptical (bistatic) sets of vectors — sometimes four to six. Irreversible steps and averaging processes are applied to all of these radar data sets in synthesizing total vector maps.

- *Synthesis of total vectors*: Here is what happens in synthesizing total vectors. Radials and/or elliptical scalar components of the true total 2D vector field are estimated from several radars (transmitters and/or receivers). Those are then combined at a central site as follows. All of these measured scalar estimates are collected within a circular radius about a given total-vector grid point. The circle radius is user-selectable. The best-fit total vector at the grid point is estimated from all of the constituent scalars. This is usually done as an overdetermined least-squares fitting, but options are available to choose other methods, for example, four nearest neighbors, maximum likelihood (the latter being a weighted least squares approach), optimal interpolation, open-mode analysis, etc. All of these inherently involve averaging many data points together, which is an irreversible process.
- *The quality issue being addressed*: There may be a question about the quality or accuracy of these synthesized total vectors. Sometimes there may be an obviously questionable region. In other cases, there may simply be a desire to analyze the constituent synthesis process better and see whether it appears to be optimal. But the impact of a given radar's scalar input to the resulting 2D vector at any point is no longer obvious. The tool being discussed here allows that decomposition to be made, so that errors or poor data quality from one site's data may now become obvious.

- ***"RadialFromCurrent"*** *Tool*: This tool allows one to open a GUI window. Then one drops onto this window: (i) A radial/elliptical site "header" file or the configuration folder for the sites to be analyzed; (ii) The total vector file that is to be decomposed back into the constituent radials and ellipticals. The tool will then create the decomposed radials and ellipticals that were requested, as a file in the normal LLUV format of the originals.
- *How does this help?*: Now one can look at the decomposed radial vector plot for a constituting site and compare it with the original field that went into the synthesis process. Do this for all the constituent radials/ellipticals. They will not be identical, of course, because of the irreversible averaging that had been done to get the 2D plot. If five sets of radials or ellipticals were used, and four originals and decomposed sets agree well with each other, but one set doesn't, this suggests the culprit. If this happens again and again with total vector files from these sites, this confirms that one site is definitely not healthy; or is at least the weak link in the grouping producing the total vectors.

J. Simulations to study/understand factors influencing data quality

Often one wants to see how well the CODAR processing or MUSIC direction- finding and their controlling parameters works for a given input current pattern. The tools **"CSSim.m"** and **"BSSim.m"** are MATLAB applications with convenient graphical user interfaces (GUIs). These allow one to set a desired current pattern for study. The purpose is to create "CSS" cross-spectral files for this pattern, also allowing for its evolution with time. These CSS files are the outputs and are in exactly the same format as those created from "SeaSondeAcquisition" in the field SeaSondes. The ultimate objective is to process these with our normal "Currents" tool, with whatever MUSIC and other processing parameters one wishes to vary. The question to be answered is: how well did I recover the original pattern that was inputted, and hence, which processing parameters work best? Or, where in bearing angle do the radial (or elliptical) velocities fail the worst and why, as I make the current pattern ever more challenging? This is yet another way of "examining and understanding quality."

"CSSim" creates averaged CSS cross-spectral files for backscatter radar geometries. "BSSim" creates averaged CSS cross-spectral files for bistatic radar geometries.

The simulation of sea echo and the resulting cross spectra for input current patterns follows the models for HF sea scatter derived by Barrick ~42 years ago. Highlights of this and the parameter settings available are:

- The ocean wave heights and the scattered signals are zero-mean Gaussian random variables.
- The Bragg wavelengths define the first-order echo used for current extraction.
- Additive Gaussian white noise is added to the Gaussian sea echoes; the user specifies the desired sea-echo signal-to-noise ratio desired.
- The Bragg-wave angular pattern is inputted by the user, usually conforming to the wind-wave pattern. This determines the positive/negative Bragg-peak ratios and appearance.
- The desired current pattern that the user specifies is defined by polynomials of radial velocity as a function of bearing, for each range cell. We usually select and study reasonably complex (but realistic) currents that have both single and dual- angle behavior (and often triple-angle or more) to see how well the MUSIC algorithms will handle known, input, complex current patterns.
- The simulator generates time-series signals for two crossed loop antennas (at whatever orientation the user specifies, plus the omni-directional monopole/ dipole.
- The simulator user can assume either idealized sine/cosine/omni antenna patterns, or input an actual set of measured, distorted antenna patterns. The echo signals will depend on these patterns. This allows study of distortion effects on current pattern retrieval.
- The simulation begins by calculating the time series of the sea echo plus noise.
- From this, unaveraged cross spectra (CSQ files) are generated at whatever radar frequency and time-series length the user desires. This defines the Doppler and velocity resolution that will be available upon processing.

- The user specifies how many of these CSQ cross-spectral files are to be averaged to produce a CSS file that is to be written in the same format as the field radar software. This allows study of the effect of spectral averaging on current accuracy.

These programs and user-evolved variations have allowed study of the effect of signal and processing parameters on the retrieved current patterns compared with their inputs. In addition to extensive experience gained by CODAR staff, others have used this tool to study and report on the effects of system and environmental parameters on output current quality. Some of these are: Kip Laws; Tony di Paolo; Simone Cosoli.

K. “GDOSA.m” – A simulation tool to optimize geometry for 2D vector coverage quality

In many network scenarios, 2D currents at a point on the ocean are being synthesized from multiple radar looks. These are often overlapping backscatter HFSWRs with more than two able to see that point. More frequently, they include multi-static geometries where a separated transmitter (perhaps from the consecutive adjacent radars in the network) observes that point also. This can increase the coverage area. More often than not, the main advantage lies in the added quality of the resulting 2D total vectors: their increased accuracy and robustness. That is, more data being used in the synthesis of the 2D map gives more accurate total vectors. The question arises: can this added quality be predicted based on site location selections?

CODAR has developed a GUI-based MATLAB tool, **“GDOSA.m”**, to assess total vector coverage and quality based on site locations. Contributing radars can be backscatter and/or bistatic, up to any desired number. The user inputs candidate locations, maximum expected range, and cell size. Assumed is a uniform input measurement error in radial/elliptical constituents. These errors are propagated through to obtain error in the 2D total vectors at each point in the coverage area. This is referenced (normalized) to the assumed input errors (cm/s) in the radials/ellipticals. It includes both: (i) GDOP (geometrical dilution of precision) — an angle-based error that accounts for input radials, for example, that are close to parallel so that resolution of the perpendicular component becomes difficult. (ii) Varying area resolution and density of the input radials in their polar coordinates and ellipticals in their elliptical system. Hence the name GDOSA that includes both (for geometric dilution of spatial accuracy).

The outputs are maps of color shading within the coverage area, representing quality of the expected 2D vectors. Dark colors are high quality. Contours are also shown for the magnification of error; low numbers represent the lowest error propagation from the constituent inputs at that point. The methodology behind it is precise and described in a widely circulated CODAR document by Barrick titled “***Geometrical Dilution of Statistical Accuracy (GDOSA) in Multi-Static HF Radar Networks***” (2002).

This tool is useful not only for planning and design of new network installations, but also for assessing expected weak and strong areas of 2D vector quality within existing networks.

L. Example of long-term QA/QC system/data health assessment plan

The normal SeaSonde installation and calibration process can take several weeks to deal with site-specific debugging and optimization challenges that typically arise. Some call this the “commissioning” or “certification” period. During this phase, both CODAR and client are paying close attention to the radar operation and data quality.

After this period, the culture of how the system is maintained over time varies widely, we have found. Worst case, the operator pays little attention to the day-to-day operation or data outputs. When the operator does pay attention, it is often only to observe that there are no radial velocities being produced by the site. Or, that the radial velocities suddenly appear unrealistic. Often the operator also has other non-radar responsibilities or many other radars to attend. Too often only “the squeaking wheel gets the grease” (or attention). We have observed SeaSonde systems that operated nearly continuously for periods of 10 years with almost no attention. Although outputs may continue to look good superficially, inevitable wear by the elements and equipment aging will lead to degradation in quality of output data. This is unfortunate and can be avoided by minimal pro-active attention to the diagnostics being produced and stored in the folder archives.

NOAA’s US IOOS has put together a national plan to assess the needs and future for its national HFSWR network. It is called “***A Plan to Meet the Nation’s Needs for Surface Current Mapping***”, September 2009 (downloadable from the US IOOS website). This is based on inputs from dozens of HFSWR owners and operators in the US tracking the experience from ~130 radars (about 122 of them SeaSondes) that lined our coasts at that time (the number has increased since then). Some of the SeaSondes involved go back 20 years. It was found that approximately two full-time persons (radar technicians) are required to adequately maintain seven SeaSonde radars (and two persons for four WERA radars). We are finding that new networks of SeaSondes being created in many other countries – particularly in Asia – rarely maintain this ratio, sometimes dropping below one technician for ten SeaSondes. This is not enough.

As a result, recommend pro-active plans to such clients, that we hope will be seriously considered in order to maintain acceptable QA/QC and head off degradation and failure problems before they occur. One such plan was prepared for an Asian client with a network of a dozen SeaSondes. It contains a checklist, with tasks to be executed for each radar at regular intervals (as often as once a week). Nearly all of these can be done remotely with internet access; the checks can take less than half an hour. When significant change is encountered, maintenance can be initiated on their own or in consultation with CODAR Support staff.

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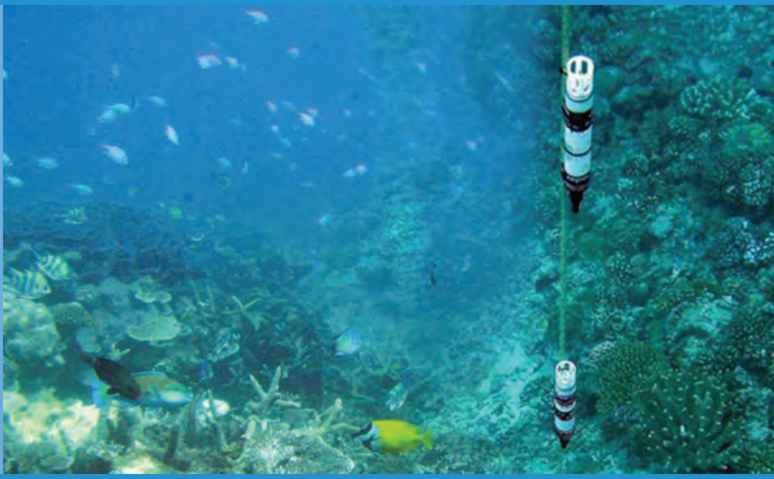
Ocean Observation



Sensing conductivity, temperature, pressure and dissolved oxygen using Sea-Bird Electronics' sensors and instrumentation

Sea-Bird Electronics, Inc. is the largest manufacturer of marine instruments for measurement of salinity, temperature, pressure, dissolved oxygen and related oceanographic variables. Major products include conductivity, multi-bottle *in-situ* water samplers, moored CT recorders, wave/tide recorders, dissolved oxygen sensors, and thermosalinographs. Customers include research institutes, ocean observing programs, national and local government agencies, engineering firms and navies throughout the world. As part of our commitment to advancing the science of ocean measurement, we are deeply invested in engineering, metrology, calibration, software development, scientific analysis and other essential technologies that make our products more accurate, reliable and broadly useful.

Introduction

Sea-Bird Electronics, Inc. is the largest manufacturer of marine instruments for measurement of salinity, temperature, pressure, dissolved oxygen, and related oceanographic variables. Major products include Conductivity/Temperature/Depth (CTD) profilers, multi-bottle in-situ water samplers, moored CT recorders, wave/tide recorders, dissolved oxygen sensors, and thermosalinographs. Customers include research institutes, ocean observing programs, national and local government agencies, engineering firms, and navies throughout the world.

Type of sensors dealt with

Conductivity, Temperature, Pressure and Dissolved Oxygen

Description of individual sensors and instruments

Conductivity sensors

Conductivity is measured directly on seawater contained within a glass cell by the frequency of an AC signal. Conductivity sensors are available as either standalone sensors or integrated into instruments along with temperature and pressure. Measurement range is 0 – 9 S/m. Figure 1 shows an SBE 4 oceanographic conductivity sensor.

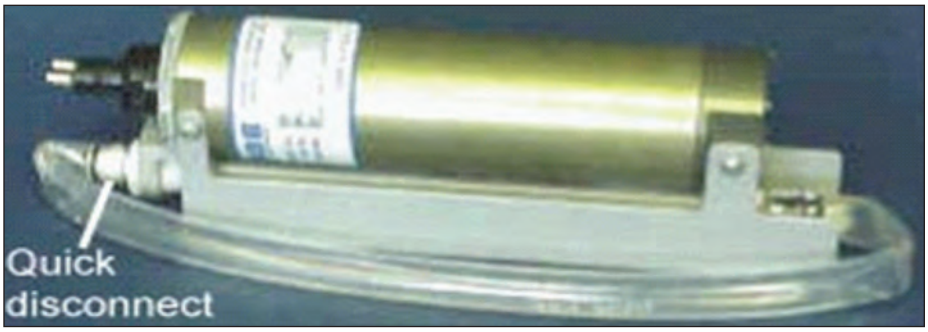


Figure 1. SBE 4 Conductivity sensor with Tygon® loop used for storing the sensor

Temperature sensors

Temperature is measured by a thermistor contained in a pressure-resistant metal sheath. Temperature sensors are available as either standalone sensors or integrated into instruments along with conductivity and pressure. Measurement range is -2 to 35 degrees C. An SBE 3 oceanographic thermometer is shown in Figure 2.

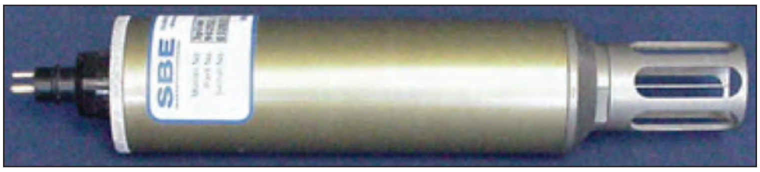
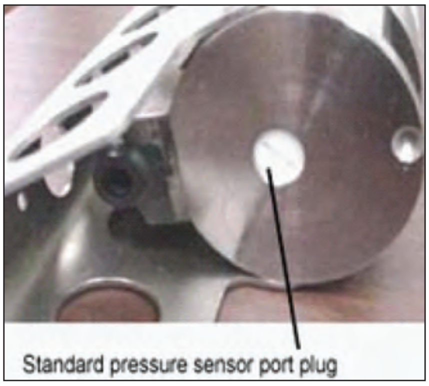


Figure 2. SBE 3 Temperature sensor

Pressure Sensors

Sea-Bird does not manufacture pressure sensors, rather installs sensors made by other manufacturers. Pressure is measured by either a strain-gauge or a quartz-crystal based sensor. Strain-gauge sensors are available as standalone sensors (Figure 3b). However, strain-gauge and quartz-crystal based sensors are typically integrated into an instrument, as shown in Figure 3a.

a) 

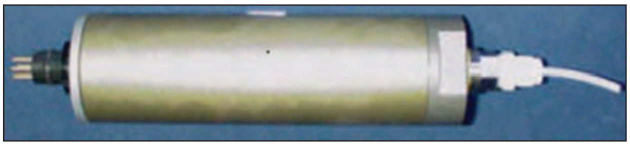
b) 

Figure 3 a) Integrated strain-gauge pressure sensor port on an SBE 37 MicroCAT, and b) SBE 29 modular strain-gauge pressure sensor

Oxygen Sensors

Oxygen is measured by either a Clark electrode (electrochemical) sensor or optically by the luminescence method. Sensors are available as either standalone units or are integrated into instruments along with conductivity, temperature and pressure. Figures 4 and 5 show the Clark electrode type sensor and the optical type sensor, respectively.

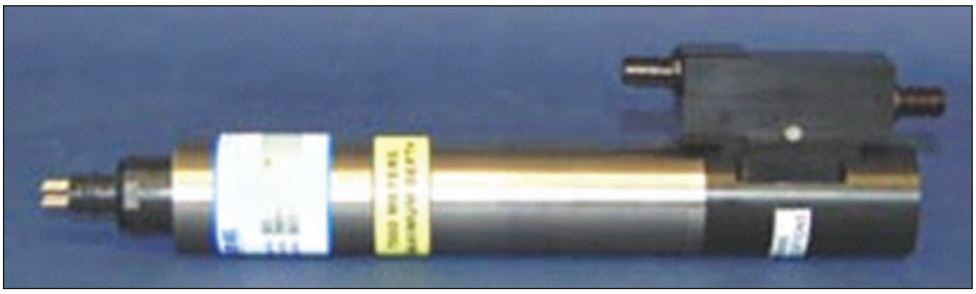


Figure 4. SBE 43 modular Clark electrode dissolved oxygen sensor, equipped with a black plenum to help prevent *in situ* bio-fouling for moored applications

In addition to standalone, modular sensors, Sea-Bird offers numerous integrated instruments designed for profiling and mooring applications in coastal or offshore waters.

Profiling instrumentation

Sea-Bird Electronics makes several types of real-time sampling and internally recording moving platform CTDs (Table 1). Figure 6 shows two examples of the CTD line offered by Sea-Bird, including the real-time SBE 9plus (with SBE 11plus deck box controller) and the internally recording SBE 19plus V2 CTDs.

In addition to these more traditional CTD options, Sea-Bird also manufactures the CTD integrated on over 99% of all Argo profiling floats deployed in the world's oceans during the past decade. Tethered profilers (SBE 52) and most recently, a line of glider and AUV CTD products, supply Sea-Bird data acquisition capabilities to the latest generation of remote sampling platforms.

Sea-Bird's CTD products are designed to make use of the best sensor technologies available for moving platform applications, and are engineered to reduce dynamic errors inherent with moving platform sampling. Optimal pump rates, sensors with known response times and plumbing configurations are specifically selected for each CTD product to ensure best performance and best data quality return.

Figure 5. SBE 63 optical dissolved oxygen sensor

Table 1. Sea-Bird Electronics family of shipboard profiling CTDs

SBE	Sampling rate	Channels for auxiliary sensors	Memory	Power internal/ external	Real-time data transmission	Comments
911 *plus*	24 Hz	8A/D	16 Mb with optional SBE 17 plus V2	External, Internal with SBE 17 *plus* V2	Yes	World's most accurate high resolution CTD, water sampler control
25 *plus*	16 Hz	8 A/D; 2 RS-232	2 Gb	Both	Yes -- may require SBE 36 Deck Unit & PDIM	High resolution logging CTD with multi-parameter support, water sampler control with SBE 33 Deck Unit
19 *plus* V2	4 Hz	6 A/D; 1 RS-232	64 Mb	Both	Yes -- may require SBE 36 Deck Unit & PDIM	Personal CTD, small, self-contained, adequate resolution, water sampler control with SBE 33 Deck Unit
49	16 Hz	No	No	External	Yes – may require SBE 36 Deck Unit & PDIM	Intended for towed vehicle, ROV, AUV

a)

b)

Figure 6 a) SBE 9plus profiling CTD equipped with integrated quartz pressure sensor and modular temperature and conductivity sensors and pumps. Below is the SBE 11plus deck box. b) SBE 19plusV2 profiling CTD equipped with integrated pressure, temperature and conductivity sensors and a modular SBE 43 dissolved oxygen sensor and modular pump

Moored Instrumentation

Sea-Bird makes a suite of moored instruments suitable for various oceanographic and freshwater applications (Table 2).

The moored CTD line includes the SBE 37 MicroCAT family (Figure 7a), the SBE 16plus V2 SeaCAT (Figure 7b), as well as the SBE 39 and SBE 56 temperature sensors (Figure 8). Each moored instrument type typically offers a variety of integrated and modular sensor options to suit various customer applications.

a)

b)

Figure 7. a) SBE 37 MicroCAT equipped with an integrated SBE 63 optical oxygen sensor b) SBE 16plus V2 equipped with a modular SBE 43 oxygen sensor and pump, and black Tygon® tubing to prevent *in situ* bio-fouling

Table 2. Select Sea-Bird Electronics moored instrumentation and capabilities

SBE	Measures (C, T, P)	Auxiliary sensors	Memory	Power		Communication	Real-time data	Comments
				Internal	External			
16*plus* V2	C, T, P*	6 A/D; 1 RS-232	64 Mb	✓	✓	RS-232	✓	Optional pump
19*plus* V2	C, T, P	6 A/D; 1 RS-232	64 Mb	✓	✓	RS-232	✓	*Programmable mode* -- profiling or moored
37-SM	C, T, P*		8 Mb	✓	✓	RS-232 or -485	✓	
37-SMP	C, T, P*		8 Mb	✓	✓	RS-232 or -485	✓	Integral pump
37-SMP-IDO	C, T, P*	Integrated DO	8 Mb	✓	✓	RS-232 or -485	✓	Integral pump
37-SMP-ODO	C, T, P*	Integrated Optical DO	8 Mb	✓	✓	RS-232 or -485	✓	Integral pump
37-IM	C, T, P*		8 Mb	✓		Inductive modem	✓	
37-IMP	C, T, P*		8 Mb	✓		Inductive modem	✓	Integral pump
37-IMP-IDO	C, T, P*	Integrated DO	8 Mb	✓		Inductive modem	✓	Integral pump
37-IMP -ODO	C, T, P*	Integrated Optical DO	8 Mb	✓		Inductive modem	✓	Integral pump
37-SI	C, T, P*		8 Mb		✓	RS-232 or -485	✓	
37-SIP	C, T, P*		8 Mb		✓	RS-232 or -485	✓	Integral pump
37-SIP-IDO	C, T, P*	Integrated DO	8 Mb		✓	RS-232 or -485	✓	Integral pump
37-SIP-ODO	C, T, P*	Integrated Optical DO	8 Mb		✓	RS-232 or -485	✓	Integral pump
39	T, P*		32 Mb	✓	Optional	RS-232	Optional	
39-IM	T, P*		32 Mb	✓		Inductive modem	✓	
56	T		64 Mb	✓		USB		
26*plus*	T, P	C optional	32 Mb	✓	✓	RS-232	✓ (tides, waves, & wave statistics)	Wave & tide recorder

C = conductivity, T = temperature, P = pressure, DO = dissolved oxygen
** = optional*

a)

b)

Figure 8. a) SBE 39 moored internally recording temperature sensor rated to full ocean depth (7000 m). b) SBE 56 internally recording temperature sensor rated to 1500 m

Principle of operation of Sea-Bird sensors

Temperature

The sensing element is a glass-coated thermistor bead, pressure-protected in a thin-walled stainless steel tube. Figure 9 shows a cross-section of a thermistor probe:

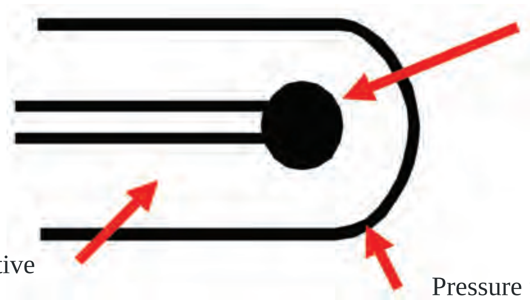


Figure 9. Cross-section of typical thermistor probe used on a Sea-Bird temperature sensor

Sea-Bird makes a variety of temperature sensors to fit the sensor response and characteristic needs for different applications. For example, faster sensor responses are required for moving platforms than for moored stationary platforms.

Exponentially related to temperature, the thermistor resistance is the controlling element in an optimized Wien Bridge oscillator circuit. The resulting sensor frequency is inversely proportional to the square root of the thermistor resistance and ranges from approximately 2 to 6 kHz, corresponding to temperatures from -5 to +35 °C.

Conductivity

Conductivity sensors are available as integrated sensors on instruments or modular, self-contained devices. They measure conductivity from 0 to 9 S/m (Siemens/meter), covering the full range of freshwater and oceanic applications. The sensors have electrically isolated power circuits and optically coupled outputs to eliminate any possibility of noise and corrosion caused by ground loops. Interfacing is simplified by the square-wave variable frequency output signal (nominally 2.5 to 7.5 kHz, corresponding to 0 to 7 S/m). The sensors offer improved temperature compensation, smaller fit residuals, and faster turn-on stabilization times. Supply voltage range is 6 to 24 volts.

Conductivity is a measure of resistance of water. The actual measurement is made between wet electrodes. Therefore, keeping the dimensions of the cell geometry stable is critical to the accurate measurement of conductivity.

For Sea-Bird conductivity sensors, the conductivity sensing element is a cylindrical, flow-through, borosilicate-glass cell with three internal platinum electrodes (Figure 10). The electrode arrangement offers distinct advantages over inductive or open external-field electrode cells. The outer electrodes are connected, therefore, electric fields are confined inside the cell, making the measured resistance (and instrument calibration) independent of calibration bath size or proximity to protective cages or other objects. The cell resistance controls the output frequency of a Wien Bridge oscillator circuit.

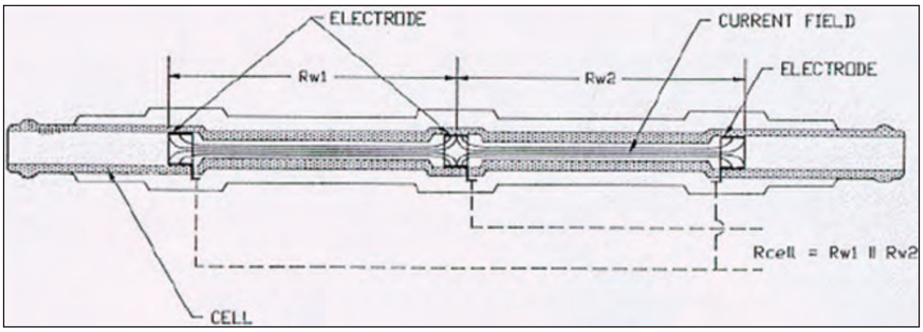


Figure 10. Cross-section of a Sea-Bird glass conductivity cell

Several factors influence the response characteristics of conductivity cells, regardless of the design (electrode or inductive). These include the flow rate of the sample water through the cell or sensing body, the temperature of the cell and heat capacity of the materials that make up the sensor, the electrode condition, and as already mentioned, the stability of the cell geometry. Except for Sea-Bird and Guildline Autosal, available electrode cells have partly external fields, while all existing inductive cells have external fields. Sensors with external fields shift calibration if nearby objects distort the external field. Anti-foulant materials and paints can also shift calibrations as they too will distort the external field. Sensors with external fields rely on the descent rate of the instrument package (CTD) to supply a flow past the sensor, because a pump attached to these sensors would also distort the external field. Since conductivity cell response time is flow dependent, achieving a constant response time for un-pumped cells requires a constant descent rate, something that is near impossible to achieve in most shipboard and moving platform applications.

A constant flow, as can be provided by a pump, guarantees a constant response time for the Sea-Bird sensor, which is not subject to external field distortion. It also guarantees the same water parcel is sampled by each sensor in the plumb-line. Anti-foulant protection can also be applied at the cell ends for moored and long-term deployment applications without distorting the conducting measurement. The response time of the SBE conductivity sensor is 30 milliseconds (0.030 sec). To control the response time of the sensor and match its response to temperature (0.070 sec), flow is controlled (slowed) through the conductivity sensor using a temperature-conductivity duct (TC duct) and by varying pump speed. This ability is critical to the accurate computation of salinity, as mismatched responses in T and C measurements will result in salinity spiking and errors in salinity calculations in general.

Another advantage of the SBE design is that the pump-controlled flow allows for an accurate mathematical representation of the cell thermal mass response of the conductivity sensor, which is inversely related to the flow rate of the sample water through the cell. This means dynamic errors can be reduced in post-processing of data when the conductivity sensor is pumped at a known flow rate, regardless of the temperature gradients encountered in the field. This is a critical correction, because a 1^0C temperature change experienced by the conductivity sensor on a moving platform would result in a practical salinity error in the order of 0.03. Being able to dynamically correct data for TC sensor alignment and response characteristics like this has enabled three decimal place salinity accuracy in Sea-Bird CTD field measurements.

Oxygen

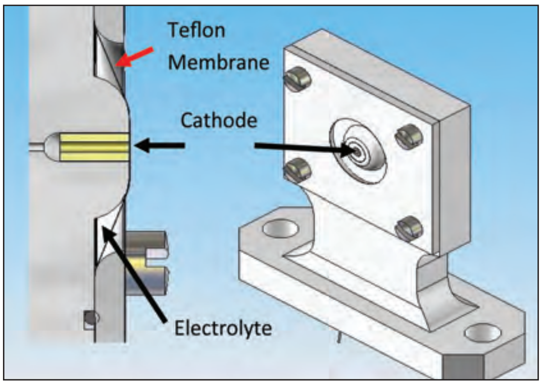
SBE 43 Clark Electrode Oxygen Sensor

The SBE 43 is a polarographic membrane, electrochemical oxygen sensor with a single output signal of 0 to +5 volts (Figure 11). The voltage is proportional to the temperature-compensated current flow occurring when oxygen is consumed under the membrane. A Sea-Bird CTD that is equipped with an SBE 43 oxygen sensor records this voltage for later conversion to oxygen concentration using an algorithm described in Edwards, Murphy, Janzen and Larson (2010).

The SBE 43 determines dissolved oxygen concentration by *counting* the number of oxygen molecules per second (flux) that diffuse through the membrane from the aquatic environment to the working electrode. At the working electrode (cathode), oxygen gas molecules are converted to hydroxyl ions (OH-) in a series of reaction steps where the electrode supplies four electrons per molecule to complete the reaction. The sensor counts oxygen molecules by measuring the electrons per second (amperes) delivered to the reaction.

At the other electrode (anode), silver chloride is formed and silver ions (Ag+) are dissolved into solution. Consequently, the chemistry of the sensor electrolyte changes slowly but continuously as oxygen is measured, resulting in a gradual loss of sensitivity that produces a predictable drift in the sensor calibration with time. This *electro-chemical* drift is accelerated at high oxygen concentrations and falls to zero

a)



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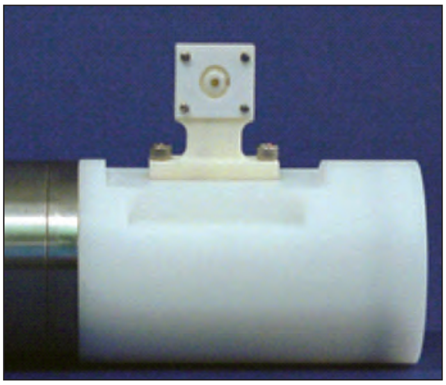


Figure 11. SBE 43 Clark electrochemical dissolved oxygen sensor. a) Cross-section of the sensor b) Sensor spar assembled onto the electrolyte chamber of the modular sensor

when no oxygen is being consumed. Sea-Bird engineered the SBE 43 to significantly reduce this effect in part by increasing the electrolyte chamber volume. Sensor storage and deployment strategies are also helpful at minimizing electrochemical degradation. For example, keeping the sensor in a zero- or near zero-oxygen environment when the sensor is not being sampled substantially reduces electro-chemical drift, reducing the need for maintenance and electrolyte refills while also improving long-term data quality.

Fouling of the gas permeable membrane also contributes to sensor drift by altering the oxygen diffusion rate through the membrane, thus reducing sensitivity. Non-biological fouling, occurring for example if the SBE 43 was profiled through an oil slick, typically produces an immediate jump toward low oxygen that may partially recover with sample flushing as the sensor exits the slick. Biological fouling affects not only the diffusion rates of oxygen through the membrane, but can be troublesome due to the fact that living organisms either consume or produce oxygen. Without protection and/or routine cleaning, a micro-environment around the sensor membrane can produce oxygen levels that are different from the true ambient conditions. By recognizing fouling, both episodic and gradual in nature and promptly cleaning the sensor using the procedures described in application notes on the Sea-Bird website, accuracy can often be restored. (See Useful Weblinks at the end of this document for more information on application notes).

SBE 43s intended for mooring applications are typically equipped with a thicker membrane (1 millimeter) and plumbed with black Tygon® tubing to prevent light from entering the system, hence reducing *in situ* biological growth along the sensor pathway. In contrast, SBE 43s intended for profiling applications are usually equipped with a thinner membrane (0.5 millimeter) and plumbed with clear tubing, since the profiling application affords less *in situ* biological fouling risk but demands faster sensor response characteristics.

The concentration of oxygen in the environment can be computed given the flux of oxygen and the geometry of the diffusion path. The permeability of the membrane to oxygen is a function of temperature and ambient pressure, which is taken into account in the calibration equation. The algorithm to compute oxygen concentration requires measurements of water temperature, salinity, pressure and oxygen sensor output voltage. When the oxygen sensor is interfaced with a Sea-Bird CTD, all of these parameters are measured by the CTD system automatically. If not, they must be provided from some other source in order to compute oxygen concentration.

The oxygen sensor consumes the oxygen in the water very near the surface of the sensor membrane on all Clark type electrochemical sensors. If there is insufficient flow of new water past the membrane, the sensor will give a reading that is lower than the true oxygen concentration. Additionally, if the flow *rate* is not *constant*, the sensor response time will vary, causing dynamic error similar to non-constant flow in a conductivity sensor. Therefore, maximum accuracy requires that water be pumped across the membrane at a constant flow rate if possible. Rates ranging between 20 to 40 ml/sec are provided on all Sea-Bird CTDs equipped with SBE 5T or 5P pumps.

Temperature differences between the water and oxygen sensor due to sensor thermal mass can also lead to errors in the oxygen measurement. The SBE 43 minimizes this difference by using materials that equilibrate rapidly with the environment and by incorporating a thermistor placed under the membrane at the cathode, for accurate temperature compensation. As a result, the SBE 43 is less susceptible to dynamic and thermal mass errors when profiling in water columns with large temperature gradients.

SBE 63 Optical Oxygen Sensor

The optical sensor operates by measuring the phase difference between a sinusoidal excitation signal of blue light and the emitted luminescent sinusoidal signal of red light. The presence of oxygen quenches the luminescent process, resulting in a non-linear phase response to increasing oxygen concentration. The sensor signal is characterized by a modified Stern-Volmer equation. Figure 12 shows the sensor in cross-section.

Optical oxygen sensors are to some degree less susceptible to fouling drift than Clark electrode membrane sensors. This is because the sensor does not rely on the flux of oxygen across a permeable membrane, nor does it go through a chemical reaction in the same way a Clark sensor does. However, experience with existing technologies has shown that bio-fouling can occur and impair oxygen measurements on optical technologies. Biological organisms are known to congregate around the sensing foil on optical oxygen sensors and alter the local oxygen environment there. And growth of materials can obscure the sensing foil from receiving a fresh sample of water for a measurement. Flushing of the sensor is known to improve the response of the sensor and older designs of other optical oxygen technologies are now incorporating better flushing characteristics and protective membranes to reduce the effect of bio-fouling attraction.

Other issues that can affect the accurate measurement of oxygen on optical sensors include ambient light interference and sensor thermal response. As with all oxygen measurements, an accurate sensor temperature is required to determine the thermal response of the sensor measurement.

Sea-Bird has taken these known issues with optical oxygen measurements into consideration and engineered a sensor to significantly reduce these known effects. The SBE 63 is a pumped sensor, as are most Sea-Bird sensors. Pumping of the sensor guarantees a constant response for the sensor foil by supplying it with fresh sample during the measurement cycle. It also allows for alignment of the oxygen measurement with critical conversion parameters like temperature and salinity, and guarantees the suite of measurements are all made on the same water parcel. Plumbing the sensor also allows for superior bio-fouling protection, by keeping the sensor isolated from the fouling environment and taking advantage of the anti-foulant protection afforded by the conductivity cell plumbing apparatus. By pumping and plumbing the sensor, rather than leaving it exposed to the elements, the problem of ambient light distortion on the sensor measurement is also eliminated. The SBE 63 is currently deployed on moored and slow moving platforms (*i.e.*, Argo profiling floats that profile at 10 cm/s). Future designs will likely be integrated onto faster moving platform applications, but for now, the faster response of the SBE 43 sensor is preferred on such applications.

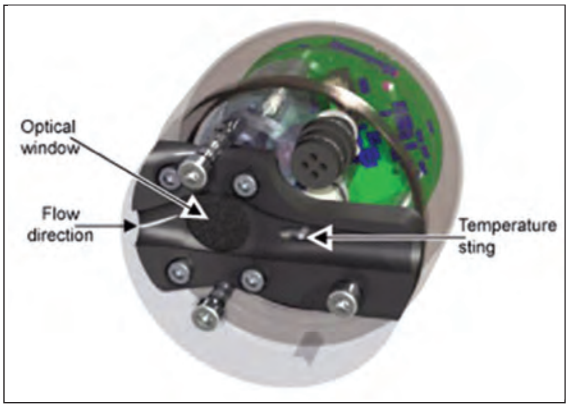


Figure 12. Cross-section of SBE 63 optical oxygen sensor

Sampling Methodology

Sea-Bird offers a wide range of products for acquiring and storing measurements made on natural waters. These products are often termed "CTD". A CTD measures **C**onductivity, **T**emperature, and **D**epth. Despite the name, all CTDs actually measure pressure, which is not quite the same thing as depth. The relationship between pressure and depth is a complex one involving water density and compressibility, as well as the strength of the local gravity field. The CTD data can be used to calculate salinity, density, sound velocity, and other parameters of interest. The term *CTD* is often used today to describe a *package* that includes the actual CTD as well as auxiliary sensors to measure other parameters (such as dissolved oxygen, pH, turbidity, fluorometer, altimeter, etc.) and a water sampler to collect water samples for later analysis in the lab.

A profiling CTD measures water parameters as it travels through the water, whether lowered over the side of a ship with a winch to take measurements of a vertical column of water or integrated with an autonomous vehicle or glider. Common to all Sea-Bird CTDs are purposeful designs built to perform under the unique dynamic conditions found on varying measurement platforms. Most products Sea-Bird makes are pumped and ducted for constant flow and for matched temperature and conductivity response. Pumping also guarantees measurements are all made on the same sample of water with a predictable delay and predictable flow effects. All of this engineering effort allows for alignment and coordination of measurements using post-processing software, or for some models, during real-time data acquisition.

A moored instrument typically measures water parameters in one location, over an extended period of time, providing a time series of data. To reduce costs, a moored CTD may not include a pressure sensor, because the deployment depth is known (approximately); therefore, the pressure sensor is optional in Sea-Bird moored CTDs. Sea-Bird also manufactures moored temperature sensors as well as instruments for high-accuracy pressure measurements (SBE 26 wave and tide recorder, SBE 53 bottom pressure recorder, and SBE 54 tsunami sensor).

As remote platforms continue to be deployed in the ocean and lakes, more capabilities are required for both platforms and instruments like CTDs. Sea-Bird is continuously meeting these demands, and currently offers a multitude of designs including moored profiling CTDs, completely self-contained glider/AUVs CTDs (with optional oxygen capability), and inductive communication capable instruments (allowing for real-time data transmittal). The same technologies and considerations are applied to all the Sea-Bird product line, but are specialized for the given application. Therefore, it is critical to understand what the sampling needs are prior to determining what instruments to use on a given project. Oceanographers and application engineers are available at Sea-Bird to help product-users determine what instruments will best serve their needs.

Best Practices (Do's and Don'ts)

Conductivity

Since any conductivity sensor's output reading is proportional to its cell dimensions (geometry), it is important to keep the cell clean of internal coatings. Also, cell electrodes contaminated with oil, biological growths, or other foreign material will reduce sensitivity and cause low of correct conductivity readings (hence lower salinity). A desire to provide better control of growth of bio-organisms in the conductivity cell led Sea-Bird to develop the various rinsing and cleaning recommendations (described in detail on the Sea-Bird website, Application Note 2D.

http://www.seabird.com/application_notes/AN02d.htm

It is very important not to insert anything into the conductivity cell to clean it. Doing so can damage the electrodes or the interior glass walls. If an object gets lodged in the cell and cannot be removed with routine cleaning procedures (rinsing), Sea-Bird recommends sending the instrument back to the factory.

A dilute bleach solution is extremely effective in controlling the growth of bio-organisms in the conductivity cell. Lab testing at Sea-Bird indicates no damaging effect from use of a dilute bleach solution in cleaning the conductivity cell. Sea-Bird now recommends cleaning the conductivity sensor in a bleach solution.

Triton X-100® is a mild, non-ionic surfactant (detergent), valuable for removal of surface and airborne oil ingested into the CTD plumbing as the CTD is removed from the water and brought on deck. Sea-Bird had previously recommended, and continues to recommend, rinsing and cleaning the conductivity sensor in a Triton X-100® solution.

Sea-Bird had previously recommended acid cleaning for eliminating bio-organisms or mineral deposits on the inside of the cell. However, bleach cleaning has proven to be effective in eliminating growth of most bio-organisms. Bleach is much easier to use and to dispose of than acid. Furthermore, data from many years of use show that mineral deposits are an unusual occurrence. Therefore, Sea-Bird now recommends that, in most cases, acid should not be used to clean the conductivity sensor. In rare instances, acid cleaning may still be required for mineral contamination of the conductivity cell. Sea-Bird recommends that you return the equipment to the factory for this cleaning if it is necessary.

Sea-Bird had previously recommended storing the conductivity cell filled with water to keep the cell wetted, unless the cell was in an environment where freezing is a possibility (the cell could break if the water freezes). However, no adverse effects have been observed as a result of dry storage, as long as the cell is rinsed with fresh, clean water before storage to remove any salt crystals. This leads to the following conductivity cell storage recommendations:

- Short-term storage (less than 1 day, typically between casts): If there is no danger of freezing, store the conductivity cell with a dilute bleach solution in Tygon® tubing looped around the cell. If there is danger of freezing, store the conductivity cell dry, with Tygon® tubing looped around the cell.
- Long-term storage (longer than 1 day): Since conditions of transport and long-term storage are not always under the control of the user, we now recommend storing the conductivity cell dry, with Tygon® tubing looped around the cell ends. Dry storage eliminates the possibility of damage due to unforeseen freezing, as well as the possibility of bio-organism growth inside the cell. Filling the cell with a Triton X-100® solution for 1 hour before deployment will *rewet* the cell adequately.

Note that the Tygon® tubing looped around the ends of the conductivity cell, whether dry or filled with a bleach or Triton solution, has the added benefit of keeping air-borne contaminants (abundant on most ships) from entering the cell.

If the CTD is equipped with an oxygen sensor, we do not recommend storing the series of plumbed sensors in bleach or Triton-X 100® solution unless the conductivity and oxygen sensors are isolated from each other. (See Best Practices: Dissolved Oxygen).

Temperature

Thermistor-based thermometers require little special handling, as they are not sensitive to mechanical shock. The only precaution is against overheating the sensor. Thermometers that are subject to temperatures above 50 ºC may drift faster than the factory-specified drift rate. Although no permanent damage is incurred, thermometers that have been exposed to temperatures exceeding 50^0C should be returned to the factory for recalibration.

Pressure

Sea-Bird manufactures instruments with either strain-gauge or quartz-type sensors. Modern strain-gauge sensors are constructed of titanium and do not require special handling. Products with capillary fittings on their pressure ports, such as older SBE 9, SBE 16 and 19 SeaCATs ,and SBE 25 CTDs, have pressure sensors with steel internal components that are protected from corrosion by filling the pressure port with silicon oil. If the oil inside the capillary fitting is not visible, the capillary must be refilled. Application note 12-1 covers the details of the procedure.

http://www.seabird.com/application_notes/AN12_1.htm

Occasionally, on moored instruments, the port plug of the pressure sensor (Figure 3a) needs to be cleared of biological fouling or muds. This is easily done with visual inspection and removal of any deposits or materials that might interfere with the pressure measurement.

SBE 43 Clark Electrode Oxygen

Avoid fouling the oxygen membrane with oil or grease as this causes a calibration shift toward erroneously low readings. An oil-fouled or biologically fouled membrane can be cleaned using the procedures described here and in more detail in Application Note 64.

http://www.seabird.com/application_notes/AN64.htm

During service and storage, Sea-Bird recommends maintaining temperatures at or below 30 ºC (86 ºF). If temperatures are raised above 40 ºC (104 ºF), SBE 43 oxygen sensors can exhibit a temporary increase in sensitivity of a few percent. This relaxes back to historical sensitivity after a few days when temperatures return below 30 ºC (86 ºF).

Preventive Field Maintenance Between Profiles: After each cast, flush with a 0.1% solution of Triton X-100®, using a 60 cc syringe (see: Application Note 34).

http://www.seabird.com/application_notes/AN34.htm

- Then rinse thoroughly with fresh water.
- Between casts, ensure that the membrane remains shaded from direct sunlight and stays cool and humidified. Plugging the inlet and exhaust of the plumbing after rinsing will trap sufficient humidity (Figure 13).

Figure 13. Tygon tubing with damp sponge looped around inlet and exhaust of SBE 43 sensor for storage

Routine (post-cruise) cleaning (no visible deposits or marine growths on sensor) – Follow this two-step procedure:

A. **Flush** the sensor for **1** minute with a **1%** solution of **Triton X-100®** warmed to 30 ºC (86 ºF). **Drain and flush** thoroughly with warm (not hot) fresh water for **5 minutes**.

B. **Soak** the sensor for **1** minute in a **500 - 1000 ppm** solution of **Bleach**. After the soak, **drain and flush** thoroughly with warm (not hot) fresh water for up to up to **5 minutes**.

Cleaning severely fouled sensors (visible deposits or marine growths on sensor): **Soak the sensor in de-ionized water** overnight to loosen deposits. Repeat the two-step *Routine Cleaning* procedure shown above up to 5 times. **Do not attempt to clean the membrane with high pressure flow or by wiping or touching the membrane.**

Long-term storage (after field use): **Do not fill the tubing with water, Triton solution, or Bleach solution.**

- If there is no danger of freezing, loop tubing from inlet to outlet. Place a small piece of clean sponge, *slightly dampened* with fresh, clean water in the center of the tubing (not near the membrane) (Figure 13).
- **If there is danger of freezing,** shake all excess water out of the plenum and loop tubing from inlet to outlet, leaving the sensor membrane dry. The electrolyte has a depressed freezing point, but it too can freeze and damage the membrane. If working in cold climates, it is recommended you remove the sensor or bring the instrumentation indoors.
- Because the sensor is continuously polarized by an internal battery, oxygen flowing through the plenum and tubing will continue to be consumed by the sensor, depleting the electrolyte and causing a slow drift. Storing the sensor in a zero-oxygen environment will stop calibration drift between uses. To minimize drift during storage, if possible, connect one end of the tubing loop to the plenum, displace the air in the plenum and tubing with Nitrogen gas, and connect the other end of the tubing to the plenum. If tubing is not available, displace the air in the plenum with Nitrogen gas and close off the plenum with a cap on each end (tape can be used if nothing else is available); do not insert a cap or plug inside the plenum. At a minimum, it is recommended that the inlet and exhaust of the plenum be plugged or sealed (tape, caps, or tubing).

- **Calibration**

Sea-Bird calibrates every sensor produced as part of the manufacturing process. Calibrations are performed in computer-controlled temperature baths for temperature, conductivity and dissolved oxygen. Pressure is calibrated by either dead weight testers or automated pressure calibrators (Larson 1993).

Standards

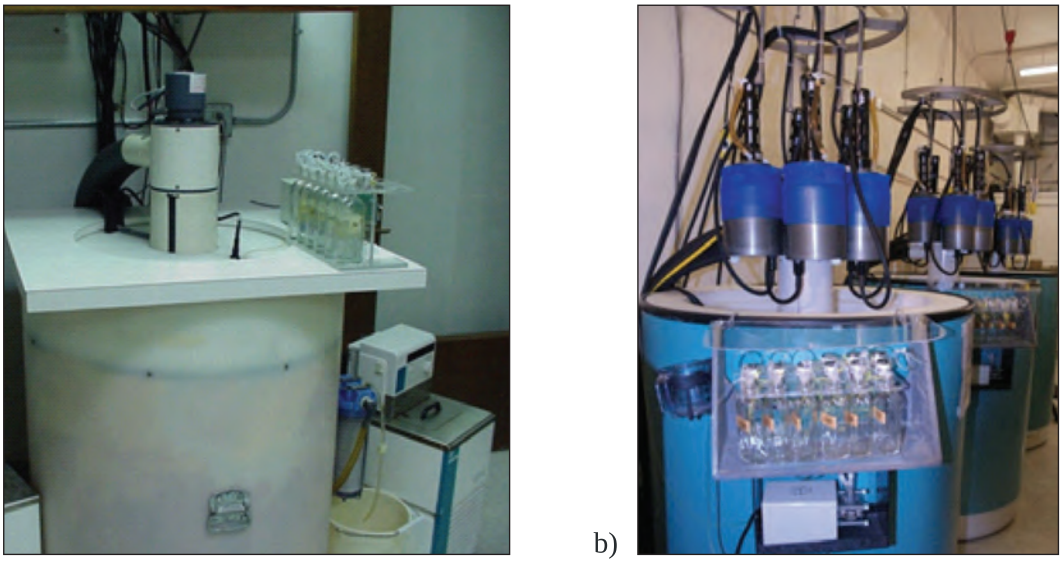
Sea-Bird maintains triple-point-of-water cells and gallium melt cells that are certified by the U.S National Institute of Standards and Technology. These physical standards are used to calibrate a standards-grade platinum resistance thermometer. The platinum resistance thermometer is used to calibrate SBE 3 reference thermometers that act as secondary references for calibration activities throughout the factory.

IAPSO water is used as a conductivity primary standard. In addition, Sea-Bird bottles secondary standard seawater that is used to confirm the conductivity of the IAPSO water (Howell, Guenther, Janzen and Larson, 2010).

Pressure calibrations are performed using Digiquartz pressure sensors that have been screened for drift. (Reiter, Murphy and Larson, 2012) The secondary standard pressure sensors are changed each year for a freshly calibrated Digiquartz sensor that has been calibrated against NIST-certified calibration equipment at the point of manufacture.

Process

Calibrations of temperature, conductivity and dissolved oxygen are performed in highly insulated, computer-controlled temperature baths (Figure 14). The computer-controlled baths are designed to operate unattended with a 12 to 14 hour cycle. The operator loads sensors to be calibrated into the bath and starts



a) b)

Figure 14. a) SBE 4 conductivity sensor calibration bath, b) Argo profiling CTD calibration baths

the calibration cycle at the end of the working day. The next morning the calibration process has completed. The operator archives the collected data from each sensor and the secondary standards and performs quality checks before accepting the calibration data set. A complete history for each sensor or instrument is kept in archive at Sea-Bird's office in Bellevue, Washington, USA.

Temperature calibrations are done at 11 points over the oceanographic range of -1.5 to 32.5 deg C for SBE 3 thermometers and at seven points over the range of 1 to 32.5 deg C for larger, sensor-integrated instruments such as SeaCATs and MicroCATs. Calibration results for premium SBE 3 thermometers are evaluated over a 4 to 6 month period to ensure they meet drift specifications.

Conductivity calibrations of SBE 4 conductivity sensors are done in natural seawater at six points over the range of 2 to 6 Seimens/meter. At each of the calibration points, water is pumped out of the calibration bath into salinity sample bottles. The salinity samples are measured with an Autosal laboratory salinometer that is calibrated with IAPSO standard seawater. For larger instruments with integrated conductivity sensors, such as the SBE 37 MicroCAT and the SBE 16 and 19 SeaCAT family, calibrations are conducted in a lab-made salt solution using an SBE 4 conductivity sensor as secondary standard. A conductivity sample is collected at one point in the bath run for analysis on the Autosal laboratory salinometer, and the reference SBE 4 is corrected when necessary using this conductivity sample.

Dissolved oxygen sensor calibrations are performed over a matrix of 6 temperatures and 3 oxygen concentrations for the SBE 43 Clark electrode, and 6 temperatures and 4 oxygen concentrations for the SBE 63 optical sensor. SBE 43 sensors are used as secondary standards, and are calibrated against Winkler titrations once a week.

Case studies: Technical case studies during the usage of instruments
(Hyperlinks to location on the Sea-Bird Website: www. seabird.com)

Physical Oceanographic Data from Seaglider Trials in Stratified Coastal Waters Using a New Pumped Payload CTD. Carol Janzen (Sea-Bird Electronics), Elizabeth Creed (iRobot Corporation), Proceedings of Oceans 2011 MTS/IEEE Kona, September 19 - 22, 2011.

Improving CTD Data from Gliders by Optimizing Sample Rate and Flow Past Sensors Carol Janzen (Sea-Bird Electronics), Ocean News & Technology, Volume 17, Issue 7, August 2011.

Considerations for CTD Spatial and Temporal Resolution on Moving Platforms Carol Janzen (Sea-Bird Electronics), Ocean News & Technology, Volume 15, Issue 6, September 2009.

Long-Term Oxygen Measurements. Carol Janzen, Nordeen Larson, and David Murphy Sea-Bird Electronics International Ocean Systems, Volume 12, Number 2, March/April 2008.

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In-situ Temperature Calibration: A Remark on Instruments and Methods . G. Budeus and W. Schneider, Alfred-Wegener-Institutfür Polar- und Meeresforschung, Bremerhaven, Germany Int. WOCE Newsletter, #30, March 1998, 16-18.

Irish, J.D., Ward, L.G., and Boduch, S., "Correcting and Validating Moored Oxygen Time-Series Observations in the Gulf of Maine", MTS 1-410-884-5330, IEEE Catalog Number CFP08OCE-CDR, ISBN 978-1-4244-2620-1, Library of Congress 2008904879.

Moored Salinity Time Series Measurements at 0°, 140° W . McPhaden, M.J., H. Paul Freitag and Andrew J. Shepherd, Journal of Atmospheric and Oceanic Technology (JAOT), V7(4), August 1990, p 568-575.

Assessing the Calibration Stability of Oxygen Sensor Data on Argo profiling floats using routine WOCE monitoring data from HOT . Carol Janzen and Nordeen Larson, Sea-Bird Electronics. Poster Presentation, 2008 Ocean Sciences Meeting, Orlando Florida, 2 - 7 March 2008.

Getting More Mileage out of Dissolved Oxygen Sensors in Long-Term Moored Applications Carol Janzen, David Murphy, Nordeen Larson, Sea-Bird Electronics Proceedings of Oceans 2007 MTS/IEEE Vancouver, B.C., Canada, October 1 - 4, 2007

A Year of Oxygen Measurements from Argo Floats Nordeen Larson, Sea-Bird Electronics. Poster Presentation, 1st ARGO Science Workshop, Tokyo, Japan, 12 - 14 November 2003.

Getting More Mileage out of Dissolved Oxygen Sensors in Long-Term Moored Applications Carol Janzen, David Murphy, Nordeen Larson, Sea-Bird Electronics Proceedings of Oceans 2007 MTS/IEEE Vancouver, B.C., Canada, October 1 - 4, 2007

A Year of Oxygen Measurements from Argo Floats . Nordeen Larson, Sea-Bird Electronics. Poster Presentation, 1st ARGO Science Workshop, Tokyo, Japan, 12 - 14 November 2003.

Riser, S.C and Johnson, K.S., "Net production of oxygen in the subtropical ocean", Nature, January 2008, p. 323 - 325. (abstract)

"Supercalibration on the High Seas" (1997), NMi News, NederlandsMeetinstituut, V11(2), 3.

Larson, N.G. (1996) "Using a Primary Temperature Standard at Sea: A Case Study on WOCE P-15S", International Marine Technicians Workshop (INMARTECH '96), Southampton England, Final Report.

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Reiter, Joel, Dave Murphy, and Nordeen Larson. Sea-Bird Electronics, Inc. Drift Measurements in Pressure Sensors. Poster Presentation, 2012. Ocean Sciences Meeting, Salt Lake City, Utah, USA, 19-24 February 2012

Howell, Genevieve Haviland, Richard Guenther, Carol Denise Janzen, Nordeen Larson. On the Use of a Secondary Standard to Improve Autosal Calibration. Sea-Bird Electronics, Inc. Poster Presentation, AGU Ocean Sciences, Portland, Oregon, USA, 22 - 26 February 2010.

Edwards, B., Janzen, C., Murphy, D., Larson, N., "Calibration, Response and Hysteresis in Deep-Sea Dissolved Oxygen Measurements", Journal of Atmospheric and Oceanic Technology, Volume 27, Issue 5, May 2010. (abstract) .

Larson, N.G. (1993) "Calibration of Oceanographic CTD Instruments: Methods and Traceability", Journal of Advanced Marine Technology Conference V7, 3-13.

- **Useful Website Links**

Sea-Bird Electronics, Inc. Main Website: http://www.seabird.com/

Sea-Bird Electronics Application Notes: http://www.seabird.com/application_notes/ANindex.htm

Training Materials and Schedule: http://www.seabird.com/training/trainingclass.htm

Technical Papers/Materials: http://www.seabird.com/technical_references/paperindex.htm

Sensor and Instrument Specifications and Manuals: http://www.seabird.com/products/ModelList.htm

* * *

Optical and nutrient measurements for long term biogeochemical monitoring using WET Labs and Satlantic Instrumentation

WET Labs is dedicated to develop and manufacture underwater instrumentation to detect vital biological, chemical and geological parameters and processes of the earth's oceans, lakes and streams. All WET Labs products and services are backed by cutting edge research and development. They provide the technology and expertise to meet the aquatic sciences needs of the 21st century.

Introduction

WET Labs, Inc. and Satlantic LP develop, design and manufacture marine instruments for measurement of biological, chemical and geological parameters. WET Labs' instruments measure the Inherent Optical Parameters of absorption and attenuation as well as fluorescence and backscattering. WET Labs has recently introduced a line of *in-situ* wet chemistry instruments. Satlantic instruments measure the ambient light field, spectral reflectance and the key biochemical parameters of pH and nitrate concentration. As part of Sea-Bird Scientific, WET Labs and Satlantic customers include research institutes, ocean observing programs, national and local government agencies, engineering firms and navies throughout the world. As part of our commitment to advancing the science of ocean measurement, we are deeply invested in engineering, metrology, calibration, software development, scientific analysis, and other essential technologies that make our products more accurate, reliable, and broadly useful.

- Type of sensors dealt with:

Attenuation and Absorption Meters, Fluorometers, Backscattering meters, Nutrient (Nitrate and Phosphate) Sensors, Photosynthetically Active Radiation (PAR) sensors, pH sensors, water quality monitoring sensors.

- Description of individual sensors and instruments:

The ac-s spectral attenuation and absorption meter

The ac-s performs concurrent measurements of the water's attenuation and absorption characteristics by incorporating a dual path optical configuration in a single instrument. Each path contains its own source, optics, and detectors appropriate to the given measurement. The two paths share a common filter wheel, control and acquisition electronics. The beam performing the attenuation measurement has a collimated beam, and a narrow aperture detector. The beam used to make the absorption measurement has a collimated beam and a diffuse detector.

Figure 1. WET Labs ac-s

Single wavelength attenuation meters

Beam attenuation meters measure the loss of light across a fixed length scale. Light loss during propagation through water can be attributed to scattering and absorption. By projecting a collimated beam of light through the water and placing a focused receiver at a known distance away, one can quantify these losses. The ratio of light gathered by the C-Star's receiver to the amount originating at the source is known as the beam transmittance (Tr). This is the fundamental measurement performed by the C-Star. Suspended particles, phytoplankton, bacteria and dissolved organic matter all contribute to the losses sensed by the C-Star. They, combined with the intrinsic optical properties of the water itself, govern the radiative transfer properties within the earth's natural waters. Thus, the information provided by the C-Star provides both an indication of the total concentrations of matter in the water as well as a value of the water clarity.

An LED light source provides light that is focused and collimated by an aperture and lens that transmits the light within a given narrow bandwidth. The light passes through a beam splitter so that a portion of the transmitted light can be monitored by the reference detector and used as feedback to account for variations in the LED source over time as well as changes in the instrument's internal temperature. The light enters the sample volume after passing through the first pressure window, transits the sample volume and enters the receiver optics after passing through the other pressure window. The light passes through additional focusing optics and finally strikes a silicon photodiode detector that converts the amount of received light to a corresponding voltage signal, which represents the amount of light received.

WET Labs builds the C Star transmissometers with two available pathlengths: 10 and 25 cm. The BAM (beam attenuation meter) is designed for compact and flush faced operations such as on an AUV or glider.

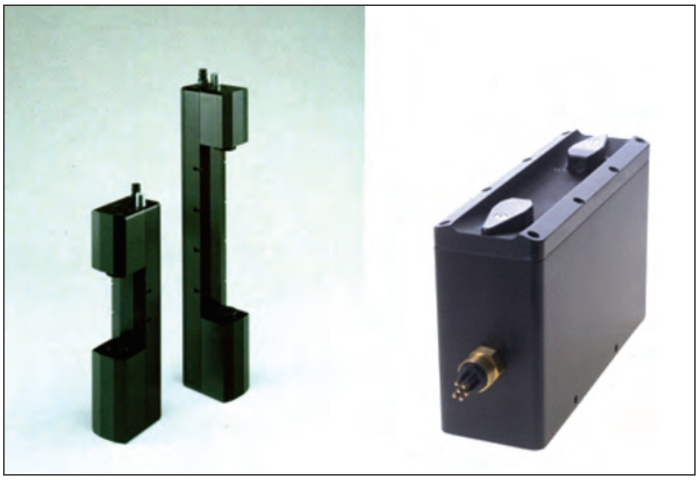


Figure 2. WET Labs' C Star transmissometers in 10 cm and 25 cm pathlengths (left), and WET Labs' BAM (beam attenuation meter) right

Fluorescence and backscattering sensors

The ECO line of fluorometer and backscattering instruments are a family of instruments using a common optical design for measurement consistency with the flexibility of specific designs for specific applications. The ECO line is available with passive and active bio-fouling prevention for extended deployments, memory and batteries for standalone applications and vehicle specific designs for incorporation into autonomous vehicles for ocean observation programs. The breadth of ECO designs allows for measurement consistency across the entire range of ocean observing technologies.

The ECO fluorometer optics allows the user to measure relative chlorophyll, CDOM, uranine, phycocyanin, or phycoerythrin concentrations by directly measuring the amount of fluorescence emission in a sample volume of water. The ECO uses an LED to provide the excitation source. An interference filter is used to reject the small amount of out-of-band light emitted by the LED. The light from the source enters the water volume at an angle of approximately 55–60 degrees with respect to the end face of the unit. Fluoresced light is received by a detector positioned where the acceptance angle forms a 140-degree intersection with the source beam. An interference filter is used to discriminate against the scattered excitation light.

Figure 3. WET Labs ECO Triplet-w

The ECO backscattering optics design is based upon work by Drs. Emmanuel Boss and Scott Pegau of Oregon State University (Boss and Pegau, 2001). The ECO BB measures scattering at 117 degrees. This angle was determined as a minimum convergence point for variations in the volume scattering function

(VSF) induced by suspended materials and water itself. As a result, the signal measured by this meter is less determined by the type and size of the materials in the water and is more directly correlated to the concentration of the materials. Conversely, the meter provides unparalleled accuracy, for any single-angle measurement, in determining the optical backscattering coefficient—an important parameter for remote sensing and in-water bio-optical applications.

As an example of the ECO line, the ECO Triplet-w provides three sensor channels of both fluorescence and backscattering. Each sensor channel is independently tuned and calibrated.

The WET Star fluorometer allows the user to measure relative chlorophyll, CDOM, or other concentrations by directly measuring the amount of fluorescence emission from a given sample of water. The sample media is pumped through a quartz tube mounted through the long axis of the instrument. These samples, when excited by the WETStar internal light source, absorb energy in certain regions of the visible spectrum and emit a portion of this energy as fluorescence at longer wavelengths. Figure 5 shows a simplified illustration of how the WET Star works.

Figure 4. WET Labs WET Star fluorometer

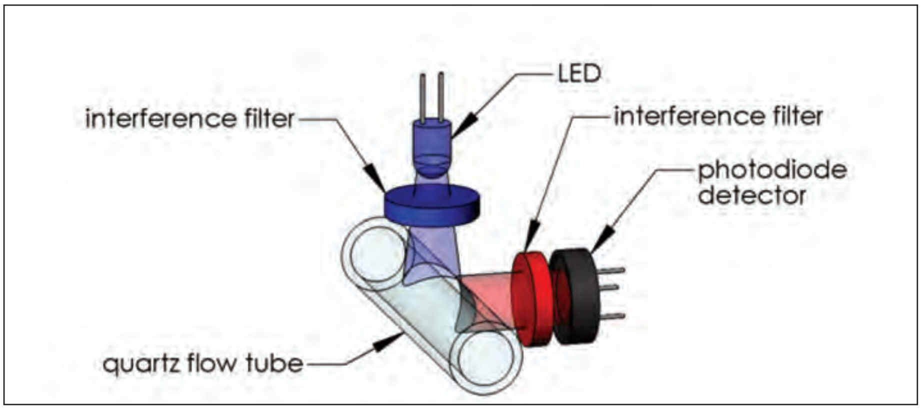


Figure 5. Light path through a WET Star fluorometer

Nutrient sensors

Nitrate: Satlantic's SUNA UV Nitrate Sensor provides real time, chemical-free nitrate measurements in coastal and freshwater environments using Satlantic's advanced UV absorption technology. The SUNA sensor is based on the proven MBARI-ISUS UV Nitrate Sensor and has been re-designed for lower cost and easy integration into existing water quality monitoring systems. The SUNA is in extensive use around the world providing accurate and stable long-term *in situ* nitrate measurements for environmental monitoring and research applications in both fresh water and marine environments.

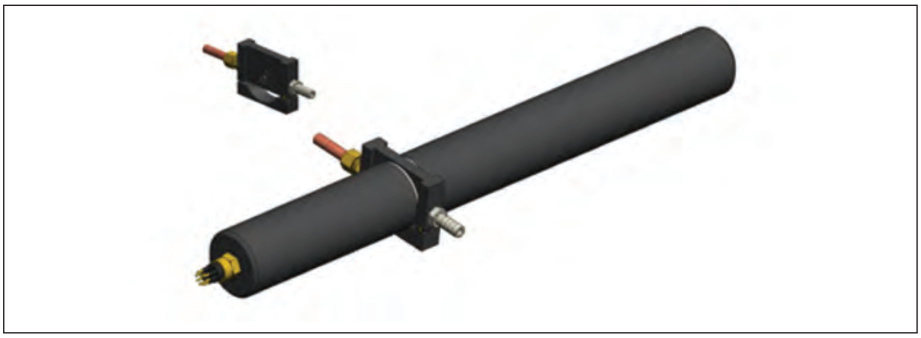


Figure 6. Satlantic SUNA UV nitrate sensor with flow-cell

Phosphate: WET Labs' Cycle-PO4 *in-situ* dissolved phosphate analyzer measures labile dissolved phosphate using the standard molydate colormetric technique. The Cycle system is designed for unattended long-term moored operations. The Cycle combines precision fluidics with state-of-the-art optics to provide unparalleled precision and accuracy in operational *in-situ* monitoring of nutrient concentration.

Figure 7. WET Labs' Cycle-PO4

Photosynthetically Active Radiation (PAR) meters

Satlantic and WET Labs' series of Photosynthetically Active Radiation (PAR) sensors provide highly accurate measurements of PAR (400 – 700 nm).

The ideal spectral response for a PAR sensor is one that gives equal emphasis to all photons between 400 – 700 nm. Satlantic and WET Labs PAR sensors use a high quality filtered silicon photo-diode to provide a near equal spectral response across the entire wavelength range of the measurement.

Equipped with quality precision optics and proven Bio-wiper™ technology, the ECO-PAR™ sensor can be deployed for extended periods without a reduction in data quality caused by biofouling. Additionally, the ECO-PAR™ has optional internal data logging and power capabilities, precluding the need for an external logging device and battery pack.

Figure 8. Satlantic PAR sensor

SeaFET ocean pH sensor

The SeaFET Ocean pH Sensor was developed by Dr. Kenneth Johnson of the Monterey Bay Aquarium Research Institute (MBARI) and Dr. Todd Martz of the Scripps Institution of Oceanography, University of California, San Diego. Satlantic has collaborated with MBARI and Scripps to make the instrument commercially available to the research community.

Figure 9. ECO PAR sensor with Bio-wiper

The sensing element of the SeaFET is an ion sensitive field effect transistor (ISFET). This class of device has been used for pH sensing in industrial processes, food processing, clinical analysis and environmental monitoring. The advantages of the ISFET include robustness, stability and precision that make it suitable for ocean pH measurement at low pressure.

The SeaFET reports pH determined potentiometrically in two different ways. The ISFET potential is measured against a reference electrode bearing a liquid junction (internal reference) and against a solid state reference electrode without a liquid junction (external reference). This approach provides the user with the ability to quality assess instrument performance and ultimately achieve a greater understanding of the state of acid/base equilibria in seawater.

Figure 10. Satlantic SeaFET Ocean pH Sensor

Water quality monitor

WET Labs and Sea-Bird Electronics have teamed to bring offshore research-grade measurement technology to long term monitoring by incorporating multiple anti-biofouling technolgies and reducing the number of failure points through integrated sensor packaging. The WQM incorporates WET Labs' ECO sensors and Sea-Bird's CTD sensors, providing temperature, salinity, depth, dissolved oxygen, chlorophyll and CDOM fluorescence, turbidity and backscattering data.

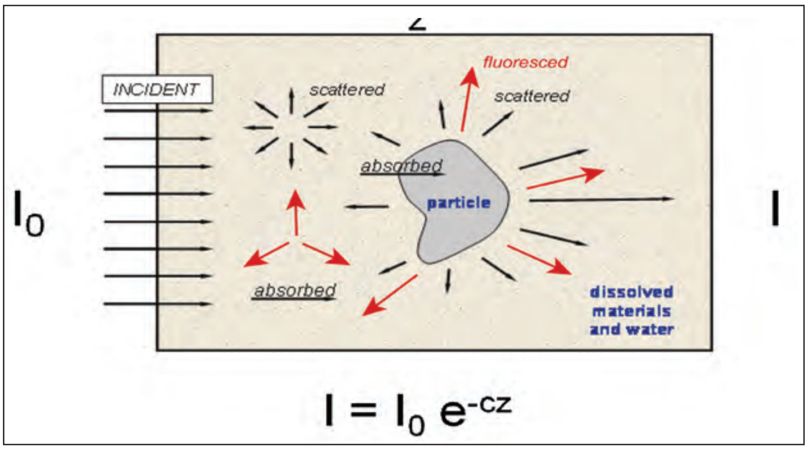
The WQM's sensors have the accuracy and precision to track subtle long-term changes in even the cleanest marine systems. By combining multiple active and passive anti-fouling features, the WQM assures this data quality in coastal and inshore regimes. Extensively tested, field trials and users experiences have demonstrated the WQM's unprecedented long-term stability in biologically rich waters.

Typically, biofouling and sediment loads are the dominant factors that degrade and limit the data quality. These factors can overwhelm inadequately protected sensors and invalidate their data—often in just a few days. Effective long-term monitoring demands the highest data quality over weeks and months. The key to cost effective data collection requires a sensor package that can withstand the environmental hazards of biologically active waters. The WQM employs active flow control, passive flow prevention, light-blocking, active biocide injection and passive inhibitors to effectively and safely combat internal and external fouling. With fouling minimized, the superior inherent stability of the WQM sensors translates directly to superior long-term data quality. Further instrument stability is achieved by eliminating interconnecting cables and connectors.

Figure 11. WET Labs' WQM Water Quality Monitor

- **Principle of operation of WET Labs and Satlantic sensors**

The fundamental principle that WET Labs and Satlantic optical sensors use to measure materials and processes in the water column is Beer's Law, which relates the light received at a particular length from a known light source to the loss and generation terms within the intervening volume.



- **Sampling methodology**

WET Labs and Satlantic instruments offers a wide range of methods for acquiring and storing measurements made in natural waters. The three main methods are profiling, moored and incorporated into complex systems (which themselves are generally profiling or moored). The intent is to capture and deliver data in four dimensional with inherent stability and reference across the widest range of all four dimensions.

Examples of complex systems

Autonomous Floats:

http://navis.sea-birdscientific.com/

Integrated Moored Packages:

http://satlantic.com/lobo

Optical Profiler:

http://satlantic.com/profiler

Biofouling mitigation

One of the most problematic aspects of a moored deployment of any optical device is accumulation of biological growth on the optical surfaces. WET Labs and Satlantic have designed and developed multiple anti-biofouling technologies and incorporated them into our instruments either directly or as part of a system. For example, the ECO overcomes this with the use of a copper face plate on the optical face of the instrument and a mechanical wiper system that rotates prior to the sample, removing material (splat and biofilms) from the optics/water surface. Additional protection against biofouling may be provided by using copper tape on the body of the instrument:

http://www.wetlabs.com/technicalnotes/biofoulnote.htm

Examples of biofouling, biofouling prevention strategies and quality control and assurance methods that WET Labs and Satlantic recommends are available here:

http://www.wetlabs.com/Research/presentations/Barnard-QARTOD03.pdf

WET Labs and Satlantic instruments have been successfully deployed on long-term moorings throughout the world with excellent biofouling preventions results as displayed by the coherence and stability of maximum and minimum values throughout the data set.

However, there is no perfect solution to biofouling prevention. Any technology, particularly any active technology, is subject to failure. Life is tenacious and almost invariably will win in the end. The technologies that WET Labs and Satlantic utilizes to minimize loss of data have proven exceedingly effective, but we continue to invest in new techniques and technologies.

- **Best practices (Do's and Don'ts)**

WET Labs and Satlantics' manuals and websites are the best source of information for the do's and don'ts of particular instruments. See the listing below for web links.

- **Calibration:**

WET Labs and Satlantic are committed to delivering the most accurate calibrations possible, designing instruments that eliminate or minimize dynamic errors and preserving initial accuracy throughout a deployment. This section describes in depth our calibrations of some of our optical instruments. Full details on all instrument calibrations are available in our instrument manuals and on our websites.

The scientific literature is a source of common and accepted practices for calibrations and use of our instruments in the field. Our websites list references. We are always interested in receiving copies of recent scientific papers using our instruments and will disseminate your results through our website and frequent talks and visits to scientific institutions around the world.

Attenuation and absorption meters

WET Labs' ac meters are engineered to produce the most accurate data possible and undergo an extensive characterization and calibration procedure. Accuracy begins with stable sensors and circuits, a complete optical characterization, environmental test facilities and calibration using a pure water standard. The calibration facilities are maintained by a highly trained experienced technician, who performs all characterization and calibration procedures according to written protocols. Characterization and calibration procedures and standards data are monitored regularly and are reviewed for consistency by the production floor manager.

All WET Labs ac meters are supplied fully calibrated with pure water calibration coefficients recorded in device files and are provided with the instrument. An additional air tracking data file is also provided, and can be used to track the instrument stability over time by the customer (described below). The pure water device file and air tracking file includes instrument serial number, internal temperature compensation correction coefficients, pure water and air calibration coefficients, calibration temperature, number of wavelengths, center value for each wavelength, pathlength, and instrument serial baud rate.

Absolute calibration standard

Absolute calibration of any underwater optical absorption or attenuation sensor is difficult as there are no absolute standards that can readily be used. The most obvious choice for a calibration medium, pure water, is difficult to obtain, is unstable once it is made, and its absolute optical properties are not well known. Nevertheless, pure water is the baseline for all oceanic inherent optical property measurements (Mueller *et al.*, 2005). At WET Labs, we produce our calibration water with Barnsted NANO-pure™ water purification system, which is used to produce the standard, provides 18.2 MO-cm water with less than 1 ppb total organic carbon (TOC). After de-ionization, the water is processed by a series of filters and held in a 60-liter reservoir that recirculates through an ultraviolet chamber and additional filters. Water for calibration is drawn through a final 0.01-micron ultrafilter before being used to calibrate an ac-s. This system allows the highly reactive de-ionized water to equilibrate, and the ultra-violet chamber prevents any biological contamination from entering the reservoir. Pure water calibration of the ac-s, performed at a water temperature of ~20 oC, is repeated until the accuracy of the absorption and attenuation readings are within +/- 0.003 the cleanest values are achieved.

The ac-s is a dual path absorption and attenuation meter whose output values are related to a specific reference medium that is optically clean water. The instrument is calibrated to provide a reading of 0.0 for all channels in clean fresh water. The offset value, determined during our calibration process, is the number which, when added to the raw instrument output in clean water, provides zeroes for all wavelengths with the meter at a specific temperature.

Factory pre-calibration procedures

The pre-calibration procedures at the factory confirm that the meter is operating within specifications before it goes through calibration. These procedures include testing the light source, optical alignment and registration of the linear variable filter (LVF), and a 12-hour burn-in period. A series of environmental tests are then performed to insure proper and quantified operation. Briefly, the test procedures include:

- Check lamp throughput exceeds minimum intensity specification (30k counts signal; 20-25k counts reference).
- Linear variable filter quantification and registration (< 20nm bandpass across measurement range). LVF wavelength range must extend > 720nm in the red.
- Stability test (drift <0.005 m-1 over 10 minutes).
- Precision test (standard deviation <0.001 m-1) for wavelengths > 440nm.
- Pressure test for leakage of pressure housing seals (40psi 30 minute, operational check).
- Condensation test of optical windows (meter at room temperature, 1.0^{0}C water through flow tubes for 10-15 minutes). No visible clouding of optical windows, no change in air readings.
- Mechanical stability test performed by subjecting the meter to shaking/vibrations in both the horizontal and vertical positions (30 minutes in each; 40Hz and 18Hz). Less than 0.005 m-1 shift in each wavelength.
- Mechanical shock test to make certain that the output of the meter is not altered during normal shipping and handling procedures.
- LVF filter registration test using discrete optical filters (< 2 nm wavelength variation for 9 discrete filters).

Internal temperature compensation correction

Beyond confirming basic instrument operation and alignment, internal temperature compensation corrections are performed to compensate for thermal variations in the internal optical and electrical components of the ac-s. The temperature coefficients provide a correction factor for temperature for each channel of the ac-s. The temperature calibration data is also used to identify unusual instrument performance issues causing the output of the meter to change dramatically as a function of temperature.

The WET Labs temperature compensation calibration is performed by placing the meter in a water bath. Initially, the meter's flow tubes are completely dried, filled with argon or nitrogen gas, and sealed off, preventing any moisture from reaching the flow path or the windows. The water bath temperature is cooled from ~35^{0}C down to approximately 2 to 5^{0}C over a 90-minute period. This water temperature range corresponds to an internal instrument temperature range of approximately 10–40^{0}C. Data is recorded during this period. After a complete temperature cycle, the data is examined to determine if there are any unusual features in the absorption and attenuation values as a function of internal instrument temperature. If changes over temperature of the meter vary too greatly (> 0.01 m-1 overall) or if severe non-linearities are detected, the instrument is sent back to the production floor for examination and necessary modifications. This process may include replacement of detectors, lamps, and/or electronics depending on the cause of the problem. If the instrument passes the initial temperature cycle, the internal temperature compensation coefficients are calculated and applied to the device file that is ultimately supplied with the meter.

Acquisition software, including versions of WETView 5.0 and higher and COMPASS, employ a correction algorithm that uses multiple offset values obtained by measuring output differences over small temperature increments. Instrument values are collected and averaged every 1 to 2^{0}C through the operational temperature range of the instrument. A look-up table of temperature compensation offsets is generated and is recorded in the instrument's device file. The host software then applies the internal temperature compensation algorithm for given temperatures in the table. For temperatures that fall between table values, the program applies a linear interpolation upon the data for further correction. By using this scheme, any non-linear changes due to temperature in the instruments' output are effectively compensated for. For examples and an explanation of device files, refer to the Post-Processing section of the ac-s User's Guide.

The internal instrument temperature range, defined for each individual meter, may vary by a few degrees although typically the range extends from about 10 to 40^{0}C. The exact temperature range is specified for each meter on the Calibration Sheet that is supplied for every new calibration. The ac-s will remain within the factory temperature specifications over the internal instrument temperature range specified. Operation within this range is necessary to obtain results within the specifications of the device. For most accurate results, avoid operating the meter above ~35^{0}C. Typically, temperature characterizations below 10^{0}C are not required, as even in the coldest waters, the internal heat generated by the lamp and electronics maintain internal temperatures at or above this level.

Factory pure water calibration

The purpose of the WET Labs water calibration is to determine the offset values of absorption and attenuation that result in a zero reading with optically clean water in the sample volume of the flow tubes. This is analogous to a blank used in any spectrophotometer. These water offset values are listed on the Calibration Sheet and included in the device file for each meter's new calibration.

Before conducting a water calibration, the ac-s optics are properly cleaned and the meter is allowed to warm up for at least 15 minutes. WET Labs maintains a custom water purification system that includes a commercial deionization system and filtration system. After primary de-ionization, the water is processed by a Barnstead purification unit and stored in a 60-liter holding tank that recirculates through an ultra-violet chamber and additional purification filters. Water for calibration is drawn through a final 0.01-micron ultra-filter at the point of delivery. The circulating holding tank allows the highly reactive de-ionized water to equilibrate with the ambient conditions and the ultra-violet chamber prevents any biological contamination from entering the reservoir. The system is continuously monitored and water quality is checked using a simple scattering detection test prior to each calibration to maintain consistent and accurate water calibrations.

During the water calibration, water from the pure water system is flushed continuously through both flow tubes of the meter at a rate of approximately 1.5 L/min. Values of absorption and attenuation are collected using WETView and the results are used to create a device file. Thus, with optically clean water in the flow tubes, the ac-s should read zero on all channels when using this device file. In order to confirm that the offsets are accurate, the cleaning process is repeated until the results are repeatable to within +/- 0.003 m-1 at each wavelength greater than 440 nm for both the absorption and attenuation measurements. Once the final offsets are collected, they are used to create the final water calibration values in the factory device file specific to that meter. The offsets are thereafter automatically applied when running WETView with that device file.

The pure water standard temperature and the internal instrument temperature are important parameters for the user to consider when processing data, trying to obtain water calibrations in the field, or reproducing pure water calibrations in the laboratory. The water temperature is recorded during the calibration with typical values ranging from less than 5 to 35^{0}C. When processing data, it is important to correct for changes in the absorption of pure water that occur as a result of temperature fluctuations. These changes are a physical phenomenon as the absorption and attenuation properties of pure water are dependent on the temperature (and to a lesser degree, salinity). Knowledge of the water temperature during calibration is thus a critical parameter in order to accurately calibrate the ac-s using pure water. Internal instrument temperature is also recorded for each water calibration. It is important that the internal temperature value fall within the temperature range specified in the temperature calibration. Both the water temperature and the internal temperature of the instrument during calibration are recorded on the Calibration Sheet.

Factory air calibration

The purpose of the WET Labs air calibration is to determine the offset values of absorption and attenuation that result in zero readings with dry, particle free air in the sample volume of the flow tubes. These air offset values are listed on the Calibration Sheet and included in the air tracking device file for each meter's new calibration. Before conducting an air calibration, the exposed optics are properly cleaned and completely dried, the flow tubes are filled with dry argon or nitrogen, and the meter is allowed to warm up for at least 15 minutes. Every measure is taken to insure that the exposed optics and flow assemblies of the meter remain absolutely dry and that the air in the flow tubes be devoid of humidity.

During the air calibration, the meter's absorption and attenuation values are collected using WETView and the values used to create a device file for air. With these offsets applied, the ac-s should thus read zero on all channels. To confirm the offsets are accurate, the cleaning process is repeated until the results are repeatable to within +/- 0.003 m-1.

Once the final air offsets are collected they are used to create a final factory device file for air tracking.

The air calibration file is similar to the pure water calibration file and can be applied in WETView in the same manner. The difference in the two files is that the device file provides the clean water offsets so that when measuring clean, fresh water, the instrument's output should be zero for all channels if the instrument has not experienced any drift. The air calibration file provides the offsets that provide zero values when the instrument is clean and dry and the flow tubes are filled with dry argon or nitrogen gas. It is important to block light entering the flow assemblies by covering the inlet and outlet nozzles with tape or the black plastic caps provided by the factory.

An important parameter to consider when trying to confirm or reproduce air calibrations is the internal temperature of the instrument during the air calibration. Because the output of the ac-s is only compensated for temperature over the temperature range specified on the Calibration Sheet, any operation outside of this range may result in offsets in the data. This is most often a concern with air calibrations because the instrument is operating in air, meaning a large portion of the heat generated internally by the ac-s is not rapidly dissipated to the surrounding environment. The temperature of the instrument during the WET Labs air calibration is recorded on the Calibration Sheet.

Precision

Precision is determined by running the meter for an interval of time (approximately 20 minutes) and determining the standard deviation of the signal at each wavelength for at least 100 samples. The precision determination is performed using dry argon or nitrogen filled flow tubes of the ac-s. With one-second binning of the signals, nominal performance is approximately 0.001 m-1 for wavelengths below 450 nm, and approximately 0.002 m-1 for wavelengths 450 and above. It should be noted that both air value and water value measurements can be difficult to perform by a customer. In determining the precision using the air calibration method, every precaution must be taken to insure that the flow tubes, windows and o-rings are completely clean and dry and that no ambient light is entering the flow cells. Our calibration protocols call for a cap or black tape to seal the flow tube nozzle openings. When performing pure water calibrations on the instrument, it is critical that the highest purity clean water, free of bubbles and particles is used, and that flow rates through the instrument do not exceed 1–2 liters per minute in order to insure consistent results.

Every precaution is undertaken during both air and pure water calibrations in our facilities to ensure stable results are consistently obtained.

Final performance test

A final performance test is performed by collecting data with the meter on the bench. After a sufficient warm-up period, the raw precision of each channel should be approximately 0.001 m-1 or less. Precision is determined by taking the standard deviation of a one minute air data file, measured in inverse meters at approximately 1 Hz.

Linearity and dynamic range

WET Labs periodically tests ac-s meters to determine linearity of the absorption and attenuation detection systems. The test procedure utilizes a consistent "white" scattering particle material, of known particle size distribution and composition (*e.g.* Arizona Road Dust). Linearity is tested by incrementally adding known concentrations of scattering agent to pure water, and placing the sample into the detection chambers of the ac-s. Linearity is determined through a regression of particle concentration versus "a" and "c" for selected wavelengths. Typically linearity in "c" throughout the dynamic range is extremely high with a regression coefficient of 0.9999. Linearity in "a" exceeds 0.998. Although this test doesn't truly measure "a," it does give a good indication of linearity response in the a-side detection optics.

ac-s sensor calibration drift

To ensure the highest level of measurement accuracy and instrument performance, WET Labs recommends returning the ac-s to WET Labs for calibration on an annual basis . In principle, it is possible for ac-s calibration to be performed elsewhere, if the calibration facility has the appropriate equipment and training. WET Labs can provide a field calibration system, as well as training on use of the system. However, the system requires an optically pure water production system similar to our production system be used to produce the pure water standard. The necessary equipment is quite expensive to buy and maintain, and thus we recommend that the pure water calibrations be performed at WET Labs for the ac-s meters. We do recommend that air calibration procedures be performed in between factory pure water calibrations to document potential drift.

The ac-s sensor utilizes a rotating linear variable filter (LVF) to produce the spectral bandwidth across the measurement spectrum. The internal optics and LVF are highly sensitive to moisture and particles. Even small amounts of moisture or particles can affect the measurement accuracy by imparting a thin coating on the LVF and the inside of the pressure windows. Even small amounts of electronics out-gasing due to long-term use can change the calibrations and cause drift through "clouding" of the optical windows and LVF. Every precaution is taken during assembly and test of the ac-s to insure the pressure housings free of moisture and particles, including purging each pressure housing with dry argon or nitrogen and electronics burn-in periods before installation. Desiccant packets are also installed within the pressure housing to assist with moisture absorption. A condensation test procedure is also conducted to identify if moisture is present within the housings. Typically, degradation of optical windows or LVF due to moisture or particles within the pressure can is rare. However, we recommend servicing of the ac-s once per year to examine the windows and LVF.

The primary mechanism for calibration drift in ac-s sensors is the fouling of the optical windows by chemical or biological deposits. Fouling changes optical geometry of the measurement cell through changes in absorption and scattering of the fouling material. Accordingly, the most important determinant of long-term sensor accuracy is the cleanliness of the cell. We recommend that the ac-s sensor be calibrated before and after deployment, but particularly when the cells have been exposed to contamination.

ECO fluorometers and backscattering sensors

WET Labs' ECO sensors are engineered to produce the most accurate data possible and undergo an extensive characterization and calibration procedure. Accuracy begins with stable sensors and circuits, a complete optical characterization, environmental test facilities, and calibration using 'golden' instruments and external calibration tests. The calibration facilities are maintained by a highly trained experienced technicians, who perform all characterization and calibration procedures according to protocols. Characterization and calibration procedures and standards data are monitored regularly, and are reviewed for consistency by the production floor manager.

All WET Labs ECO sensors are supplied fully calibrated with calibration or characterization coefficients recorded in device files and documents provided with the instrument. Instrument stability over time by the customer can be determined utilizing straightforward laboratory procedures. Field calibration using linear regression of the instrument output versus appropriately collected samples is straightforward is laborious and time consuming and documented in a rich literature (see references in the Past Performance volume). WET Labs tracks instrument performance over time (drift) by pre-calibrating instruments when they are received for service. WET Labs data tracking for instruments that have not been retuned or had upgrades to their electronics indicates drift rates of the sensors of a few percent per year. A field comparison of instruments on gliders (seven instruments over multiple years) deployed in the NW Pacific indicated that changes in individual instruments or between instruments in the time series were insignificant relative to the natural variability (Perry *et al*., 2008).

Calibration issues are a significant issue within the context of large programs where instrument histories should be less significant than instrument output, i.e. instruments should be interchangeable. WET Labs is continuously reviewing ECO calibration procedures to ensure that we are minimizing inter-instrument variability and maximizing cross-instrument responses.

Calibration standards

Absolute calibration of any underwater optical sensor is difficult as there are no absolute standards that can readily be used. The most obvious choice for a calibration medium, pure water, is difficult to obtain, is unstable once it is made, and its absolute optical properties are not well known. Nevertheless, pure water is the baseline for all oceanic inherent optical property measurements (Mueller et al 2005). At WET Labs, we produce our calibration water with Barnsted NANO-pure™ water purification system, which is used to produce the standard, provides 18.2 MO-cm water with less than 1 ppb total organic carbon (TOC). After de-ionization, the water is processed by a series of filters and held in a 60-liter reservoir that recirculates through an ultraviolet chamber and additional filters. Water for calibration is drawn through a final 0.01-micron ultrafilter before being used to produce calibration solutions. This system allows the highly reactive de-ionized water to equilibrate, and the ultra-violet chamber prevents any biological contamination from entering the reservoir.

The ECO sensors output is related to an offset (or blank) value that is sensitive to the impedance of the system in which the instrument is used.

To determine a 'dark count' value or 'offset' for your ECO we recommend that the instrument be configured in as close a manner to the actual deployment mode as possible. This means the meter should be installed on the cage or logging system (CTD or other data logger), powered and deployed in water as it will be during operation.

1) Cover the LED and Detector with black electrical tape or a black static cling sticker and turn the system on.
2) Record the ECO's output. Use the minimum or average value as your offset.

WET Labs records sixty seconds of data at 1 Hz and reports the minimum value on the calibration worksheet. We commonly see variability of 1 to 2 counts.

Please contact WET Labs' support team if your variability is more than 10 counts.

Please contact WET Labs' support team if your offset value is more than 20 counts from the calibration value.

The calibration procedure for CDOM fluorescence utilizes a 'golden' instrument that has been calibrated to NIST traceable Quinine Sulfate Dihydrate dissolved in 0.1 N sulfuric acid and diluted to 100 ppb with calibration water (described above).

The characterization procedure for Chlorophyll a fluorescence utilizes a 'golden' instrument that has been calibrated to a series of centric diatom cultures. Because of the variability of chlorophyll fluorescence response to chlorophyll concentration *in situ*, WET Labs supplies a characterized, not a calibrated instrument. The relationship between in-situ chlorophyll fluorescence and chlorophyll concentration is a complex relationship between the target population and the instrument. A recent paper (Earp *et al*., 2011) covers the consideration relative to a continental scale ocean observing system.

Factory pre-calibration procedures

The pre-calibration procedures at the factory confirm that the meter is operating within specifications before it goes through calibration. These procedures include electronics testing, LED qualification (the light source), pressure and temperature regime testing and a burn-in period. A series of environmental tests are then performed to insure proper and quantified operation.

ECO performance tests:

1. Dark counts: The meter's baseline reading in the absence of source light is the dark count value. This is determined by measuring the signal output of the meter in clean, de-ionized water with black tape over the detector.
2. Pressure: To ensure the integrity of the housing and seals, ECOs are subjected to a wet hyperbaric test before final testing. The testing chamber applies a water pressure of at least 50 PSI.
3. Mechanical Stability: Before final testing, the ECO meters are subjected to a mechanical stability test. This involves subjecting the unit to mild vibration and shock. Proper instrument functionality is verified afterwards.
4. Electronic Stability: This value is computed by collecting a sample once every 5 seconds for twelve hours or more. After the data is collected, the standard deviation of this set is calculated and divided by the number of hours the test ran. The stability value must be less than 2.0 mV/Hour.
5. Noise: Noise is computed from a standard deviation over 60 samples. These samples are collected at one-second intervals for one minute. A standard deviation is then performed on the 60 samples, and the result is the published noise on the calibration form. The calculated noise must be below 2 counts.
6. Voltage and Current Range Verification: To verify the ECO operates over the entire specified voltage range (7–15 V), a voltage test is performed at 7 and 15V, and the current draw and operation is observed. The current must remain constant at both 7 and 15V.

WQM data sets and maintenance

http://buoybay.noaa.gov/news-listings/115.html

http://buoybay.noaa.gov/

WQM, SUNA Nitrate data:

http://buoybay.noaa.gov/locations/susquehanna.html

WQM, Cycle-PO4, ECO CDOM, SUNA Nitrate

http://recon.sccf.org/

http://kentcounty.loboviz.com/

http://yaquina.loboviz.com/

General Link to live data:

http://www.wetlabs.com/real-time-data

Live Data from NAVIS Biogeochemical floats:

http://navis.sea-birdscientific.com/

Australia's Ocean Observing System reference station documentation:

http://imos.org.au/fileadmin/user_upload/shared/ANMN/NRS_rationale_and_implementation_100811.pdf

Cited references

Earp *et al*., "Review of fluorescent standards for calibration of in situ fluorometers: Recommendations applied in coastal and ocean observing programs," Optics Express, 19, 30 (2011)

E. Boss and W. S. Pegau, "Relationship of light scattering at an angle in the backward direction to the backscattering coefficient," Applied Optics. 40(30):5503–5507 (2001).

Mueller, J.L., G. S. Fargion, C. R. McClain, S. Pegau, J. R. V. Zaneveld, B. G. Mitchel, M. Kahru, J. Wieland, and M. Stramska. 2003. Inherent Optical Properties: Instruments, Characterizations, Field Measurements and Data Analysis Protocols. Ocean Optics Protocols for Satellite Ocean Color Sensor Validation, Revision 4, Volume IV.

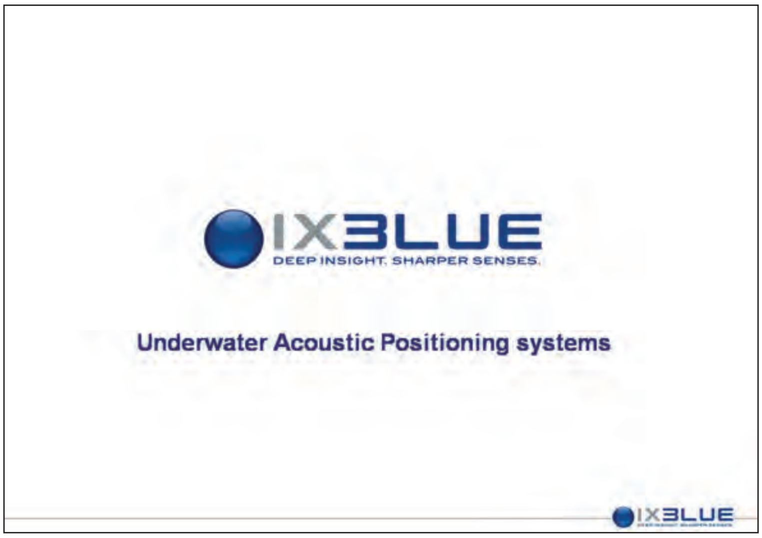
Perry, M.J., B.S. Sackmann, C.C. Eriksen, and C.M. Lee. 2008. Seaglider observations of blooms and subsurface chlorophyll maxima off the Washington coast, USA. Limnology and Oceanography 53:2,169–2,179.

Main Websites: *http://www.satlantic.com/; http://www.wetlabs.com/*

* * *

Underwater positioning solution using acoustic and inertial technologies

iXBlue is a privately owned French technology company incorporating a wide range of capabilities to deliver world leading solutions to the marine, land, air and space markets. Formed in 2010 by the merging of a number of companies within the iXCORE group including iXSEA, SODENA, iXMOTION, iXWAVES, H2X, iXELEK, iXFIBER and iXSURVEY, iXBlue combines the proprietary technologies of these companies to deliver integrated solutions to meet the challenging requirements of today's world with innovation, flare and efficiency. iXBlue comprises three main business areas: equipment and systems, components, services and platforms. Currently IXBLUE is headed by Mr Philippe DebaillonVesque (ENST Paris) who is the President and CEO of the company. iXBlue employs more than 500 people worldwide and in 2011 had a turnover in excess of $100m.



Underwater Acoustic Positioning Systems

USBL principle

3

Principle…

- 1 single transponder installed on the target
- 1 acoustic array on surface to interrogate/ receive
- Interrogate
- Receive answer on the acoustic array
- Calculate slant range 'R' and angle 'θ', then position

Advantage / disadvantage

- Easy to operate (Single beacon)
- No limit in navigation area
- Lower accuracy compared to LBL

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Underwater Acoustic Positioning Systems

GAPS…

4

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Underwater Acoustic Positioning Systems

GAPS…

5

- All what you need for positioning of your subsea equipment (vehicle, towfish, instrumentation, etc) :
  - Compact and lightweight housing
  - Pre-calibrated for immediate setting to work
  - The highest performance on the market
  - Proven performance in all deployment conditions

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Underwater Acoustic Positioning Systems
GAPS, the first acoustic & INS USBL

6

- GAPS includes
  - A high performances FOG based INS and motion sensor (PHINS grade)
  - An innovative 3-D acoustic USBL head for high performances and wide coverage
  - All together with electronics in a single, compact and lightweight housing for unrivalled ease of use
  - a GPS active antenna (external) for absolute positioning

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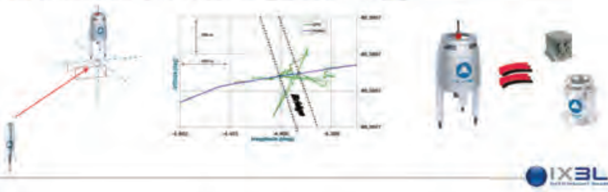
Underwater Acoustic Positioning Systems
Why do you want an INS?

INS INSIDE

7

- The INS is mechanically coupled to the USBL antenna for electronic stabilization. (accuracy 0.01deg HARS, 100Hz for ideal motion compensation)
  The system is pre-calibrated in factory
- The INS improves (x 3) GPS data, replaces GPS (limited outage) and GAPS provides immediate absolute positioning of the tracked vehicles (Long, Lat)
- INS data is available as such: 2 instruments in one



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Underwater Acoustic Positioning Systems
the "3-D" GAPS acoustic head

8

- 3-D receiving acoustic head for wide antenna aperture
- Sophisticated signal processing for operation in challenging and reverberating conditions
- Wideband signal modulation
- GAPS performs in
  - High noise conditions
  - High elevation tracking
  - Deep to extreme shallow water

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Underwater Acoustic Positioning Systems

GAPS standard performance (*)

9

- Performance:
  - Tracking range — up to 4,000m
  - Positioning accuracy — 0.2% x slant distance
  - Frequency range — 20~30kHz, 191dB, WB
  - Compact and lightweight — 295Ø x 640mm, 15kg in air
  - Construction carbon fiber housing
  - Deployment machine not required
- Packing: (2 reusable GRP case with…)
  - GAPS head
  - Main junction cable (50m)
  - GPS active antenna and 15m cable
  - ECB junction/power supply box
  - Configuration/display software

(*) Performance depends on conditions (ambient noise, sound velocity compensated, GPS grade, water depth)

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Underwater Acoustic Positioning Systems

example of GAPS installation

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Van Oord, Sakhalin island
Aug 2005
GAPS on fixed (rusty) pole.

Marin Mätteknik, Sweden
GAPS on side rotating pole.

FSME Fugro, Abu Dhabi
GAPS on side pole.

PETROBRAS - Brazil
GAPS on Agile.

IXSea test boat (catamaran)
GAPS on rear rotating pole

E-Marine, Abu Dhabi
GAPS on 30m pole

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Underwater Acoustic Positioning Systems

example of GAPS installation

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P/O Maritime, Ireland
GAPS fixed under keel.

NAVO, USA
GPS in a through-moon pool

Marin Mätteknik, Sweden
GAPS, 2 versions.

IXSea low-cost deployment machine solution
600 or 1200 mm magnitude
Electrically powered
GAPS external Ø 296mm
(<12 inch)

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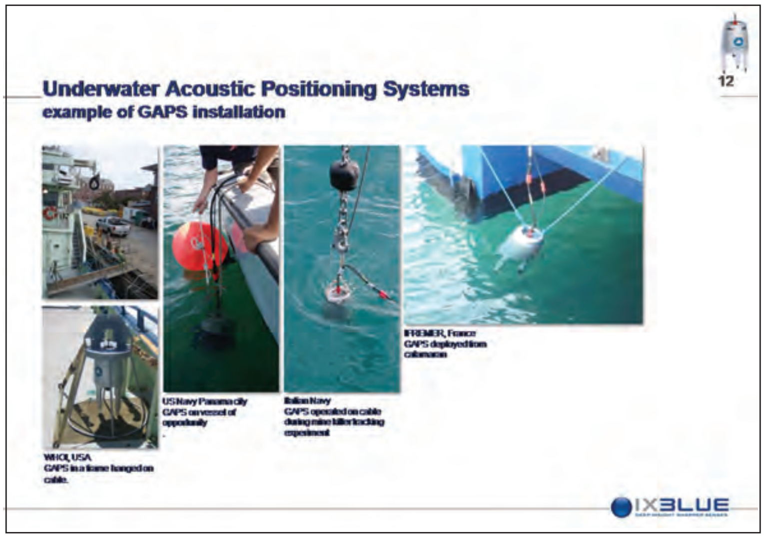
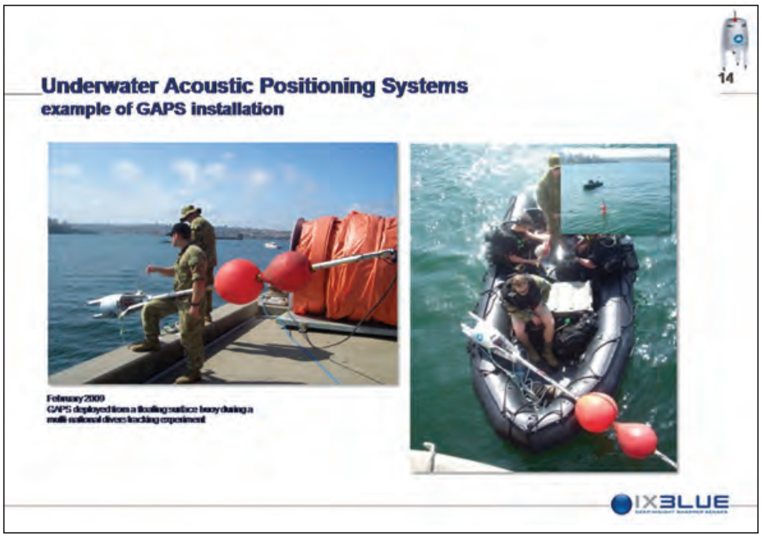

Underwater Acoustic Positioning Systems
example of GAPS installation
12
WHOI, USA
GAPS in a frame hanged on cable.
US Navy Panama city
GAPS on vessel of opportunity
Italian Navy
GAPS operated on cable during mine killer tracking experiment
IFREMER, France
GAPS deployed from catamaran


Underwater Acoustic Positioning Systems
example of GAPS installation
13
July 2007
Towed 4m x 2.5m catamaran with onboard energy (48h operation), GPS, and remote radio communication link. GAPS is installed at the end of a retractable mast in a protective cage
May 2010
Yuzhmorgeologya / Russia
Nov 2008
Instituto Hidrografico, Portugal

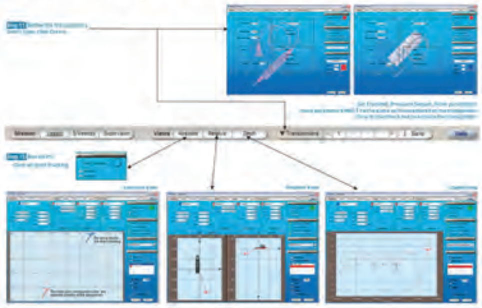

Underwater Acoustic Positioning Systems
example of GAPS installation
14
February 2009
GAPS deployed from a floating surface buoy during a multi national divers tracking experiment

15

Underwater Acoustic Positioning Systems

GAPS configuration and display software (MMI)

- All communication is RS232c using NMEA0183 compatible data telegrams and library of standard protocols



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Underwater Acoustic Positioning Systems

GAPS transponders: MT9x2 series

- Internal rechargeable batteries with internal battery charger, external power supply
- Transponder / Responder mode
- Omni-directional transducer head
- 4 interrogation frequencies
- 12 reply pulses (CHIRP)
- Ruggedized construction for harsh environment
- Stainless steel + polyurethane coating
- Dimensions: 370 x 91diam. mm
- Weight: 3.9kg (air); 2kg (water) for 1,000m depth

MT912S (1,000m water depth) is free to export

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Underwater Acoustic Positioning Systems

GAPS transponders: MT8x2 series

- Transponder / responder mode
- Internal backup battery: up to 45,000 pings @188dB output level
- External power supply through Subconn plug
- aluminum alloy + hard anodizing
- Dimensions: 370 x 70diam. mm
- Weight: 3.0kg (air); 1.3kg (water) for 3,000m depth

Product range:

- Aluminium housing 3,000m WD
- Stainless steel housing 6,000m WD
- Integral / remote transducer head
- OEM electronics for easier integration in existing vehicles
- Long battery life version

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Underwater Acoustic Positioning Systems

GAPS Q&A…

18

- What is included in the 0.2% x range accuracy?
- Is an PHINS grade INS required for GAPS?
- Is GAPS compatible with other beacons?
- How many GAPS are operated, and which market?
- Is GAPS working in extreme shallow water?
- And what about deeper water?

- Other question???

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Underwater Acoustic Positioning Systems

POSIDONIA II…

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Underwater Acoustic Positioning Systems

POSIDONIA II…

20

- Compared to GAPS, POSIDONIA II is a conventional USBL system (not pre-integrated)
- Originally designed in the early 2000, a complete redesign of the system fully qualified end 2010
- POSIDONIA is a USBL (Ultra Short BaseLine) positioning system designed for:
  - Extreme ranges application (up to 10,000m)
  - High accuracy (typ 0.2% x range)
  - Operating in low frequency range (12 to 18 kHz)
- POSIDONIA II shares with GAPS most of the electronics and software

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Underwater Acoustic Positioning Systems

2 x acoustic array versions: deployable

21

- DEPLOYABLE or PORTABLE version
  - For vessel of opportunity, mostly over the board installation (pole mount)
  - Ideally installed with AHRS in line (OCTANS)
  - Slightly better in range performances in horizontal mode, but more sensitive to radiated noise
- Main characteristics (acoustic array only)
  - Height, diam., weight : 410mm x Ø580mm; 34kg
  - Aperture @ -3dB: +/- 35 deg
  - Maximum ship's speed 3 to 4 knots in operation

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Underwater Acoustic Positioning Systems

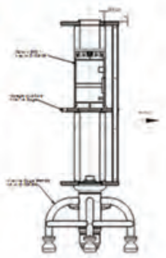
2 x acoustic array versions: deployable

22

Pole mount

Deployment machine

Pre-calibrated mount



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Underwater Acoustic Positioning Systems

2 x acoustic array versions: flush mount

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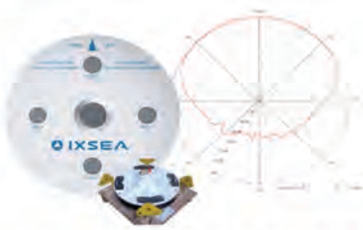
- FLUSH mount version
  - For permanent installation under the ship (requires dry-docking)
  - No protruding part from hull (Flush)
  - Allows faster ship's speed
- Main characteristics (acoustic array only)
  - Height, diam., weight : 800mm x Ø340mm; 120kg
  - Aperture @ -3dB: +/- 55 deg
  - Maximum ship's speed 7 to 8 knots in operation



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Underwater Acoustic Positioning Systems
2 x acoustic array versions: flush mount

R/V Beautemps Beaupré (French Navy)

R/V Pourquoi Pas? (IFREMER)

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Underwater Acoustic Positioning Systems
A new topside electronics: USBL-Box

- Simply speaking, all GAPS electronics & software, adapted to LF band (Low Frequency), in one single 19" electronic rack

- New / additional features
  - Longer range, improved accuracy, wider antenna aperture
  - Immediate acquisition of the target(s)
  - Full wideband (with ET9/RT9 series)
  - Intuitive WEB-based user interface
  - Compatible with previous antenna/transponders/communication protocols
  - Full Ethernet interfacing (AHRS, GPS, external sensors)
  - More simultaneous transponders capability
  - Realtime noise level monitoring at antenna level

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Underwater Acoustic Positioning Systems
A full range of transponders

- All iXSea RT8x1 / ET8x1 / MT8x1 are supported:
  - RT8x1 Recoverable Transponder (flexible, universal)
  - ET8x1 Expendable Transponders (for subsea vehicles installation)
  - MT8x1 Miniature / expendable transponder (when size and weight matter!)
- New RT9x1 / ET9x1 series
  - Full wideband transponders (emission & reception)
- Optionnal features
  - Remote transducers, directionnal transducers, pressure sensor, cable cutter, etc)
- ALL...
  - can be used in transponder or responder mode
  - Can be fitted with remote transducer head
  - Have batteries inside, with external power input

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Underwater Acoustic Positioning Systems
A full range of transponders

27

IXBLUE

Underwater Acoustic Positioning Systems
software: control & command WEB-based interface

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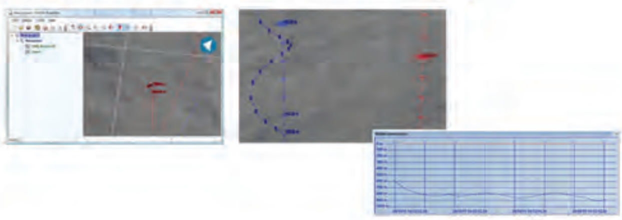
- WEB-based interface:
  (log on with your favorite WEB browser)
- Intuitive menu screens,
  IXSEA standard WEB interface progressively deployed on the whole products range

IXBLUE

Underwater Acoustic Positioning Systems
software: DELPH RoadMap display utility

29

- 2D / 3D visualisation
- Smoothly interfaces with the DELPH software range for imaging sensors processing (sonar, sub-bottom profiler, magnetometer)
- Seabed texture with standard format
- A range of tools (zoom, event marker, measurements, etc..)



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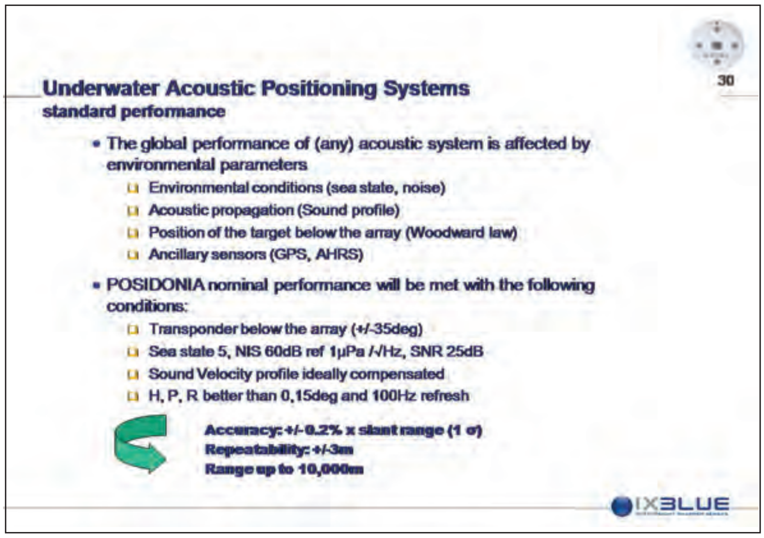
30
Underwater Acoustic Positioning Systems
standard performance
• The global performance of (any) acoustic system is affected by environmental parameters
Environmental conditions (sea state, noise)
Acoustic propagation (Sound profile)
Position of the target below the array (Woodward law)
Ancillary sensors (GPS, AHRS)
• POSIDONIA nominal performance will be met with the following conditions:
Transponder below the array (+/-35deg)
Sea state 5, NIS 60dB ref 1µPa /-/Hz, SNR 25dB
Sound Velocity profile ideally compensated
H, P, R better than 0,15deg and 100Hz refresh
Accuracy: +/-0.2% x slant range (1 σ)
Repeatability: +/-3m
Range up to 10,000m
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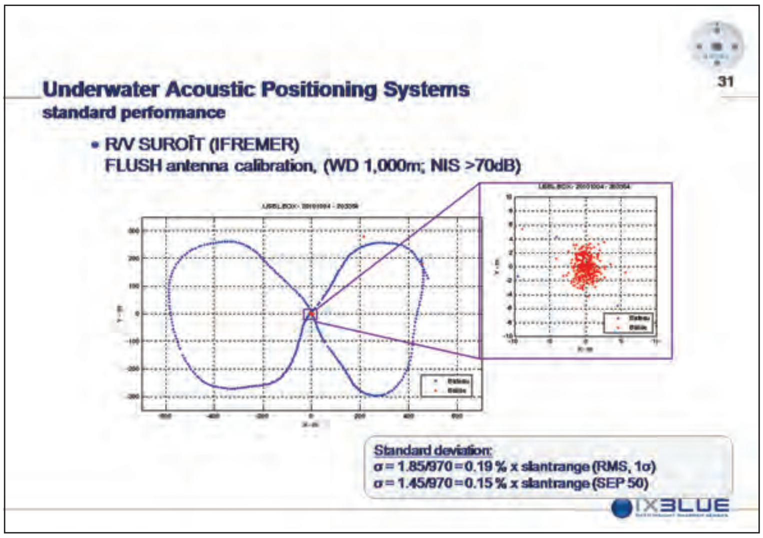
31
Underwater Acoustic Positioning Systems
standard performance
• R/V SUROÎT (IFREMER)
FLUSH antenna calibration, (WD 1,000m; NIS >70dB)
Standard deviation:
σ = 1.85/970 = 0.19 % x slantrange (RMS, 1σ)
σ = 1.45/970 = 0.15 % x slantrange (SEP 50)
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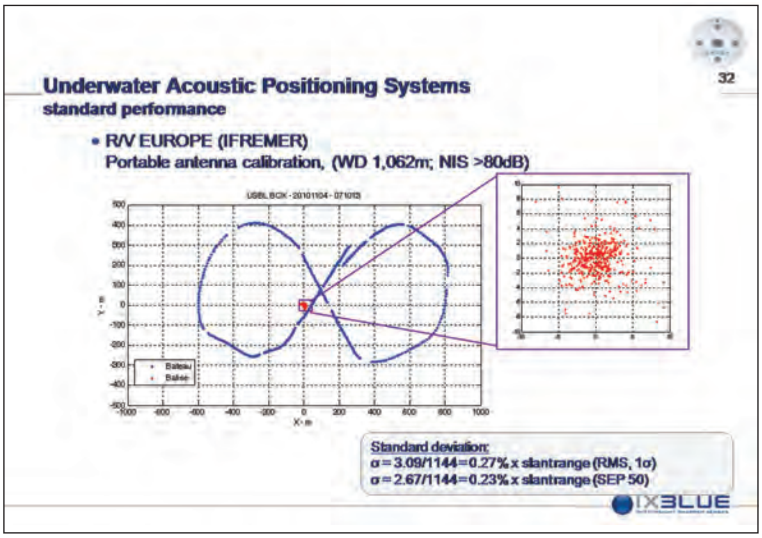
32
Underwater Acoustic Positioning Systems
standard performance
• R/V EUROPE (IFREMER)
Portable antenna calibration, (WD 1,062m; NIS >80dB)
Standard deviation:
σ = 3.09/1144 = 0.27% x slantrange (RMS, 1σ)
σ = 2.67/1144 = 0.23% x slantrange (SEP 50)
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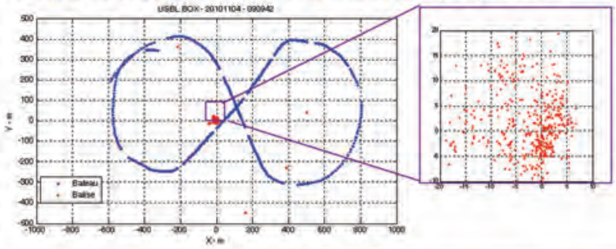
Underwater Acoustic Positioning Systems
standard performance

33

- R/V EUROPE (IFREMER)
  Portable antenna calibration, (WD 1,062m; NIS >80dB), 3 hydrophones



Standard deviation:
σ = 3.09/1144=0.39% x slantrange (RMS, 1σ)
σ = 2.67/1144=0.32% x slantrange (SEP 50)

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Underwater Acoustic Positioning Systems
POSIDONIA II Q&A...

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- Do you really need a system capable of 10,000m tracking range?
- How many systems are operated? Which market?
- Is POSIDONIA II compatible with DP?

- Other question???

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Underwater Acoustic Positioning Systems
RAMSES 6000...

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Underwater Acoustic Positioning Systems
Why RAMSES?

	INERTIAL only	+ ACOUSTICS only	= Combined: inertial & acoustics
Position	smooth	Jumpy	smooth
Update rate	high	low	high
Drift (position)	yes	no	no
measurements	Heading, pitch, roll, position, ...	Slant ranges angles	all
Robustness	Robust (if high grade INS)	Acoustic conditions dependent	Extremely robust (GPS, acoustics ...)

Inertial + Acoustic, a perfect combination !

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Underwater Acoustic Positioning Systems
What is RAMSES

- The missing link for a perfect underwater positioning system
- An acoustic rangemeter with many more functionalities
- Self contained positioning system
- The ideal companion for INS
- Spare array navigation
- SLAM (Simultaneous Localization and Mapping) for underwater application

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Underwater Acoustic Positioning Systems
RAMSES general principle

- Basically RAMSES runs an internal Kalman filter to calculate its own position using external available information including:
  - Range to transponders
  - Speed and position from INS
  - USBL or LBL positions
- The best performance will be obtained with RAMSES coupled to INS (PHINS, ROVINS).
  - The natural drift of the INS is fully contained by high accuracy ranges to transponders,
  - RAMSES aided by INS refine its own position and transponders position estimate
  - Sparse array naturally available
  - SLAM for auto-calibration of the transponders field

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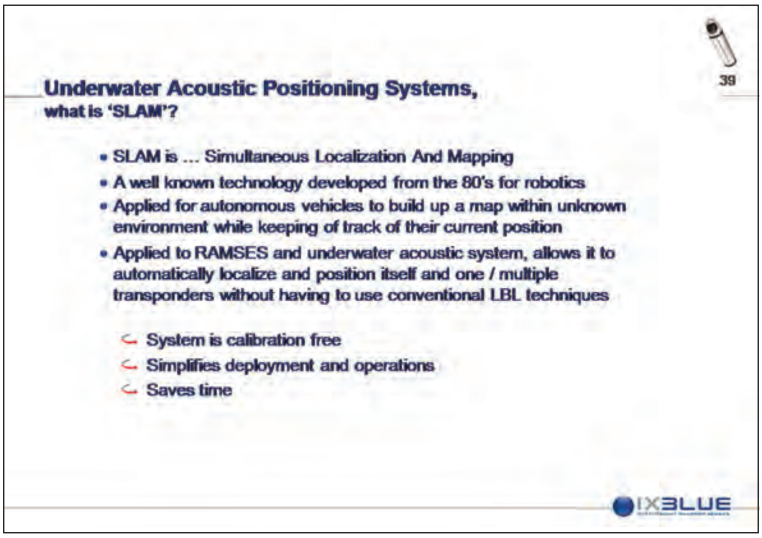
39
Underwater Acoustic Positioning Systems,
what is 'SLAM'?
• SLAM is … Simultaneous Localization And Mapping
• A well known technology developed from the 80's for robotics
• Applied for autonomous vehicles to build up a map within unknown environment while keeping of track of their current position
• Applied to RAMSES and underwater acoustic system, allows it to automatically localize and position itself and one / multiple transponders without having to use conventional LBL techniques
System is calibration free
Simplifies deployment and operations
Saves time
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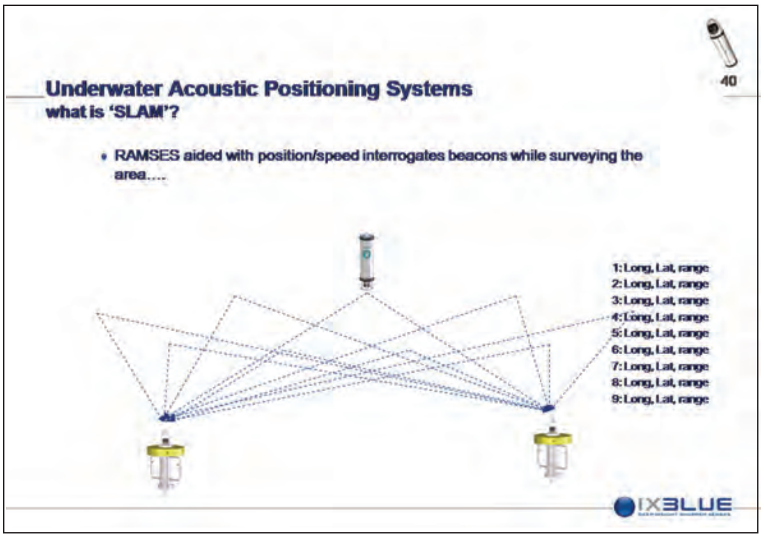
40
Underwater Acoustic Positioning Systems
what is 'SLAM'?
• RAMSES aided with position/speed interrogates beacons while surveying the area….
1: Long, Lat, range
2: Long, Lat, range
3: Long, Lat, range
4: Long, Lat, range
5: Long, Lat, range
6: Long, Lat, range
7: Long, Lat, range
8: Long, Lat, range
9: Long, Lat, range
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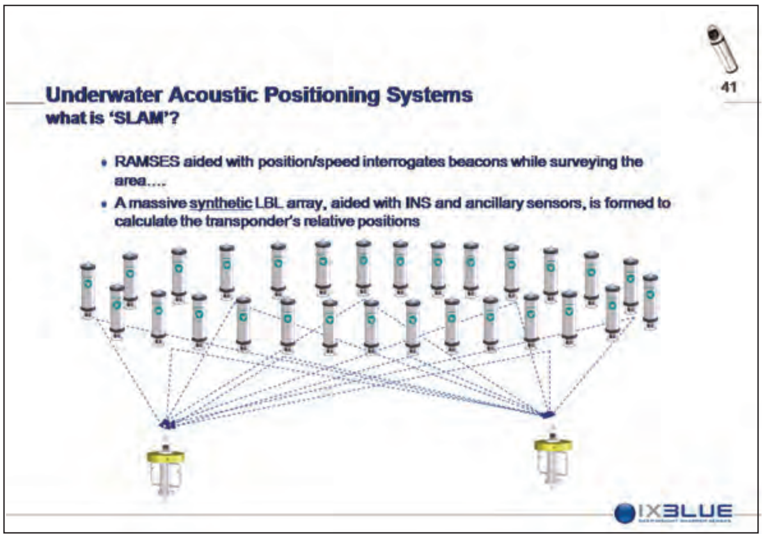
41
Underwater Acoustic Positioning Systems
what is 'SLAM'?
• RAMSES aided with position/speed interrogates beacons while surveying the area….
• A massive synthetic LBL array, aided with INS and ancillary sensors, is formed to calculate the transponder's relative positions
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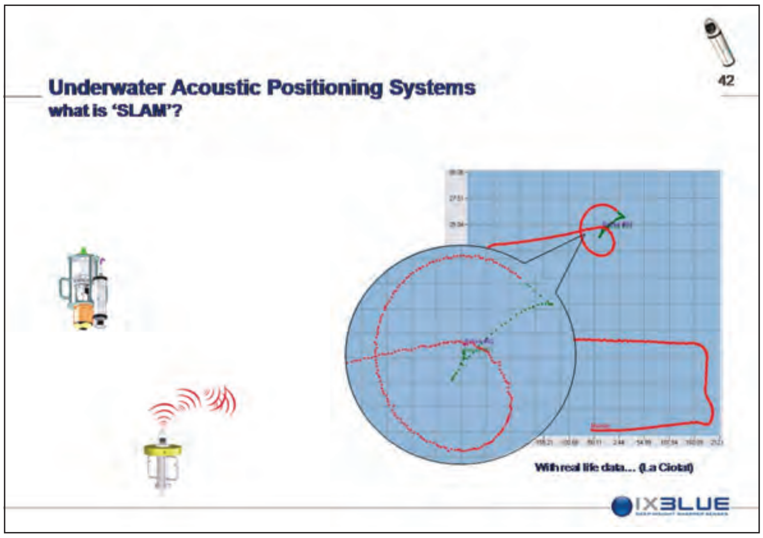
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Underwater Acoustic Positioning Systems
what is 'SLAM'?
With real life data… (La Ciotat)
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Underwater Acoustic Positioning Systems
what is 'sparse array' navigation?
Unlike when LBL navigation is used with a large number of transponders, Sparse array mode is able to offer same performance with very limited number of beacons, ideally 2 along 2 axis…
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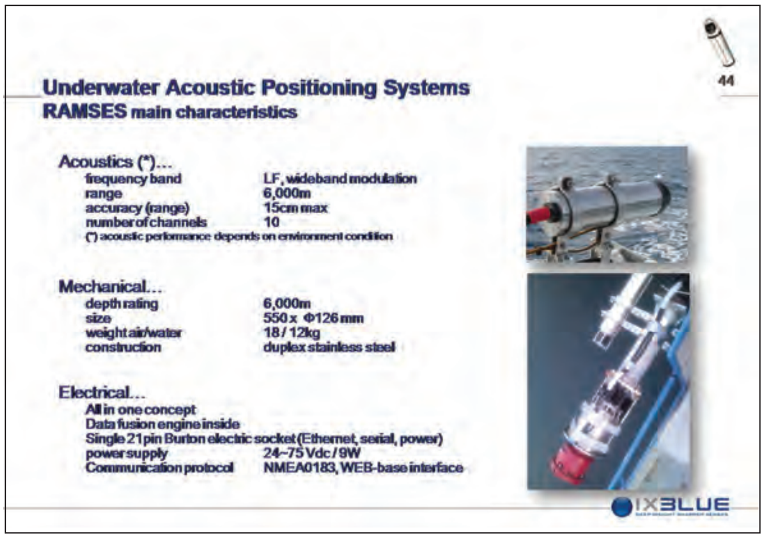
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Underwater Acoustic Positioning Systems
RAMSES main characteristics
Acoustics (*)…
frequency band LF, wideband modulation
range 6,000m
accuracy (range) 15cm max
number of channels 10
(*) acoustic performance depends on environment condition
Mechanical…
depth rating 6,000m
size 550 x Φ126 mm
weight air/water 18 / 12kg
construction duplex stainless steel
Electrical…
All in one concept
Data fusion engine inside
Single 21pin Burton electric socket (Ethernet, serial, power)
power supply 24~75 Vdc / 9W
Communication protocol NMEA0183, WEB-base interface
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Underwater Acoustic Positioning Systems
RAMSES main characteristics
Depth-rating 6,000 m
Release function YES
Autonomy 2 years (listening)
100 000 pings
Batteries C-size Alkaline or Lithium
Detection Wide band signals (MFSK)
Dimensions 660 x 130 mm
Weight in air / water 25 kg / 17 kg
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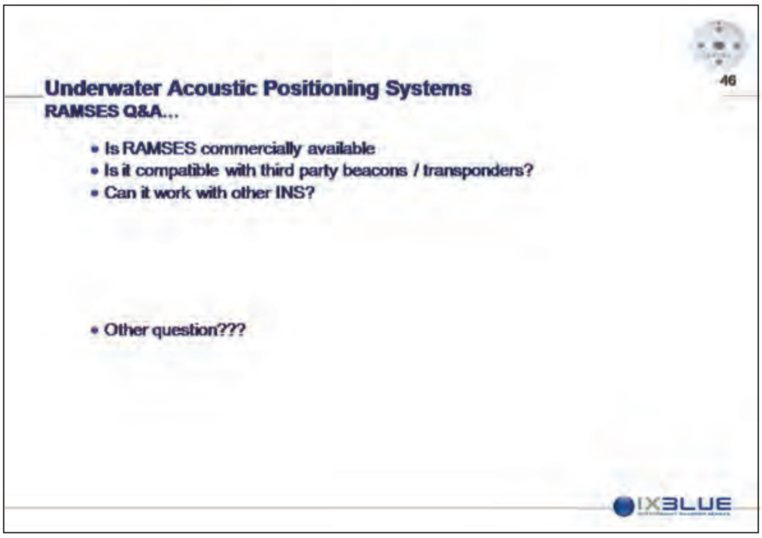
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Underwater Acoustic Positioning Systems
RAMSES Q&A…
• Is RAMSES commercially available
• Is it compatible with third party beacons / transponders?
• Can it work with other INS?
• Other question???
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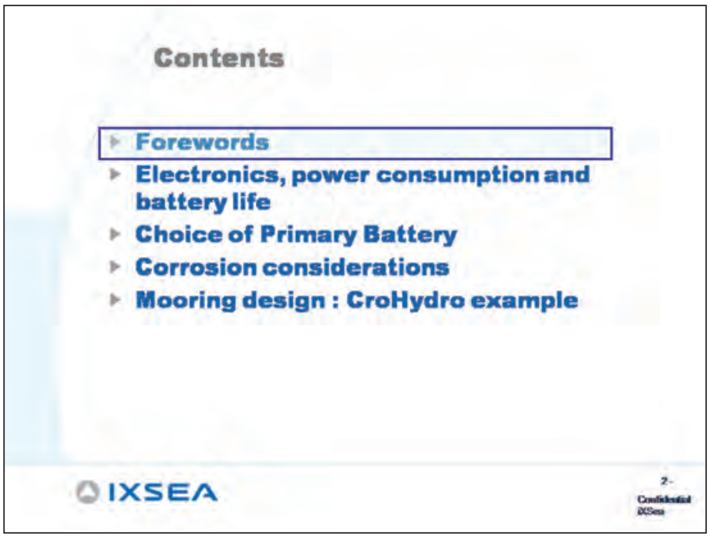
* * *

Acoustic releases application

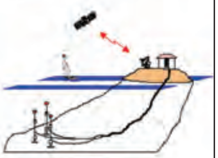
iXBlue is a privately owned French technology company incorporating a wide range of capabilities to deliver world leading solutions to the marine, land, air and space markets.Formed in 2010 by the merging of a number of companies within the IXCORE group including IXSEA, SODENA, IXMOTION, IXWAVES, H2X, IXELEK, IXFIBER and IXSURVEY, iXBlue combines the proprietary technologies of these companies to deliver integrated solutions to meet the challenging requirements of today's world with innovation, flare and efficiency.iXBlue comprises three main business areas: equipment and systems, components, services and platforms. Currently IXBLUE is headed by Mr Philippe DebaillonVesque (ENST Paris) who is the President and CEO of the company. Mr.DebaillonVesque is formerly vice-president of the "surface vessel sonar and torpedoes" Business Unit of the Thales Group. iXBlue employs more than 500 people worldwide and in 2011 had a turnover in excess of $100m.

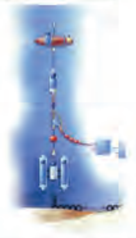


FOREWORDS - Project #1 : CROHYDRO

"CROzet HYDROphone stations"

- Hydroacoustic moorings (triplets) to monitor compliance with Comprehensive Nuclear –Test –Ban Treaty (CTBT)
- Station deployed off coast Crozet Island (South Indian Ocean), being part of the International Monitoring System (IMS)
- Project for CEA (French Atomic Agency), in cooperation with INSUE (French Research Institute)
- Real-time capture of underwater acoustic signals in 1-100 Hz frequency bandwidth
- Digital Hydrophone with very low system noise and high dynamic range (120 dB)
- Long term deployment (10 years) with possible remote recovery for maintenance
- Static/dynamic Behaviour and Reliability studies





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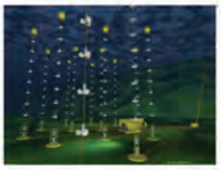
FOREWORDS - Project #2 : ANTARES

Astronomy with a Neutrino Telescope & Abyss environmental RESearch

- Collaboration for the construction of an underwater Neutrino Telescope (http://antares.in2p3.fr)
- 0.1 km² prototype Detector
- Deployed offshore Toulon-France in 2400 msw
- 13 strings with optical modules to detect Cherenkov light emission of upward-going muons (signature of neutrino-muon interactions through the earth)
- Long term deployment (5-7 years)
- String positioning within 10m target
- Remote recovery for string maintenance



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FOREWORDS : Challenges with both projects

- Two projects with different objectives but raising similar technical challenges :
  - Deployment requiring remote recovery in case of emergency or maintenance by use of Acoustic Releases
  - Extreme long term (up to 10 years)
  - Energy power consumption
  - Primary Batteries
  - Marine corrosion considerations
  - Mooring Design
  - Positioning of each mooring required for accurate deployment at sea

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Contents

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ELECTRONICS, POWER CONSUMPTION & BATTERY LIFE

- Aim : Looking at solutions to achieve the best operational life
- Parameters contributing to the overall performance :
  - Power consumption of electronics
  - The way to extract the available energy from primary batteries
  - Energy budget for 10 years life

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ELECTRONIC POWER CONSUMPTION

- CMOS Power consumption
  - Dynamic power : $P = \alpha \cdot F_C \cdot C_L \cdot V_{DD}^2$
- Three degrees of freedom in lower power design :
  - Supply voltage (VDD) :
    - Quadratic relation ship to power : the most direct way
  - Physical capacitance (C_L) :
    - Use of small IC devices : high integration
    - Interconnections / Reduce nets
  - Switching activity (F_C) :
    - Power-down mode
    - Clock frequency → 32 kHz main oscillator for receiving section

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ELECTRONIC POWER CONSUMPTION

- **3.3 VDC components in Acoustic Release PCB's**
  - **Use of latest development in electronics for portable device**
  - **Low power oriented components such as FPGA's and Micro controllers**
  - **Results : more than 100% gain of battery life**

	Alkaline cells		Lithium cells	
	5V techno	3.3V techno	5V techno	3.3V techno
Listening life at 20°C	36	74	72	115
Listening life at 0°C	24	60	48	98

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ELECTRONIC POWER CONSUMPTION

- **How to extract most of the energy from a battery**
  - **Use of efficient and specifically designed DC/DC switching converters to cover the various modes of operation of the AR :**
    - Wide input voltage range from 5 to 35 VDC
    - Provide stable power supply over battery discharge
    - Very low current drain for listening mode → few mWatt power
    - High power when transmitting acoustic acknowledgements → about 1 Watt power over about 1-2 seconds
    - Release mechanism operation → several Watts power over several seconds
  - **Power consumption optimal for voltage ranging from 7 to 25 VDC for all modes of operation**
  - **DC/DC converter required for Release mechanism to limit current drain and to overcome cell's internal resistance effects**

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ELECTRONIC POWER CONSUMPTION

- **Comprehensive analysis of power consumption (75 standard Acoustic Releases) :**

Mode	Unit	Supply Voltage (nominal)			
		5v	7.5v	15v	25v
LISTENING	I (mA)	1.4	0.87	0.43	0.26
	P (mW)	6.9	6.5	6.5	6.5
	E (kJ/day)	0.59	0.56	0.54	0.56
TRANSMIT	I (mA)	140	94	50	34
	P (mW)	700	705	750	850
	E (J/pulse)	1.47	1.41	1.27	1.19
RELEASE no DC/DC converter	I (mA)	1,100	1,100	1,100	1,100
	P (mW)	5,500	8,250	16,500	27,500
	E (J)	110	165	330	550
RELEASE with DC/DC converter	I (mA)	835	510	235	145
	P (mW)	4175	3825	3525	3625
	E (J)	83	76	70	72

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ELECTRONIC POWER CONSUMPTION

- **Energy Budget for 10 years**
  - Standby/listening mode : most of the energy although very low current
  - Transmit Mode
  - Release Operation : most consuming operation but less 0.5% of the energy budget

Mode	Supply voltage (external)			
	5v	7.5v	15v	25v
6 months storage	118	114	111	110
1,000 transmit	1.5	1.4	1.2	1.2
10 years listening	2367	2298	2225	2210
100 release + 200 transmit	8.6	7.9	7.3	7.6
Total energy (in kJoules)	**2495**	**2422**	**2345**	**2329**

Mode	Supply voltage (external)			
	5v	7.5v	15v	25v
6 months storage	4.74%	4.74%	4.74%	4.74%
1,000 transmit	0.06%	0.06%	0.05%	0.05%
10 years listening	94.9%	94.9%	94.9%	94.9%
100 release + 200 transmit	0.35%	0.33%	0.31%	0.32%
Total energy	100%	100%	100%	100%

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Contents

- Forewords
- Electronics, power consumption and battery life
- Choice of Primary Battery
- Corrosion considerations
- Mooring design : CroHydro example

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CHOICE OF PRIMARY BATTERIES

- **Strategy for OCEANO Acoustic Releases**
  - Operation from standard D-size off-the-shelf batteries
  - Best flexibility for batteries replacement
  - Depending on the application : Alkaline or Lithium cells
- **LiSOCl2 Lithium Technology from SAFT LS or LSH models evaluated for long term deployments in terms of :**
  - Capacity / High Energy density
  - Maximum drain current
  - Low self-discharge rate
  - Wide operating temperature range
- **Final Choice : LS33600 primary Lithium battery is the most appropriate choice for the application**
  - Higher nominal capacity (17 Ah @ 20°C)
  - Low loss of capacity @ 0°C (≈5%)
  - Lower self-discharge (< 1%)
  - Max drain current (250 mA) compatible with electronic power consumption and battery pack arrangement

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CHOICE OF PRIMARY BATTERIES

- **Battery Arrangement for 10 years operating life**
  - **Standard acoustic Release**
    - 3 parallel banks of 6 cells in series each
  - **CROHODRO project**
    - Acoustic Release 600 series with conventional 5Vdc components PCB (latest generation not ready yet) et specific DC/DC converter for Release mode
    - Battery pack extended to 3x8 LS33600 cells → longer housing by 150mm
    - Safety margin of 20% on the 10 years required deployment
  - **ANTARES project**
    - Standard latest OCEANO 800 series with 3.3V components and including separate DC/DC converter for Release mode
    - Standard Battery pack (3x6 cells)
    - 20% safety margin even pack capacity is 30% less
    - OCEANO AR's are virtually compatible for extreme long term moorings in challenging conditions , with no modifications

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MARINE CORROSION CONSIDERATIONS

- **Difficult problem to face and no universal solution**
  - Multiple sources depending on :
    - Materials used for housings and fittings
    - Temperature
    - Chemical characteristics of the sea water
  - Strategy to be implemented depending on the application/project
- **Super Duplex Stainless Steel (UNS 32550) Housing solution**
  - Standard for OCEANO Releases for more than 20 years
  - PREN factor > 40 provides high resistance to Pitting and Crevice corrosion
  - Best compromise in terms of mechanical characteristics, corrosion performances
  - Cost efficient grade for offshore and marine applications
  - Several successful moorings in excess of 5 years continuous deployment
  - Solution for CROHYDRO project (very cold water)

OCEANO 2500S Universal

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MARINE CORROSION CONSIDERATIONS

- **Titanium Housing solution**
  - TA6V grade provides very good behaviour
  - Drawback : higher costs and high variability of delivery and retail price
  - Solution used for ANTARES due to Mediterranean Sea conditions

- **Carbon Fibre Housing alternative**
  - Attractive alternative for tube Housing
  - Cage and Release hook mechanism still metal made
  - Gain in weight and price
  - Experience to be accumulated before acceptance by the market

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MARINE CORROSION CONSIDERATIONS

- **Reducing / Preventing the risks of corrosion**
  - No dissimilar materials in contact
  - Simple design and smooth profile to minimize sources of crevice / pitting corrosion
  - Passivation of all SDSS parts
  - Compatible rigging material
    - Master links or Release Rings made of SDSS
    - Galvanic isolation at top and bottom part of the Acoustic Release
  - Cathodic protection by means of sacrificial anodes (Zn or Al-In-Zn)

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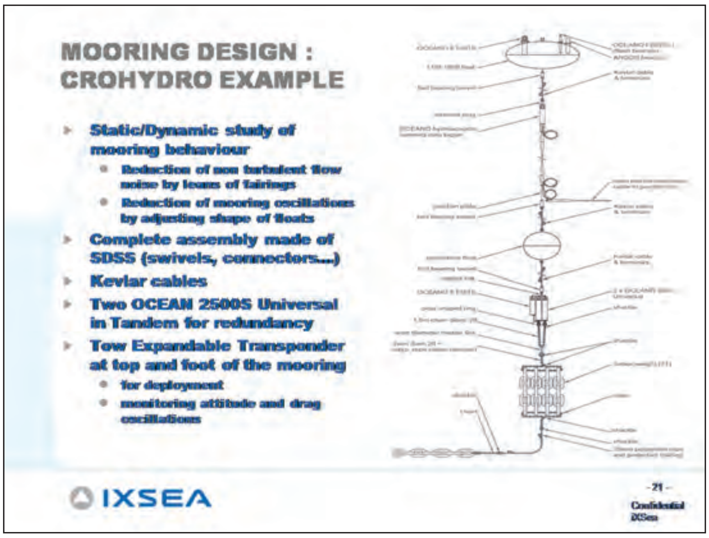
MOORING DESIGN :
CROHYDRO EXAMPLE
Static/Dynamic study of mooring behaviour
Reduction of non turbulent flow noise by leans of fairings
Reduction of mooring oscillations by adjusting shape of floats
Complete assembly made of SDSS (swivels, connectors...)
Kevlar cables
Two OCEAN 2500S Universal in Tandem for redundancy
Tow Expandable Transponder at top and foot of the mooring
for deployment
monitoring attitude and drag oscillations
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* * *

Multi-parameter observations from coastal waters to the deep sea: focus on quality control and sensor stability

Aanderaa Data Instruments AS (AADI), headquartered in Bergen, Norway, designs, manufactures and sells sensors, instruments and systems for measuring and monitoring in demanding environments. We export more than 80% of our products and services around the world and we are an international market leader in several of our product areas. Our main market areas are marine transportation, oil and gas, aquaculture, environmental research, road and traffic and construction.

We are dedicated to find reliable and long lasting solutions for our customers and we are working hard for a safer environment by measuring the processes in our industries and in the nature around us.

Abstract: *Decades of technical development in electronics, telecommunication, optics and acoustics measuring techniques have opened new possibilities for multi-parameter monitoring of the marine environment. This presentation will give examples on how fixed multi-parameter platforms are used in a wide variety of applications ranging from shallow coastal on-line observatories down to measuring in the deepest Ocean trenches. Focus will be on long-term (years) stability and the challenge to maintain satisfactory quality control throughout the deployments. Parameters that will be discussed include: Currents, Conductivity/ Salinity, Temperature, Pressure, Oxygen, Turbidity and Chlorophyll. The performance of emerging technologies e.g. optical sensors to monitor* CO_2 *will also be discussed.*

Introduction to Aanderaa data instruments

AADI with more than 40 years experience in serving the industry and the scientific research markets have recently obtained a technology breakthrough in commercially available Remote Underwater Observation Systems. Our new Seaguard Host and an expanding line of distributed Smart Sensor technology, as well as our new AADI Real-Time Communication System, marks a turning point in distributed instrumentation for underwater and atmospheric measurements of Hydro Acoustic, Electro-Optical, Electro-Chemical, Pressure, Temperature, Meteorological data in observing networks and self-contained instrumentation.

AADI is known for its ability to develop uncompromising state-of-the-art instrumentation that is both reliable and robust for long-term observations of the marine environment. We are a trusted source to many Oceanographic Institutes, Universities, Geophysical Surveyors, Navies, Offshore Oil & Gas E&P Companies, Drilling Companies, Port &Harbour Authorities, Government Agencies, Water Authorities, and Electric Power Utilities internationally.

AADI is ISO 9001:2008 certified and has currently over 100 highly skilled employees working in our facilities, including engineering, manufacturing, calibration and test areas. In-house expertise includes instrument technicians, scientists, engineers, sales, marketing and support personnel.

We have operational and administrative offices strategically placed in Norway, the US and Spain, as well as representation via agents in 40 different countries. Hence, we are ideally positioned to meet the needs of our clients and provide world-class product and services with the highest levels of quality and safety.

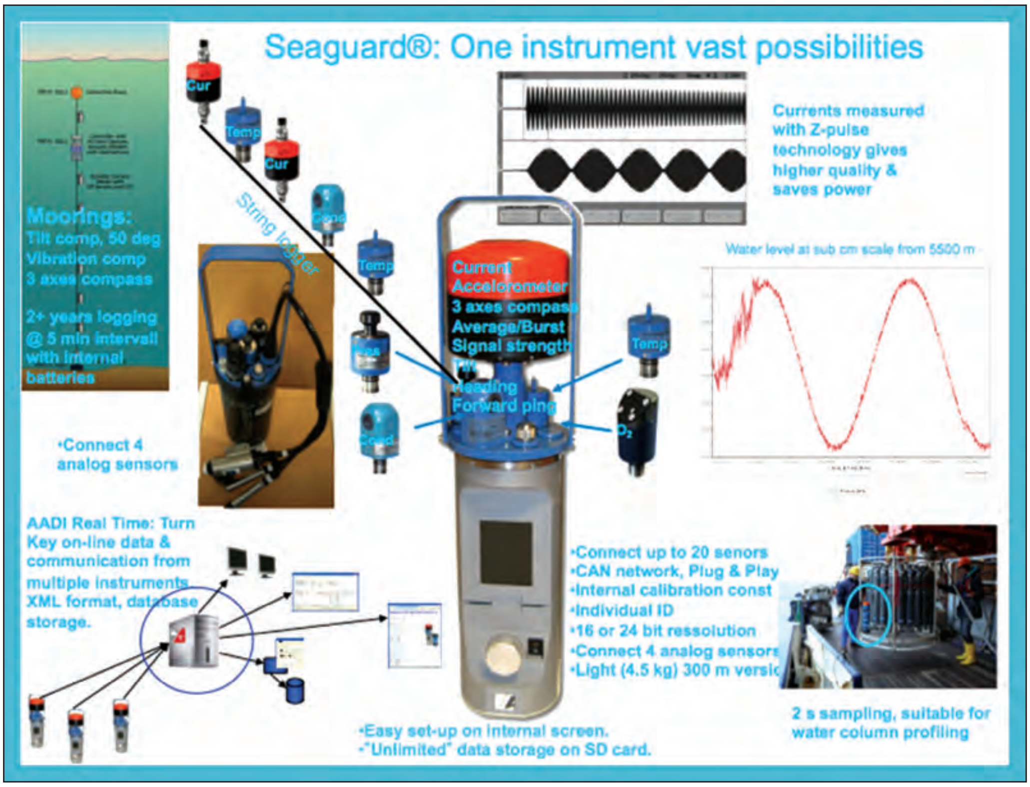
Type of sensors dealt with:

Currents, Conductivity/Salinity, Temperature, Pressure, Oxygen, Turbidity, Chlorophyll and pCO2

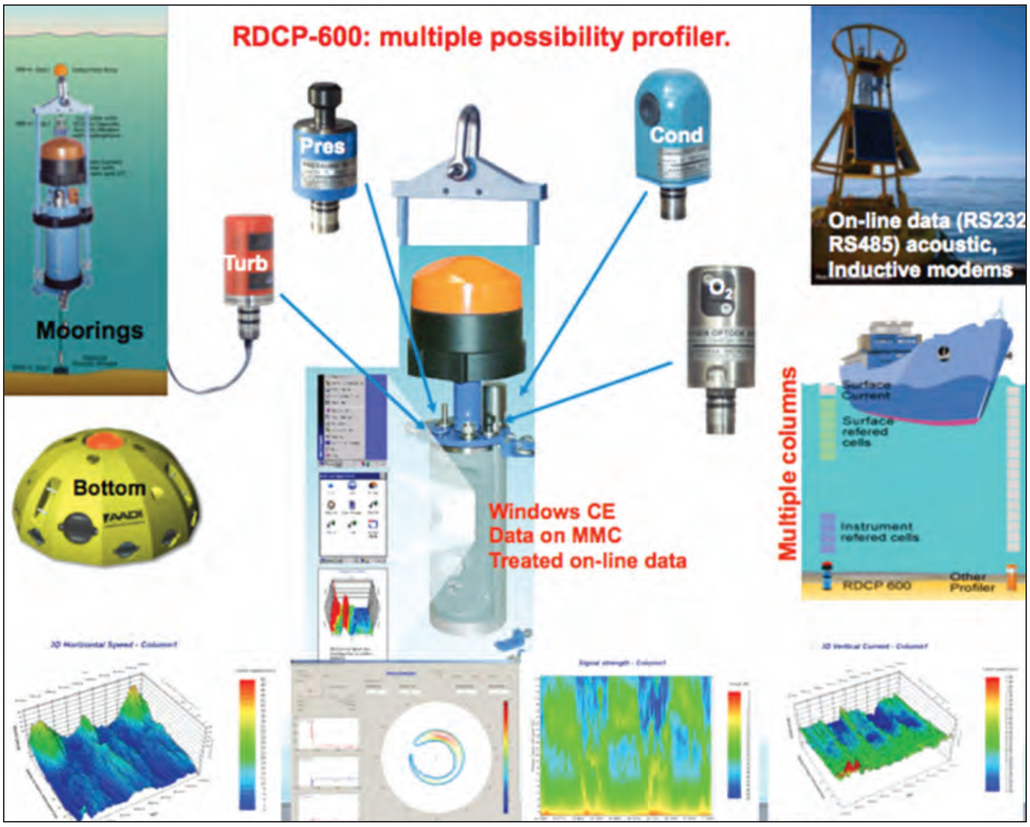
Multiple Output:
- Cond: Cond,Sal,Temp,Sound speed,Raw
- Pres: Pres,Temp,Raw
- Oxygen: O_2,O_2%,Temp,Raw
- Wave & Tide: Wave,Tide,Temp,Raw
- Vented Wave & Tide: Wave, Tide, Pres, Temp, Raw
- Currents: Currents,Temp, Tilt, Signal, Strength,Raw

Communication:
- AiCaP (CAN bus)
- RS232/RS422
- Aanderaa SR10 (10 bit)
- Analog 0-5 V, 4-20 mA

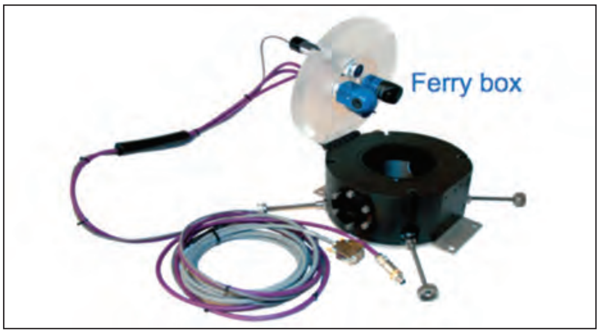
Description of individual instrument (Seaguard)



Description of individual instrument (RDCP)



Description of individual instrument (Smartguard)



Case Study

Case Study: Koljoefjord, multi sensor observatory with monthly sampling for quality control

User value: On-line coastal observatory with multi level measurements at high temporal resolution

System Stability

Data quality control by monthly reference data

Fouling effects on sensors checked by compact CTD profiling

Open for addition of sensors and instruments

System description: The observatory consists of a main hub, which is cable connected to communication and power system on land. The node is prepared to host four experimental modules communicating either with Ethernet or serial protocol. When installed in April 2011 one monitoring module with approximately 30 sensors was connected. Later about 20 sensors more have been added. Data are stored internally in the instruments (Seaguard with String, RDCP and YSI EXO2) and the node, and are also available online and retrieved in real-time. Remote control over the main hub is implemented and has been used for adjusting measurement system parameters over the Internet. At the moment sensors to measures Temperature, Salinity, Currents, Oxygen, pCO2, pH, ORP, ChlA, Blue-green algae, FDOM, Turbidity, Water level and Waves are operational.

For more real time measurements, see this link:

http://mkononets.dyndns-home.com:8080

The Observatory

Most aquatic life depends on oxygen. It is, thus, an alarming finding that the occurrence of hypoxic (low oxygen) conditions is increasing worldwide. This is mainly thought to be a consequence of anthropogenic eutrophication (nutrient input) and climate change. The intention of the EU-projects ESONET and HYPOX *(http://www.hypox.net/)* is to improve the capacity to monitor and predict oxygen depletion, by *e.g.* implementing reliable long-term sensors to different platforms for *in-situ* monitoring.

In the Koljoefjord an on-line observatory was installed in April 2011 to assess and model the dynamics of a system of fjords on the Swedish west coast. The observatory consists of a main hub, which is cable connected (old fiber optic ROV cable) to communication and power system on land (see figure and photos on next pages). The node is prepared to host four experimental modules communicating either with Ethernet or serial protocol. When installed in April 2011 one monitoring module with approximately 30 sensors was connected. Data are stored internally in the instruments and the node, and are also available online and retrieved in real-time to the PANGEA database *(http://www.pangaea.de/)*. Remote control over the main hub is implemented and has been used for adjusting measurement system parameters over the Internet. A web display is developed for checking, plotting and quality control of the data coming in: *http://mkononets.dyndns-home.com:8080/*

The monitoring module consist of two instruments (Seaguard with a string of sensors and RDCP) to which the following sensors are connected:

- @ 9 m: C and T
- @12 m: O2, pCO2, and T
- @15 m: O2, C and T
- @18 m: C and T
- @21 m: O2, C and T
- @28.5 m: O2, T, P, horizontal currents
- @40.5 m : O2, C, T, P.
- 3D Current profile, starting 3 m above bottom, currents every 1 m including the surface.

C/T measurements: sensor model 4319A (9-21 m)

O2/T measurements: optode sensor model 4835 (9-21 m) and 4330 (28.5 m)

P/T measurements: tide sensor model 4647C (28.5 m)

Horizontal currents: Doppler current sensor DCS 4420 (28.5 m)

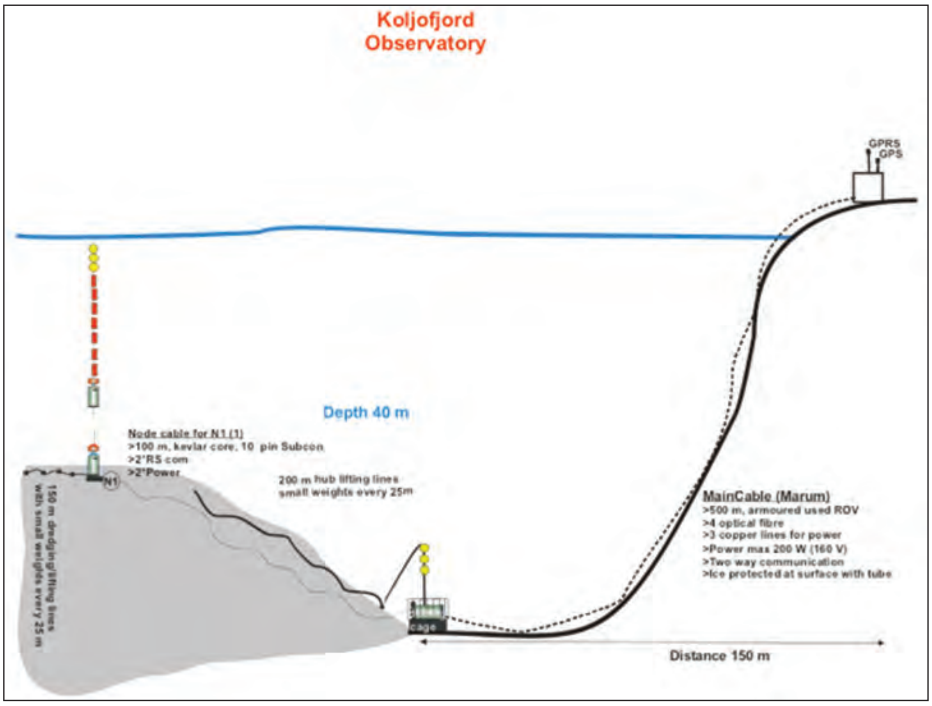
3D current profile: Doppler current profiler RDCP600 (40.5 m), also O2 optode model 3830, C/T sensor 3919A, P sensor 3187 and T sensor.

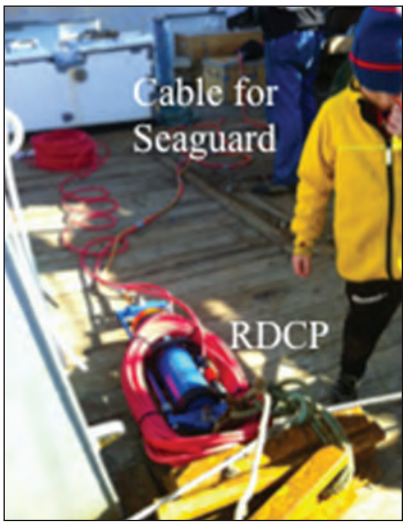
Measurement interval that has been used 2-30 min.

There is also an additional autonomous monitoring module, which is measuring at 10 min interval close to surface. It is deployed away from the fairway and offline, with data stored internally the sensors deployed are:

- @ 4 m: O2 and T (optode 3830), C and T (cond sensor 3919A)

All sensors are from AADI *(http://www.aadi.no/)*. The infrastructure (hub, node cables, land cabinet) was delivered by Develogic *(http://www.develogic.de/)*.





YSI CastAway CTD with in-built GPS and Bluetooth used for control of fouling effects.

Seaguard with sensor string

Monthly high quality reference data

The observatory is deployed very close to a sampling site of a monthly survey program run by SMHI (Swedish Meteorological and Hydrological Institution - see Fig. below). For comparing current speed measurements with surface currents and mixing we use wind data from Kristineberg Weather Station (at Sven Loven Marine Research Center run by University of Gothenburg). All the reference data are available online and retrieved for displaying automatically from the following web databases:

In October 2012 another Seaguard (Currents, Wave/Tide, 2 * pCO_2, O_2, Cond/Sal, 5 * Temp) combined with an YSI EXO2 with wiper (pH, ORP, O2, Total Algae, Bluegree Algae, FDOM, Cond, Temp) was added 5 m below surface. The focus will be to study the surface water carbon cycle during 1 year.

SMHI: *http://www.smhi.se/oceanografi/oce_info_data/SODC/download_sv.htm*

Kristineberg: *http://www.weather.loven.gu.se/data.shtml*

The Koljoefjord, markers: blue "M" for the main observatory mooring, red "S" for the SMHI sampling site, green "W" for the Kristineberg weather station. The map is created using the Eniro static map API. See http://kartor.eniro.se, Sea Chart.

SMHI data used:

- Depths 5, 10, 15, 20, 30, 39 m (0 and 2 meters are also available)
- Salinity, Temperature, Oxygen are used (Nutrients and some other parameters are available too)

Weather data used:

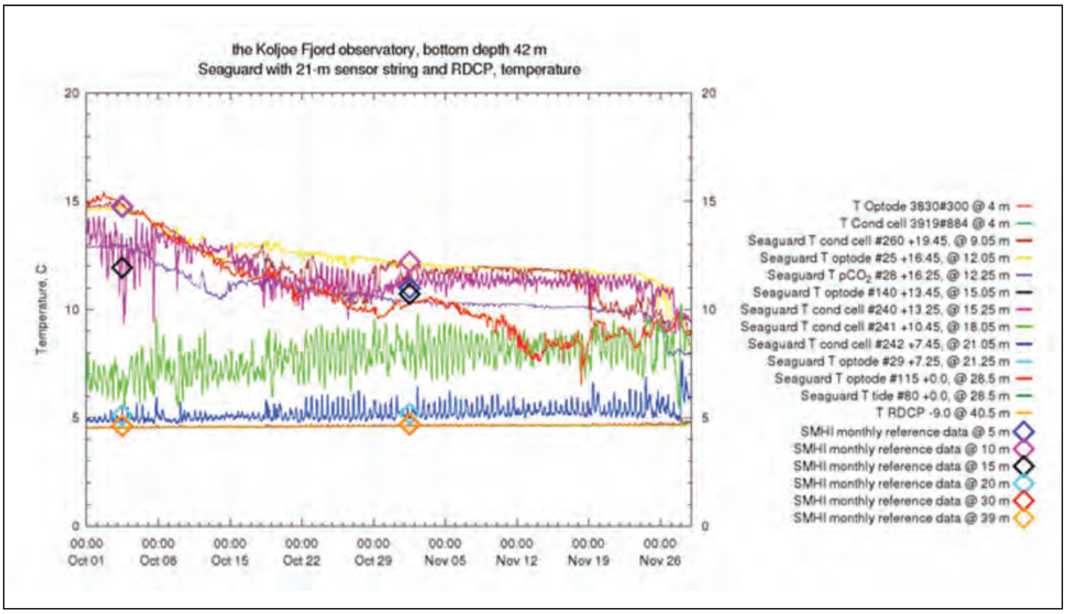
- Wind speed and direction. Many other parameters are available.

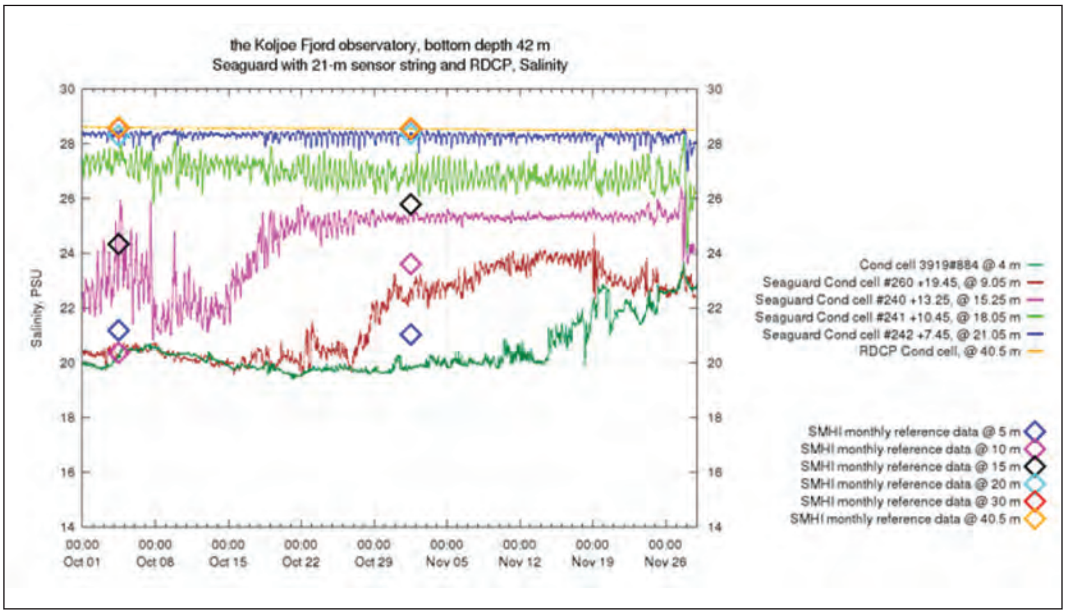
Examples of results

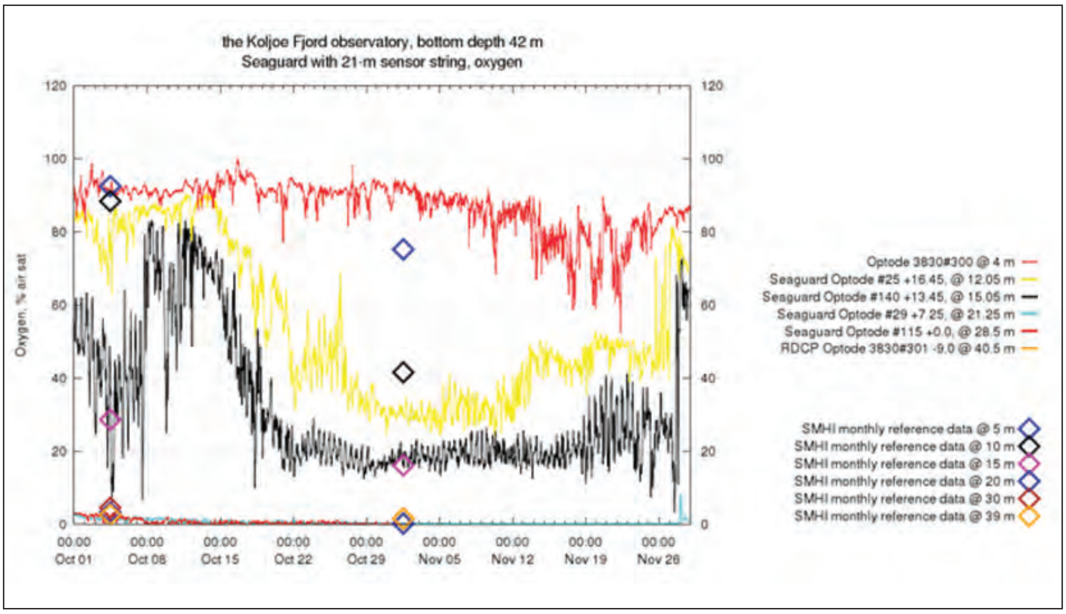
The latest ~5 weeks of data can be checked on the web:

http://mkononets.dyndns-home.com:8080/cgi-bin/recent_data_plots.script

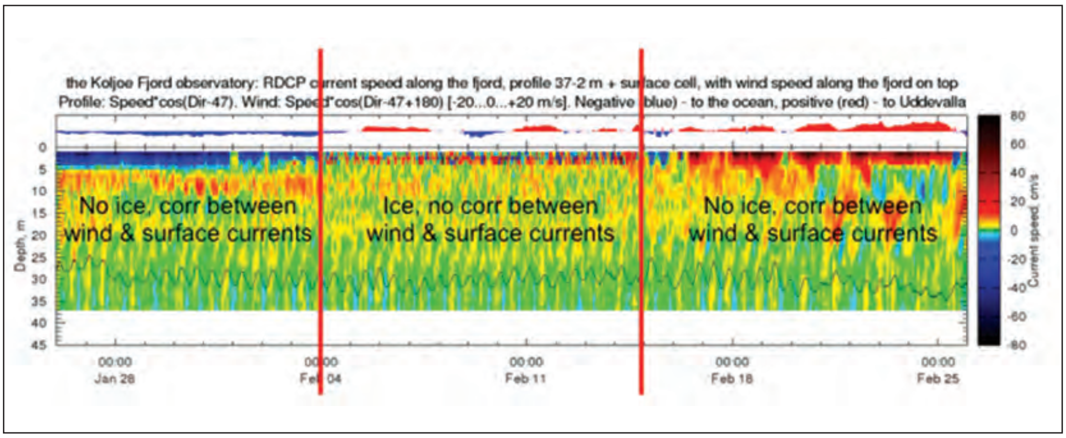
Tidal oscillations result in strong variations in the intermediate layer. Within a few hours temperature can vary with up to 10 C, salinity with up to 3 PSU, oxygen with up to 70% air saturation (see figures below). This and because the depth of sensors and reference water sampling are not always the same, differences occur frequently between observatory and reference data. Outside the intermediate layer (close to surface and deeper) agreement to reference data is generally good. A possible source of error appears at low oxygen where reference Winkler data gave higher values probably due to contamination during sampling. Biofouling was observed for O_2 and Conductivity sensor data measured close to surface (result in lower readings) in July-September 2011. Reference data are invaluable in helping to identify this type of interference and to plan how frequently sensors should be cleaned.

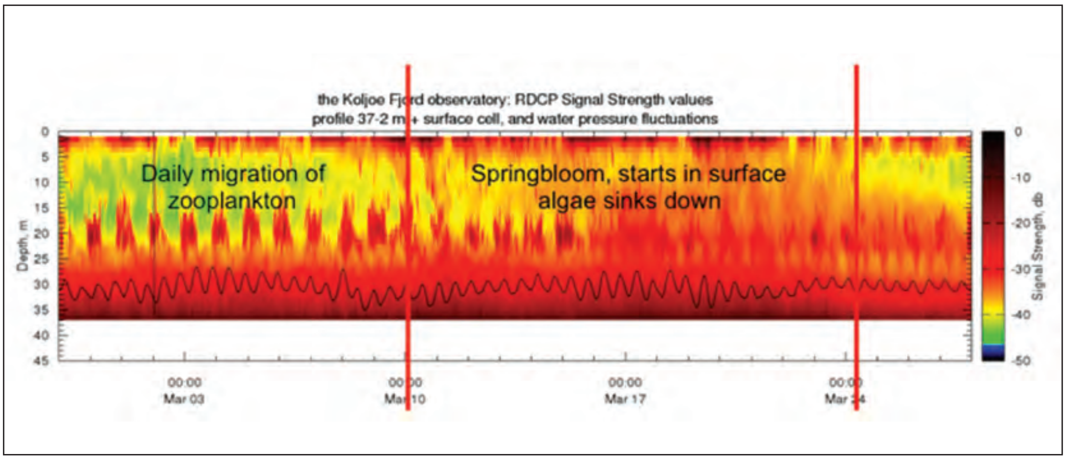




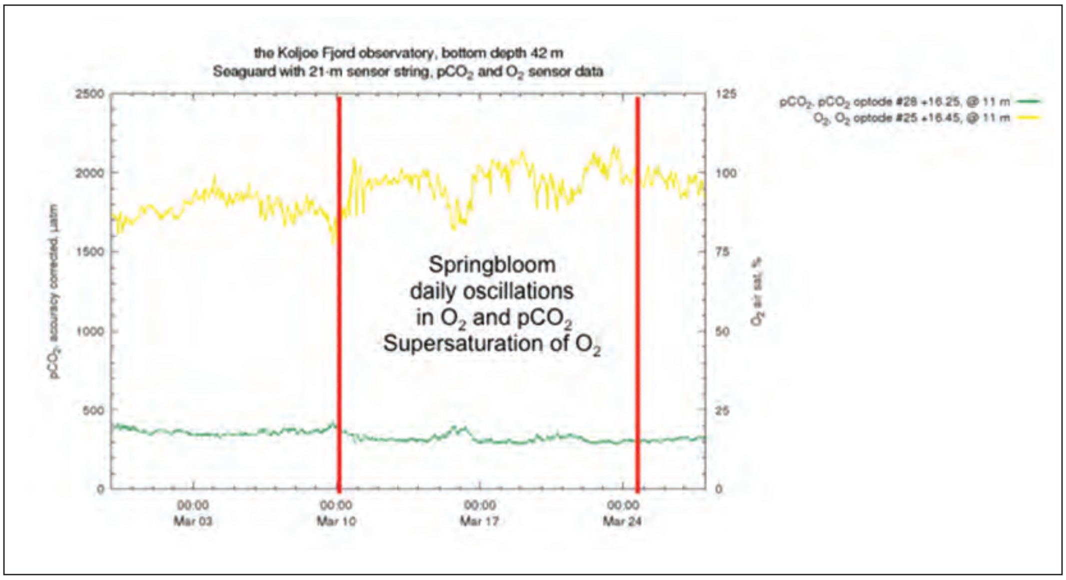


The RDCP-600 scans the entire water column and gives valuable information about currents and mixing. Onset of other events such as when ice is forming, migration of zooplankton and the spreading of phytoplankton from the spring bloom are other events visible in the data (see below).





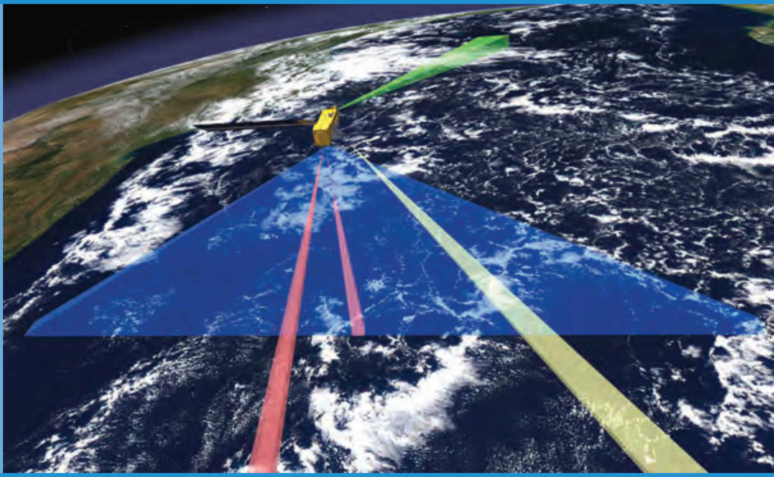
Another function of the Koljoefjord observatory is to serve as a test and development facility for instruments and sensors. The observatory is located one hour sailing time from Kristineberg Research station (http://www.loven.gu.se/english/stations/kristineberg/) where ships/boats/labs/accommodations are available. The observatory can provide power and has free ports with Ethernet/RS232/RS422/AiCaP/Analog communication. New pCO_2 optodes have/are being tested on the observatory demonstrating excellent long-term stability and, as expected, a high anti-correlation with oxygen measured at the same level (see Fig. below).



Lifting nodes or the hub for service/cleaning or to add remove sensors is done by drag lines placed on the bottom. The lifting procedure normally takes about 10 min and require no diver or ROV.

* * *

Satellite Communication

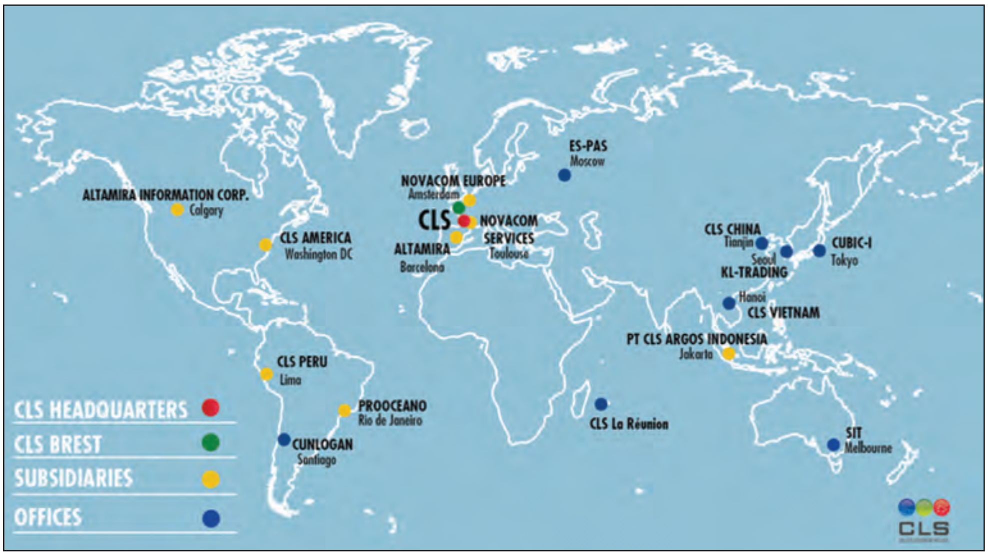


Operational ocean *in situ* data collection by satellite

CLS, a subsidiary of CNES (French Space Agency), IFREMER (French Research Institute for Exploration of the Sea) and several French financial institutions, offers satellite services in location, environmental data collection and ocean observations and monitoring to a broad range of professionals including: government, industry and the scientific community.Within this context, CLS works in close collaboration with CNES, the U.S. National Oceanic and Atmospheric Administration (NOAA), ESA (European Space Agency), MDA (MacDonald, Dettwiler and Associates Ltd), Eumetsat (Organization for the Exploitation of Meteorological Satellites), JAXA (Japan Aerospace Exploration Agency) and INPE (Instituto Nacional de Pesquisas Espaciais). CLS is an international corporation with company headquarters in Southwestern France, near Toulouse and offices and subsidiaries around the world.

1. Introduction

CLS, the subsidiary of the French Space Agency (CNES) is a group of more than 450 employees with headquarters in Toulouse, France and an international network of 17 offices.



CLS group network

CLS is a worldwide leader in environmental *in-situ* data collection. CLS has been working with the operational ocean community for 25 years and operates a full set of systems to keep ground segments, networks, redundant data processing centers and storage servers operational 24 hours a day, 7 days a week.

Image copyrights: Left: NOAA, Middle: Clearwater, Right: IMEDEA

CLS offers ocean data services to international organizations across a broad spectrum of applications. The major international oceanography programs use Argos to transmit data via satellite from ocean platforms to information networks shared by professionals around the world. CLS, exclusive operator of the Argos system since 1986, now also provides Iridium data services to users.

Since the late 1970's, oceanographers, meteorologists and climatologists have used the satellite-based data collection systems to report *in-situ* observations collected by a wide-range of buoys, fixed stations and profiling floats. These data have made significant contributions to our ability to describe, understand and predict global climate and weather on all space and time scales.

CLS provides 2 global coverage satellite systems services: Argos & Iridium.

With 3 processing centers operational 24/7, CLS is receiving, processing, validating, distributing and archiving data from these two satellite systems for all type of ocean *in-situ* platforms.

2. The Argos system

Argos is a global satellite-based location and data collection system dedicated to studying and protecting our planet's environment. It allows any mobile object equipped with a compatible transmitter to be located across the world. It also offers the possibility of collecting data from measurement sensors connected to this transmitter. The rules of the Argos system restrict its use to programs for studying and protecting the environment and protecting human life or programs of declared government interest.

The Argos system results from Franco-American cooperation involving:

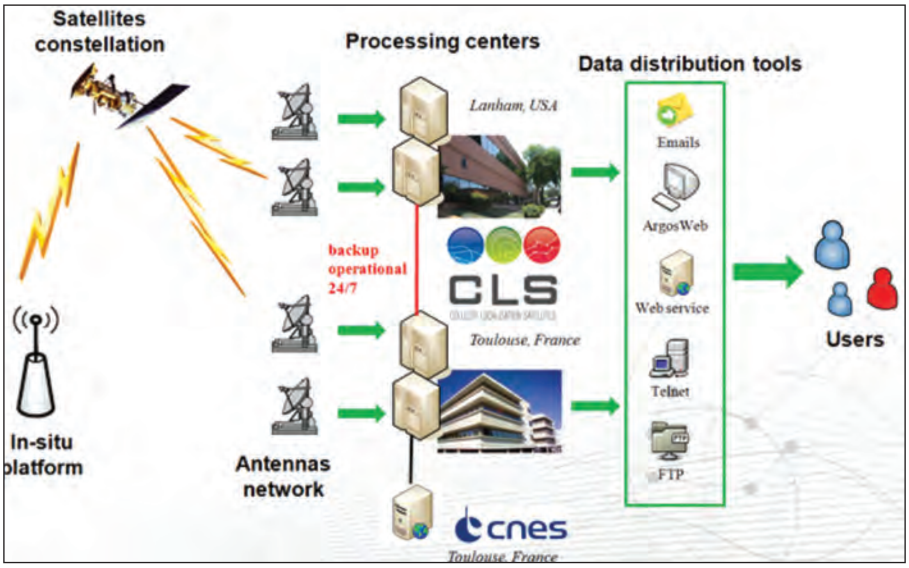
- CNES (French Space Agency),
- NOAA (National Oceanic and Atmospheric Administration), with support from NASA (National Aeronautics and Space Administration),
- Eumetsat (European Meteorological Organization)
- ISRO (Indian Space Research Organization)
- CLS (Collecte Localisation Satellites), operator of the system.

2.1 The Argos system overview

1) Argos platforms automatically transmit messages that are received by satellites in low polar orbit.
2) The satellites then transfer the messages to ground receiving stations.

3) The ground stations automatically transfer the messages to Argos Processing Centers. The Processing Centers calculate the position of the transmitters and process the data measured by the sensors.

4) Finally, the Processing Centers automatically deliver the results to the users. Several methods of data access are available.



The Argos systems overview

2.2 Argos platforms

A platform refers to any equipment integrating an Argos-certified transmitter. Each platform is characterized by an identification number specific to its transmission electronics. A platform transmits periodic messages characterized by the following parameters:

- transmission frequency (401.650 MHz ± 30 kHz), which must be stable as the location is computed on the basis of Doppler effect measurement,
- repetition period, which is the interval of time between two consecutive message dispatches, varying between 45 and 200 seconds according to the use of the platform,
- platform identification number (Argos ID)
- all collected data.

The transmission duration of each message is less than one second.

2.3 Argos satellites

Today, the Argos system is composed by 7 operational satellites:

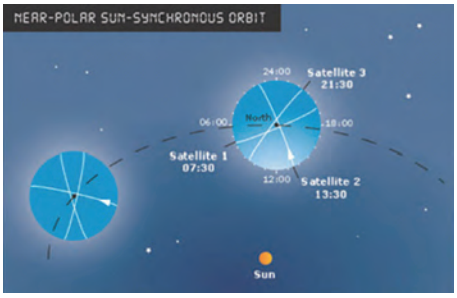
Satellites	Launch date	Instrument
METOP-B (MB)	17 September 2012	Argos-3
NOAA-N' (NP)	6 February 2009	Argos-3
METOP-A (MA)	19 October 2006	Argos-3
NOAA-18 (NN)	20 May 2005	Argos-2
NOAA-17 (NM)	24 June 2002	Argos-2
NOAA-16 (NL)	21 September 2000	Argos-2
NOAA-15 (NK)	13 May 1998	Argos-2

The next instrument will be carried on board SARAL (launch planned on December 12), of the Indian Space Research Organization (ISRO).

Argos messages are received by the satellite then simultaneously:

1) stored on the onboard recorder and retransmitted to the ground each time the satellite passes over one of the three main receiving stations: Wallops Island (Virginia, United States), Fairbanks (Alaska, United States), Mc Murdo (Antarctica) and Svalbard (Norway), or

2) retransmitted to the ground to regional reception stations in the satellite's field of view.

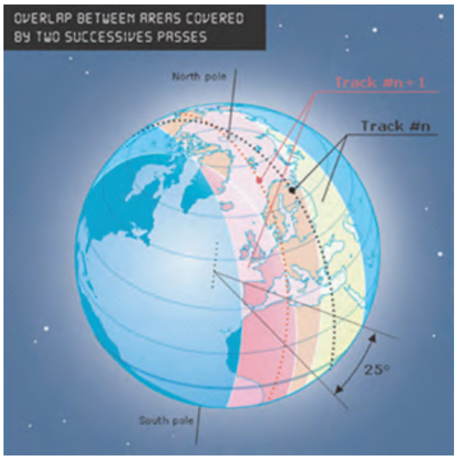


The satellites are on a polar orbit at an altitude of 850 km: the satellites see the North and South Poles on each orbital revolution.

The orbit planes revolve around the polar axis at the same speed as the Earth around the Sun, *i.e.* one revolution a year. Each orbital revolution transects the equatorial plane at fixed local solar times. Therefore, each satellite passes within visibility of any given transmitter at almost the same local time each day. The time taken to complete a revolution around the Earth is approximately 100 minutes.

At any given time, each satellite simultaneously "sees" all transmitters within an approximate 5000 kilometer diameter "footprint", or visibility circle. As the satellite proceeds in orbit, the visibility circle sweeps a 5000 kilometer swath around the Earth, covering both poles.

Due to the Earth's rotation, the swath shifts 25° west (2800 km at the Equator) around the polar axis at each revolution. This results in overlap between successive swaths. Since overlap increases with latitude, the number of daily passes over a transmitter also increases with latitude.



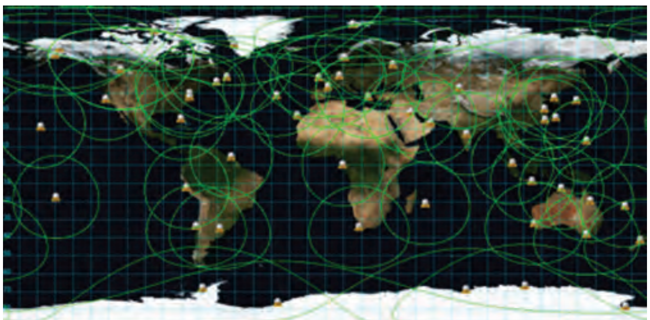
At the poles, the satellites see each transmitter on every pass, approximately 14 times per day per satellite.

The period during which the satellite can receive messages from a platform is equivalent to the time during which the platform is within its visibility. On average this is 10 minutes.

2.4 Argos receiving stations

Nearly 60 stations receive real time data from the satellites and retransmit them to processing centers.

This network of L band antennas, distributed to provide worldwide coverage, is a key element of the Argos service and allows Argos user to get their data in near real-time (20 to 60 minutes) when the Argos platform is under antenna coverage.



Real-time Argos antennas network

2.5 Argos data processing

Argos messages are sequences of binary digits. The data contained in these messages are processed then distributed by the Argos system. Data processing operations range from straightforward binary-to-decimal conversion to sophisticated transfer functions.

The Argos system can run different types of processing on the same data, so that raw data can be distributed as validated physical values as well. In addition, if the messages contain GPS positions, these may also be decoded and distributed in the same way as Argos locations.

The Argos processing system makes it possible for users to receive the decoded physical values measured by a platform's different sensors. These resulting observations are time-stamped (marked with the date and time calculated or transmitted by the platform), then the dated observations are assigned a location, based on the closest corresponding Argos or GPS position.

To take advantage of observation processing, users must provide the related data decoding and assembly parameters to their User Services Group, with a description for each different platform type (this information is generally available from the platform manufacturer).

Observation processing is mandatory for meteorological platforms that distribute their data to the GTS (Global Telecommunication Network).

Observation processing is performed independently of Message processing and therefore does not affect user's results processed and distributed in Message format.

Consultation
Map
Data table
Most recent data
Data Download
Download COM/PRV/DIAG
Observations

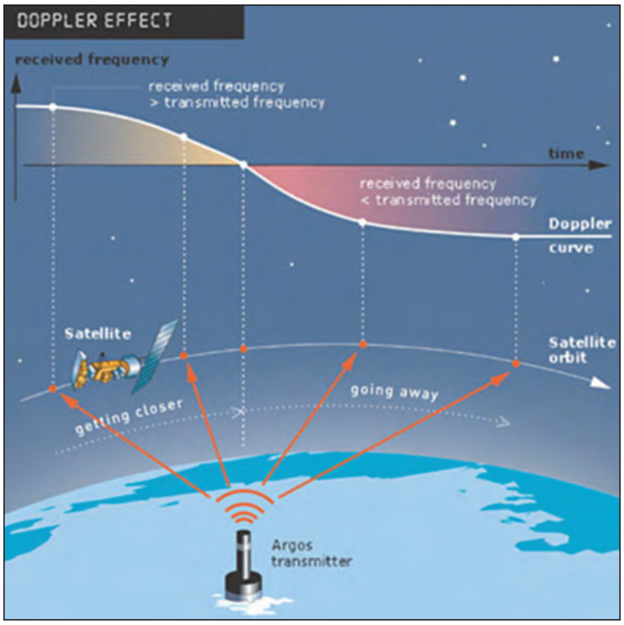
In order to consult observations, users should logon to ArgosWeb, then select the Observations tab in the Consultation menu bar.

The Observation processing module makes it possible to recover the time stamped, geo-located physical measurements made by a platform, in a useable format, simplifying interpretation. The values are arranged in chronological order by observation time, then by level (height or depth in meters above or below sea-level).

2.6 Argos locations

Argos platforms automatically transmit messages which are received by satellites and relayed to Argos processing centers to compute results and make them available. Locations are computed from all the messages received during a satellite pass. Argos system users have the advantage of two independent positioning modes:

- Argos location: Argos centers calculate a transmitter's location using the Doppler Effect on transmission frequency.
- GPS positioning: On request from the user, a specific processing module extracts the GPS positions included in the messages, validates them and distributes them in the same format as the Argos locations.



In both cases, the coordinates used are the latitude and longitude and the reference system is WGS 84 (World Geodetic System, 1984).

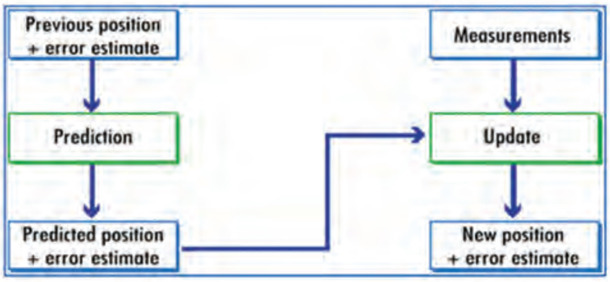
The Argos system calculates locations by measuring the Doppler Effect on transmission frequency. The Doppler Effect is the change in frequency of a sound wave or electromagnetic wave that occurs when the source of vibration and observer are moving relative to each other.

Each time the satellite instrument receives a message from a transmitter, it measures the frequency and time-tags the arrival.

In 2011, CLS introduced a location processing algorithm that takes into account platform dynamics and the use of a bank of Kalman filters to calculate positions. This method is extremely robust and positions can be calculated based on one message per satellite pass. In addition, the error estimate is an integral part of the algorithm and therefore systematically distributed to all users. Unlike the Least squares method, only the nominal location is calculated.

Kalman filtering is a 2-step process:

- The filter predicts the next position and its estimated error based on the previous position and its estimated error with a movement model,
- The filter calculates the new position and its estimated error by updating the predicted position using frequency measurements acquired during the satellite pass.



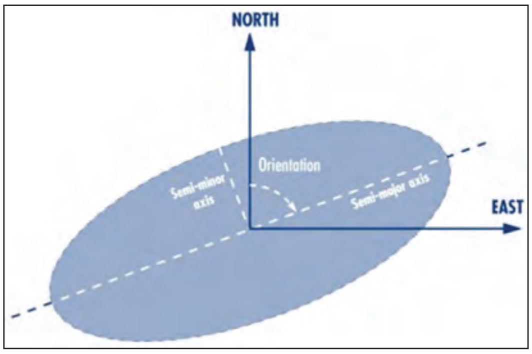
Three plausibility tests are used to validate the location:

- Coherency of measurements with the model used (in mathematical terms, we analyze the likelihood of the Kalman filter's innovation).
- Transmission frequency continuity,
- Plausibility of velocity between locations.

All tests must be positive for the location to be validated. For all locations, an estimation of the accuracy is provided. Locations computed with less than 4 messages are distributed to users if they subscribe to Service Plus/Auxiliary Location Processing.

Error estimation: Due to the satellite's polar orbit, the Argos position error is better represented by an ellipse rather than by a circle. For those users who wish to use it, CLS provides the following values corresponding to the ellipse of error for all locations:

- Error radius
- Length of the semi-major axis
- Length of the semi-minor axis
- Ellipse orientation (expressed as an angle with the North, going towards to the East)
- GDOP (Geometric Dilution of Precision)

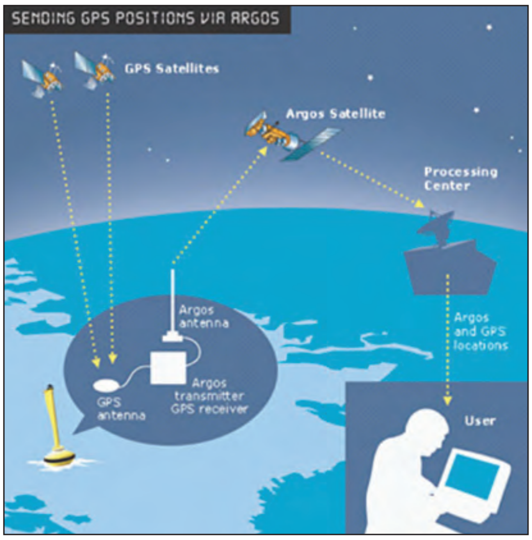


The Argos system can be used to transmit GPS positions. The advantages are:

- Positions are more accurate and do not depend on transmitter quality,
- Positions can be collected more regularly over the day.

The GPS positions are transmitted in Argos messages. To allow GPS positions to be processed and presented in Argos location form, their decoding must be declared to User Services.

Transmitting GPS data via Argos:



Location classes: Locations are classified according to the following criteria: type of location (Argos or GPS), estimated error and number of messages received during the satellite pass.

Class	Type	Estimated error	Number of messages received per satellite pass
G	GPS	<100m	1 or more
3	Argos	<250m	4 or more
2		250m< <500m	
1		500m< <1500m	
0		>1500m	
A		Unbounded accuracy estimation	3
B			1or 2

2.7 Argos data distribution

Here are several ways to access Argos data:

ArgosWeb	Argos users can access their data via the Internet, by logging on to a secure website *(http://www.argos-system.org)* with their username and password (assigned to them by User Services). A detailed description of ArgosWeb's functions and capabilities is provided by online help *(http://www.argos-system.org/cwihelp/en/globalhelp.html)* pages. Argos Web gives users secure and easy access to Argos data via an attractive and user-friendly website. With ArgosWeb, users can view platform trajectories on land and marine maps. Users can also personalize data download formats (table or map format). Users have immediate access to information on their Argos account, as well as platform and program settings.
ArgosServer	With this service, users can logon to Argos Processing Centers and access their data via TELNET. Telecommunication Network is a network protocol used by all TCP/IP compatible networks. A Telnet session with CLS's servers can be opened by typing the "Telnet" command on most operating systems (Windows, Unix...): ArgosServer.cls.fr or ArgosServer.clsamerica.com (for North American users)
ArgosDirect	ArgosDirect automatically sends data to users by e-mail, FTP or CD-ROM. ArgosDirect allows users to receive their data in table format or in the same formats as ArgosServer. ArgosDirect is a flexible service, designed to meet your needs. Subscribing to this service is easy. To do so, a program manager merely needs to fill in the ArgosDirect form which can be downloaded from our website: http://www.argos-system.org/html/userarea/forms_en.html.
WebServices	Argos WebService is a machine-to-machine interface that distributes Argos positions, error estimates, diagnostic data, raw messages and sensor data via internet. This modern alternative to ArgosServer (Telnet) makes it possible for Argos users to contact CLS’s data base directly, via internet, and receive their data in CSV, XML and KML (GoogleEarth) format. For detailed information on setting up the WebServices, please download the instructions on our website: http://www.argos-system.org/manual/webservices.pdf

2.8 Argos-3 capabilities

The Argos-3 Kenwood PMT

The third generation Argos system, Argos-3, is functioning 100%. It has been and continues to be operationally available on the METOP-A satellite since early 2007. METOP-B launched on September 2012 will be operational for users in January 2013. SARAL scheduled to be launched in December 2012 will be operational early 2013. In summer 2013, three Argos-3 satellites will be operational.

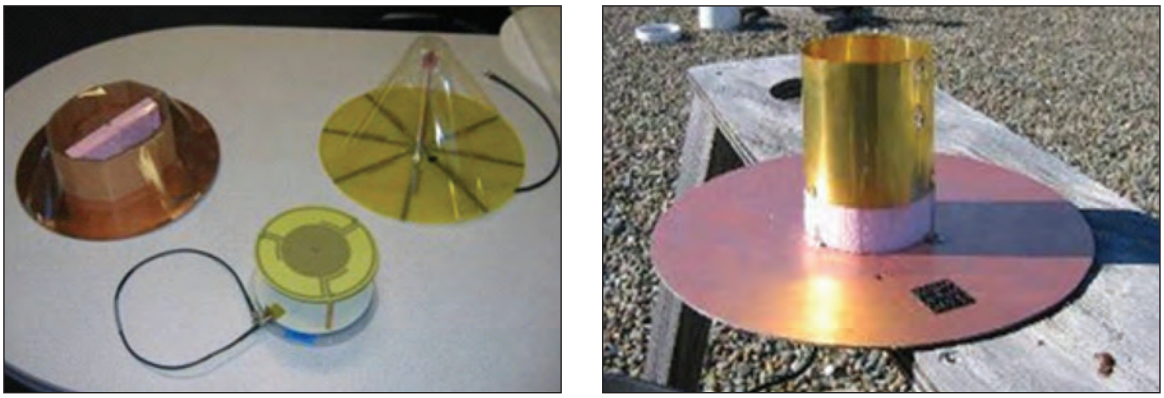
All Argos-3 capabilities can be used with the Kenwood Platform Messaging Transceiver (PMT) designed to communicate as a modem with the Argos-3 satellite constellation. New capabilities include two-way communication, transmission of greater data volume and high data rate. It also operates as an Argos-2 transmitter.

Many manufacturers have already integrated the Argos-3 PMT transceivers into their products and others are encouraged to do the same. Users are strongly encouraged to evaluate the Argos-3 capabilities for their data collection needs. To date, over 3 000 Argos-3 Kenwood PMTs have been sold to Argos manufacturers, mainly in the US.

Argos-3 in drifters: The DBCP setup a dedicated project to assess the Argos-3 system. Drifters were developed:

Argos-3 Kenwood PMT integrated in a SVP drifter

Bi-frequency antennas were designed with a low-cost approach:



Bi-frequency antennas for SVP drifter

All main drifters manufacturers have integrated the Argos-3 Kenwood PMT: Pacific-Gyre, Metocean, Clearwater, Data Buoy Instrumentation, Marlin-Yug and NKE.

The Argos-3 benefits for drifters are:

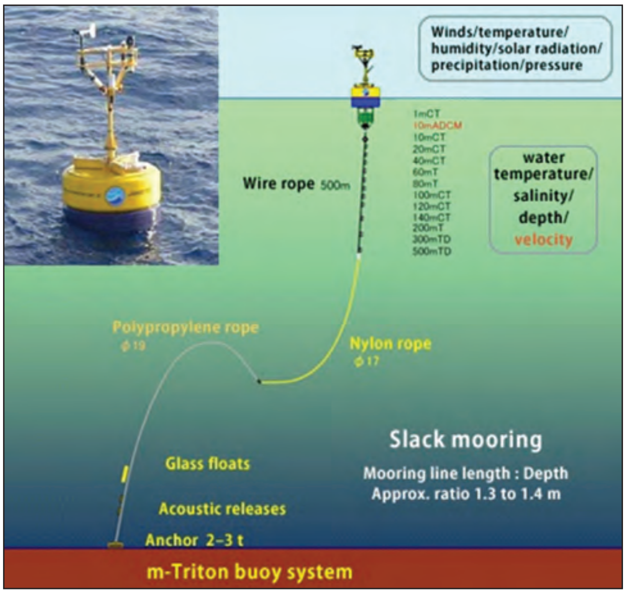
- A high performance for collecting hourly sensor acquisitions (>95%) for those buoys that are operating,
- A large reduction (~75%) of the power consumption used for the data transmission, allowing a reduction in the size of the battery pack and/or increasing the drifter lifetime,
- Improved synoptic measurements (on average, more than 22 hourly observations collected per day),
- Optimization of the transmission leading to a better use of the satellite network and then better performance for users,
- Secure uplink transmission with an automatic checksum control, and
- Remote commands via the Argos-3 downlink to change the mission parameters.

Argos-3 in moored buoys: Several moored buoys operators are using Argos-3 PMT in interactive low data rate mode or high data rate mode to transmit ocean and meteorological data in real-time. The Argos-3 system provides the stable and powerful satellite link telemetry required.

ESTOC moored buoy using Argos-3 interactive mode in Canaries

The Argos-3 benefits for moored buoys are:

- A high performance for collecting hourly sensor acquisitions (>95%) for those buoys that are operating,
- Energy consumption for the data transmission is divided by 6 as the PMT is synchronized with the satellite and transmits only during satellite passes,
- A high volume of data transmitted (more than 15 times more with Argos-2) for the same cost than Argos-2,
- Secure uplink transmission with an automatic checksum control, and
- Remote commands via the Argos-3 downlink to change the mission parameters.



m-Triton buoy using Argos-3 high data rate

3. The Iridium system

3.1 The Iridium system overview

Iridium with 66 Low Earth Orbit satellites is the world's largest commercial satellite constellation.

This global mobile satellite communications system, with voice and data solutions is owned by the Iridium Communications Inc. Company (McLean, VA, United States).

The Iridium System is a satellite-based, wireless communications network providing a robust suite of data services to virtually any destination anywhere on earth.

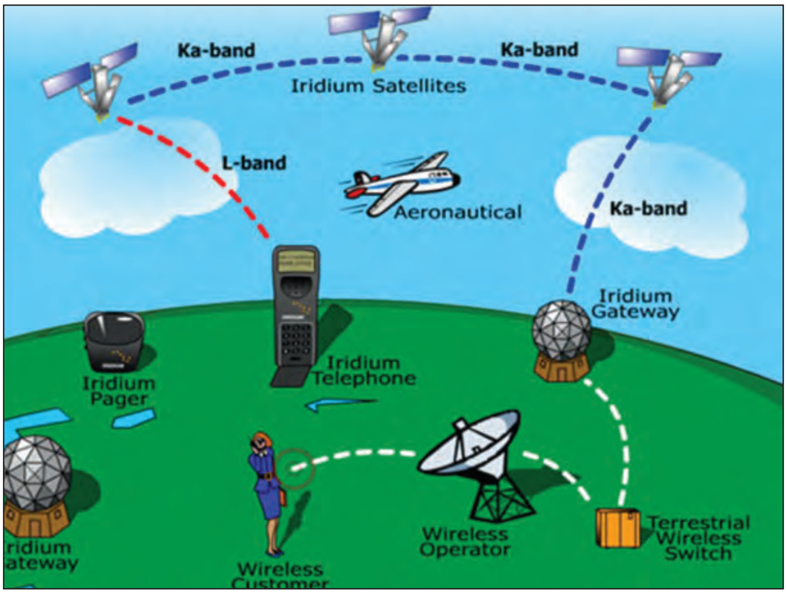
The Iridium system comprises three principal components: the satellite network, the ground network and the Iridium subscriber products including ocean platforms fitted with Iridium modems.

The Iridium constellation

The design of the Iridium network allows data to be routed virtually anywhere in the world. Data calls are relayed from one satellite to another until they reach the satellite above the Iridium Subscriber Unit and the signal is relayed back to Earth. Gateways are the terrestrial infrastructure that provides interconnection to the terrestrial data networks. Gateways also provide network management functions for their own network elements and links.

Five types of Iridium communication exist; only 2 are used by ocean platforms

- Short Burst Data (SBD)
- Circuit Switched Data / RUDICS



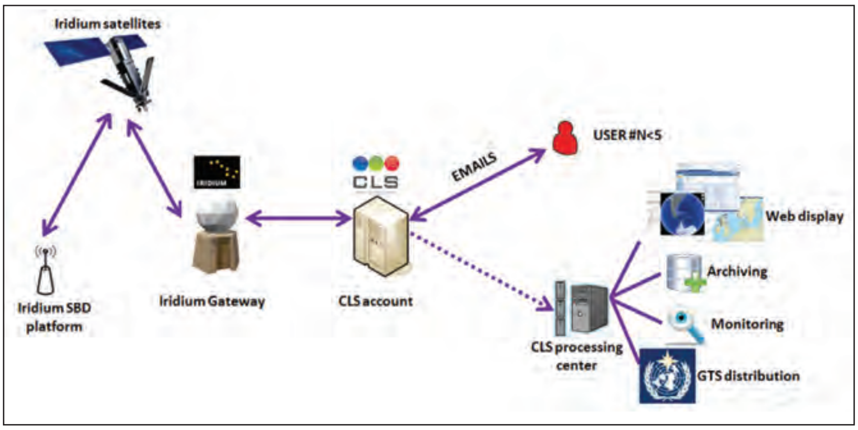
The Iridium system overview

3.2 Iridium SBD

Iridium Short Burst Data (SBD) Service is an efficient network protocol designed for shorter sized data messages. SBD uses a proprietary network protocol to transfer data messages to and from the remote terminal. It is possible to send Mobile Originated (MO-SBD) and Mobile Terminated (MT-SBD) messages. Message size for MO-SBD is between 1 and 1960 bytes. Message size for MT-SBD is between 1 and 1890 bytes.

Messages are delivered with a raw location (80% within 10 km) and data are received by email in attached file. Up to 5 different recipients email addresses are possible. Service is billed according to volume of data exchanged.

First, the field platform fitted with an iridium modem and antenna sends a burst to the iridium constellation. The burst data message is received at the Iridium Gateway on the CLS account and directly transmitted by emails to one or several users (5 maximum). Data can be sent to the CLS processing center for value added services like web display, archiving, monitoring on positions or sensors, GTS processing and distribution…



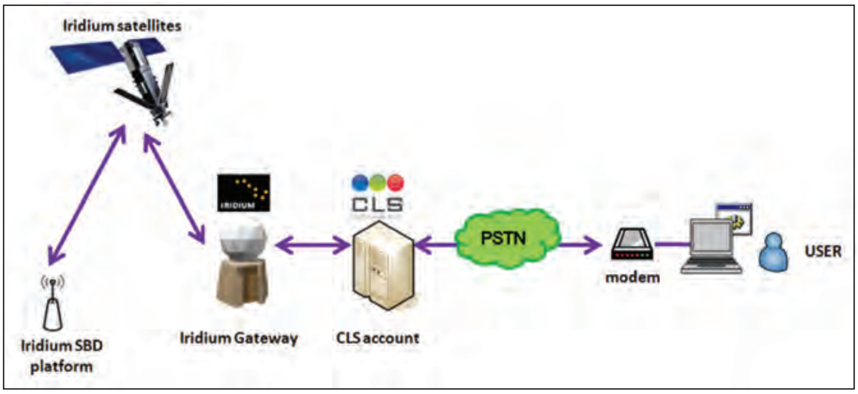
The Iridium SBD communication service at CLS

3.3 Iridium CSD/RUDICS

Circuit Switched Datab (CSD) Service supports the transfer of relatively large data volumes (10's of Kbytes and more) using the Iridium dial-up capability. The Iridium Data Module (IDM) places a call to the Public Switched Telephone Network (PSTN) or to another IDM then exchanges the data through that open circuit at approximately 2400 bits per second. The service is thus billed according to the length of the call which is in direct proportion to the volume of data being transferred. This service is bi-directional.

First, the field platform calls a number on PSTN. Call request is routed over the constellation for user authentication and call set-up. Switch makes connection to dialed number and analog modem in gateway and analog modem in host application synchronize. End-to-End connection established, between the Host Application and Mobile Application.

The Iridium Router-Based Unrestricted Digital Interworking Connectivity Solution (RUDICS) is an enhanced gateway termination/origination capability for circuit-switched data calls across the Iridium satellite network. RUDICS is a circuit switched data service designed to be incorporated into an integrated data solution. Integrated data solutions are applications such as remote asset monitoring, control and data file transfer.

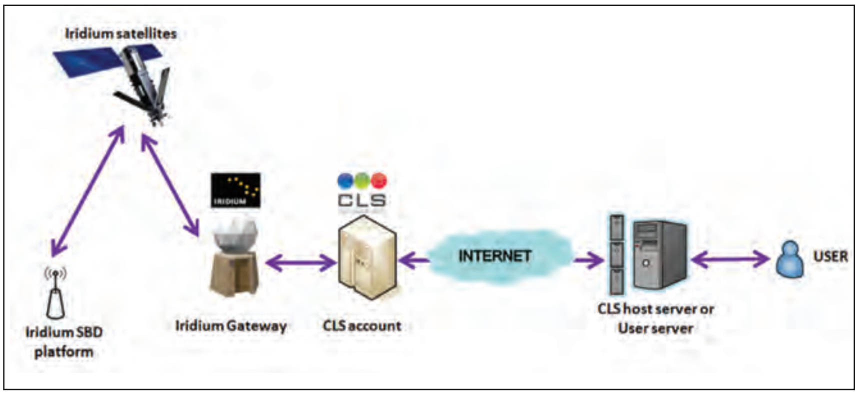


The Iridium CSD communication service at CLS

RUDICS uses circuit switched data service. The difference and key benefit comes in the equipment that is used to terminate or originate the call in the Iridium Gateway. RUDICS uses routers to allow termination and origination of circuit switched data calls to and from a specific IP address over the Internet. The capability is designed to support applications that have many field devices and one central host application. The service allows field devices to directly call the host application and the host application is able to directly call the field devices.

RUDICS is typically best suited for applications that deploy large number of units which report to a central host application. Some Iridium RUDICS applications switch automatically on CSD protocol when the RUDICS service is not accessible.

First, field application calls a custom RUDICS server number. The call request is routed over the constellation to the Gateway with user authentication and call set up. Switch connects to RUDICS server on the CLS account, secondary authentication conducted. RUDICS server terminates call to the user server. End to end IP connection established over the constellation between the host application on the user server and field application. The user RUDICS server could be hosted operationally 24/7 at CLS, in this case data are pushed by FTP to the end users.



The Iridium RUDICS communication service at CLS

3.4 Iridium modems

Today, 2 types of Iridium modem are used for data applications:

The Iridium modem 9602 is the last generation SBD unit designed for embedded applications and is ideal for machine-to-machine (M2M) solutions. It is a smaller size and form factor to its predecessor, the Iridium 9601 and includes a GPS pass through port for connection to a GPS antenna or receiver. The maximum message sizes for the 9602 are 340 bytes for MO-SBD and 270 bytes for MT-SBD.

The Iridium modem 9602

The Iridium modem 9522B is bigger than the 9602 but allows transmitting larger messages in SBD (1960 bytes for MO-SBD and 1890 bytes for MT-SBD) and the 9522B unit supports also Iridium circuit-switched data and RUDICS services. The 9522B is essentially provided as a ‘black box’ with all interfaces provided via a 26-way 0.1” pitch connector. The product provides the core transceiver module and SIM card reader.

The Iridium modem 9522B

4. The GTS processing

The Global Telecommunication System (GTS) is a network run by the World Meteorological Organization (WMO), to facilitate data exchange between national weather centers. Data from a number of Argos and Iridium programs are important for the GTS, namely because they can be fed into national weather centers' real-time weather forecasting models. Ocean platforms users can contribute by authorizing the distribution of their meteorological and oceanographic data to the GTS processing system, free of charge. Data are automatically quality-controlled and put into WMO formats in order to be posted on GTS.

A dedicated GTS processing chain operates at both CLS Processing Centers (Toulouse and Lanham, MD). Platform sensor data are decoded, processed in geophysical units, quality controlled, encoded in WMO code formats and disseminated onto the GTS in real time. This service is included in the CLS Argos and Iridium basic services. Nevertheless, posting data onto the GTS does not impact the structure or content of the initial Argos and Iridium data. Therefore, users may request other formats than GTS formats for the data they receive. For example, the CLS processing center can apply different types of processing and calibration curves according to whether the data is to go onto the GTS or to the Principal Investigator (PI). The PI can receive the raw data. Similarly, file updates on GTS requirements/specifications (*e.g.* removing a transmitter, or removing or recalibrating a sensor) have no impact on a user's Argos and iridium requirements/specifications.

Quality Control: Thanks to several automatic Quality Control (QC) checks, erroneous data are detected and not distributed on the GTS distribution. These QC tests, which can be turned off on request, are:

(a) Gross error check. Sensor data are compared with constant limits.
(b) User limits check. The limits are provided by the owner of the platform for each sensor on each platform;
(c) Sensor blockage test. Same sensor value reported consecutively a certain number of times during a certain period (this test is normally used only for Air Pressure Sensors);
(d) All bits identical test. All the bits of the sensor binary output are ones or zeros (this test is usually not used for Wind Speed, Wind Direction or Pressure Tendency);
(e) Compression Index by sensor. At least two identical sensor values for a satellite pass must be received (values don't have to be consecutive);
(f) Checksums. If the option is used, the sum encoded in the Argos message must still be consistent upon reception at the Argos centre. If not consistent, the data are not distributed on the GTS.

In addition, the following procedures are applied:

(a) If GTS dissemination of the station location is required, only the location with the highest probability of being correct is transmitted;
(b) If GTS dissemination of the station location is required, when location processing is not performed during a satellite pass, the last known location is provided;
(c) For drifting buoys, data with location more than 48 hours old are not transmitted via the GTS (24 hours for ships, longer periods or no limit for other types of platforms).

GTS distribution: GTS reports encoded using WMO codes (alphanumeric and BUFR) are grouped into what are known as bulletins. Bulletins are transmitted directly from CLS to Météo-France, Toulouse and to the National Weather Service, Washington, D.C. for dissemination over the GTS.

How to set up GTS distribution service: Users can request that their data be distributed on the GTS by contacting CLS user services and filling out a GTS technical file. The user must also contact the DBCP in order to obtain a WMO number, essential for transmitting data via GTS.

Deployers of drifting buoys are encouraged to make the data obtained from their buoys available to the global user community, both operational and research, by disseminating data over the GTS. To suspend or cancel authorization at any time, the user should contact CLS user services.

5. Become an Argos users

5.1 Filling out the SUA (System Use Agreement) form

Argos is a location and data collection system designed for studying and protecting the environment. Use of the Argos system is subject to approval from the Operations Committee made up of representatives from the Argos collaborative space agencies. The SUA form can be downloaded from https://www.argos-system.org/html/userarea/forms_en.html. To open an Argos program simply fill out an SUA and send it duly signed to CLS or CLS regional correspondent (office or branch) who will submit it to the Operations Committee for approval, see chapter 9 of this document for the contacts list,

Once the SUA is approved by the Operations Committee, the corresponding Argos program can be opened. This agreement has a time limit and must be renewed periodically as specified in Article 4 of the SUA form.

5.2 Argos Platform identification number request form (ID number)

All SUA forms must be accompanied by an ID number request form. This form is also used to request any extra ID numbers. Platform characteristics and the required message processing are also specified on this form. Platform messages are processed and decoded in compliance with the information supplied for declaration in the system. For standard platforms, models predefined in cooperation with manufacturers are applied. Users encountering any difficulty in filling out this form may contact the platform manufacturer and obtain the information required for processing. For a non-standard platform model (generating specific messages requiring an interpretation method unknown to CLS), the user must ask the manufacturer to contact the CLS user services to provide the definition of the associated processing.

5.3 Filling out the Argos service contract/order form

Once the SUA is confirmed, the CLS user services sends a service contract/order form with the applicable price list. This contractual document recapitulates the subscribed services for processing and invoicing. It must be filled out and signed by the user then sent to the User Services so that the program can be created and the ID numbers assigned.

Any modification to the service contract/order form must be expressed in writing and sent to User Services for acknowledgement.

Once the signed order form has been received, User Services sends a Program Overview informing users about their program, data access codes and the ID numbers assigned to their platforms. Upon user request, the ID numbers can also be sent to the platform manufacturer so that they can be programmed as early as possible. Users with several Argos programs may ask to keep the same data access codes (username/password pair) for all their programs or, if necessary, ask for separate access codes.

5.4 Managing an Argos program

Before deploying the platforms, it is important to test them under conditions as similar as possible to those of their operating environment to check that they operate correctly.

It is also recommended to check that the following information has been sent to the CLS user services:

- Description of Argos message processing, (especially for non-standard platforms)
- Coordinates and date of deployment
- Programmed transmitter frequency

The CLS user services is the dedicated point of contact for any modification to programs, platforms or services. Modifications can only be taken into account if confirmed in writing.

Platform technical parameters, such as message format or maximum speed of movement, allow the corresponding processing to be optimized.

If a platform is no longer used, its ID number must be turned in for recycling and reassignment to a future program. This simply requires informing User Services once.

Argos services are billed monthly and sent every 2 months. The invoice is based on requested and supplied services, the price list that applies.

To terminate a program, users must be certain that the platforms will no longer transmit and must turn in the corresponding ID numbers. They must then request permanent deletion by writing to their CLS User Services.

However, if users wish to keep the program for a future project, the corresponding SUA must be renewed upon its expiration date, if necessary redefining the program objective. User Services is the dedicated point of contact for terminating a program. Termination can only be taken into account if confirmed in writing.

6. References

1. Argos system users manual - http://www.argos-system.org/manual/
2. Information on Argos-3 system :
   http://www.argos-system.org/web/en/71-argos-3-system.php
3. Information on international ocean programs :
   http://www.argos-system.org/web/en/83-international-programs.php
4. Information on Argos platforms and services:
   http://www.argos-system.org/web/en/84-platforms-and-services.php
5. CLS Argos and Iridium one stop shopping for ocean platforms:
   http://www.cls.fr/html/solutions/oceandata/welcome_en.html

7. Contacts

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* * *

Ocean Data Collection-I

Minos X profiler with Xchange sensors

Formerly Applied Microsystems Ltd., AML Oceanographic designs, sells and supports CTD, sound velocity and environmental instrumentation. Our customers are located in more than 100 countries and include organizations involved in the fields of hydrography, science and research and environmental monitoring. Our tagline - Xchange your old ideas - brings to life our commitment to bring fresh, innovative ideas to our industry.

1. Introduction

AML Oceanographic (formerly Applied Microsystems) is an innovative manufacturer of sound velocity, CTD and environmental sensors, probes and instruments. Our customers are located in more than 100 countries and include organizations in the fields of hydrography, science and research and environmental monitoring. AML has been manufacturing CTDs **-conductivity, temperature, and pressure** instruments - since the early 80's. We have multiple models of CTD, specifically designed for vertical profiling and vehicle integration applications. What makes AML Oceanographic unique from other vendors of ocean instrumentation? Simply put, AML is the only manufacturer of oceanographic quality **Sensor Xchangeable instruments**. Our tagline **- Xchange your old ideas -** brings to life our commitment to generate fresh, innovative ideas for our industry.

2. Type of sensors dealt with: < Scope of supply of instruments from OEM >

X-Series instruments can be configured with any of the following sensors:

DO•Xchange™,T•Xchange™, SV•Xchange™, P•Xchange™, C•Xchange™, Turbidity•Xchange™ Field-swappable sensor heads

Image	Name	Function	Ranges available
	C•Xchange™	Conductivity sensor	0 - 2 mS/cm 0 - 70 mS/cm 0 - 90 mS/cm
	P•Xchange™	Pressure sensor	0 - 50 dbar 0 - 100 dbar 0 - 200 dbar 0 - 500 dbar 0 - 1000 dbar 0 - 2000 dbar 0 - 4000 dbar 0 - 5000 dbar 0 - 6000 dbar 0 - 10000 dbar
	T•Xchange™	Temperature sensor	-2 - 32 °C -5 - 45 °C 0 - 60 °C
	SV•Xchange™	Sound velocity sensor	1375 - 1625 m/s 1100 - 2000 m/s
	DO•Xchange™	Dissolved Oxygen sensor	0 - 50 mg/l
	Turbidity•Xchange™	Turbidity sensor	100 NTU 300 NTU 1000 NTU 3000 NTU

3. Description of individual instrument

AML has 5 instrument platforms to choose from, including 3 externally powered and 2 self-powered. Information relating to our entire range of instruments is available online at **www.amloceanographic.com**. This reference material will focus on the Minos X 3 sensor self contained profiler.

Minos•X

The AML Oceanographic X series instruments and sensors provide a major advancement in ocean instrumentation. The swappable and interchangeable sensor technologies dramatically improve the capabilities of ocean instrumentation. These capabilities include:

- Changing the instrument sensor types, while at sea, within seconds and without tools. For example the same instrument can be changed from a CTD to a sound speed profiler.
- The sensor ranges can be swapped as sampling conditions change to maximize the instrument's resolution and accuracy. For example, a deep pressure sensor can be swapped for a shallow pressure sensor, and the salt water conductivity sensor can be swapped for a fresh water conductivity sensor.
- Sensors from one instrument can be swapped to another instrument to maintain mission critical capabilities.
- Calibrated sensors can be sent to the instrument so that the instrument does not need to be removed from service for calibration.
- Spare sensors ensure that an instrument can be immediately returned to service after catastrophic damage, such as a high speed impact with the ship's hull.
- All calibration and traceability data resides within each sensor. There is no need update instrument configuration files or coefficients. Calibration data for all sensors is instantly available from the instrument and calibration certificates can be printed from AML Oceanographic's SeaCast software whenever the instrument is connected.
- Logged data is stamped with sensor traceability and instrument configuration data. So there is never a doubt about how the data was collected or the status of the sensor's calibration.
- Since only the sensors need to be returned for recalibration, the shipping costs are dramatically reduced.

The Minos•X is the compact, multi-sensor, data logging instrument of the X series family. It is designed primarily for small boat and hand deployed operations. It provides all the capabilities and accuracy of the large Plus•X instruments but trades off battery capacity and many additional sensor channels in favour of reduced weight and size.

The Minos•X is equipped with one primary Xchange™ sensor port (*i.e.* conductivity or sound speed) and two secondary Xchange™ sensor ports (*i.e.* temperature and pressure). One additional digital port or two additional analog ports can be added by the factory, if required.

The Minos•X is capable of logging continuously for 19 hours with a full battery charge. The actual life varies somewhat depending on the sensors installed. Sampling rates are programmable by time (25 Hz to every 24 hours), by pressure (0.1 dbar or greater increments) or by sound speed (0.1 m/s or greater increments). When logging at time intervals of 25 seconds or more, the Minos•X powers down between samples to conserve the batteries.

Communication with the Minos•X are accomplished with RS-232 or RS-485. The instrument can be powered both internally and externally.

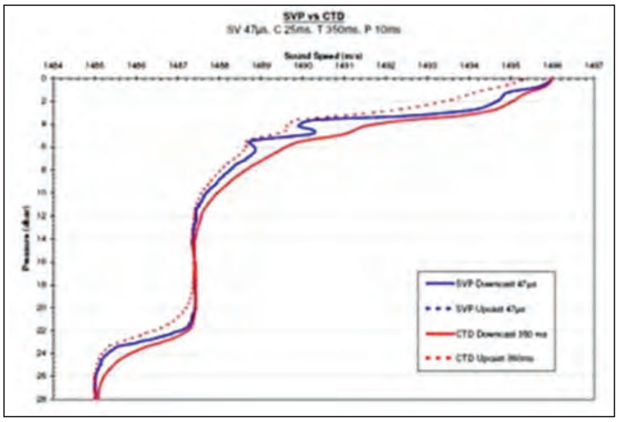
4. Principle of operation

SoundVelocity

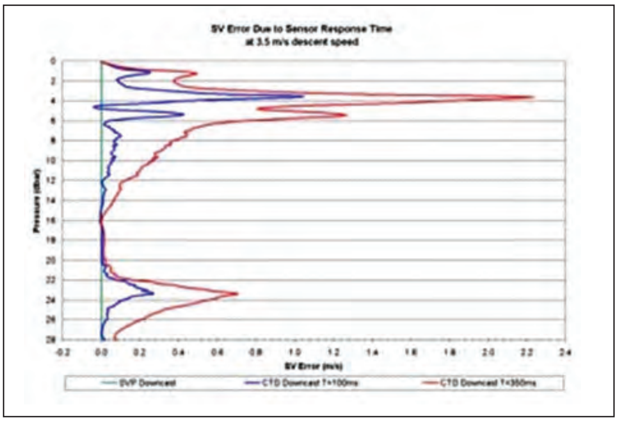
Sound speed - also called sound velocity - can be measured directly using a sound velocimeter or it can be calculated from salinity temperature and depth measurements, assuming standard ocean salt ratios. **AML invented time-of-flight sound velocity measurement**.

The direct measuring devices are known as sound velocimeters. These instruments measure the actual sound speed of the water at the location of the instrument. Sound velocimeters measure sound velocity using a time-of-flight methodology. A single acoustic pulse is transmitted into the water. The pulse travels a fixed, calibrated distance to a reflector plate and then returns through the water to the transducer. The fixed distance is achieved using rods which are thermally stable and have zero thermal response time. A high resolution, high stability timing circuit is used to measure the acoustic travel time. With travel distance and elapsed time known, sound velocity is determined. AML Oceanographic sound velocity sensors offer accuracies of up to ±0.025 m/s.

Calculation of sound velocity based on CTD results is a second, less accurate approach to sound velocity. The CTD uses three separate sensors to measure the conductivity, temperature and pressure at the location of the instrument. Each of these sensors has intrinsic errors; in addition, there are errors related to standardizing the response times of each of the three sensors, as shown in the two graphs below.



SVP vs. CTD

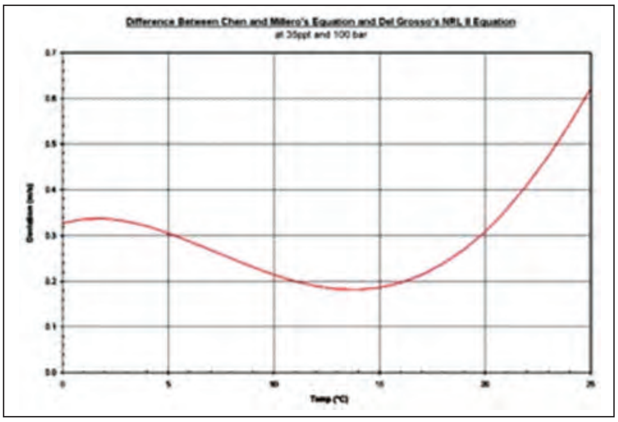


SV Error due to Response Time

Once measured, the conductivity, temperature and pressure are used to compute salinity using an equation of state. Then the salinity, temperature and pressure are used to calculate the sound speed of the water, using another equation of state. Thus CTD based sound speed data is a combination of three sensor measurements and two equation of state calculations. This pyramid like approach - calculations based on measurements - has a dramatic impact on overall accuracy.

The UNESCO Technical Paper Marine Science #44 recommends either Chen & Millero's or Del Grosso's NRL II equations of state for calculating sound speed from CTD data. These equations are assumed to be accurate in the field to within 0.25m/s. Strangely enough, the following chart illustrates that the two equations can generate differences of greater than 0.25 m/s between them, yet both are believed to be accurate.

When considering whether to measure sound velocity with time-of-flight sound velocity sensors or to calculate using conductivity, temperature, depth and salinity, two other factors should be taken into account: 1) the possibility of sound velocity spiking; and 2) acclimatization times.



Difference between Chen and Millero and Del Grasso

Improving the accuracy or reliability of any underwater acoustic system depends on understanding the acoustic environment and minimizing all sources of error in the system. Knowledge of the ambient sound speed conditions is one of the most critical and universal sources of error in underwater acoustics. Some sample relationships between sound speed and vari acoustic systems are:

- Echo sounders require an average sound speed estimate from the surface to the bottom.
- Acoustic systems utilizing hydrophone arrays require an accurate knowledge of sound speed at the array face to calculate transmission and reception angles of the acoustic pulses.
- Acoustic positioning systems and multi-beam sonar systems require accurate profiles of the sound speed from the surface to the bottom to correct for refraction.
- Acoustic doppler current profilers require sound speed to calculate the depth of each current speed measurement.
- Acoustic modems require sound speed profiles to calculate effective ranges.
- Naval sonars require knowledge of the sound speed profile to determine convergence zones, shadow zones and ducts (both surface duct and SOFAR channel) when hunting for, or trying to hide, submarines.

Errors in measuring sound speed result in proportional errors in both range and direction. This can be seen in the three equations below.

- The acoustic distance traveled is d=t*c where c is the sound speed and t is the time taken to travel the distance. Note that for an active system the acoustic distance is twice the distance between the sonar transducer and the target and the equation becomes d=t*c/2.
- The angle between an arriving acoustic signal and a line normal to the transducer array plane is ?=sin-1((t*c)/d)) where c is the sound speed, t is the phase delay between transducer elemnts and d is the transducer element spacing.
- The refraction (bending) of an acoustic ray as it travels through the ocean is described by Snell's law. sin(?1)/c1 = sin(?2)/c2. where ?1 is the propagation angle off vertical at depth 1, ?2 is the propagation angle off vertical at depth 2, c1 is the sound speed at depth 1, and c2 is the sound speed at depth 2.

Since sound speed accuracy is critical to the accuracy of underwater acoustic systems, it is important to understand where the sources of error in sound speed can arise.

With a CTD, total sound speed accuracy is a combination of the sum of the potential individual errors as follows:

- Sensor errors from individual conductivity, temperature and pressure readings
- Response time/spiking errors
- Equation of state errors

Individual sensor errors will depend upon stated accuracies, calibration dates and drift rates for all three CTD sensors: conductivity, temperature and pressure. Response time, spiking and equation of state errors are addressed in the following sections.

In theory, CTDs are generally estimated to generate sound velocity readings to a best case accuracy of 0.25 m/s. In reality, CTD accuracies for sound velocity are often around 0.50 m/s. In contrast, time-of-flight sound velocity sensor accuracies range from +/- 0.025 m/s to +/- 0.05 m/s.

A further source of error is the mis-match in response times of the three parameters which must be measured when calculating sound velocity: conductivity, temperature, and pressure. These differences in response times will cause sound velocity spiking as the instrument traverses picnoclines.

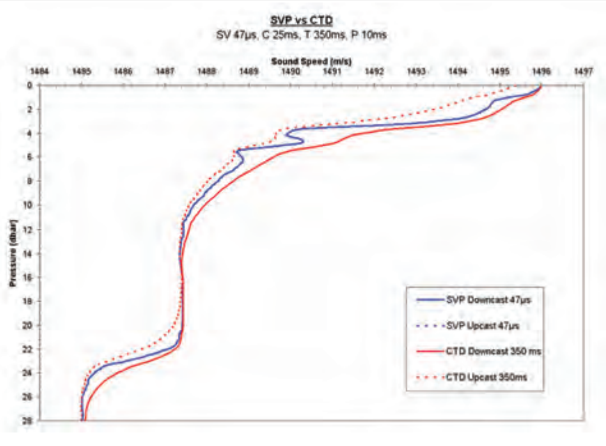
	Sound Velocity	CTD
Sensor response times (time constant)	SV: 47 microseconds	C: 25 millisconds T: 100 milliseconds P: 10 milliseconds

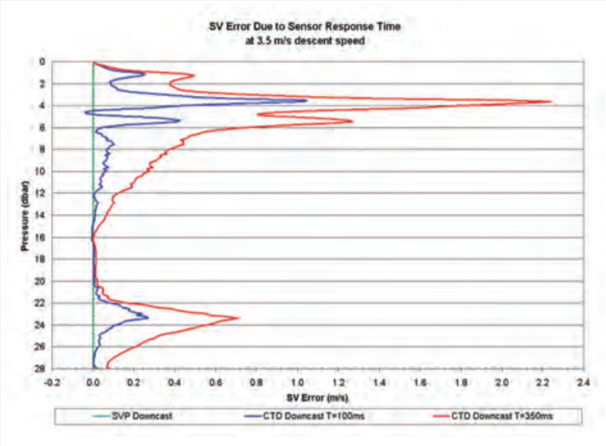
Sensor response times vary dramatically when comparing an SVP to a CTD. The near zero SV response time of the SVP means that every sound speed data sample will be accurate. The slower response time of the CTD means that there will be a lag before the CTD reports the correct sensor values and therefore the correct calculated sound speed.

In addition, the mismatch in sensor response times of the CTD causes anolmalous spikes in the calculated parameters of salinity and sound speed. This phenomenon is typically referred to as ‘salinity spiking’. The magnitude of these spikes is dependent on the sensor response time mismatches and the gradient of the change in water conditions.

The sound speed profile data from a CTD is recognizable by two characteristics.

1. A separation of the picnocline depth between the downcast and the upcast. This is shown in the first data plot below. It is a result of a) the temperature sensor response time and b) the thermal lag in the conductivity cell.
2. Large sound speed spikes which occur at the thermoclines as a result of the sensor response time mismatches of the CTD. This is shown in the SV Error plot, the second figure below.





5. Sampling methodology

Configuring sampling parameters using SeaCast

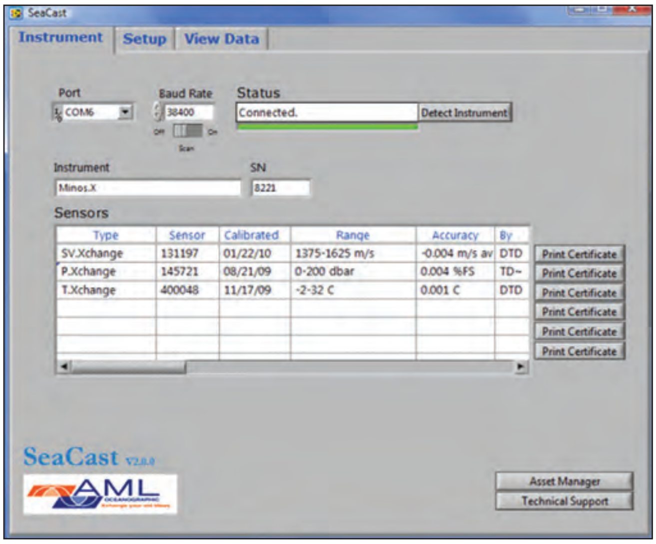
AML Oceanographic’s SeaCast application software greatly simplifies the process of setting up an instrument to complete a profile.

Full details on the instrument configuration process can be found in the SeaCast manual. Below please find a quick summary of that process:

Selecting an instrument for configuration

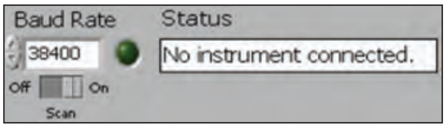
On the Instrument Tab, the first row of fields ‘Port’, ‘Baud Rate’ and ‘Status’ control and display the communications with the instrument.

The ‘Port’ field allows the user to select the computer communications port to which the instrument is connected. If uncertain about the port, the user can check the ports in the Device Manager or Hardware Manager found in the control panel in the Windows operating system. The ‘Refresh’ selection at the bottom of the list allows the user to force a new detection of available ports. This is useful if a USB connection is made after SeaCast is launched.



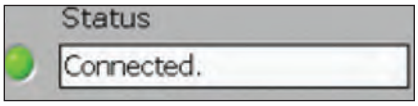
The 'Baud Rate' field is used to select the baud rate the user wishes to use while communicating to the instrument. Lower baud rates allow longer cables to be used if using RS-232/485/422. Higher baud rates shorten the data transfer times. Choose 38,400 baud whenever possible.

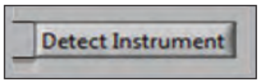
If an instrument is set to autobaud (default setting) it will detect the baud rate chosen in SeaCast and communicate at that baud rate. If the baud rate is changed in SeaCast then power to the instrument must be cycled to re-establish communications at the new baud rate.



Some instruments are set up to communicate at fixed baud rates. In this case the baud rate in SeaCast must be set to the same baud rate as the instrument. If the instrument baud rate is unknown, the 'Scan' switch below the 'Baud Rate' field can be used to have SeaCast cycle through all the baud rates to try to detect the instrument baud rate.

The "Status" field shows the status of the communications with the instrument. The green light indicates that communications have been established with the instrument. During the identification process, SeaCast is determining the type and serial number of the instrument and any connected sensors. During the settings process, SeaCast is determining the latest sampling and logging settings that were programmed into the instrument. When all the required handshaking has been completed, the 'Status' field will show "Connected" and the user may now use the instrument. Please note that the handshaking can take up to 30 seconds to complete.

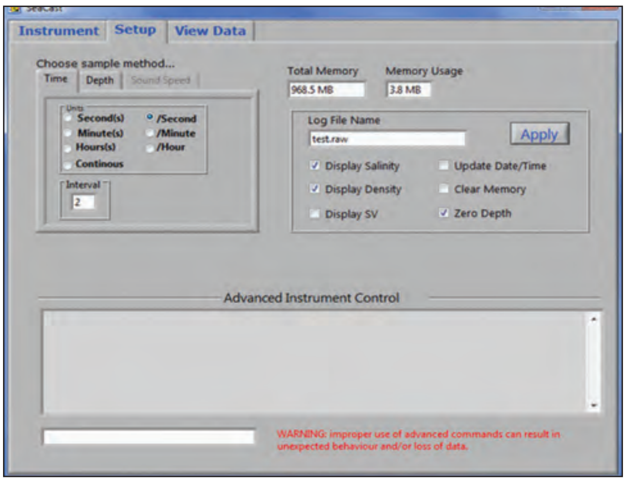




The Detect Instrument button forces SeaCast to re-detect and re-identify the instrument and its sensors.

Configuring the selected instrument

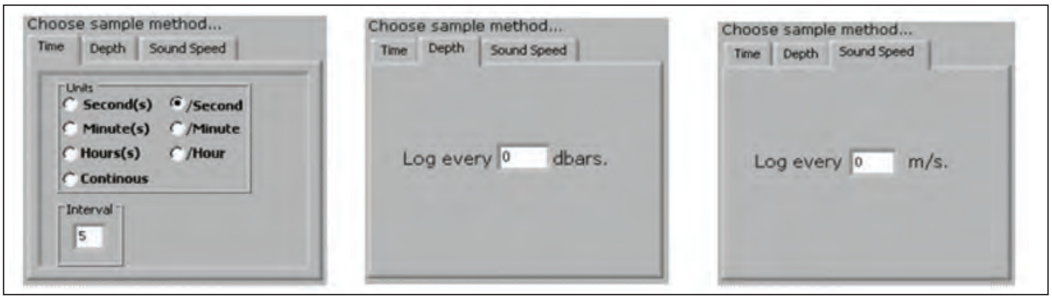
After the instrument has been detected by SeaCast, select the Setup tab at the top of the SeaCast window.



The box in the upper left of the Setup page controls the sampling of the instrument. There are three sampling methods available:

- Sampling by Time Interval (*i.e.* sample 25 times per second, 10 times per hour, every 5 seconds, etc.)

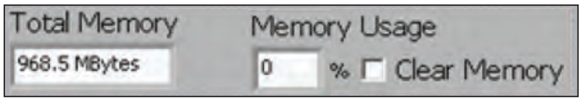
- Sampling by Depth Interval (*i.e.* 1 sample every 1 dbar, 1 sample every 20 dbars, etc.) This option is only available when a Pressure•Xchange™ sensor is installed in the instrument.
- Sampling by Sound Velocity Interval (*i.e.* 1 sample every time sound velocity changes by more than 1 m/s, 1 sample every time sound velocity changes by more than 4 m/s, etc.) This option is only available when a Sound Velocity•Xchange™ sensor is installed in the instrument.



Sampling Method Selection Tab

SeaCast will allow the user to use only one sampling method at a time. Thus, if 5 samples per second is chosen, as shown above, the depth and sound velocity increments are zeroed. This prevents conflicting sampling requirements from being programmed into the instrument.

Instrument time, memory & log file settings



The memory fields show the size of the memory installed on the instrument and the percentage of the memory that has been used. The 'Clear Memory' check box allows the user to erase the entire memory. A pop up warning window will be displayed if this check box is selected.

The 'Log File Name' field displays the current log file name that data will be logged to in the instrument memory. The instrument log file name is limited to 8 characters plus 3 characters for the file extension. For example, data.txt, profile1.raw, or april.dat. Please note this is the log file in the instrument not the export file for SeaCast.

The 'Update Date/Time' check box will synchronize the instrument clock to the computer's clock

6. Do's and Don'ts

Pre-Deployment Procedures

- 4 to 6 weeks ahead
  - Use the receiving steps above to verify the instrument is in good working order.
  - Verify the calibrations of all sensors are valid for the duration of the deployment. If not, swap the Xchange™ sensors for sensors with valid calibrations or send the Xchange™ sensors to a service center for recalibration.
  - Lightly lubricate the connectors with 3M silicone spray or equivalent.
- Before leaving the jetty
  - Verify the P•Xchange™ pressure range is appropriate for the depth of the deployment.
  - Connect the instrument to a computer using the data cable.
  - Check the instrument memory
    - Save any unsaved memory files
    - Initialize the memory using SeaCast or the 'INIT' command.

Caution: Install blanking plugs in all unused sensor ports prior to deployment. Failure to install blanking plugs will result in damage to the connectors.

C•Xchange™ & SV•Xchange™
blanking plug

T•Xchange™ & P•Xchange™
blanking plug

Maintaining the instrument

Battery care

Incorrect care can reduce the life of the batteries. Below are some guidelines to prevent damage to the batteries.

- Do not leave the data cable installed in the instrument. This turns the instrument on and depletes the battery.
- Do not leave the red shorting plug installed. This turns the instrument on and depletes the battery.
- Before storing the instrument for several months charge the battery to at least 7.3 volts (40% capacity). The battery will self discharge at a rate of 2% per month so extended storage durations can require recharging to protect the battery from fully depleting.

7. Calibration

Excerpt from Office of Coast Survey, Specifications & Deliverables (May 2008):

Section 5.1.3.3 Speed of Sound Corrections

”The hydrographer shall calibrate sound speed profiler(s) no earlier than six months prior to the commencement of survey operations...instrument(s) shall be recalibrated at intervals no greater than twelve months...In addition, the instrument(s) must be re-calibrated when the survey is complete if the completion date is later than six months from the date of last re-calibration....”

AML recommends annual calibrations for all Xchange sensors.

A CTD or sound velocimeter that is not in the field is not earning its keep. Nevertheless, users of oceanographic equipment have been packing up their instruments and shipping them back for annual recalibration for over 50 years.

Every ocean-focussed organization knows the story of kit made unavailable because of recalibration. Recal almost always takes longer than originally expected. The diagram below paints a clear picture of how complicated and cumbersome the recalibration process can be. End-to-end downtime is often six weeks.

In contrast, field-swappable sensor heads ensure that instruments stay in the field, where they belong. Instead of removing an instrument from a vessel for recalibration, recently calibrated replacement sensor-heads can be sent directly to the ship. Because any sensor-head can work on any instrument, sensor-heads are maintained in inventory and can be couriered same- day or next-day. Upon their arrival, old sensor-heads are unscrewed from the instrument and are replaced by the recently arrived, newly recalibrated sensor-heads. Recalibration is complete.

At the end-user's leisure, the old sensor-heads are sent back to the factory for their own recalibration. Upon arrival at the factory, they can be recalibrated and returned to the field for use on another instrument. Alternatively, they can be warehoused for future, just-in-time recalibration and delivery.

This change – recalibration travels to the instrument,instead of the instrument travelling for recalibration – is a game changer for all users of oceanographic instrumentation. For companies operating in countries where import/export regulations are complicated, it is even more attractive.

8. References: Please see *www.amloceanographic.com* for more details.

* * *

RBRvirtuoso BPR: depth measurements under pressure

Since 1976, RBR Ltd. has been manufacturing high precision instruments for oceanographic, freshwater, groundwater and cryospheric research. Founded by Richard Brancker, the company is now run by a team of enthusiastic engineers and oceanographers and produces instruments calibrated to WOCE standards. RBR invests considerable effort into research and development, which is carried out in collaboration with customers to ensure that the instruments produced are precisely what the customer wants and can afford. RBR is a global leader in oceanographic instrumentation, providing competitive and innovative products to scientists worldwide. RBR Europe Ltd., UK, was established in August 2007 and is fully equipped to demonstrate and sell our products. It is also the first point of contact for local customer support and a centre of technical excellence for our representatives and agents in the region.

RBR Limited is a privately owned company specialising in oceanographic instrumentation. Established in 1976 in Ottawa, Canada, it designs and manufactures instruments for the highest accuracy measurements of oceanographic parameters. These are deployed on every continent, with freshwater and marine usage down to the greatest depths.

From the small single channel temperature recorder (RBR*solo* T) to the largest multiparameter sondes (RBR*maestro*), RBR makes high precision recorders of parameters such as temperature, pressure, conductivity, pH, dissolved oxygen, and so on. Coupled with innovative telemetry options such as the high speed inductive modem and a single piece of software for deployment and data analysis of all instruments, users find RBR instruments easy and reliable.

The RBR*virtuoso* BPR is a Bottom Pressure Recorder that is designed to extract the maximum possible performance for pressure and water level measurements in extremely demanding environments. Based around the Paroscientific Digiquartz quartz resonant sensor, RBR adds measurement capability that is able to obtain ~10ppb (full scale pressure) resolution measurements in less than one second of integration time.

The patent-pending technology used in the RBR*virtuoso* BPR has been used extensively in the Bennest PPC system, deployed in ODP bore holes for the last decade. These systems have been the first to demonstrate the intrinsic long-term drift of the quartz sensor, and resolutions in 4000m of water are 40um.

The principle of operation is that the resonant frequency of a quartz crystal varies with pressure induced stress. The measurement of this frequency is the key differentiator between an adequate and an exceptional measurement of resolution. The raw pressure and temperature frequency outputs are measured and stored as raw values. The instrument is capable of recording ~30M readings (with optional upgrades to ~120M readings). All of the calibration coefficients are also stored internally and may be automatically applied in order to generate real-time streamed output in decibar if required.

The instrument is setup using the Ruskin software on either a Mac or a PC. The user simply selects a start and end date, an integration period and a sampling period. Alternately, the sampling can be initiated by an external sync pulse, as is commonly used on ocean observatories. Battery and memory usage estimates are calculated automatically and the user may optionally use these values to maximise the deployment settings. Both internal batteries and external power supplies are supported, with automatic switching used if one supply fails.

Post-deployment, downloading the complete dataset benefits from a true USB connection to minimise transfer time. Data may be viewed within Ruskin, or exported to Matlab, Excel, or plain ASCII for post-processing in other tools.

Calibration of the instrument is not required with the exception of a zero-offset verification. This should be done every few years against a dead-weight tester, or by return to Paroscientific. As the instrument contains the complete calibration coefficients, the sensor can be swapped and continue to be used while a second sensor is undergoing verification.

* * *

Automated flowing pCO2 measuring system

General Oceanics, Inc. located in Miami, Florida specializes in the design and manufacturer of ocean and environmental water sampling and monitoring equipment and provides field service consulting. The company was founded in 1966 by Professor Shale J Niskin then a research professor at the University of Miami's Rosenstiel School of Marine and Atmospheric Science. The companie's mission is to provide instrumentation to meet the needs of the oceanographic community. Besides the PCO2 system described here in, General Oceanics also manufactures Rosette, Niskin & GO-FLO water sampling systems, Ocean 7 CTDs and plankton sampling and water flow measuring equipment.

1 Type of sensors

The model 8050 Underway pCO2 Measuring System is an autonomous analytical system for measuring carbon dioxide in oceanic surface water. The system is modeled after instruments previously built by Craig Neill. The system may be used on a ship underway or, on a variety of at-sea platforms.

The present pCO2 system operates fully automatically and consists of:

8050 Underway pCO2 system

- An equilibrator that balances the CO_2 in seawater with a headspace gas that is analyzed.
- An infrared analyzer to quantify the CO_2 concentration in the equilibrator headspace and marine air.
- A network of valves and pumps that select, control and monitor flows of seawater, equilibrator headspace, marine air, and CO_2 gas standards.
- An on deck enclosure that provides a GPS signal, atmospheric pressure measurement and satellite data transfer.
- An integrated notebook computer, computer interface and software to control valves and pumps and to log data (pressures, temperatures, flows, analyzer response, date, time and position).

Different types of sensors are used throughout the system for analytical, troubleshooting and quality control purposes. Accurate measurement of temperature of the seawater in the equilibrator is critical as the isochemical dependence of fCO_2 on temperature is about 15matm 1C-1. The temperature in our system is measured inside the equilibrator by a very accurate (+/- .011C) and stable Hart digital thermometer with a thermistor probe. Temperature also is recorded inside the LICOR analyzer, the condensers, the deck box and the dry box. It has been found that the response of the analyzer is sensitive to surrounding temperature changes. To minimize this effect, an electronics board adjusts the speed of the fan ventilating the dry box automatically while it monitors the temperature inside the box containing the analyzer.

Pressure is also monitored inside the equilibrator, inside the analyzer and at the deck box. The pressure transducer for the equilibrator is differential, meaning that it measures the pressure difference between the equilibrator and the ambient air, which is given by the LICOR pressure transducer when the measurement is made in stop flow mode and vented to the air. The deck box transducer measures the atmospheric pressure, which can differ by several millibars from the pressure inside the ship due to forced ventilation.

A water flow meter measures the combined seawater flow through both equilibrators. A gas flow meter, located at the exit of the LICOR, measures the sample gas flow. Another gas flow meter on the vent of the secondary equilibrator indicates how much ambient air is coming in or out. High flows indicated by this sensor suggest leaks in the gas circulation loop, which is a common cause of biases in underway pCO2 systems. Water sensors positioned at the exit of the condenser and at the bottom of the wet box will alert the software when water is detected and will prompt the shut down of the system to prevent damage or flooding of the instrument. In addition to these regular sensors, the system is capable of interfacing with and logging data from optional external instruments with RS-232 outputs (*e.g.*, fluorometers, thermosalinographs, or optode oxygen sensors).

The analyzer used to measure the CO_2 in the sample gas stream is a non-dispersive infrared analyzer built by LICOR. The system can accommodate three models, according to the user's need: the LI-6262, LI-7000, and LI-840. The LI-840, having a lower accuracy and higher signal-to-noise ratio, will likely not meet the specified accuracy of 0.2 ppm for atmospheric air samples, but some users find it adequate for their needs. The CO_2 measurements are corrected for the dilution by water vapor and band-broadening pressure effect by the firmware internal to the analyzer such that they report a dry mole fraction.

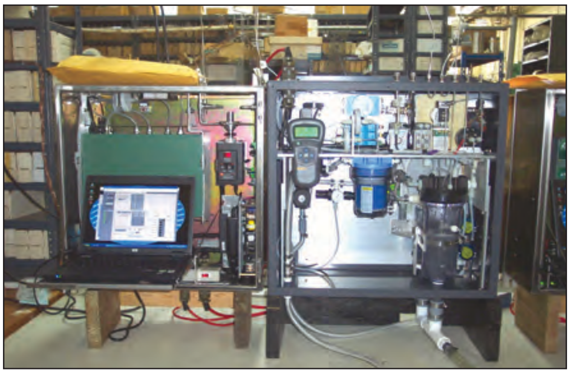


Figure 1: Wet & dry box during factory checkout

2. Description of individual instrument:

The design and mode of operation of the system were decided upon by a large group of pCO2 experts during a workshop held at the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, Florida in 2002. The system is designed to operate fully unattended with only routine maintenance in port. It was decided that the new system would be patterned after systems combining air–water equilibrators with an infrared analyzer for detection.

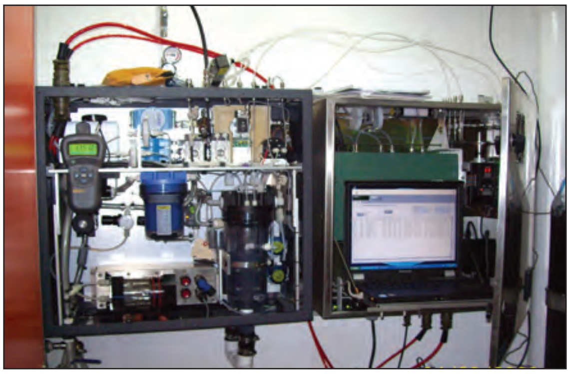


Figure 2: Wet & dry box installed

The system is compact and operates by directing seawater flow through a chamber (the equilibrator) where the CO_2 contained in the water equilibrates with the gas present in the chamber (the headspace gas). To determine the CO_2 in this headspace gas, it is pumped through a non-dispersive infrared analyzer, which measures its CO_2 mole fraction (xCO_2) instantaneously, and then returned to the equilibrator thus forming a closed loop. Periodically, atmospheric air is also pumped through the analyzer and its CO_2 mole fraction is measured. The analyzer is calibrated with four CO_2 standard gases at regular intervals (up to six standards can be used). The unattended use on ships is facilitated by its ability to shut down before its integrity becomes compromised, such as by a leak of seawater and by an automatic back-flushing routine that reduces the growth of organisms and fouling. It can run unattended for months at a time with only periodic minimal maintenance and can transmit its data daily via satellite communication, thus allowing near real-time data analysis and remote troubleshooting.

Figure 3: Satallite deck box w/ GPS & Iridium Antenna

3. Principle of operation : <8050 pCO2 System>

The world's oceans are the largest sustained sink of carbon dioxide released to the atmosphere. It is now estimated that about 1.8PgCyear-1 go into the ocean, but the uncertainty is still quite large (~0.7 PgCyear-1). Different regions of the oceans are not equivalent with respect to CO_2 absorption. Some regions, such as the Equatorial Pacific, release CO_2 to the atmosphere, whereas others like the North Atlantic absorb it. In addition to this regional variability, a large temporal variability can occur. Our ability to estimate the sources and sinks of CO_2 in the oceans depends on the accuracy of the field data used to calculate regional and global fluxes. These flux estimates, in turn, can be used to validate computer models that predict future pCO2 levels.

The flux of CO_2 across the sea surface is directly proportional to the difference in the fugacity of CO_2 (fCO_2) between the atmosphere and the seawater. The fugacity is obtained by correcting the partial pressure of CO_2 (pCO2) for non-ideality of the gas with respect to molecular interactions between CO_2 and other gases in air, thus making pCO2 an important parameter to measure.

The schematic of the system is shown in the Figure below. The system is composed of three enclosures that compartmentalize the different functions of the system. The ''wet'' box contains the elements where water circulates. It includes the equilibrators, the condenser, water flow meter and the valves controlling the water circulation. A shelf separates the pumps, electronic modules and Nafion drying tubes from the ''wet'' elements. The ''dry'' box contains the analyzer, the gas selecting valve, the computer and the power supplies. The ''deck'' box (not shown) includes the Iridium satellite modem, the GPS receiver, and an external pressure transducer. This relatively compact packaging allows the system to be installed in hostile environments such as engine rooms.

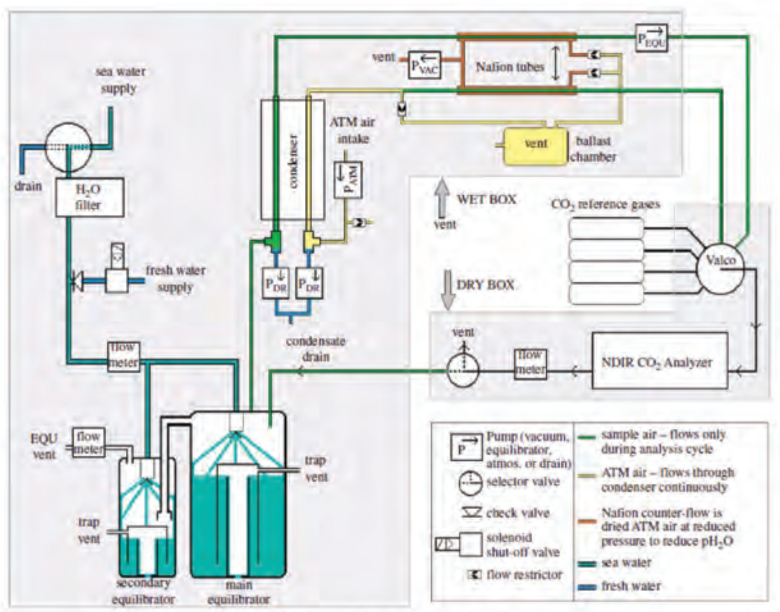


Fig. 1. Schematic of the underway pCO_2 system.

The system consists of three enclosures: the dry box, the wet box and the satellite deck box.

The dry box contains a Licor CO_2 analyzer (user supplied), electrically actuated valves to control the gas flow through the analyzer, a gas flow sensor, computer and interface with solid-state relays. There are inlets for up to eight gases. Each inlet has a needle valve for adjusting the flow rate. A three-way solenoid valve directs the gas exiting the analyzer towards a vent or towards the equilibrator (when analyzing the equilibrator headspace). The dry box utilizes an RS485 module and cables to communicate with the other two boxes.

The wet box contains main and vent equilibrating chambers, electrically-actuated valves, pressure gauge and regulating valve, reusable water filter, water flow sensor, barometer, temperature probe, condenser unit, two Naphion drying tubes, and three air pumps. After entering the wet box, seawater passes through the reusable filter, which can be automatically back-flushed with fresh water. An adjustable regulating valve after the filter sets the water pressure that is delivered to the equilibrators. The vent equilibrator keeps the CO_2 concentration in gas that exchange with the vent on the main equilibrator close to the concentration in the main headspace. The barometer and temperature probe are attached to the main equilibrator. Seawater drains by gravity out of the wet box.

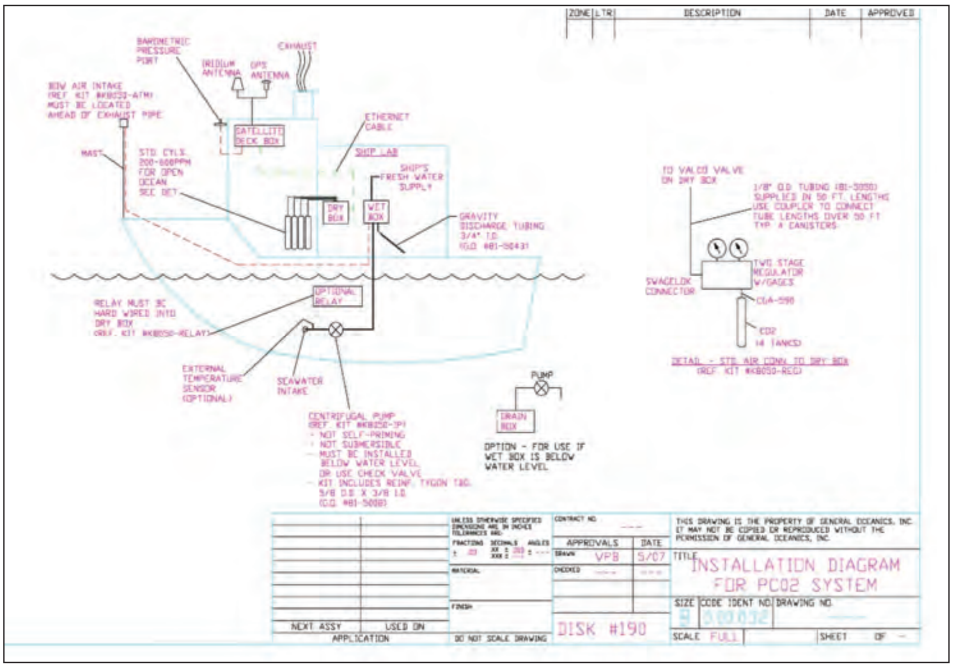
One of the air pumps in the wet box pulls the headspace gas from the main equilibrator and pushes it through the condenser, a Naphion drying tube and then the CO_2 analyzer. Another pump pulls air from an exterior inlet provided and located by the user and pushes the air through a condenser. After the condenser, this gas stream is split towards a vented chamber and towards a drying tube and then the CO_2 analyzer. The reduced-humidity air in the vented chamber is pulled through the drying tubes as counter-flow gas by the third air pump.

The weather resistant satellite deck box contains the modem for Iridium satellite communication, a high-precision barometer, a power supply and data communication modules. A GPS transducer is attached to deck box and data modules. A ten-conductor cable connects the deck box to the dry box (a 25 meter cable is provided; a cable can be up to 1000 meters long, an extra connector is provided for making a cable for a permanent installation). There is a bulkhead tube fitting for connecting a Gill pressure port to the barometer (pressure port not provided).

4. Sampling methodology : <8050 pCO2 System>

The software running the system is written in the National Instruments Labview environment. It has been written to maximize the autonomy of the system and its adaptability to different installation configurations. The software monitors the gas flow rate of the equilibrator headspace gas through the analyzer and adjusts the pump speed to keep the flow within a user-specified range. The software checks for the presence of liquid water at critical places and can close a valve to shut down the intake water and stop the operation of the system. It also monitors the GPS signal and can put the system into a sleep mode in user-selected areas, thereby avoiding contamination of the system by silt and polluted water such as that often found in ports. The user can define limits on any sensor readings, such as temperatures or flows, as a trigger to either put the system to sleep or shut it off. The analyses are done according to a sequential list of the types of samples: (*e.g.*, standards, atmospheric air, and headspace gas) to run and the number of measurements of each type to make. That, combined with the user programmable flushing times of the analyzer mentioned previously, determines how often each sample is measured.

System setup diagram:



The system is able to respond quickly to changes in the CO_2 concentration of seawater, thus capturing the fine features in the CO_2 variability of the ocean. The exchange time for the water in the main equilibrator is between 30 and 45 s, depending on flow rate.

The deck box contains an Iridium satellite modem, which can transmit the data to a shore-side computer once a day. This allows near real-time display of the data as well as a means to troubleshoot the system while at sea and service it appropriately when the ship is dockside. Additionally, two-way satellite communications on some ships allow the system to be re-configured remotely, making it flexible to changing external conditions.

Additional Sensors

The system is built in such a way that additional sensors may be installed. The Idronuat 315 seven parameter Sensor (Conductivity, Internal Temperature, Pressure, DO, Ph, Redox and external temperature) may be installed inside the wet box. http://www.idronaut.it/cms/view/products/os_315_on_line_module/s364

Other sensors that are routinely integrated Aanderaa Oxygen Optode, Sea Point Turbidity Sensors, Sea Point and Turner Designs Fluorometers, and Sea Bird TSGs.

Figure 4 Idronaut (315) 7 Parameter sensor

Specifications

	Rang e	Accuracy	Resolution	Time Constant
Pressure (Flow)	0…..10 dbar	0.2 % full scale	0.03%	50 ms
Temperature	-3…+50 ºC	0.003 ºC	0.0005 ºC	50 ms
Conductivity	0…..64 mS/cm	0.003 mS/cm	0.001 mS/cm	50 ms
Oxygen	0…25 ppm	0.1 ppm	0.01 ppm	3 s
	0 .250% sat.	1% sat.	0.1% sat.	3 s
pH	0…14 pH	0.01 pH	0.001 pH	3 s
Redox	-1000 to +1000 mV	1 mV	0.1 mV	3 s

5. Do's and Don'ts : <Precautionary care to be taken for handling instruments>

Do get factory training: This is instrument is designed to be very flexible and lets the researcher customize almost all aspects of the instrument functions. Time and duration of of all sampling aspects including valves, pumps and regulators can be controlled. We offer free factory training before delivery or insist on user training during installation.

Don't disable safety functions: The system has various safety functions which shut down the system if certain parameters are detected. Examples: water leak detection and sensors in the air circuit to detect moisture. As mentioned above all functions are selectable but turning off safety functions is not recommended.

6. Calibration

In order to calculate the pCO2 properly, a number of parameters are necessary. These are the temperature and pressure inside the equilibrator at the time of equilibration, as well as the atmospheric pressure (for atmospheric pCO2 determinations) and sea-surface temperature.

The analyzer should be calibrated every 2.5–3 hrs using a minimum of three standards, although four are recommended, with concentrations covering the range encountered in the working area and traceable to the World Meteorological Organization (WMO) scale. Two of these standards should closely bracket the atmospheric value.

Although not critical, it is preferable for the analyzer to be zeroed and spanned once a day. Each zero/span procedure should be bracketed by full sets of standards in order to properly interpolate the standard values and correct for instrument drift.

Water flow meter, pressure transducer, barometer, Hart thermometer and its probe need to be calibrate once in a year. Calibration data will provide along with the system.

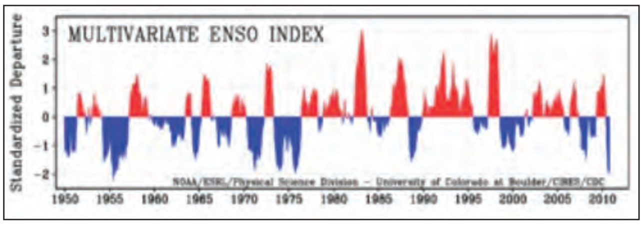
7. Case Studies

Equatorial Pacific uwpCO_2

The CO_2 group of NOAA's Pacific Marine Environmental Laboratory (PMEL) has been monitoring sea surface CO_2 concentrations in the equatorial Pacific since 1982. This is a particularly dynamic area exhibiting significant variation of CO_2 concentrations, both interannually due to the effect of periodic El Niño events, and seasonally due to the changes in wind strength and upwelling patterns. By measuring the partial pressure of CO_2 (pCO2) in both the sea surface and atmosphere, along with sea surface temperature, pressure, and wind speed, the flux of CO_2 into or out of the ocean can be calculated, affording a broader understanding of how this important greenhouse gas behaves in the ocean.

The surface ocean CO_2 concentration in most of the global oceans is less than the CO_2 concentration in the air above, resulting in a net flux of CO_2 into the oceans. The equatorial Pacific is an exception. In this region, strong trade winds bring CO_2-enriched water to the surface, and the net flux of CO_2 is out of the ocean into the atmosphere. When an El Niño event occurs, the easterly trade winds in the western and central equatorial Pacific weaken and sometimes reverse. This reversal drives warm surface water from the western Pacific eastward, leading to the development of unusually warm sea surface temperatures east of the international dateline. The lessened winds also bring less CO_2-enriched water to the surface. The flux of CO_2 out of the ocean into the atmosphere is dramatically diminished during an El Niño event.

Underway pCO2 has been routinely measured along 165°E, 180, 170°W, 155°W, 140°W, 125°W, 110°W, and 95°W between 10°N and 10°S on NOAA ships servicing the Tropical Atmospheric Ocean (TAO) Array buoys since 1992.

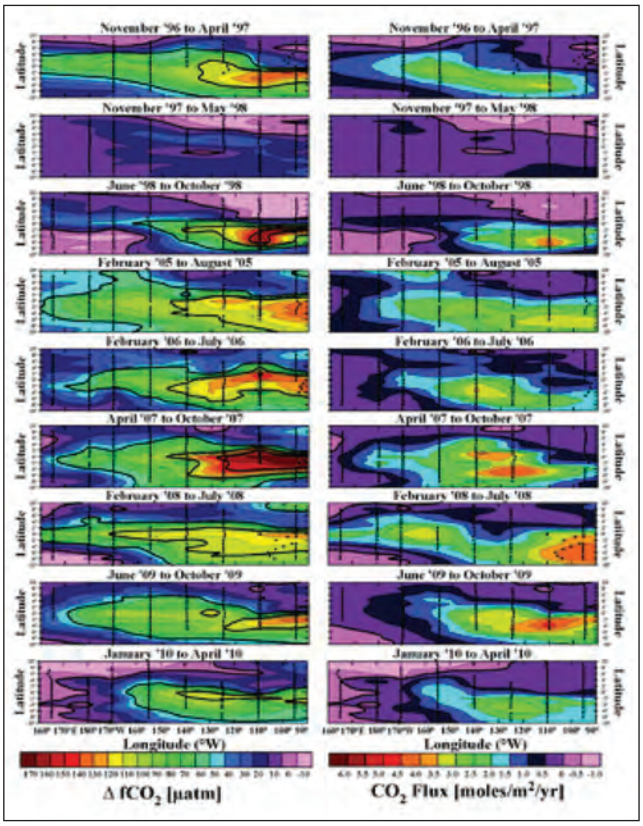


Multivariate ENSO Index

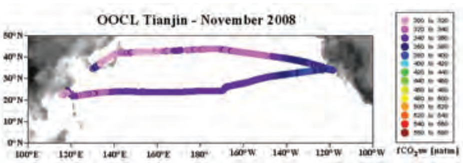
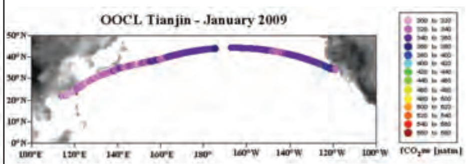
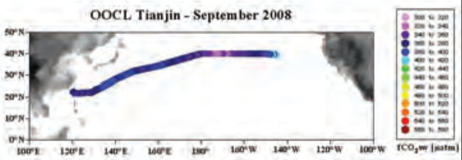
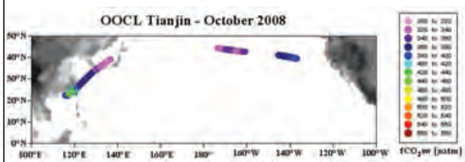
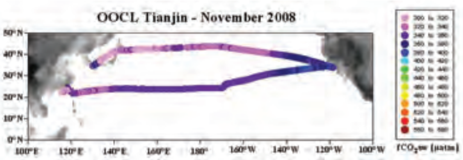
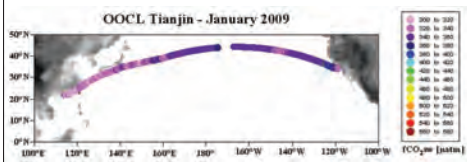
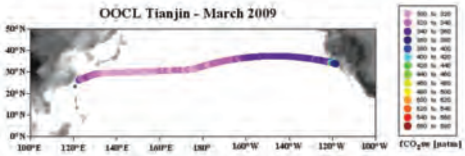
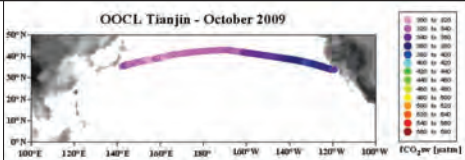
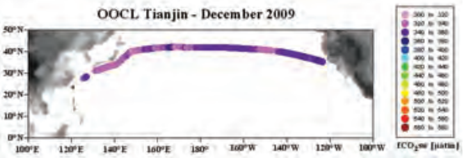
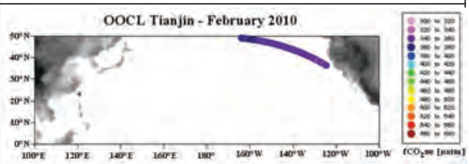
Long Beach to Hong Kong

During the summer of 2008, an fCO_2 system was deployed on the container ship OOCL Tianjin. PMEL collected data during 9 transects across the North Pacific from September 2008 through February 2010. The OOCL Tianjin is involved in studies in the North Pacific, an important sink region for atmospheric CO_2. Data will be analyzed to determine how ocean circulation and biological photosynthesis interact to control the rate of exchange of carbon dioxide gas between the atmosphere and North Pacific Ocean. This research is done in collaboration with Dr Paul Quay of the University of Washington, and Dr Kitack Lee of the Pohang University of Science and Technology. In addition to supporting our underway fCO_2 measurements, samples were also collected for carbon isotope measurements (Quay) and DIC and nutrients (Lee).

For complete information on these and other studies refer to the website below: http://www.pmel.noaa.gov/co2/story/Volunteer+Observing+Ships+%28VOS%29



∇fCO_2 and CO_2 Flux through 2010

Cruise	fCO_2sw	Cruise	fCO_2sw
Tian_2008_11 Nov 12 to Dec 11, 2008 Hong Kong to Hong Kong Data		Tian_2009_01 Jan 19 to Jan 30, 2009 Hong Kong to Long Beach Data	
Tian_2008_09 Sep 19 to Sep 29, 2008 Long Beach to Hong Kong Data		Tian_2008_10 Oct 6 to Oct 15, 2008 Hong Kong to Long Beach Data	
Tian_2008_11 Nov 12 to Dec 11, 2008 Hong Kong to Hong Kong Data		Tian_2009_01 Jan 19 to Jan 30, 2009 Hong Kong to Long Beach Data	
Tian_2009_03 Mar 31 to Apr 11, 2009 Hong Kong to Long Beach Data		Tian_2009_10 Oct 30 to Nov 7, 2009 Hong Kong to Long Beach Data	
Tian_2009_12 Dec 2 to Dec 12, 2009 Hong Kong to Long Beach Data		Tian_2010_02 Feb 18 to Feb 21, 2010 Hong Kong to Long Beach Data	

8. References

DOE (1994). Handbook of methods for the analysis of the various parameters of the carbon dioxide system in sea water; version 2. A.G. Dickson and C. Goyet, eds., ORNL/CDIAC-74.

Feely, R.A., R. Wanninkhof, H.B. Milburn, C.E. Cosca, M. Stapp, and P.P. Murphy (1998). A new automated underway system for making high precision pCO2 measurements onboard research ships, Analytica Chim. Acta, 377, 185-191, 1998.

Pierrot, D., C. Neill, K. Sullivan, R. Castle, R. Wanninkhof, H. Luger, T. Johannessesn, A. Olsen, R. A. Feely, C. E. Cosca (2009). Recommendations for autonomous underway pCO2 measuring systems and data-reduction routines. Deep Sea Research Part II: Topical Studies in Oceanography, Volume 56, Issues 8-10, Pages 512-522.

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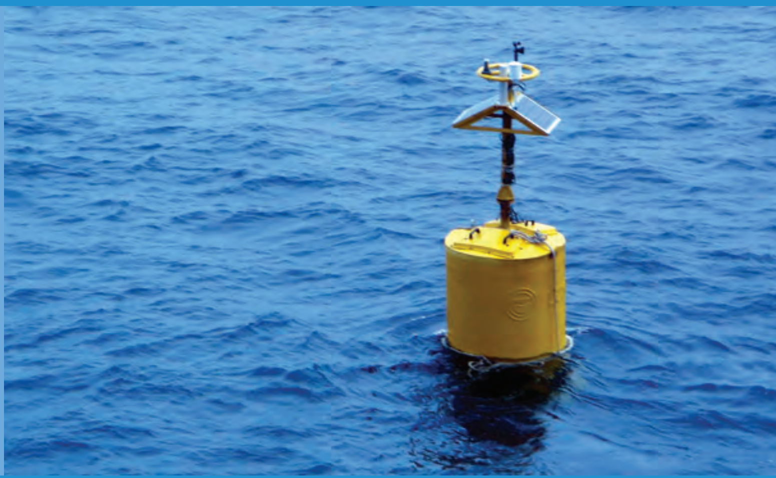
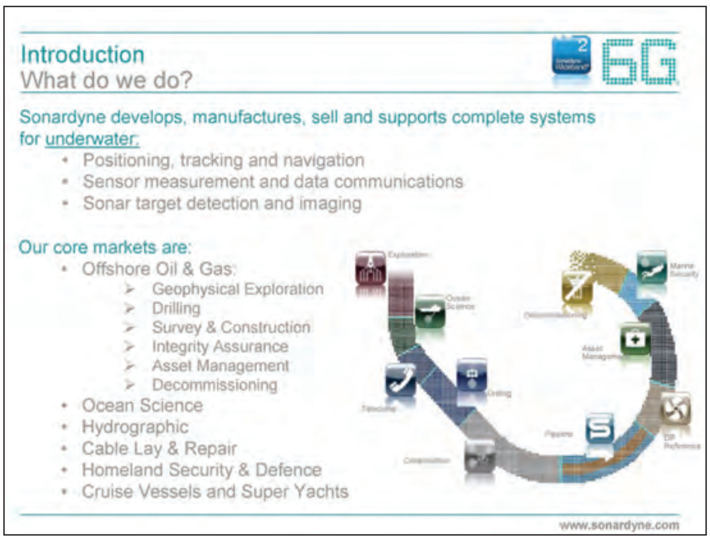
Ocean Data Collection-II

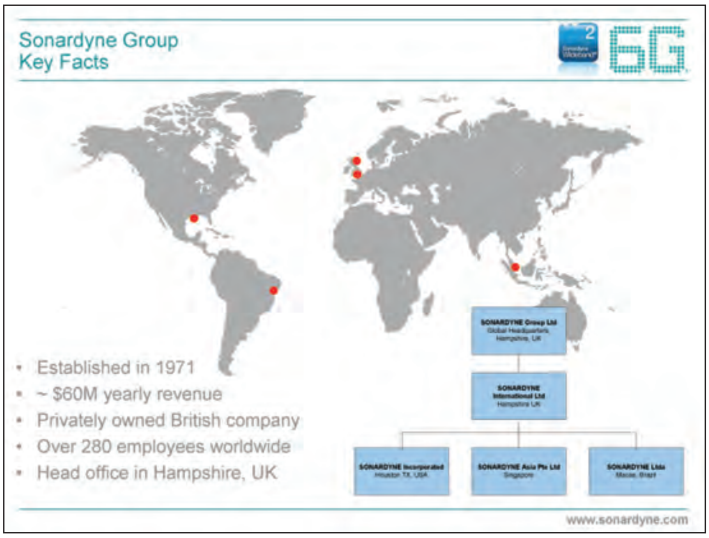


Sub-sea monitoring applications and advance acoustic telemetry techniques

Sonardyne
SOUND IN DEPTH

In 1971, Sonardyne was officially founded by John Partridge. John's vision for his Company in those early days was to improve the safety and efficiency of underwater navigation for divers through innovation in acoustic signal processing, hardware design and custom engineering. As we celebrate passing our 40th anniversary, Sonardyne has remained true to its roots as a subsea pioneer, only now we are delivering underwater innovation across a myriad of industry sectors. We proudly remain an independent manufacturing business with almost 300 employees worldwide in seven regional centres. Underwater acoustics remain at the heart of much of what we develop. But, driven by the needs of our clients and diversification into new markets, we are committed to investment in new and emerging technologies.

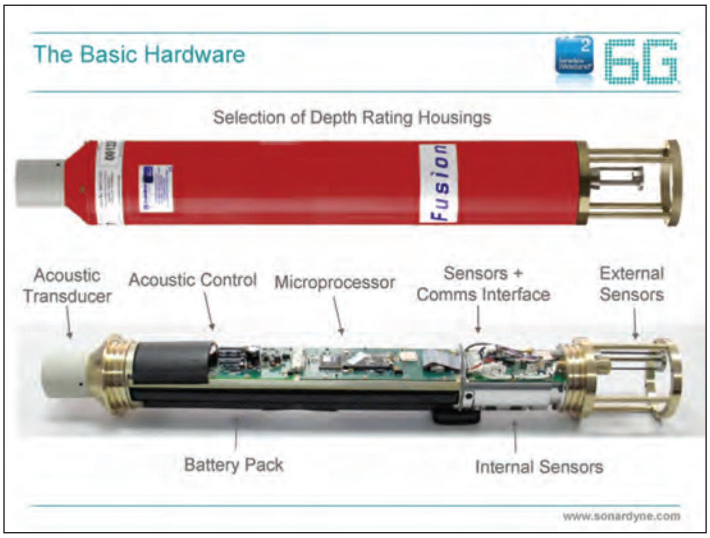


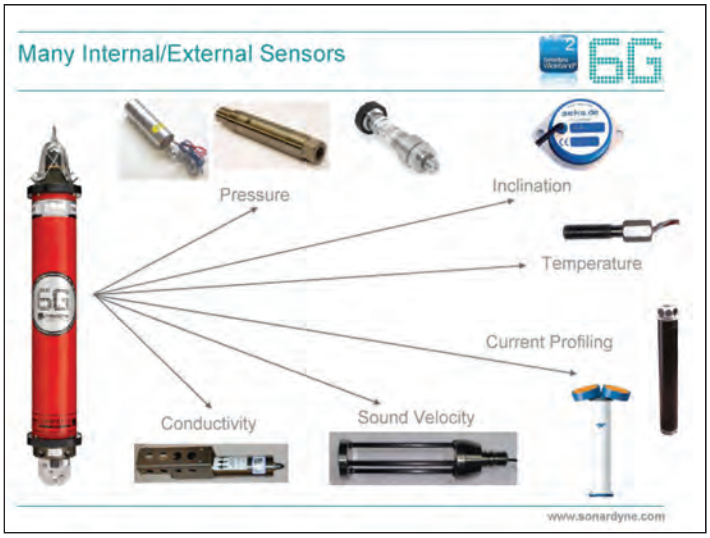


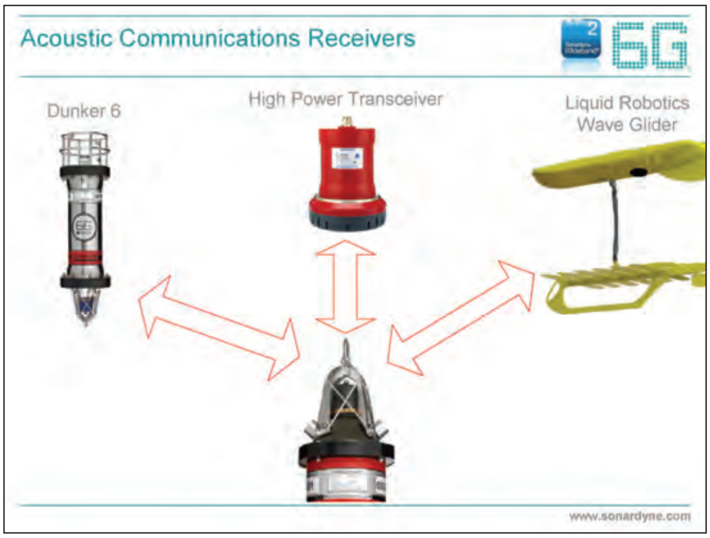
Sonardyne Group
Key Facts
6G
Established in 1971
~ $60M yearly revenue
Privately owned British company
Over 280 employees worldwide
Head office in Hampshire, UK
SONARDYNE Group Ltd
Global Headquarters
Hampshire, UK
SONARDYNE
International Ltd
Hampshire UK
SONARDYNE Incorporated
Houston TX, USA
SONARDYNE Asia Pte Ltd
Singapore
SONARDYNE Ltda
Macae, Brazil
www.sonardyne.com

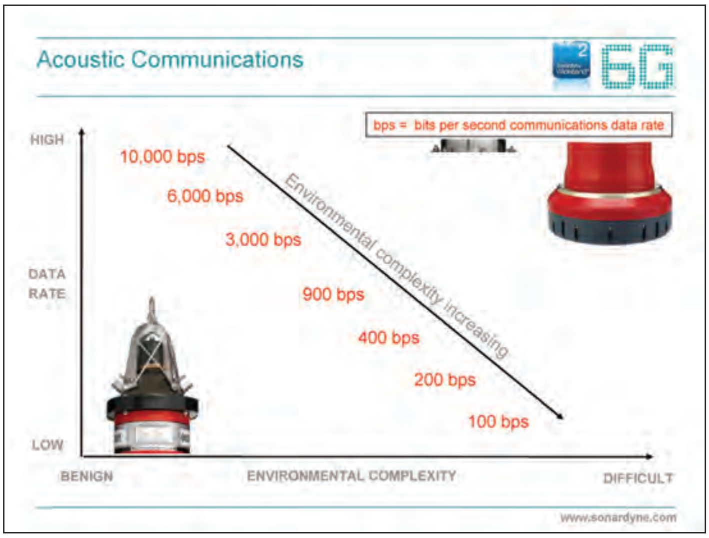
Sonardyne Group
Worldwide Office Locations
6G
Sonardyne Global Headquarters, Hampshire, UK
Sonardyne Int.
Aberdeen, UK
Sonardyne Asia
Singapore
Sonardyne Ltda.
Macae, Brasil
Sonardyne Inc.
Houston, USA
www.sonardyne.com

What is Sonardyne 6G?
6G
The 6th Generation (6G) of Sonardyne acoustic instruments
A family of flexible remote operating subsea sensors
Integral data logging and extraction via acoustic communications
Various shapes and sizes to suit individual observation roles
www.sonardyne.com

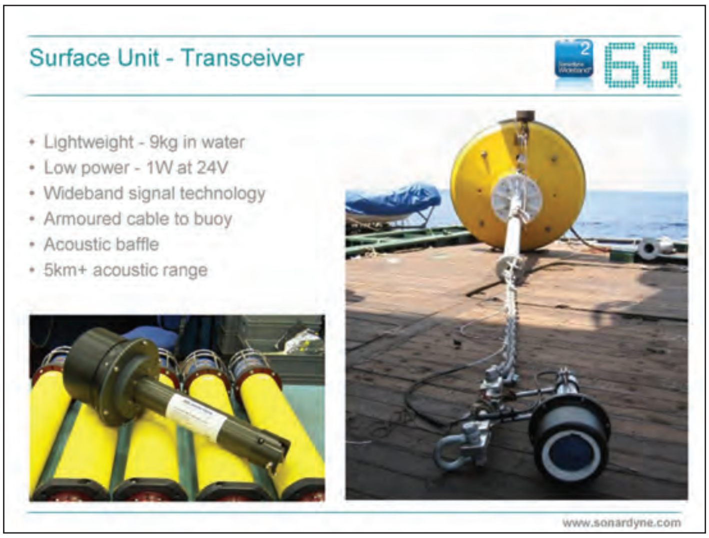

The Basic Hardware
6G
Selection of Depth Rating Housings
Fusion
Acoustic Transducer
Acoustic Control
Microprocessor
Sensors + Comms Interface
External Sensors
Battery Pack
Internal Sensors
www.sonardyne.com


Many Internal/External Sensors
6G
Pressure
Inclination
Temperature
Current Profiling
Conductivity
Sound Velocity
www.sonardyne.com


Acoustic Communications Receivers
6G
Dunker 6
High Power Transceiver
Liquid Robotics Wave Glider
www.sonardyne.com

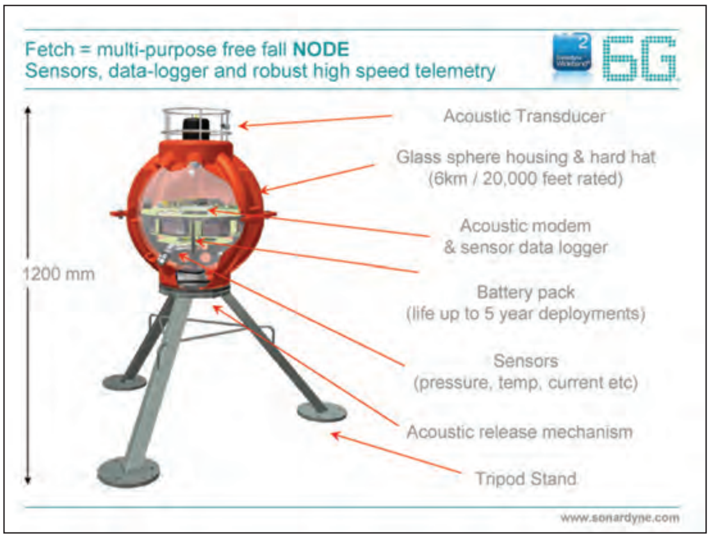

Acoustic Communications
bps = bits per second communications data rate
HIGH
DATA RATE
LOW
10,000 bps
6,000 bps
3,000 bps
900 bps
400 bps
200 bps
100 bps
Environmental complexity increasing
BENIGN
ENVIRONMENTAL COMPLEXITY
DIFFICULT
www.sonardyne.com

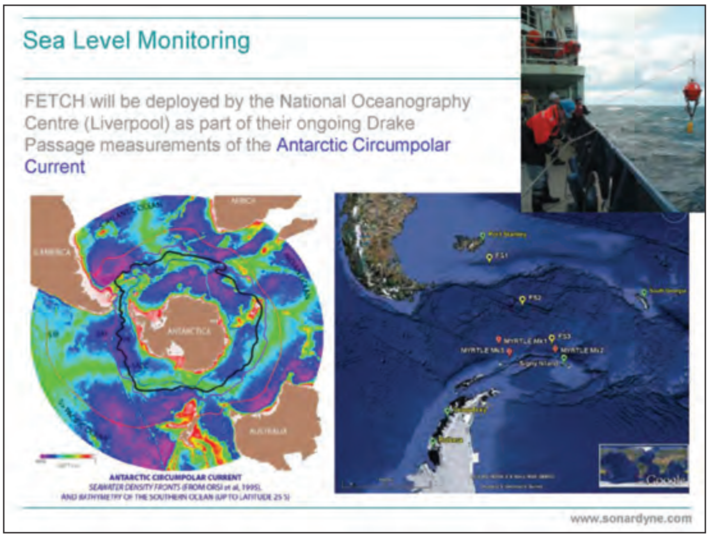

Tsunami Monitoring
Inverted Echo Sounding
Settlement Monitoring
Well Monitoring
Tide/Sea Level Monitoring
Pipeline Monitoring
Corrosion Monitoring

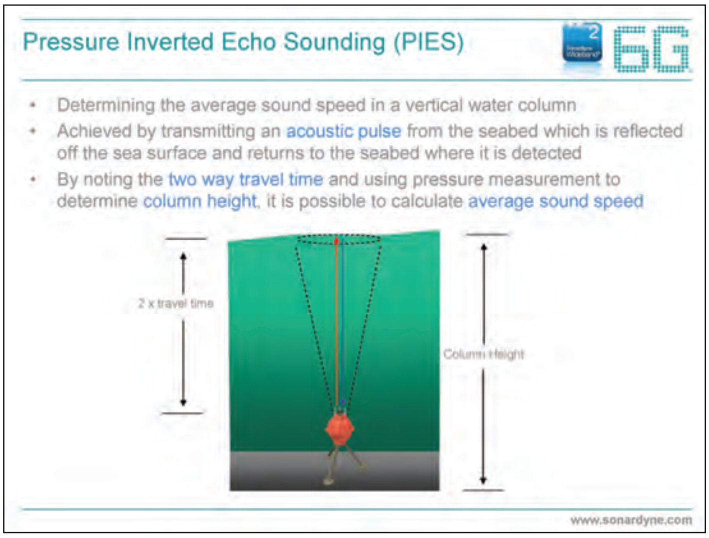

Surface Unit - Transceiver
• Lightweight - 9kg in water
• Low power - 1W at 24V
• Wideband signal technology
• Armoured cable to buoy
• Acoustic baffle
• 5km+ acoustic range
www.sonardyne.com

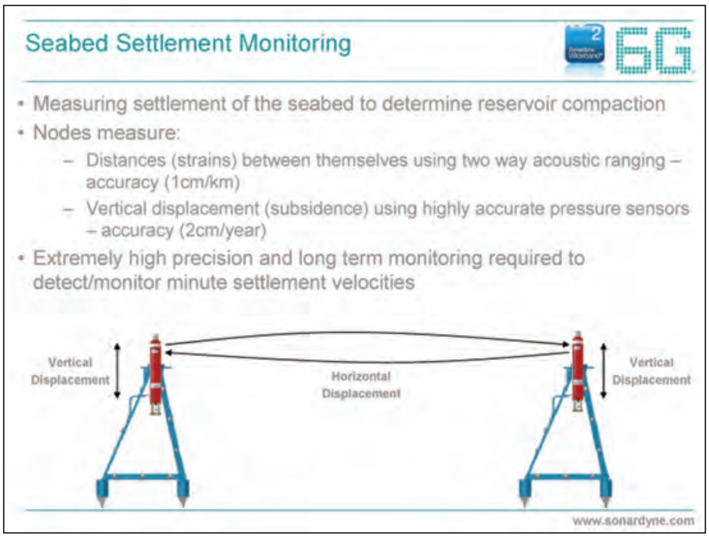

Tsunameter – Deployment in the Bay of Bengal
6G
www.sonardyne.com

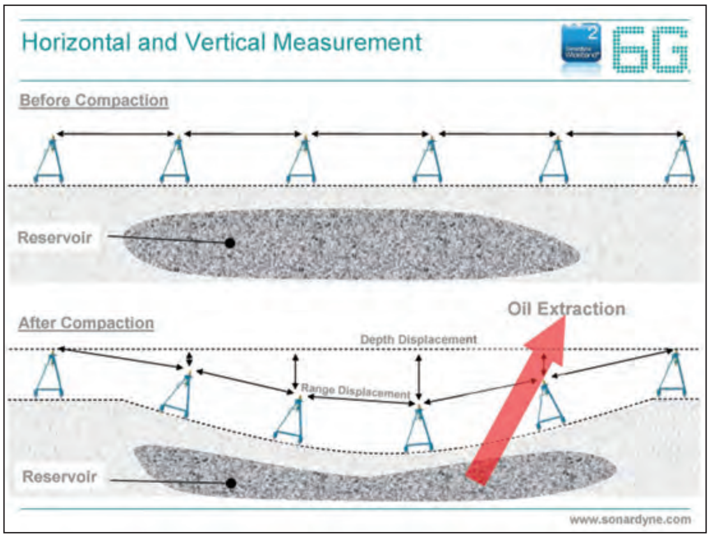

Tsunami Monitoring (IOOS/NOAANDBC)
6G
• 6G Tsunami Sensor
• Wave Glider Vehicle Acoustic to Satellite Gateway
www.sonardyne.com


Fetch = multi-purpose free fall NODE
Sensors, data-logger and robust high speed telemetry
6G
Acoustic Transducer
Glass sphere housing & hard hat
(6km / 20,000 feet rated)
Acoustic modem
& sensor data logger
1200 mm
Battery pack
(life up to 5 year deployments)
Sensors
(pressure, temp, current etc)
Acoustic release mechanism
Tripod Stand
www.sonardyne.com


Sea Level Monitoring
FETCH will be deployed by the National Oceanography Centre (Liverpool) as part of their ongoing Drake Passage measurements of the Antarctic Circumpolar Current
ANTARCTIC CIRCUMPOLAR CURRENT
www.sonardyne.com


Pressure Inverted Echo Sounding (PIES)
6G
Determining the average sound speed in a vertical water column
Achieved by transmitting an acoustic pulse from the seabed which is reflected off the sea surface and returns to the seabed where it is detected
By noting the two way travel time and using pressure measurement to determine column height, it is possible to calculate average sound speed
2 x travel time
Column Height
www.sonardyne.com


Seabed Settlement Monitoring
6G
Measuring settlement of the seabed to determine reservoir compaction
Nodes measure:
– Distances (strains) between themselves using two way acoustic ranging – accuracy (1cm/km)
– Vertical displacement (subsidence) using highly accurate pressure sensors – accuracy (2cm/year)
Extremely high precision and long term monitoring required to detect/monitor minute settlement velocities
Vertical Displacement
Horizontal Displacement
Vertical Displacement
www.sonardyne.com

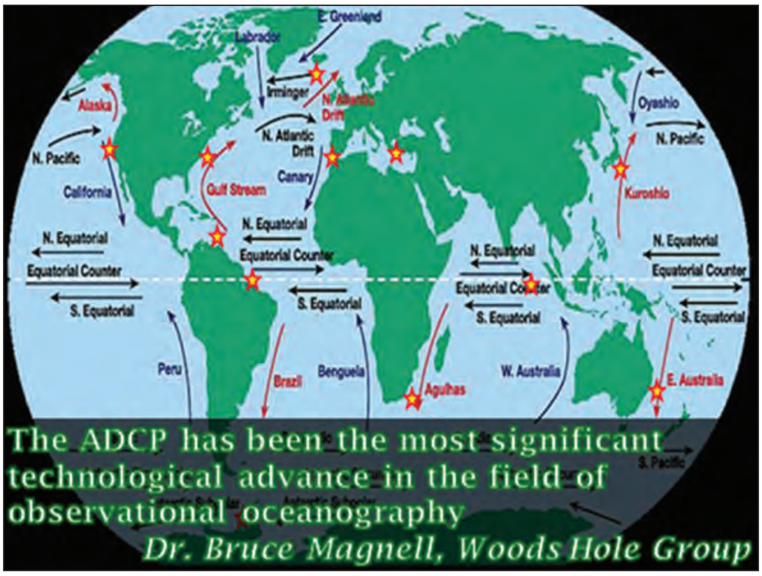

Horizontal and Vertical Measurement
Before Compaction
Reservoir
After Compaction
Oil Extraction
Depth Displacement
Range Displacement
Reservoir
www.sonardyne.com

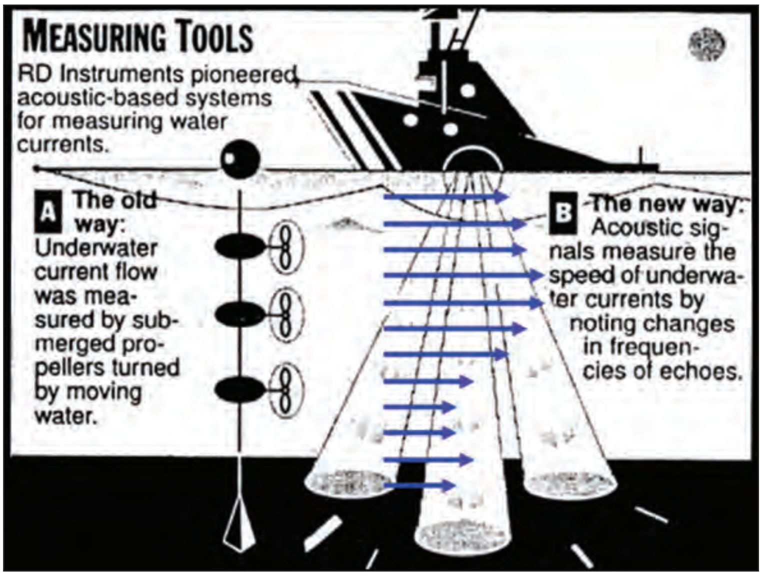

Final Remarks
6G Key Features
Flexible sensors = Measure many subsea phenomena
Low power/ energy efficient = Long endurance
Large data storage = High sampling rate
Acoustic comms = Wireless operation
Surface vehicles = Easy data recovery
www.sonardyne.com

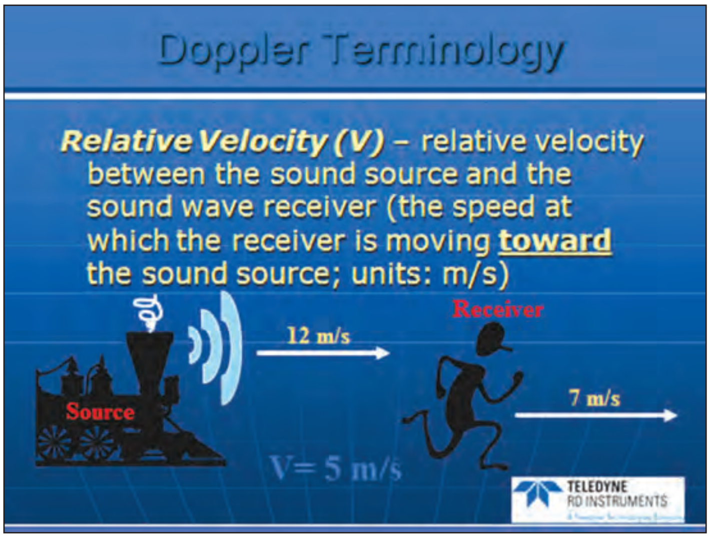
* * *

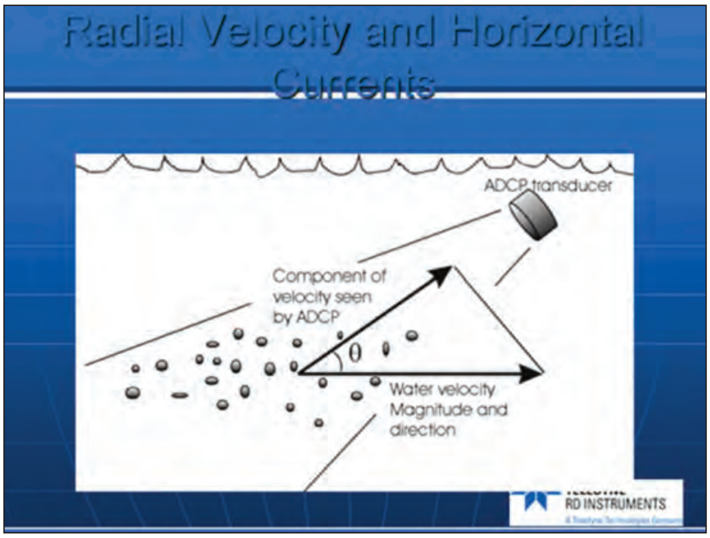
ADCP technology

Teledyne RD Instruments, Inc., located in San Diego, California, specializes in the design and manufacture of underwater acoustic Doppler products for a wide array of current profiling and precision navigation applications. Originally founded as RD Instruments, the company was formed in 1982 by Fran Rowe and Kent Deines as a result of their development of the industry's first Acoustic Doppler Current Profiler (ADCP), a revolutionary device capable of profiling currents at up to 128 individual points in the water column.

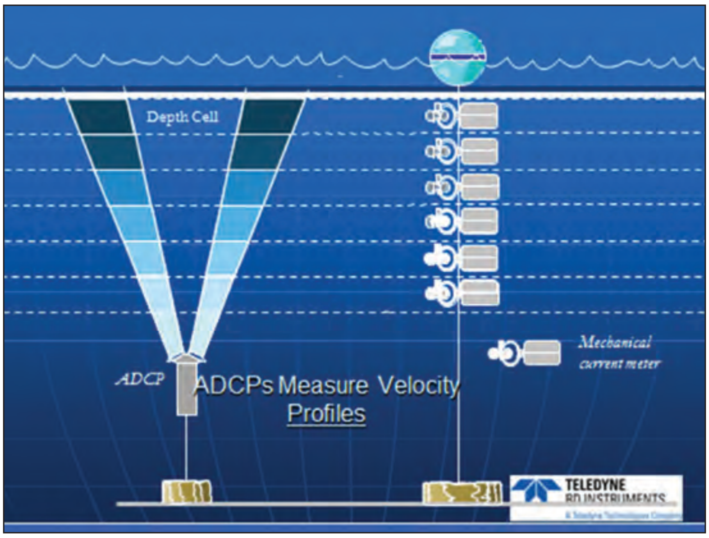


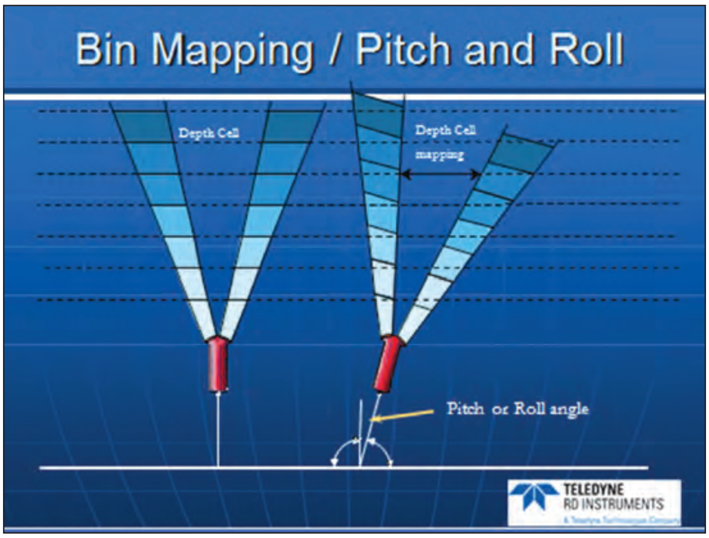


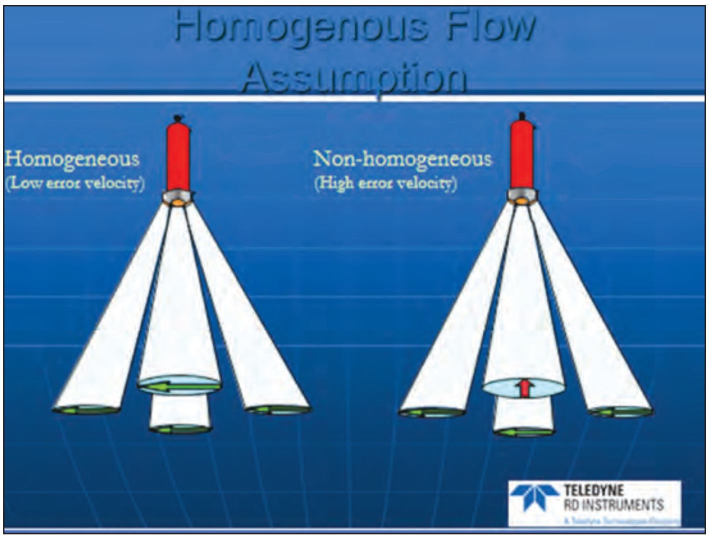




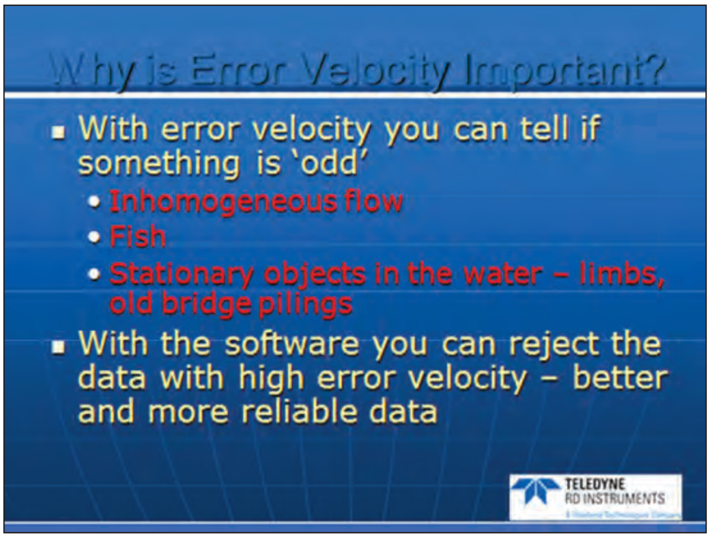
ADCP's can be deployed from a boat or mounted on the streambed. This particular graphic shows an upward looking ADCP mounted on the stream bed. We mentioned that the ADCP measures a complete velocity profile. It is comparable to having a whole string of velocity meters deployed. It measures the velocity in discrete water layers by range gating the reflected acoustic energy. In other words it processes small parts of the entire echo individually thus producing multiple velocity measurements. The water layer is frequently referred to as a depth cell or bin. A measurement consisting of a single ping (burst of acoustic energy) can be made in less than a second. Typically a single profile measurement consist of several pings averaged together. Still the typical time for a profile measurement is 3-5 seconds.

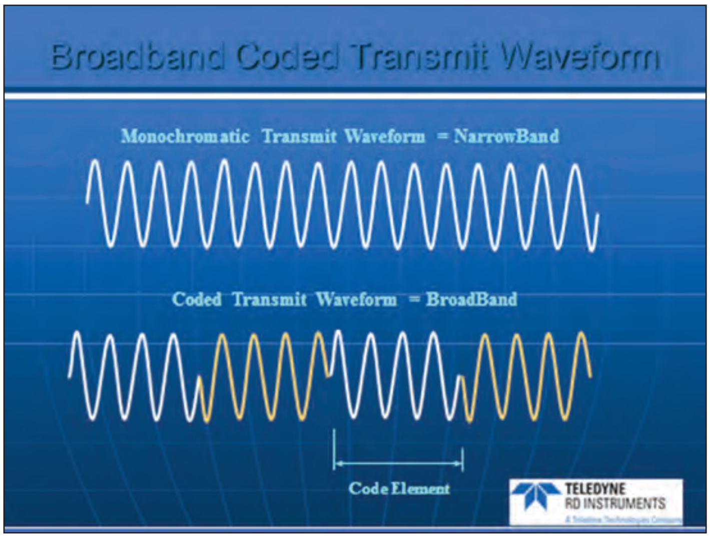


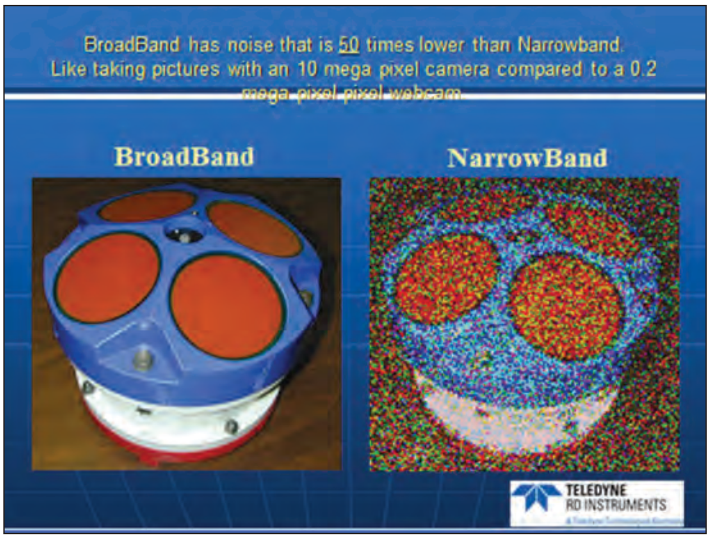


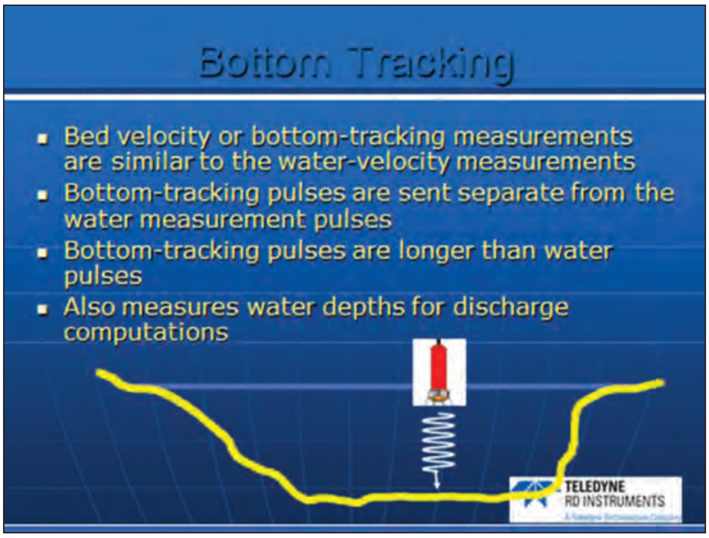


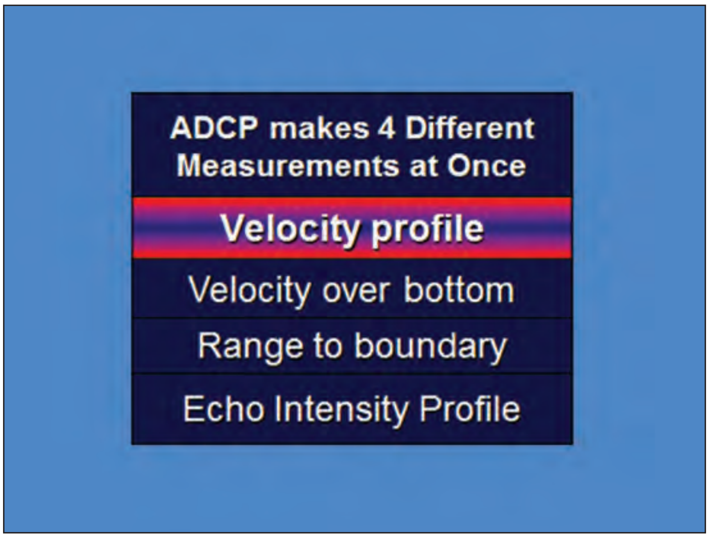
RDI ADCPs by default will “throw out” any measurements of velocity where one or more transducers measures something significantly different than the others. They assume homogeneous flow to help filter out bad velocity measurements.

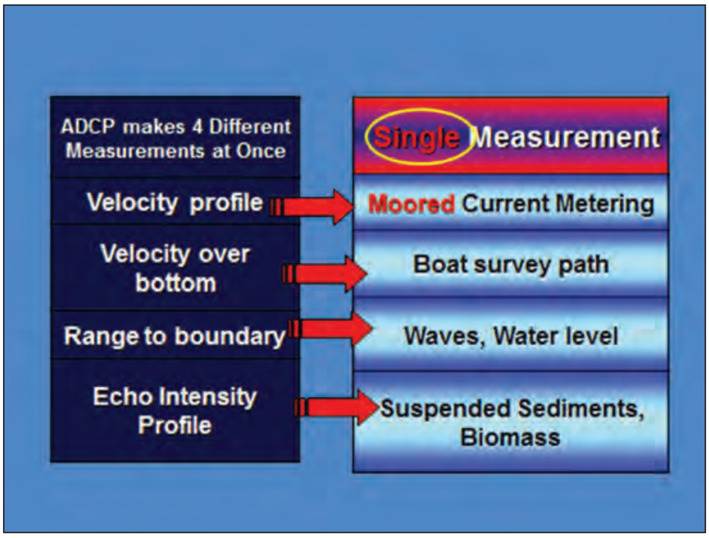

Why is Error Velocity Important?
With error velocity you can tell if something is 'odd'
Inhomogeneous flow
Fish
Stationary objects in the water – limbs, old bridge pilings
With the software you can reject the data with high error velocity – better and more reliable data
TELEDYNE RD INSTRUMENTS

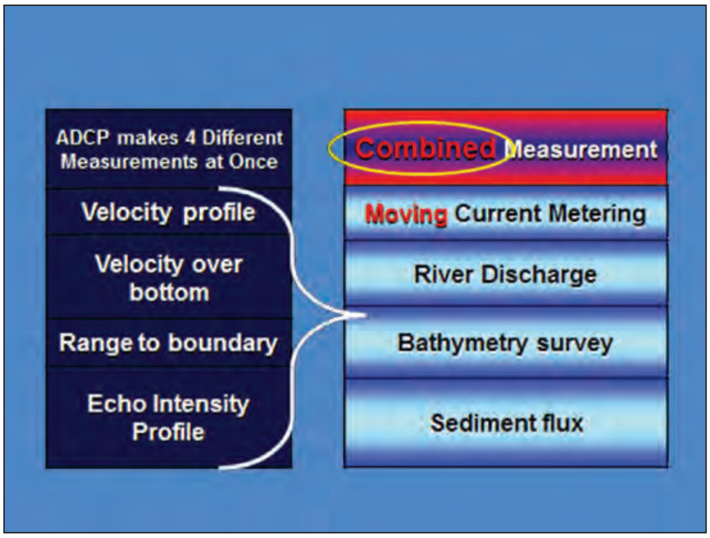

Broadband Coded Transmit Waveform
Monochromatic Transmit Waveform = NarrowBand
Coded Transmit Waveform = BroadBand
Code Element
TELEDYNE RD INSTRUMENTS

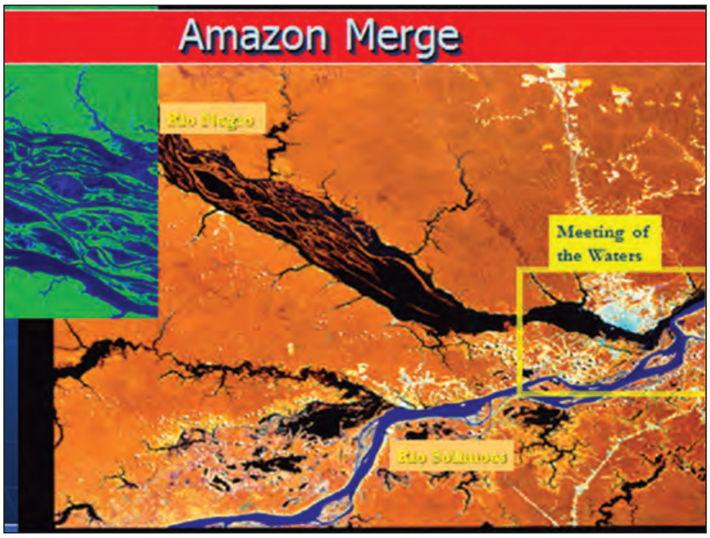

BroadBand has noise that is 50 times lower than Narrowband.
Like taking pictures with an 10 mega pixel camera compared to a 0.2 mega pixel pixel webcam
BroadBand
NarrowBand
TELEDYNE RD INSTRUMENTS

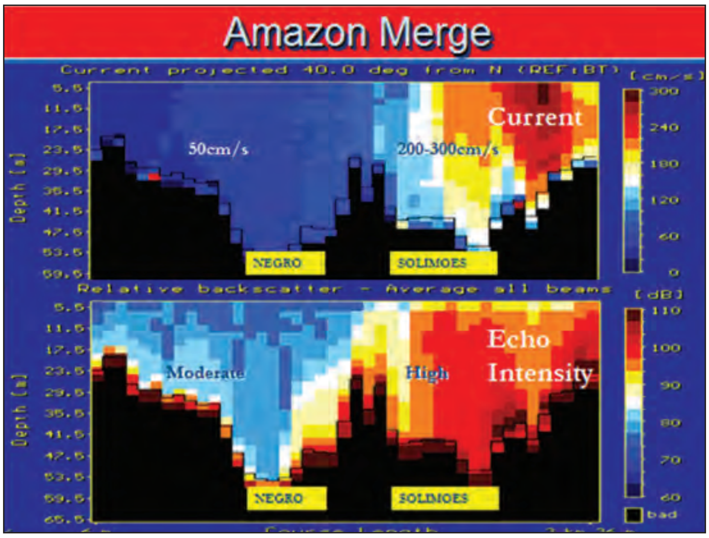

Bottom Tracking
Bed velocity or bottom-tracking measurements are similar to the water-velocity measurements
Bottom-tracking pulses are sent separate from the water measurement pulses
Bottom-tracking pulses are longer than water pulses
Also measures water depths for discharge computations
TELEDYNE RD INSTRUMENTS

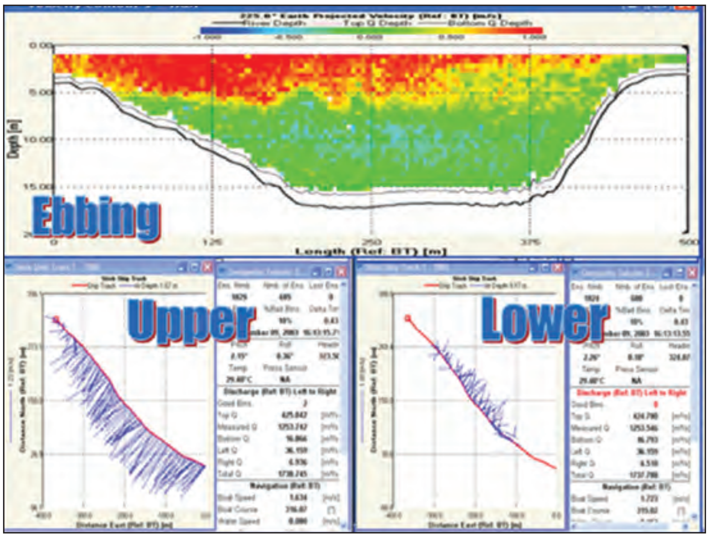

ADCP makes 4 Different Measurements at Once
Velocity profile
Velocity over bottom
Range to boundary
Echo Intensity Profile

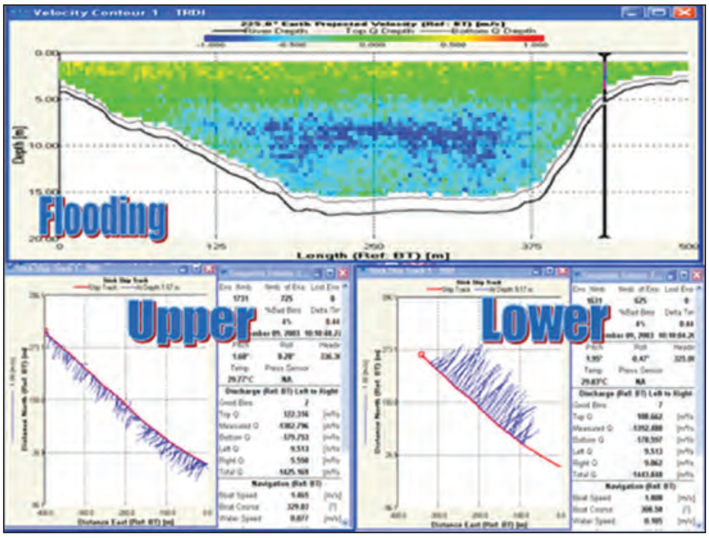

ADCP makes 4 Different Measurements at Once
Velocity profile
Velocity over bottom
Range to boundary
Echo Intensity Profile
Single Measurement
Moored Current Metering
Boat survey path
Waves, Water level
Suspended Sediments, Biomass

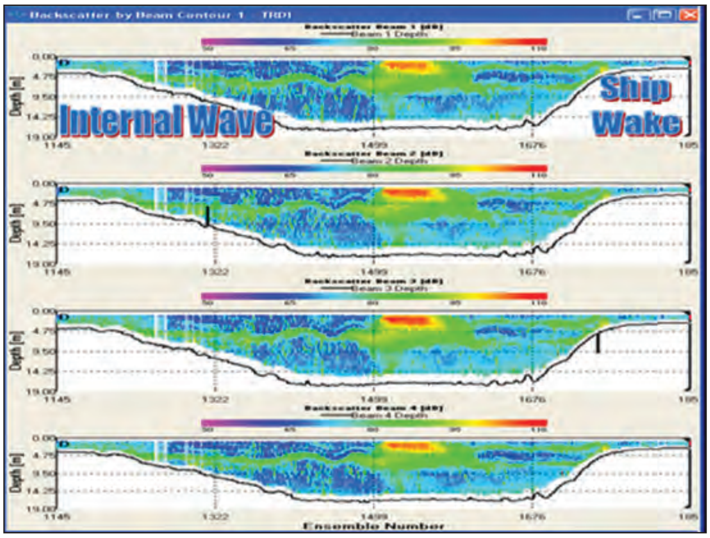

ADCP makes 4 Different Measurements at Once
Velocity profile
Velocity over bottom
Range to boundary
Echo Intensity Profile
Combined Measurement
Moving Current Metering
River Discharge
Bathymetry survey
Sediment flux

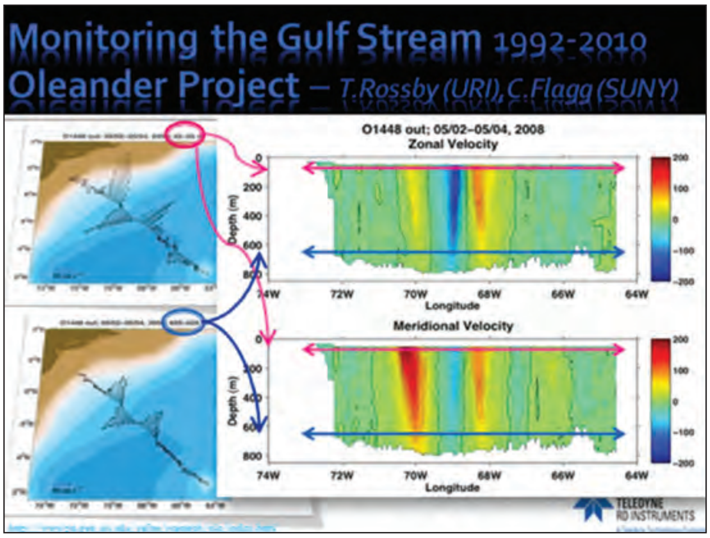

Amazon Merge
Meeting of the Waters


Amazon Merge
Current
50cm/s
200-300cm/s
NEGRO
SOLIMOES
Echo
Intensity
Moderate
High
NEGRO
SOLIMOES


Ebbing
Upper
Lower

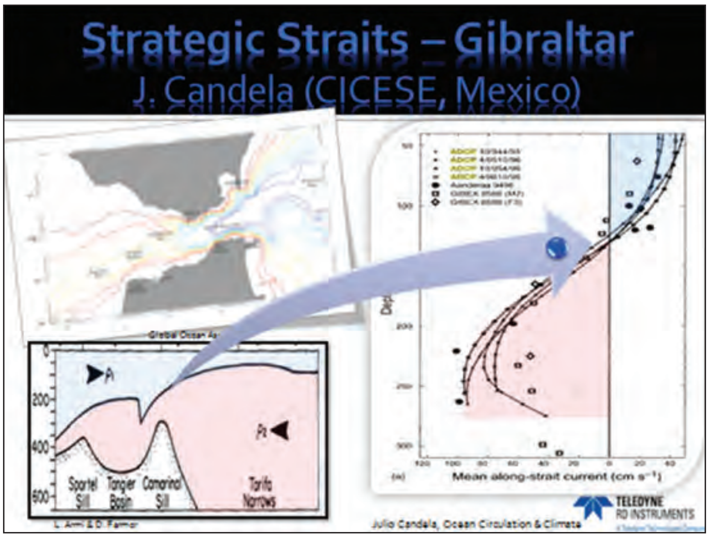

Flooding
Upper
Lower





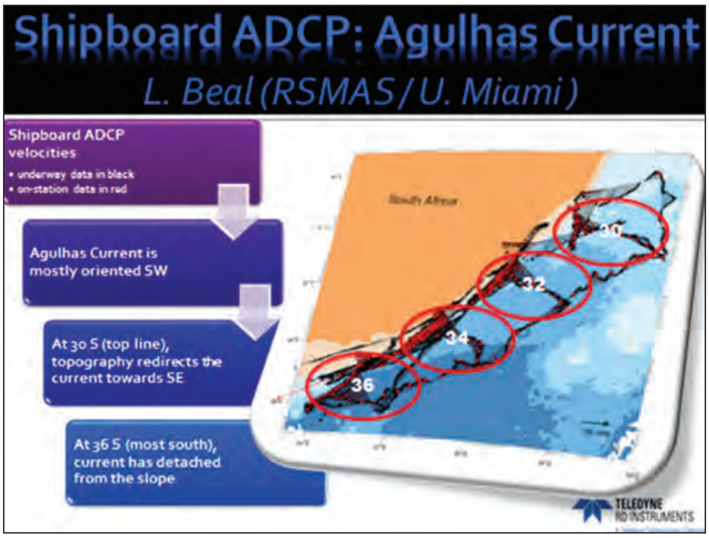
Gulf Stream meanders around more than it is wide, need a method for repeatedly sampling the horizontal structure of the current acoustic Doppler current profiler with global positioning system (GPS) to provide accurate current measurements from a fast moving vessel

http://www.po.gso.uri.edu/rafos/research/ole/index.html



Exchange flows between the Mediterranean and Atlantic through the Strait of Gibraltar have a striking 2-layer pattern. Moving into the Mediterranean at the surface and exiting to the Atlantic at depth. There is, however, significant variability at seasonal and interannual time scales. Gibraltar … Mean along-strait current measured at the sill in the Straits. Bottom mounted ADCP. Measured whole water column with 10 m resolution. 4 deployments at 6-month each from Oct 94-96.

MAP: Strait of Gibraltar. Location of ADCP on sill. Depths > 400 m shaded blue.



This map shows shipboard ADCP velocities, with underway data in black and on-station data in red. The Agulhas Current is oriented southwestward, except at Richards Bay where the continental slope topography guides it to the southeast around the Natal Bight. At the southernmost line, off Port Elizabeth, the current has detached from the slope.

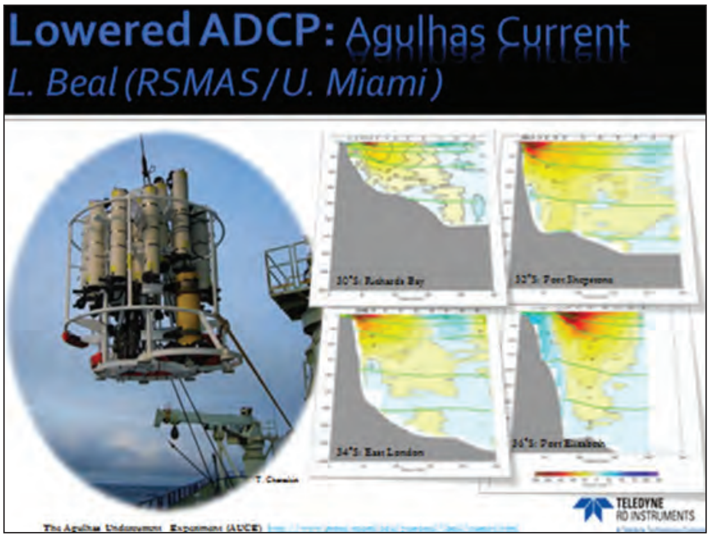
36°S: Port Elizabeth

Here the Agulhas Current is the strongest and deepest with a 125 Sv southwestward transport. It has separated from the coast so that the core is on over 3000 m water depth. Isopycnals rise by 12 m per kilometre on the cyclonic or onshore side of the current.

The undercurrent is attached to a fast subsurface flow which sits at the shelf break. Notice that because of the steeply sloping isopycnals, most of this northward flow is within the intermediate water layer.

Like other western boundary currents, the Agulhas Current is quite fast. At the surface, it can reach maximum speeds of 200 cm s^{-1} (Boebel *et al*., 1998). Beal and Bryden (1999) examined the deep velocity structure by using Lowered Acoustic Doppler Current Profiles (LADCP) and found that their results were different from those of previous studies that used geostrophic estimates. Beal and Bryden found that the level of no motion across the Agulhas Current displays a V-shaped pattern. They were also able to detect an Agulhas undercurrent at 800 m depth. The undercurrent is directly beneath the surface core of the poleward flowing Agulhas Current, and it flows equatorward with maximum speeds near 30-40 cm s^{-1} (Beal and Bryden, 1999; Donohue *et al.*, 2000).

As one of the major currents in the Southern Hemisphere, the Agulhas Current system transports large volumes of water. One of the earliest measurements of the geostrophic volume transport of this current came from Gordon (1985), who found it to be 67 Sv (1 Sv = 1 x 10^6 m^3 s^{-1}). Several years later, Toole and Warren obtained a much higher estimate of 85 Sv. However, several researchers pointed out that the geostrophic reference level that Toole and Warren used did not resolve the counter-flowing Agulhas Undercurrent. Beal and Bryden (1999) found the geostrophic volume transport as referenced to LADCP to be 73 Sv, which was only 3% different from the direct LADCP transport estimate. Then, Donohue *et al.* (2000) attempted to refine previous transport calculations by removing barotropic tides and by estimating instrumental and sampling errors. The two LADCP sections that they used yielded a net southward transport of 78±3 and 76±2 Sv. The latest estimate comes from Bryden *et al.* (2003) who find an average volume transport, calculated from year-long moored current meter measurements of 69.7±4.3 Sv.



Critical factor for coastal region

Beaches … summer fun, winter destruction

Coastal economy

Safety

Shipping & boating: ocean routes, coastal lanes

Coastal destruction: storm surges, tsunamis

Coastal and offshore engineering

Shore protection, structures: design, survival

Mechanism for restoring natural equilibrium

Energy source: wave & tidal power

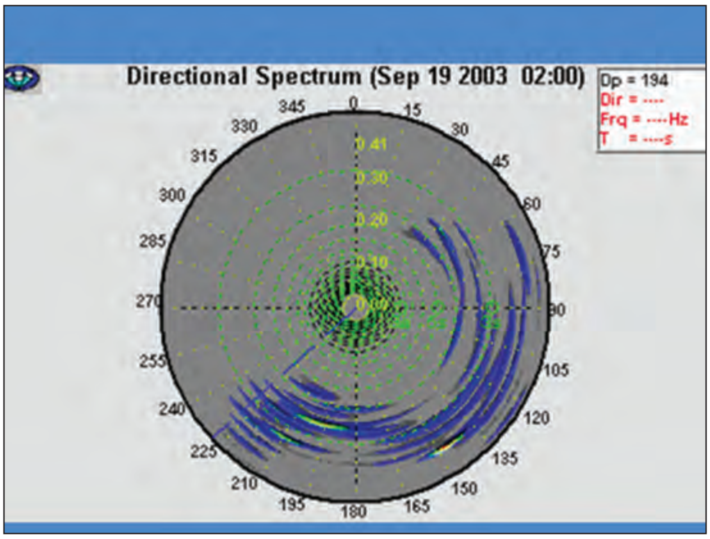
Wave measurements for terminals, marinas and docks

Wave data is generally required for marina and dock design and construction. Often the wave and current regime will determine the berth alignment, and may dictate construction of a breakwater. Numerical modelling is often used as well to test "what if" scenarios.

Wave direction: generally requires multiple instruments of bottom-mounted

ADCP: wave direction using just a single instrument

Back up measures are pressure sensor and range to surface.



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Glossary

1. **Absolute humidity**

   The mass of water vapor present per unit volume of space.

2. **Adiabatic process**

   A thermodynamic change of state in a system in which there is no transfer of heat or mass across the boundaries of the system.

3. **Advection**

   The horizontal transfer of any property in the atmosphere by the movement of air (wind).

4. **Anemometer**

   An instrument that measures the speed or force of the wind.

5. **Barometer**

   The instrument for measuring atmospheric pressure.

6. **Barometric pressure**

   The pressure exerted by the atmosphere at a given point.

7. **Biosphere**

   The parts of the Earth where life exists; it comprises the lower part of the atmosphere.

8. **Calibration**

   A test during which known values of measurand are applied to the transducer and corresponding output readings are recorded under specified conditions.

9. **Capacitor**

   A device that consists of two conductors (such as parallel metal plates) insulated from each other by a dielectric. A capacitor introduces capacitance (*i.e.,* the ratio of the charge on one of the conductors of a capacitor to the potential difference between the conductors) into a circuit, stores electrical energy, blocks the flow of direct current and permits the flow of alternating current.

10. **Capacitive sensors**

    Capacitive sensors are noncontact devices used for precision measurement of a conductive target's position or a nonconductive material's thickness or density.

11. **Carbon dioxide**

    A gas (CO_2) present in the atmosphere to the extent of more than 0.03% by volume and playing an important role in the greenhouse effect.

12. **Chlorophyll**

    A green pigment contained in the leaves of plants that absorbs solar energy.

13. **Conductivity**

    It is a measure of the ability of water to pass an electrical current.

14. **CTD**

    Conductivity, Temperature, Depth.

15. **Dew point temperature**

    The temperature to which a given parcel of air must be cooled at constant pressure and constant water-vapor content in order for saturation to occur. When this temperature is below 0 °C, it is called the frost point.

16. **Dissolved oxygen**

    The amount of oxygen gas dissolved in a given volume of water at a particular temperature and pressure, often expressed as a concentration in parts of oxygen per million parts of water.

17. Eutrophication

A process driven by enrichment of water nutrients, especially nitrogen and/or phosphorus compounds, leading to: increased growth, primary production and biomass of algae; changes in the balance of organisms; and water quality degradation. The consequences of eutrophication are undesirable if they appreciably degrade ecosystem health and/or the sustainable provision of goods and services.

18. Gradient

Change rate of any element value with distance in any given direction.

19. Hydrosphere

Part of the Earth covered by water and ice.

20. Inertial measurement units

Inertial navigators, also known as inertial navigation systems, are self-contained systems that can automatically determine the position, velocity and attitude of a moving vehicle by means of the double integration of the outputs of accelerometers that are either strapped to the vehicle or stabilized with respect to inertial space.

21. Mesosphere

Region of the atmosphere, situated between the stratopause and the mesopause, in which the temperature generally decreases with height.

22. Relative humidity

A ratio expressed in percent of the amount of atmospheric moisture present relative to the amount that would be present if the air was saturated. As such, relative humidity by itself does not directly indicate the actual amount of atmospheric moisture present.

23. Psychrometer

An instrument used for measuring the water vapor content of the atmosphere

24. Ionosphere

That part of the atmosphere, extending approximately from 70 to 500 km, in which ions and free electrons exist in sufficient quantities to reflect electromagnetic waves.

25. Isobar

Line joining points of equal pressure on a surface (level surface, vertical cross-section, etc.

26. Observation

Evaluation of one or more meteorological or oceanographic elements.

27. Oceanography

The study of the physical, chemical, geological and biological features of oceans and ocean basins.

28. pH value

It is the measure of hydrogen ion activity of a system.

29. Precipitation

A Hydrometeor which consists of a fall of ensemble of particles. The forms of precipitation are: rain, drizzle and snow, snow grains.

30. Radar

Radio Detection and Ranging is a radio method of determining at a single station the direction and distance of an object. The distance is determined by the time taken by signals emitted by the station to reach a distant object and return.

31. Sampling

A process used in statistical analysis in which a predetermined number of observations will be taken from a larger population.

32. Satellite

A body which orbits another and it is usually applied to planetary moons and artificial satellite. The latter are placed in various orbits: 24-hour equatorial for communications, polar for global coverage, and tilted low-altitude for mapping and surveillance.

33. Temperature

A physical quantity, characterizing the mean random motion of molecules in a physical body.

34. Turbidity

Turbidity is a principal physical characteristic of water and is an expression of the optical property that causes light to be scattered and absorbed by particles and molecules rather than transmitted in straight lines through a water sample. It is caused by suspended matter or impurities that interfere with the clarity of the water.

35. Uncertainty

Uncertainty of measurement is the doubt that exists about the result of any measurement.

36. Weather

State of the atmosphere at a particular time, as defined by the various meteorological elements.

37. Wind

The horizontal movement of the air with respect to earth surface.

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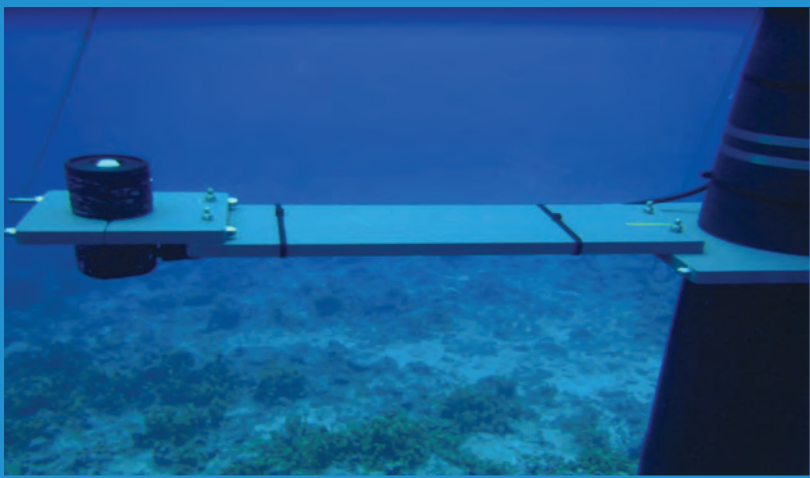

Curriculum Vitae of the Core Team

Dr M A Atmanand

Dr M A Atmanand, currently the Director of the National Institute of Ocean Technology (NIOT) has done pioneering work in the area of deep sea technologies in India. An Instrumentation and Control Engineer by profession, he took his undergraduate degree from the University of Calicut in Electrical and Electronics Engineering and post-graduate and doctorate degrees from the Indian Institute of Technology, Madras (Chennai).

Dr Atmanand led a team of Engineers for the design and development of underwater crawler for sand mining from up to a depth of 450 m. He and his team developed the *in situ* soil tester which was tested at a depth of 5200 m in the Central Indian Ocean Basin. It was under his supervision that the design of Electrical, Instrumentation and Control system of the India's first Remotely Operable Vehicle was done. This was later tested at a depth of 5289 m water depth. He has also guided various indigenization programmes for Ocean observation and under water systems. His areas of interest include (i) Development of underwater vehicles with specific reference to their control; (ii) Development of components for deep sea applications; (iii) Development of test protocols for testing of deep sea devices; and (iv) Project Management.

Dr Atmanand has been involved in international collaborative programmes with Germany, Russia and USA. He is the founding chairman of IEEE Oceanic Engineering Society in India and now a senior member of IEEE. He is also a member of Academic Council of Anna University, Chennai, India. Dr Atmanand has published 45 papers in International Journals, International and National Conference, etc. He has two patents to his credit and has received National Geoscience Award 2010 from Ministry of Mines and the International Society for Offshore and Polar Engineers (ISOPE) Ocean Mining Symposium award in the year 2009. Dr Atmanand has widely travelled to countries like Russia, USA, Germany, Portugal, Korea, etc. He can be contacted at *atma@niot.res.in*

Dr R Venkatesan

Dr R Venkatesan (Scientist G) presently holds the position of Programme Director and Group Head, Ocean Observation Systems at the National Institute of Ocean Technology (NIOT), Ministry of Earth Sciences, Chennai India. He holds a M. Tech Degree from Karnataka Regional Engineering College and a Ph.D. Degree from the Indian Institute of Science, Bangalore. He also has a PG Diploma in Marine Environmental Pollution and Management from Annamalai University and Post Diploma Certificate in International Business Management from the Indian Institute of Foreign Trade, New Delhi. He has been working in the ocean science and technology discipline for the past 30 years with 15 years of unstinted tenure at the National Institute of Oceanography, Goa.

Dr Venkatesan is responsible for the NIOT programme on moored buoys and for an Indo-Bulgarian S&T Project between NIOT and University of Chemical Technology, Sofia, Bulgaria. He is also responsible for societal activities to support livelihoods of coastal fishers through alternate employment such as sea farming and installation of Fish Aggregation Devices at various sites along the Indian coast. He worked as a Regional Coordinator. South Asian Seas Programme, South Asia Cooperative Environment Programme (SACEP), Sri Lanka and led mission to UN, New York; UNEP, Nairobi; International Coral Reef Initiative General Meeting at Monaco (2010) & Phuket (2009); GESAMP, Bangkok; and Regional Seas Meeting, Bangkok. He is holding the position of Vice-Chairman for Asia of Data Buoy Cooperation Panel (DBCP) of WMO and

UNESCO-IOC, Member of the Executive Council of DBCP and Chair of International Tsunameter Partnership. He has also been appointed by the Government of India as a National Consultant for marine litter management activity under SACEP, Sri Lanka.

He is a receipt of Tamil Nadu State Scientist award (2006); NDRF Award- Institution of Engineers (2009), MOSCOT National Award from Electrochemical Society of India, Indian Institute of Science Bangalore (2007); best PhD award from NACE in 2002 instituted by the Oil and Natural Gas Commission for his doctoral thesis. He has 130 technical publications, of which 30 of them are in referred national and international journals and is a co-author of book by Springer Germany and Editor of three conference proceedings. He has co-guided 4 PhD scholars and 28 Post Graduate students for dissertation and has two patents to his credit. He was associated in initiating M Tech course in IIT, Madras and is a member of NIOT- IIT Cell. He is instrumental in conceptualizing and executing national competition on Autonomous Underwater Vehicle for College Students. As a scientist he has logged around 1500 sailing days in scientific expeditions and has traveled to more than 30 countries. Dr Venkatesan can be contacted at *dr.r.venkatesan@gmail.com*

Dr G Latha

Dr G Latha has received her Master's degree in Mathematics and Doctorate degree in Mathematics from Indian Institute of Technology, Madras, India during the years 1987 and 1993 respectively. She is currently the Joint Project Director at the National Institute of Ocean Technology (NIOT) and heading the Ocean Acoustics and Modeling programme of NIOT. She joined NIOT in 1994 and has carried out extensive research in the areas of ocean ambient noise, development of autonomous systems for passive measurements and numerical modeling of ocean processes. She has published more than twenty papers in National and International refereed journals. She is a member of Acoustical Society of America and IEEE Signal Processing. Dr Latah can be contact at *latha@niot.res.in*

Mr Tata Sudhakar

Mr Tata Sudhakar is presently the Head, Ocean Electronics Group, National Institute of Ocean Technology, Ministry of Earth Sciences, Chennai, India. He received his M. Tech degree in Electronics and Control and has over 30 years experience in Oceanographic Institutions at different levels. He worked in the Indian Data Buoy Programme from 1997-2009. Mr Sudhakar played a major role in establishing the National Data buoy Programme and bottom pressure recorders used in Tsunami early warning systems for India. He received National Geo Science Award for Excellence of the Ministry of Mines, Government of India in the category of Disaster Management for the contributions to the establishment of Indian Tsunami Warning System. He has participated in many research campaigns both at national and international levels including the Fifth Indian expedition to Antarctica and the Commonwealth Science Council Program (CORE) for Caribbean islands. He has filed three patents to his credit. He can be contacted at tata@niot.res.in.

Mr Etienne Charpentier

Mr E Charpentier is currently supporting the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) from a WMO perspective, and particularly concerning marine meteorological and oceanographic observations (addressing the requirements for numerical weather prediction, climate applications, ocean meso-scale forecasting, and maritime safety services), and related implementation, data collection and exchange, data management, and quality management. He is also supporting the WMO Rolling Review of Requirements. He has an extensive experience in international affairs, including coordination of specific activities with national agencies and international organizations, organization and running of official international meetings, and support to executive bodies.

Before joining the World Meteorological Organization (WMO) in 2006, Mr Charpentier was the Technical Coordinator of the Data Buoy Cooperation Panel (DBCP) and the Ship of Opportunity Programme (SOOP). From that position, he has been providing technical support to national components of international ocean observation programmes on aspects such as data collection and location from satellites, quality control, data exchange and archiving, including acting as a focal point between data users, data producers, observing platform manufacturers, and data collection providers (*e.g.* Service Argos, Iridium).

During 1999-2000, in collaboration with the Argo Steering Team, he has contributed to the establishment of the Argo Information Centre (AIC) and with other ocean observations Panels to the establishment of the JCOMM *in situ* Observations Programme Support Centre (JCOMMOPS), which was then formally established by JCOMM-1 in 2001. He also has experience in software development and database management systems, and has been leading the development of key applications for the collection, data processing, quality control, archiving, and distribution of environment data, as well as observing network monitoring tools, including web development, and Geographical Information Systems.

In the beginning of his career at Météo France, he has been leading the development and implementation of a regional network of regional Automatic Weather Stations in North-East France. Mr Charpentier graduated in 1984 from the National Meteorological Engineer School, Toulouse, France. He can be contacted at *echarpentier@wmo.int*

Mr Al Wallace

Mr Al Wallace is the Director of the Meteorological Service of Canada, Pacific and Yukon Region of Environment Canada. He has vast experience in the field of meteorology. He has been elected as Chairman of the Data Buoy Cooperation Panel (DBCP) since 2009 and has also served at the Chairman of the DBCP-PICES North Pacific Data Buoy Advisory Panel (NPDBAP). From those positions, Mr Wallace has been instrumental in strengthening these groups and developing their activities. In particular, under his leadership, the DBCP is now increasingly involved in pilot projects such as wave measurements, satellite data telecommunication, impact studies, etc. and many new capacity building activities in different regions. He can be contacted at *al.wallace@ec.gc.ca*

Mr C M Muralidharan

Mr C M Muralidharan works as a consultant with the Bay of Bengal Large Marine Ecosystem (BOBLME) Project of the Food and Agriculture Organization (FAO) of the United Nations, providing operations support to the project. The BOBLME Project contributes towards laying the foundations in 8 countries for a coordinated programme of action designed to improve the lives of the coastal populations through improved regional management of the Bay of Bengal environment and its fisheries. He is a post graduate in Mariculture from the Central Marine Fisheries Research Institute with more than 27 years working experience in fisheries, fisher livelihoods and coastal management sector. Earlier, he had worked with MATSYAFED, Kerala, MPEDA and a national level NGO - Action for Food Production (AFPRO). For the past 6 years he has been working for the FAO first as the Fisheries Coordinator in the UN tsunami recovery work in India and the National Project Coordinator for the Fisheries Management for Sustainable Livelihoods (FIMSUL) Project, implemented in Tamil Nadu and

Puducherry, India. His areas of expertise include fisheries livelihoods, community based disaster preparedness, participatory methodologies, project management and coordination. He has contributed considerably to integrated fisheries development approach in Andhra Pradesh and Tamil Nadu, coastal community based disaster preparedness along Andhra Pradesh coast, addressing sustainable livelihoods of fishers in Tsunami recovery work in Tamil Nadu and coordinating an important fisheries policy project in Tamil Nadu and Puducherry. Mr Muralidharan can be contacted at *chavakat.muralidharan@boblme.org*

Dr Y S Yadava

Dr Yugraj Singh Yadava heads the Bay of Bengal Programme Inter-Governmental Organisation (BOBP-IGO). With a distinguished career spanning 35+ years in fisheries and aquaculture, Dr Yadava started his career as a Fisheries Scientist with the Indian Council of Agricultural Research in 1976 followed by a brief stint as Advisor Fisheries to the North-Eastern Council. In June 1994 he took over as Fisheries Development Commissioner to the Government of India and continued in this position until April 2000. In August 2000 he moved to the Bay of Bengal Programme (BOBP), then a field project of the Food and Agriculture Organization of the United Nations and in April 2003 converted the BOBP into an Inter-Governmental Organization (BOBP-IGO). Concurrent with other positions, Dr Yadava also held the important post of Member Secretary, Aquaculture Authority (July1997 – April 2000 & August 2001 – November 2005) and subsequently the Coastal Aquaculture Authority from December 2005 – November 2007.

Dr Yadava's scientific and developmental works *inter alia* include pioneering studies on large river ecosystems and their floodplains in the Brahmaputra valley; popularization of sustainable aquaculture practices (both fresh and brackish water) in rural areas; fisheries development in small reservoirs in north-east India; setting up of seasonal uniform ban on marine fishing in India; establishment of the Aquaculture Authority and later the Coastal Aquaculture Authority; setting up of the BOBP-IGO as a regional fisheries body; raising the profile of safety at sea of small-scale fishers and disaster preparedness in the Bay of Bengal region; popularization of the Code of Conduct for Responsible Fisheries; capacity-building in the BOBP-IGO member-countries on aspects such as formulation of management plans for commercially important species, elimination of Illegal, Unreported and Unregulated Fishing, and improving Monitoring, Control and Surveillance, etc in the member-countries.

Besides extensively working in the BOBP-IGO member-countries, Dr Yadava has also worked under different projects in Indonesia, Japan, Philippines, Thailand and Vietnam. Well-known in the national and international fisheries, Dr Yadava has contributed to a large number of expert consultations, ad-hoc working groups, inter-governmental meetings, regional and global conferences, GEF- funded Large Marine Ecosystem Project, etc. A cogent and prolific writer and a photographer, he has published about 150 papers in books, research journals, scientific and popular magazines and reports and has about 30 000 quality pictures of various facets of coastal and marine fisheries in his photo archives. Dr Yadava holds a PhD degree in Fisheries Management in Floodplain Lakes. He can be contacted at *yugraj.yadava@bobpigo.org*

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Curriculum Vitae of the Industry participants

Dr Anders Tengberg received his Masters Degree in Civil Engineering from Lund University of Technology, Sweden in 1990. Later he also completed a Masters Degree in Hydraulic Engineering from Toulouse University of Technology, France in 1991. In 1997, Dr Tengberg received a PhD Degree in Environmental Sciences from the Chalmers University of Technology, Göteborg, Sweden and completed his Post Doctoral in 2000. He is currently a Scientific Advisor/Product Manager to Aanderaa Instruments A/S (AADI), Bergen, Norway as well as an Associate Professor at Göteborg University in Marine Chemistry, Sweden. He has to his credit about 70 oral presentations and about 30 scientific reports in scientific conferences. He is fluent in both written and spoken Swedish, English, French and Spanish has good knowledge of Norwegian, Danish, Russian and German. Dr Tengberg has reviewed about 20 scientific publications in International peer reviewed journals and has chaired the Swedish Society for Marine Sciences during 2005-2007. Dr Tengberg is also a member of the Board of Directors of Aanderaa Instruments A/S 1997-2004. He can be contacted at *anderste@chem.gu.se; anders.tengberg@Xyleminc.com.*

Mr Arve Jon Berg received his Master of Science Degree in Civil Engineering from the University of Trondheim, Norwegian Institute of Technology. Later he took advanced courses at the University of Trondheim, Norwegian Institute of Technology on Town and Regional Planning, Building Technology and Applied Hydraulics. He is currently the Project Director, Fugro OCEANOR AS. He has worked on numerous projects on Environmental Monitoring, Water Supply and Sanitary Engineering, Aquaculture and Hydropower and water resources. Mr Berg can be contacted at *a.berg@oceanor.com*

Dr Carol D Janzen graduated in Oceanography from the University of Washington, USA and did her Masters and Doctorate in Marine Studies/Oceanography from the University of Delaware, USA. Dr Janzen has also received Graduate Fellowship Award from NSF Coastal Oceanography and Sea-Grant Award for excellence in Master's Research. Presently, she is a senior researcher at Sea-Bird Electronics, Inc. She can be contacted at *cjanzen@seabird.com*

Sonardyne
SOUND IN DEPTH

Mr Daniel Tan received his Diploma in Electronic and Communication from Singapore Polytechnic in 1991 and later a BSc Degree in Computer Science and Management from Singapore Institute of Management (University of London) in 2003. Starting his career with Kenwood Electronics Technologies, Singapore as Product Development Engineer in 1993, he later shifted to Cosmotec Enterprises Pte Ltd as a Sales Manager in 2001. In 2007, Mr Tan took over as a Regional Sales Manager at Sonardyne Asia Pte Ltd where he is taking care of the Sales & Market development of Sonardyne for India, Taiwan, Vietnam, Thailand, Sri Lanka, Philippines etc. He can be contacted at *daniel.tan@sonardyne.com*

SBE Sea-Bird Electronics

Mr David J Murphy holds a graduate degree in Chemistry and a BS in Oceanography from the University of Washington and a MS in Electrical Engineering from the Georgia Institute of Technology. As a Director of Science at Sea-Bird Electronics he researches in sensing technologies and characterization of sensor response and rendering meteorology and manufacturing support and training. Mr Murphy can be contacted at *dmurphy@seabird.com*

Westenberg Engineering
Ingenieurbüro für Strömungstechnik

Mr Dennis Knabben holds a graduate Diploma in Mechanical Engineering and works in construction and development of wind tunnels at Westernberg Engineering. He also conducts various seminars in fluid dynamics. Mr Knabben can be contacted at *dennis.knabben@gmx.de*

CODAR OCEAN SENSORS

Dr Donald E Barrick received his Bachelor, Master and Doctoral Degrees in Electrical Engineering from the Ohio State University, Columbus, Ohio, USA. Dr Barrick's doctoral work involved interpretation of radar scatter from rough interfaces, including sea and planetary surfaces. He joined the staff of Battelle Memorial Institute in Columbus, Ohio where he led work in radar scattering and signal processing as an Institute Fellow until 1972. During this period he taught electromagnetic, radar and communications theory at the Ohio State University's Electrical Engineering Department as an Adjunct Professor. From 1972-1983 he served as the Chief of the Sea State Studies Division (which he created) of the US National Oceanic and Atmospheric Administration's Wave Propagation Laboratory in Boulder, Colorado, where he also developed the compact HF radar systems for real-time mapping of ocean currents and waves. Since 1983 he has been associated with the industry, founding and heading CODAR Ocean Sensors, Ltd. as its President. Dr Barrick can be contacted at *don@codar.com*

RBR

Dr Greg Johnson is the President of RBR Limited. He holds an undergraduate degree in Electrical Engineering from McGill University, Canada and a Doctoral Degree in Material Science from Manchester University, UK. He has previously worked at the Rutherford Appleton Laboratory in Oxford, England, the University of Manchester and at the European Synchrotron in Grenoble, France. Prior to becoming President of RBR, Dr Johnson was the Director of Research and Development. He can be contacted at *greg.johnson@rbr-global.com*

IXBLUE

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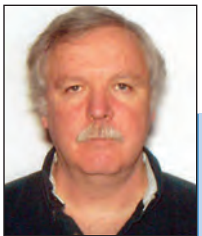
Mr Hubert Pelletier graduated from the Ecole Nationaled' Ingénieurs de Brest in 1981, with specialization in analog and electronic engineering. He began his career as R&D Engineer in small business manufacturing oceanographic equipment and designed some of the first micro-processor based self-contained ocean monitoring tools. With a solid technical background and experience in marine industry, he progressively switched to a commercial position and developed the domestic and international business. After almost 30 years experience spent in the marine industry and specialization in underwater positioning sensors and systems, and good communication skills, Mr Pelletier is now Sales and Marketing Director with the iXSea Acoustic Product Division based in Brest-France. He can be contacted at *hubert.pelletier@ixblue.com*



WET Labs

Dr Ian Walsh graduated in BS from the Case Institute of Technology and completed his Master's Degree at the College of Oceanography, Oregon State University in Marine Geology. Dr Walsh obtained his Doctorate from Texas A& M University. Currently he is the Senior Oceanographer and Vice President of Sales and Marketing at WET Labs Inc. He has a vast experience of 36 oceanographic cruises, covering over 580 days at sea. He can be contacted at *ian@wetlabs.com*

AML OCEANOGRAPHIC

Xchange your old ideas

Mr James Walton holds a degree in BSc Engineering and works at AML Oceanographic as a Manager for International Sales. Mr James major career focus is on technical sales and client relations. At AML Oceanographic, he is responsible for managing sales and distributor relations in Europe, Asia, and South America. While working at Nicholson Manufacturing, he generated sales and provided customer support to international clientele, resulting in sales averaging $1 million per month. As an independent contractor for the Alberta Government, Mr James managed a successful marketing project to increase child care spaces by 14 000 over 3 years. As a public employee in Japan, he delivered English language education and managed many projects over six years to facilitate cross-cultural communication among thousands of learners. Mr Walton can be contacted at *james.walton@amloceanographic.com*

Ms Julie Rodriguez graduated in Interior Design from the Oregon State University, USA. She has also completed a minor in psychology and courses in design studio, technical writing, mathematics and business. Presently, Ms Rodriguez works as marketing coordinator at Sea-bird Scientific and her assignment includes coordination and administration of trade shows/conferences, training sessions, demonstrations, equipment manager, and group marketing coordination and production She can be contacted at *jrodriguez@seabird.com*

Mr Maarten van Beelen graduated in 1995 from the Hoge School of Amsterdam, specializing in Maritime Electronics. He started his career as Survey Engineer at Orisis. Mr Maarten has carried out several survey projects around the world and has also worked for four years as Project Manager at IHC Systems. In 2003 he joined iXSEA as sales manager and a year later became the Managing Director of iXSEA BV (later known as iXBLUE). In 2011 he moved to APAC region to take position as Business Development Manager, India. Mr Maarten can be contacted at *maarten.vanbeelen@ixblue.com*

Mr Martin Kratzenberg is the Head of Sales of Westerberg Engineering and Wind Tunnels. Mr Kratzenberg also works in areas related to construction of wind tunnels, calibration and in fluid dynamics laboratory. He is responsible for sales development, foreign markets, public relations and marketing presentations and fair planning. Prior to joining Westernberg, he worked for Rittmeier and Partner GmbH, Keyproducts GmbH and Keyfile-Corporation. Mr Kratzenberg can be contacted at *kratzenberg@westenberg-engineering.de*

Mr Max Audric graduated from Ecole Supérieure d'Electricité (ESE/Supélec) in 1973 with Electronics Engineering and Computer Sciences background. Mr Audric started his career as an R&D Engineer in the Acoustics and Oceanographic Department at Electronique Appliquée (ELA). Later he had long association with OCEANO Instruments in different positions until 2002, when he joined iXSEA/iXBLUE as an OCEANO Product Line Manager (Acoustic Release & Positioning Transponders Range). He can be contacted at *hpe@ixsea.com*

Mr Nanda Kumar holds a Graduate degree in Chemistry. Joining the Merchant Navy in 1981 as a Radio Officer (Marine Electronics), he has worked in diverse situations controlling air traffic, undertaking drilling operations and as a traditional Radio Officer on Merchant ships till 1990. Later moving to deck side, he became the Chief Officer before he quit and started his own marine electronics company. Based on his vast experience in installation of wireless, satellite communication & navigation equipment, his company has grown exponentially. He is often consulted on maritime communication issues and was the first non-government person to be nominated to attend IMO meetings on behalf of the Government of India. Mr Kumar is a member of the Committee Internationale Radio Maritime also known as CIRM and is part of many working groups relating to new maritime safety and communication regulations. He can be contacted at *nanda@elektroniklab.com*

Mr Regis S Cook is the owner of General Oceanics and currently holds the title of CEO and Director of Marketing. Mr Cook has been employed by General Oceanics since 1976 and has held numerous positions within the company. His previous position was financial controller for the company and was actively involved in the administration of all the SBIR/STR contracts including the US National Science Foundation award to develop the prototype for pCO2 System exhibited at this conference. He holds a BS degree in accounting from Saint Francis College and also a BA degree in computer information systems from Florida International University. He can be contacted at *RegisC@generaloceanics.com*

Mr Ron Hippe holds a BS Degree in Engineering Mechanics and has worked in projects ranging from deep space - right down to the ocean's abyss. Since joining Teledyne in 2001, Mr Hippe has applied his vast mechanical and acoustic skills to the marine environment, where he has undertaken product commissioning, training, troubleshooting and project management tasks. He has well-honed customer service skills and vast product/application knowledge. In his work territory, Mr Hippe is responsible for sales and customer contact in Asia, Australia, Middle East and South Pacific regions. This includes customer training of Teledyne's new products, lectures on the use of ADCP's in the Marine environment, customer on-site demonstrations and all aspects of the purchase of Teledyne Marine Products, which include ADCP's for moored and vessel marine applications, CTD's, Carbon sensors and CO2 sensors. Mr Hippe can be contacted at *rhippe@teledyne.com*

rotronic
MEASUREMENT SOLUTIONS

Mr S Sinnathurai holds a Bachelor Degree in Electrical Engineering from the University of New South Wales, Sydney, Australia and a Post-Graduate Degree in Business Administration from the University of Birmingham, United Kingdom. Mr Sinnathurai has 11+ years of experience in customer relationship, operations support, sales and marketing in manufacturing industry. Currently he is holding the position of Sales Director, Rotronic South East Asia Pte Ltd. He is responsible for overseeing implementation of projects for plant builders and MNC customers. Apart from implementing ROTRONIC products for projects, Mr Sinnathurai has successfully set up Primary Standard Humidity Calibration Laboratory in Singapore, India, Indonesia and Brunei. He can be contacted at *sinna@rotronic.com.sg*

Sonardyne
SOUND IN DEPTH

Mr Shaun Dunn is a Chartered Engineer with 15 years of experience in the areas of underwater acoustic communications, wideband signal processing and embedded system design. Mr Dunn has a successful career in the management of complex technical projects and in leading inter-disciplinary engineering teams. He is currently an engineering business development manager and is responsible for delivery of new technologies and product development ventures in the areas of subsea acoustics, navigation and seismic acquisition. Mr Dunn is the author/co-author of over 50 technical reports, journal papers, articles and project proposals. He is named as inventor on several patents. He has participated in many high profile naval sea trials involving UK and US submarines, surface ships, underwater vehicles, divers and remote seabed sensors both in UK waters and overseas. Mr Dunn can be contacted at *shaun.dunn@sonarydyne.com*

SOLITONOCEAN

Dr Steve Ramp received his MS and PhD Degrees in Physical Oceanography from the University of Washington and the University of Rhode Island, USA respectively. His career began in Fisheries Oceanography at the NMFS Northeast Fisheries Science Center in Woods Hole, Massachusetts, USA, followed by a long stint with the Navy as a Professor at the Naval Postgraduate School in Monterey, California and as a Program Manager at the Office of Naval Research in Washington, D.C. Dr Ramp is also the founding Director of the Central and Northern California Ocean Observing System (CeNCOOS). A sea-going scientist by trade, Dr Ramp has participated in over 80 research expeditions in different parts of the world, serving as Chief Scientist about half the time. These cruises have resulted in 56 publications in refereed literature and countless oral presentations at national and international symposia. Dr Ramp can be contacted at *sramp@solitonocean.com*

Mr Yann Bernard received his Masters Degree in oceanographic sciences from the University of Bordeaux 1 in 2005 and later completed another Masters Degree in spatial technologies in 2006 from the University of Paul Sabatier. In the same year he joined CLS as a Technical Engineer Trainee and in a short span of time became the Ocean Programs Manager. Mr Bernard's responsibilities at CLS include development and promotion of the CLS data collection and localization services for oceanographic and meteorological programs. His other activities include development of projects using new satellite systems capacities (Argos-3, Iridium). Mr Bernard can be contacted at *ybernard@cls.fr*

CADDEN

Mr CLEMENT Frédérick presently works at CADDEN as an export manager in the field of Oceanography instrumentation and Global Positioning Systems (GPS). He has completed Electronic Engineer Diploma in 1993. Before joining CADDEN, Mr. CLEMENT was with Petrotest GmbH Berlin, PAC (Petroleum Analyzer Company), France and DUPONT BAYEUX France.

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Curriculum Vitae of the Country participants

Mr M Arul Muthiah

Mr M Arul Muthiah (India) holds a Bachelor Degree in Electrical and Electronics Engineering from Madurai Kamaraj University and Masters Degree in Electronics Engineering from Regional Engineering College, India. He has over nine years of experience in design, development, installation and maintenance of offshore instrumentation platforms such as moored data buoy systems and deep ocean tsunami buoy systems. He has also excellent hands-on working experience with various makes and models of meteorological and oceanographic sensors, tsunami bottom pressure recorders and offshore communication systems and has developed indigenized tsunami buoy and data buoy data acquisition systems. Currently he is working as Scientist at the National Institute of Ocean Technology (NIOT), Chennai, India and leading the instrumentation team of Ocean Observation Systems Programme of the Institute. Mr Muthiah can be contacted at *arul@niot.res.in*

Mr Indawan Sani

Mr Indawan Sani (Indonesia) holds a Bachelor Degree in Agro-meteorology from Bogor Agricultural University, Indonesia and a Masters Degree in Geography from the University of Indonesia, Indonesia. He is working with the Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) and is entrusted with providing advice on agriculture climatology and marine climatic conditions. Mr Sani is based in Jakarta and can be contacted at *indawansani@yahoo.com*

Mr K M L D Sucharitharatne

Mr K M L D Sucharitharatne (Sri Lanka) is a trained Meteorologist with the Department of Meteorology, Government of Sri Lanka. He has also received advance training in meteorology in India. Presently, he is heading the Radar and Radiosonde Division and the Instrument Division of the Department of Meteorology. Additionally, he is also working at Meteorology Briefing Center of the Colombo International Airport. Mr Sucharitharatne is based in Colombo and can be reached at *msucharitharane@yahoo.com*

Mr Mir Tanweer Ali Agha

Mr Mir Tanweer Ali Agha (Pakistan) is a trained Meteorologist with the Tropical Cyclone Warning & Marine Meteorology Centre of the Pakistan Meteorological Department. He is working as a Meteorologist (Technical) as well as Administrator of Tropical Cyclone Warning & Marine Meteorology Centre, Karachi. His responsibilities include managing and supervising the work allocated to the technical team in respect of installation, up gradation of the equipments and issuance of tropical cyclone bulletins and warnings. He can be contacted at *tanweeragha@gmail.com*

Mr Ye Htut

Mr Ye Htut (Myanmar) has a Bachelor Degree in Physics and a Diploma in Applied Physics with Specialization in Electronics. He is presently engaged as the Assistant Engineer in the Department of Meteorology and Hydrology under the Ministry of Transport, Government of Myanmar. Mr Htut is based in Nay Pyi Taw and can be reached at *yehtut41@gmail.com*

Dr V V Gopalakrishna

Dr V V Gopalakrishna (India) holds a Doctoral Degree in Physical Oceanography from the Andhra University, Visakhapatnam, India. He is working as a Scientist (Grade G) with the National Institute of Oceanography, Goa, India. He is also the focal point of the National Focal Point for the Indian Ships of Opportunity Program. His research interests include Physical Oceanography (variability of thermohaline fields in the north Indian Ocean) and has published many research papers. Dr Gopalakrishna is based in Goa and can be reached at *gopal@nio.org*

Mr Mohamed Fadli Yusof

Mr Mohamed Fadli Yusof (Malaysia) holds a Bachelor Degree in Applied Physics from Universiti Sains Malaysia, Malaysia and has also completed training programme in Basic Meteorology Course. Presently, he is holding the position of Assistance Director in the Marine Meteorology and Oceanography Division of Malaysian Meteorological Department (MMD). His responsibilities include issuance of marine weather forecast and warning for areas around the coastal regions of Malaysia and the adjacent seas and preparing marine weather reports, voluntary observation ship (VOS) data, recording doppler current profiler (rdcp) and acoustic doppler current profiler (adcp) data around the coastal areas of Malaysia for clients. Mr Mohamed Fadli can be contacted at *fadli@met.gov.my*

Mr Hiram Ndirangu Njuguna

Mr Hiram Ndirangu Njuguna **(**Kenya) holds a Bachelor Degree in Science and Diploma in Meteorology. He has also taken trainings programmes in related fields. Presently, he is working as Ag-Meteorological Superintendant in Geosciences & Tsunami Information Services Sub-branch of Kenya Meteorological Department. His duties and responsibilities include monitoring occurrences of earthquakes, tsunami and issuing early warning and post-disaster management and correlated work. He is also working on deployment of 3 metero-ocean buoys in Lake Victoria and 5 Argo Floats in Indian Ocean. Mr Hiram Ndirangu is based in Nairobi and can be reached at *hiram@meteo.go.ke*

Mr Jamal AL-kharoosi

Mr Jamal AL-kharoosi (Oman) holds a Diploma in Avionics from Civil Aviation College and also a Diploma in Meteorological Engineering from Meteorological Office College in UK. He is currently working as a Meteorological Engineer for the Public Authority of Civil Aviation (PACA), Department of Operation & Technical Services at Muscat Airport and is a part of a team that looks after the acquisition of meteorological data via networks from several & different types of automatic weather stations distributed all over Oman including marine stations and ensure an accurate influence of data from the stations to the meteorological centre at Muscat Airport. His work includes calibrating meteorological sensors and supervising the maintenance of the stations as well as updating meta-data and installing new stations. Mr Jamal is based in Muscat and can be reached at *j.alkharusi@met.gov.om*

Mr Md Muzammel Haque Tarafdar

Mr Md Muzammel Haque Tarafdar (Bangladesh) holds a Bachelor and Masters Degree in Engineering from Bangladesh University of Engineering & Technology, Dhaka, Bangladesh with specialization in Electrical and Electronics. Presently, he is working as the Senior Communication Engineer in National Meteorological Communication Centre of Bangladesh Meteorological Department. He is responsible for installation and maintenance of departmental communication equipment and exchange of met-ocean and tsunami information at national and international levels. He is also involved in administration and technical capacity in the Storm Warning Centre of the Department. Mr Tarafdar is based in Dhaka and can be reached at *muzammel_tarafder@yahoo.com*

Mr Teeratham Tepparaj

Mr Teeratham Tepparaj (Thailand) is working as Marine Meteorological Officer in the Marine Meteorological Center of the Thai Meteorological Department. Mr Teeratham is based in Bangkok and can be reached at *teeratham2000@hotmail.com*

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