IMOS Data Streams and their Uncertainties

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Document Purpose

This document is the output of the project specified in *IMOS Uncertainty Project Brief V1.1*. This document contains a calculation or estimation of the uncertainty for each of the data streams that will be provided by IMOS. In a small number of cases the data stream itself is not yet fully specified, which renders it unfeasible to fully quantify errors in these cases.

Contents

Document Overview

The first section of this document consists of a table that lists the uncertainty for each IMOS data stream, grouped by the parameter being measured. Hence there are groups of sea temperature data streams, and another group for ocean current data streams, for example.

The second section is arranged by individual IMOS facility. It contains more information on the uncertainties, the instruments to be used, and how the uncertainties are calculated and supported.

Finally, there are a number of appendices that contain information relating to classes of instruments that are used across several IMOS facilities, as well as some general comments on calibration issues.

Introduction

What is the difference between accuracy and uncertainty? The term 'accuracy' is in widespread general use and has a multitude of meanings, some subtly different from others, and it is open to different interpretations. To avoid ambiguity, this report has focussed on the term 'uncertainty' instead. The term uncertainty is here defined as "the parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand". This is consistent with Australia's National Measurement Institute (*Assessment of Uncertainties of Measurement for Calibration and Testing Laboratories. Cook, 1999)*, and also NIST (*Technical Note 1297, 1994 edition).*

The goal of this report is to provide an end user the information required to estimate how close the reported value in an IMOS data stream is from the original underlying measurand. As an example, a temperature measurement may be given as "20.12 °C with a 95% confidence interval. of 0.01°C". To rephrase this, there are 5 chances in one hundred that the real temperature (the measurand) was outside the range 20.12 °C ± 0.01 °C.

Many of the uncertainties presented in this report follow the methods laid out in ISO document *Guide to the Expression of Uncertainty in Measurement (ISO GUM).* Generally these are for instruments that the CSIRO Marine and Atmospheric Research Calibration Facility (CMAR Calibration Facility) has extensive recalibration experience with. These uncertainties are flagged in this document by a suffix "95% c.i.". This indicates that the uncertainty value indicated is a 95% confidence interval.

However there are a number of instruments and system where the uncertainty values have had to be determined via other less rigorous means. Generally these rely on information taken from manufacturer's specification sheets. Some effort has been made to contact manufacturers to gauge whether the value provided is a fully expanded uncertainty, or instead an optimistic sales ambit claim. In all cases the manufacturer believed that their instruments performed according to the published specification, but there is insufficient information available at this stage to support a claim that the figures are as rigorously calculated as those underpinned by ISO GUM derived values.

In addition to the initial calibration uncertainty, an effort has been made to estimate the additional uncertainty that accrues due to instrument calibration drift once it leaves the calibration facility or the manufacturer. As a standard approach in this report, the uncertainty of each sensor after a nominal one year deployment is presented. Some instruments have drift rates specified by the manufacturer. Some other instruments the staff at CMAR Calibration Facility are able to make judgements based on recalibration histories of current instruments.

Within this document uncertainties that are expanded to provide 95% c.i. are more conservative and robust and defendable than other estimates.

Table 1. IMOS Data streams grouped by parameter.

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Sea Temperature			
Skin temperature			
SRS	Satellite radiometric AVHRR	± 0.5°	Australian w aters
SRS	Satellite radiometric MODIS	± 0.4°	Australian w aters
SRS	Satellite radiometric ATSR	± 0.25°	Australian w aters
SOOP (c)	IR Radiometer on *Fantasea* Whitsunday Ferry	± 0.004°	Transects Shute Harbour – Hardy Reef
Surface temperature			
SOOP (a)	SBE38 on *L'Astrolabe*	± 0.004°	Transects from Hobart to Antarctica
SOOP (b)	SBE38 on *RV Cape Ferguson*	± 0.004°	Transects in Coral Sea
SOOP (b)	SBE38 on *RV Solander*	± 0.004°	Transects off NW Shelf
SOOP (b)	Water Sampling program	± 0.2°	Spot samples at 2m depth
SOOP (c)	SBE48 hull sensor on BoM Fleet	± 0.4°	Ship tracks in Australian waters and further afield
SOOP (c)	SBE38 on Rottnest Ferry *Seaflyte*	± 0.004°	Transects from Hillarys to Rottnest Island
SOOP (c)	Gladstone to Heron Island Ferry	± 0.004°	T ransects from Gladstone to Heron Island
ANMN (NRS)	CTD data during biogeochemical sampling	± 0.004°	National Reference Station sites
ANMN (NRS,GBROOS,WAIMOS)	SBE37, SBE39	± 0.004°	At mooring locations
Marine National Facility (in kind) SOOP (d)	Thermosalinograph SBE3 on *RV Southern Surveyor*	± 0.004°	During normal ship operations
Australian Antarctic Division (in kind) SOOP (d)	Thermosalinograph SBE38 on *RSV Aurora Australis*	± 0.004°	During normal ship operations
Victorian EPA (in kind) SOOP (c)	Thermosalinograph SBE38 on *Spirit of Tasmania I*	± 0.004°	Transects from Melbourne to Devonport

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Sub surface temperature			
ANMN (NRS,GBROOS,WAIMOS)	SBE37, SBE39	± 0.004°	At mooring locations
ANMN (NRS, GBROOS, SAIMOS, WAIMOS)	*Wetlabs* WQM	± 0.004°	At mooring locations
ANMN (SEAMOS)	Aqualogger 520	± 0.05°	At mooring locations
ANMN (SAIMOS)	*FSI* NXIC	± 0.006°	At mooring locations
ANMN (SAIMOS, GBROOS)	Measurements from Aanderaa Thermistor strings	specification unavailable from manufacturer	At mooring locations
FAIMMS	SBE37 and SBE39	± 0.004°	At mooring locations
FAIMMS	MEA Thermistor (linked to SBE37 reference)	± 0.1°	At mooring locations
AATAMS	Vemco acoustic tag with T and D sensor	± 0.5°	Instantaneous measurement from tag location
AATAMS	*Minilogger* at VEMCO Listening stations	± 0.4°	At listening station location
AUV	SBE37 CT	± 0.004°	Mission specific areas
Vertical temperature profiles			
ARGO	SBE41 on Webb Research ARGO floats	± 0.004°	Oc eanic waters
SOTS	SBE41 on Webb Research ARGO float	± 0.004°	Nea r SOTS site
ANFOG	SBE41 on *Slocum* instruments	± 0.004°	Mission specific areas, with profiles to 2 00m
ANFOG	SBE41 on *Seaglider* instruments	± 0.004°	Mission specific areas with profiles to 10 00m
ANMN (NRS)	CTD casts during biogeochemical sampling	± 0.004°	National Reference Station sites
SOOP (a)	XBT profiles	± 0.2°	Vessel transects on IX1, IX28, PX2, PX15, PX30 and PX34 lines

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Sea Conductivity/Salinity			
ARGO	SBE41 on Webb Research ARGO floats	± 0.001 S/m	Oceanic waters
SOTS	SBE41 on Webb Research ARGO floats	± 0.001 S/m	Near SOTS site
SOTS	SBE37 on Met-buoy for Sea Surface salinity	± 0.004 S/m	Near SOTS site
ANMN (NRS,GBROOS,WAIMOS)	SBE37, SBE39	± 0.004 S/m	At mooring locations
ANMN (NRS, GBROOS SAIMOS, WAIMOS)	*Wetlabs* WQM	± 0.004 S/m	At mooring locations
ANMN (SAIMOS)	*FSI* NXIC	± 0.004 S/m	At mooring locations (See ANMN section)
ANMN (NRS)	Salinity bottle samples	± 0.0002 S/m	At National Reference Station sites
ANMN (NRS)	SBE19+ CTD casts during biogeochemical sampling	± 0.0006 S/m	National Reference Station sites
ANFOG	SBE41 on *Slocum* instruments	± 0.004 S/m	Mission specific areas, with profiles to 200m
ANFOG	SBE41 on *Seaglider* instruments	± 0.004 S/m	Mission specific areas with profiles to 1000m
SOOP (b)	SBE21on *RV Cape Ferguson*	± 0.004 S/m	Transects in Coral Sea
SOOP (b)	SBE21 on *RV Solander*	± 0.004 S/m	Transects off NW Shelf
SOOP (b)	Water Sampling program	± 0.0002 S/m	Spot samples
Marine National Facility (in kind) SOOP (d)	SBE21 on *RV Southern Surveyor*	± 0.004 S/m	During normal ship operations
Australian Antarctic Division (in kind) SOOP (d)	SBE21 on *RSV Aurora Australis*	± 0.004 S/m	During normal ship operations
Victorian EPA (in kind) SOOP (c)	SBE45 on *Spirit of Tasmania I*	± 0.004 S/m	Transects from Melbourne to Devonport
Victorian EPA (in kind) SOOP (c)	Water Sampling program	± 0.0015 S/m	Spot samples
Dissolved Oxygen			
ARGO	Aanderaa Optode on Web Research Float	± 2%	Profiles from a subset of floats.
SOTS	Aanderaa Optode on Web Research Float	8uM/kg or 5%	Near SOTS site
ANFOG	SBE43 on *Slocum* instruments	± 2%	Mission specific areas, with profiles to 300m
ANFOG	Optode on *Seaglider* instruments	8uM/kg or 5%	Mission specific areas, with profiles to 1000m
ANMN (NRS, GBROOS SAIMOS, WAIMOS)	WQM using SBE43	± 2%	Mooring location
ANMN (SAIMOS)	SBE43 on SBE19+	± 2%	Mooring location
ANMN (NRS)	Dissolved Oxygen samples	± 0.01 ml/l + 0.5%	At National Reference Station sites

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Radiation Flux			
SOOP (d)	*RV Southern Surveyor* PIR and Pyranometer	± 5 W/m^2	During normal ship operations
SOOP (d)	*RSV Aurora Australis* PIR and Pyranometer	± 5 W/m^2	During normal ship operations
SOTS (from ASIMET AWS)	PIR and Pyranometer	± 4 W/m^2	At SOTS location
ANMN (GBROOS)	PIR and Pyranometer	Not calculated	At moorings location
Meteorology			
SOOP (d)	Optical Rain Gauge	± 5%	During normal ship operations, with the *RV Southern Surveyor:* operating in Australian waters, and the *RSV Aurora Australis* operating in sub Antarctic and Antarctic waters
RV Southern Surveyor and	Air Temperature	± 0.3°	
RSV Aurora Australis	Relative Humidity (HMT333)	± 1%	
	Relative Humidity (HMT230)	± 3%	
	Ultrasonic Wind Sensor: Direction	± 3°	
	Ultrasonic Wind Sensor: Speed	± 2%	
	Mechanical Wind Sensor: Direction	± 4°	
	Mechanical Wind Sensor: Speed	± 0.3 m/s or 1%	
	Siphoning Rain Gauge	± 1mm	*RV Southern Surveyor* only
SOTS (From ASIMET AWS)	Barometric Pressure	± 2 hPa	At the SOTS site
	Atmospheric Temperature	± 0.1°	
	Relative Humidity	± 2%	
	Rainfall	± 1mm accum.	
	Rainfall rate	± 1mm/hour	
	Ultrasonic Wind Sensor: Direction	± 2°	
	Ultrasonic Wind Sensor: Speed	± 2%	
ANMN & FAIMMS	Barometric Pressure	± 1 hPa	At mooring locations
(From Vaisala WXT520)	Air Temperature	± 0.4°	
	Relative Humidity	± 5%	
	Wind Speed	± 5%	
	Wind Direction	± 3°	
	Rainfall	± 0.01 mm	

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
pCO_2			
SOOP (a)	GO 8050 system on *RV Southern Surveyor*	± 2 μ atm.	Underway surface data during voyages
SOOP (a)	GO 8050 system on *L'Astrolabe*	± 2 μ atm.	Underway surface data during voyages
SOTS	moored PMEL system	± 2 μ atm.	Surface values at SOTS site
Optical, Fluorescence	Instruments calibrated to give data in "fluorescence equivalent to chlorophyll a extract" in ug/litre		See appendix A
ANMN (NRS, GBROOS SAIMOS, WAIMOS)	*Wetlabs* WQM	± 1.5%	At mooring locations
SOTS	*Wetlabs* FLNTU	± 1.5%	At SOTS site
ANFOG	*Wetlabs* BBFL2	± 1.5%	Mission specific areas
AUV	*Wetlabs* ECO Triplet	± 1.5%	Mission specific areas
SOOP (b)	*Wetlabs* FLNTU on *Cape Ferguson*	± 1.5%	Transects in Coral Sea
SOOP (b)	*Wetlabs* FLNTU on *RV Solander*	± 1.5%	Transects off NW Shelf
SOOP (c)	*Wetlabs* FLNTU on Heron Island Ferry	± 1.5%	Transects from Gladstone to Heron Island
SOOP (c)	*Wetlabs* FLNTU on *Spirit of Tasmania 1*	± 1.5%	Transects, Melbourne and Devonport
Optical, Turbidity			
ANMN (NRS, GBROOS SAIMOS, WAIMOS)	*Wetlabs* WQM	± 1.5%	At mooring locations
ANMN (SAIMOS)	*Wetlabs* FLNTU	± 1.5%	At mooring locations
SOTS	*Wetlabs* FLNTU	± 1.5%	At SOTS site
ANFOG	*Wetlabs* BBFL2	± 1.5%	Mission specific areas
AUV	*Wetlabs* ECO Triplet	± 1.5%	Mission specific areas
SOOP (b)	*Wetlabs* FLNTU on *Cape Ferguson*	± 1.5%	Transects in Coral Sea
SOOP (b)	*Wetlabs* FLNTU on *RV Solander*	± 1.5%	Transects off NW Shelf
SOOP (c)	*Wetlabs* FLNTU on Heron Island Ferry	± 1.5%	Transects from Gladstone to Heron Island
SOOP (c)	*Wetlabs* FLNTU on *Spirit of Tasmania 1*	± 1.5%	Transects, Melbourne and Devonport
SOOP (b)	Water Sampling program – total suspended solids	unknown	Periodic Spot samples

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Optical, CDOM			
ANFOG	*Wetlabs* BBFL2	± 1.5%	Mission specific areas
AUV	*Wetlabs* ECO Triplet	± 1.5%	Mission specific areas
Chlorophyll *a*			
SOOP (c) (Vic. EPA, in kind)	Water Sampling program	at 0.2ug/l ± 18% at 1.0ug/l ± 6% at 5.0ug/l ± 3%	Melbourne
SOOP (b)	Water Sampling program	unknown	Spot samples
SRS	*Chlorophyll a,* based on ocean colour	± 35%	All Australian waters
Optical, Clarity			
ANMN (Nat Ref Stations)	Secchi Disk Measurements	± 1m or ± 5% Interoperator variability	At National Reference Station sites
Current Measurement			
ANMN (SEAMOS,SAIMOS,GBROOS)	*RDI 300 kHz workhorse*	± 0.5%	At mooring locations
ANMN (GBROOS)	*RDI 150 kHz Quartermaster*	± 1%	At mooring locations
ANMN (SAIMOS)	*RDI 75 kHz Long Ranger*	± 1%	At mooring locations
ANMN (GBROOS)	*Nortek Continental 190 kHz*	± 1%	At mooring locations
ACORN	*WERA* system	± 10 cm/s per component	At WERA sites
ACORN	*CODAR* system	± 10 cm/s per component	At CODAR sites
AUV	Based on vehicle drift, and DVL	varies	Mission specific areas
ARGO	Based on float drift between reports	varies	Oceanic waters
ANFOG	Based on glider drift between reports	varies	Mission specific areas

Facility and Parameter	Measurement Technique	Uncertainty (Annual)	Coverage
Biogeochemical			
ANMN	Nutrient samples	± 1% of top standard	At National Reference Station sites
Biological			
AATAMS	Identification of presence of tagged species	see AATAMS	At listening stations
SOOP (a)	Continuous Plankton Counter Phytoplankton identification and enumeration	see SOOP	On IX28 and EAC transects
SOOP (a)	Continuous Plankton Counter Zooplankton identification and enumeration	see SOOP	On IX28 and EAC transects
SOOP (a)	Continuous Plankton Counter Phytoplankton Colour Index	± 1 level	On IX28 and EAC transects
ANMN (NRS)	Samples for phytoplankton enumeration	ID	At National Reference Station sites
ANMN (NRS)	Samples for zooplankton enumeration	ID	At National Reference Station sites
Bathymetry			
AUV	bathymetric maps from Imagenex mbes	unknown	Mission specific sites
Stereo imagery and sizing			
AUV	Data from stereo stills cameras	to be finalised	Mission specific sites

Facility 1. Array for Real-time Geostrophic Oceanography (ARGO)

Data Streams

A set of data are telemetered from each float, via either the ARGOS or Iridium satellite systems. This transmission occurs autonomously at the completion of each 10 day data acquisition cycle. The data are near real time, and there is no provision for on board logging and later retrieval of data.

The data sets that are transmitted are:

1. Temperature against Pressure, and
2. Salinity against Pressure.

The geographic location of the float at the time of the data transmission is acquired through the normal ARGOS location process or through GPS from the Iridium floats, and is recorded as an additional parameter to both datasets.

Additionally, there are a small number of ARGO floats that collect and transmit dissolved oxygen against pressure.

After reception of the data from the float, a dataset of conductivity versus pressure is calculated and added to the data set.

The data sent to GODAE and Coriolis are as described above. Data sent to the GTS however is stored as sensor data against depth, rather than pressure, to better fit the requirements of the GTS system.

Timeframes

The bulk of the data are acquired during the float's ascent from 2000 dBar to the surface, a process that takes approximately eight hours. Once on the surface the float transmits autonomously to the ARGOS (or Iridium) satellite network, and the data are available from ARGOS within a couple of hours and from Iridium as a file left on a dial-up modem within minutes. These datasets are then decoded from the hex transmission, converted into the Argo netcdf file format and uploaded to GODAE, Coriolis and the GTS within 24 hours, after initial, automated, quality control.

The float data is also subjected to a vigorous Delayed Mode Quality Control (DMQC) process to remove bad data, and to provide some post calibration of the Conductivity, and thereby the Salinity, datasets. This process usually runs over a period of more than 12 months. The modified datasets are uploaded to the GODAE as replacement datasets, and the real-time datasets are removed, as soon as they are available

Data Availability

Data are available from the GDACs (GODAE and Coriolis) and the GTS. Datasets are discoverable through eMII.

Uncertainty Values

Temperature	± 0.004 °C 95% c.i.
Pressure	± 2.4 dBar 95% c.i.
Conductivity	± 0.001 S/m 95% c.i.
Salinity	± 0.01 (PSU) 95% c.i.
Dissolved Oxygen	± 2% + 0.5% per annum

Location	
Location Flag = G	Uc < 10m radius (95%) (GPS)
Location Flag = 3	Uc < 500 m radius (95%) (ARGOS)
Location Flag = 2	Uc < 1000 m radius (95%) (ARGOS)
Location Flag = 1	Uc < 3000 m radius (95%) (ARGOS)
Location Flag = 0	Uc > 3000 m radius (95%) (ARGOS)

Support for Uncertainty

Currently there is no method for easily identifying or correcting non-catastrophic drift with the temperature and pressure sensors, and it is assumed that these sensors behave as per manufacturer's expectations. The manufacturer (Seabird Inc) has undertaken investigations into the long term stabilities of its sensors, and has provided feedback on initial uncertainties, and expected calibration drift rates over time. A small number of floats have been recovered after lengthy deployments, and the recalibration of the sensors support the values stated here.

It is expected, and has been found, that the conductivity sensor is less stable than the temperature and pressure sensors. To identify drift and to permit the correction of the drift in the conductivity sensors, the conductivity data from the floats is compared to existing climatological databases, and compared to nearby floats. This process is in accordance with the methodology published by Wong, Johnson and Owens (WJO). (Wong et al, 2002) An output from the WJO comparison process is an estimate of uncertainty, and this figure supports the conservative ±0.01 (PSU) value. An uncertainty figure is calculated for each profile of each float, and is stored with the datasets.

A small number of the floats deployed by this facility have *Optode* oxygen sensors manufactured by Aanderaa. It has been found that the original calibration for these oxygen sensors as supplied by the manufacturer are only representative of the batch of oxygen sensors and does not provide data of sufficient accuracy for individual sensors. To correct this, the oxygen sensors are individually calibrated by a third party prior to the float being deployed. The number of oxygen sensors deployed is small, and the resultant datasets limited, making it more difficult to derive in situ sensor stabilities. See Appendix B. (Larson 2003, Janzen and Larson 2008)

The majority of floats use the CLS ARGOS service, and location uncertainties are based on the location quality flags that are received from CLS ARGOS service. The published figures are calculated for one sigma. The values in this report assume the distribution to be Gaussian, and are therefore the values are doubled to derive 95% c.i. values. A small number of floats use Iridium telemetry service, which incorporates a GPS positioning device. These cases are indicated by a location flag 'G', and the location uncertainties are based on GPS uncertainty figures, which are lower than ARGOS uncertainties.

It should be noted that the locations where the oceanographic data are collected (during the float ascent) are separated in time and distance from the final position calculated during the concluding satellite data transmission. This difference is dictated by local currents and local surface winds.

References

Wong, P. S., G. C. Johnson, and W. B, Owens 2002: Delayed-Mode Calibration of Autonomous CTD Profiling Float Salinity Data by *θ–S* Climatology. *Journal of Oceanic and Atmospheric Technology*, **20**, 308 - 318

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

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

Facility 2. Ships Of Opportunity (SOOP)

The SOOP facility is spread over four components. These are: (a) *Multidisciplinary Underway Network*, (b) *Sensors on Tropical Research Ships*, (c) *Sea Surface Temperature Sensors* and (d) *Research Vessel Real Time Air-Sea Fluxes*. Each of these components are addressed individually below.

***Data Streams* - Multidisciplinary Underway Network**

There are three strands in the *Multidisciplinary Underway Network*. These are: XBT temperature profiles, pCO_2 analysis and Continuous Plankton Recorders. These instrument and systems will be deployed on a number of Ships of Opportunity as part of IMOS.

1. **XBT Temperature Profiles**

   Ships of Opportunity are fitted with XBT deployment systems. The XBT systems collect ocean temperature data against depth. The GPS position for each profile is recorded when the XBT probe enters the water. A profile takes several minutes to acquire the data. The data are then packaged and an automatic preliminary QC takes place, to remove obvious problems such as wire breaks and spike removal. The data are telemetered via an Iridium satellite link and sent to the GTS within the hour, and from there are forwarded to NODC.

2. **Underway pCO_2**

   The research vessels *RV Southern Surveyor* and *L'Astrolabe* have pCO_2 underway monitoring systems installed.

3. **Continuous Plankton Recorder (CPR)**

   CPR programs will be undertaken in two distinct areas. One area will be in the Southern Ocean, and generally follow the IX28 line between Tasmania and the Antarctic continent. This line will run during the Austral summer, when the vessel *L'Astrolabe* undertakes Antarctic resupply and science voyages. The second area will cover the EAC, with a transect running down the eastern and south eastern coast of Australia. This line will be conducted throughout the year and will require the use of commercial shipping.

Plankton are collected on a long length of silk that is wound onto a drum during the voyage. At the conclusion of the voyage the silks are shipped to either CMAR Cleveland, or to personnel located at the Australian Antarctic Division where the plankton are counted and identified. Initially, the "phytoplankton colour index" will be assessed for each silk sample. This is a number ranging from 0 (for clear silk that has captured very little chlorophyll) to 3 (for silk samples that have retained a high level of chlorophyll). The silks will then be processed using a combination of "on-silk" and "off-silk" counting methods. On-silk methods are initially undertaken to count phytoplankton. This is followed by off-silk counting, where each silk piece is washed to collect the organisms, which are then identified and counted. Off-silk is primarily used to enumerate zooplankton.

Additionally, the CPR used for the EAC line will be fitted with a sensor that records and logs temperature, pressure, pitch and roll. These data sets will be downloaded at the end of each line.

***Timeframes* - Multidisciplinary Underway Network**

1. **XBT** data is available in 24 hours. Some data sets are collected on vessels with no Iridium real time satellite link, and in these cases the data are stored on board and become available once the vessel reaches port. Data are processed through a DMQC process within a week of the ship delivering the full resolution data, and uploaded to NODC approximately once per year.

2. Subsets of the pCO_2 data are transmitted from the *RV Southern Surveyor* to CSIRO Marine and Atmospheric Research every six hours and are available immediately. There is no QC on this real time data. At the conclusion of each voyage the datasets are QC and processed, and available within a week of the end of the voyage. This final QC process requires ancillary datasets to be processed and released by the Marine National Facility, and delays in this process can delay the release of final pCO_2 data sets. Data from *L'Astrolabe* are generally not available in real time. The data are collected and processed at the conclusion of each voyage in the same way as data from *RV Southern Surveyor*.

3. **Continuous Plankton Recorder**

   The work of processing a silk cassette takes approximately 4 weeks. There will be periods when there are a number of silks arriving at once, which will cause delays to the data being finally worked up. It is planned that the final data will be ready within 3 months of the arrival of a cassette with the processing teams.

Data Availability **- Multidisciplinary Underway Network**

1. **XBT Temperature profiles**
   a. GTS and through the GTSPP real-time web site
   b. GTSPP best-copy web site or GTSPP user-defined dataset web site. It will also be available through emII.
2. **pCO_2**

   Discussion are taking place with eMII.
3. **Continuous Plankton Recorder**

   eMII

   SCAR

Uncertainty Values **- Multidisciplinary Underway Network**

1. **XBT**

Temperature:	± 0.2°C
Depth:	± 5% reading
GPS Location:	± 20 metres

(Due to variation in offset from GPS antenna to XBT drop point, as well as standard GPS 95% Uc of ± 10m .)

2. **pCO_2**

pCO_2:	± 2 micro atmospheres

3. Continuous Plankton Recorder

Organisms will be identified as closely as possible. For the Southern Ocean the following breakdown has been observed in the past:

64% of organisms can be identified to the species (or finer scale)

6% of organisms are identified to the genus

30% of organisms identified only to the family, or are unclassifiable

A philosophy has been followed that if there is some ambiguity in providing an identification at one taxonomic level, it is instead identified at the next highest level (i.e. if the identification of a particular organism at *species* level is uncertain, then it is identified to the level of *genus* only.)

For each piece of silk, all of the organisms will be counted, hence there is minimal error in the reported values. However taking this data and extrapolating it to derive populations in the study area based on the CPR counts will require assumptions to be made on the spatial homogeneity of the organisms in the area sampled, which will carry with it uncertainty.

The phytoplankton colour index is a 4 category visual index, literally reporting the “green-ness” of the silks. As it is a simple variable that ranges from zero (for clear) to three (for very green), it is rather coarse. However it has proven to be a useful parameter when comparing with satellite ocean colour data and in-situ chlorophyll measurements. It is considered that the error would be, at worst, a difference of ± 1 level.

Phytoplankton Colour Index	± 1 level (range 0 to 3)

The silks are cut in sections that represent samples from 5nm runs. These cuts are calculated from ship based GPS information, and data from logbooks detailing CPR deployment and retrieval times and locations.

The uncertainty in the inferred location for the silk sampling is dependent on a number of factors that have not been quantified in this report. Some factors that have an impact on the geographic precision are the resolution of the GPS (being recorded once a minute), the broad assumption that the apparent current experienced by the CPR for the duration of a deployment is approximately constant, and the assumption that the speed of the silk transport mechanism is constant through the period of the silk cassette deployment. Some of these assumptions have been tested and verified. The silk speed has been measured during deployments by several groups, and the speed has been reported to be satisfactorily constant. Problems where the current experienced by a vessel (and its attendant CPR) occur sometimes when a vessel makes large variation to its course. This can be addressed by retrieving the CPR and physically annotating the silk when the course change takes place. Issues with resolution of the GPS logging rate (once per minute), and issues of GPS accuracy are of a minor nature, and do not affect final data quality.

Information from the North Atlantic SOOP CPR survey suggests that the position assigned to CPR samples is accurate to within 10–20 nautical miles (Richardson et al. 2006 Progress in Oceanography 68: 27-74).

Star-Oddi *DST Pitch & Roll Logger*

Temperature:	± 0.1 °C
Pressure:	± 0.4% of sensor range
Pitch:	± 1°
Roll:	± 1°
Time:	± 1 minute per month

***Support for Uncertainty* - Multidisciplinary Underway Network**

1. XBT.

Sippican 2005 *MK21 Oceanographic Data Acquisition System 2005*

Hallock, Z, R and W. J. Teague 1991 *The Fall Rate of the T-7 XBT*, Journal of Atmospheric and Oceanic Technology. **9** pp. 470–483

2. pCO_2

The figure of ± 2 microatmospheres was provided by Bronte Tilbrook, CSIRO. It is based on a number of different observations, including intercomparison between the current equipment and previous systems, the specifications for the reference gases used to calibrate the system, and an assessment of the sources of error. An international intercomparison of this and other systems is planned for 2009.

3. Continuous Plankton Recorder

Discussions with Graham Hosie (Australian Antarctic Division) and Anthony Richardson (CMAR Cleveland)

Star-Oddi *DST Pitch & Roll Logger* specifications taken from manufacturer's datasheet.

Richardson et al. 2006 *Progress in Oceanography* 68: (27-74)

***Data Streams* - Sensors on Tropical Research Ships**

Two research vessels operated by AIMS are in the scope of this facility. These are the *Cape Ferguson* and the *Solander*. They will be instrumented with a *Seabird Inc.* thermosalinograph (model SBE21). These instruments will be installed with the remote temperature probe option (model SBE38), and combined with a *Wetlabs inc* FLNTU optical sensor. The principal data streams will:

1. Sea surface temperature
2. Salinity
3. Turbidity and
4. Fluorescence

Instrumentation has been installed on the *Cape Ferguson* and it is currently operating in the Coral Sea. *Solander* is currently operating on the NW margin of Australia, and this has contributed to a delay in the planned installation of the required instrumentation, now planned for the end of 2008.

Additionally, a water sampling program undertaken on a regular cycle. This will entail collecting surface water for later analysis in the laboratory for salinity, chlorophyll *a* and total suspended solids (TSS). The temperature of the surface water will be measured and recorded during the sampling.

***Timeframes* - Sensors on Tropical Research Ships**

Data will be collected on voyages deemed to be of sufficient length and in areas of interest. The data will not be telemetered in real time, but will be stored on board and sent to AIMS in Townsville at the end of the voyage. The data will then pass through an initial quality control process before being placed on a server at AIMS for wider dissemination. This process may take several weeks to complete after the conclusion of the voyage.

***Data Availability* - Sensors on Tropical Research Ships**

Data will be available from servers at AIMS.

***Uncertainty Values* - Sensors on Tropical Research Ships**

It is planned that the instruments will be deployed and then not routinely calibrated. The standard operating and maintenance procedures will be followed for the instruments. Hence the uncertainty values provided below are controlled by the manufacturer's delivery specifications, plus an allowance for sensor drift with time.

Underway sensors on research ships

Sea Surface temperature.	±0.002°C + 0.002°C per year	95% c.i.
Conductivity	±0.001 S/m + 0.004 S/m per year	95% c.i.
Fluorescence	±1.5% + 1% per year	
Turbidity	±1.5% + 1% per year	

Water Sampling Program

Sea Surface temperature	±0.2°C
Salinity	±0.002 (PSU)
Chlorophyll a	unknown
Total Suspended Solids	unknown

***Support for Uncertainty* - Sensors on Tropical Research Ships**

It is planned that bottle samples of water will be collected several times each year on voyages that have trained staff. This will allow turbidity sensor data to be translated from engineering values (volts) to realistic scientific values (NTU). This will provide some ground truthing to the fluorometer and turbidity data sets, although it is not easy to calculate the final datastream uncertainty using this approach. (See Appendix A).

Bottle salinity samples will also allow the conductivity/salinity sensor to be checked, allowing a possible reduction in the salinity uncertainty. This will make it feasible to get the long term salinity uncertainty down to approximately 0.05 PSU.

It is planned to use a comparison of the temperatures indicated by the internal temperature sensor and the remote temperature probe to judge the calibration health of the temperature sensors. This has potential, although it will be difficult to identify any sensor problems of a magnitude smaller than 0.1°C. This is because the thermosalinograph canister temperature is naturally affected by the internal temperature of the vessel (where it is generally located), and can be different from the original seawater temperature by 0.5 °C or more. This unavoidable variability will make comparisons for the purpose of calibration checking difficult.

As part of the water sampling program a sea surface temperature measurement will be taken. This will be measured using an existing temperature sensor incorporated in the vessel’s echo sounder, which has a resolution of 0.1 °C. Comparisons between this sensor and the SBE19+ CTD instrument generally show agreement to within 0.1 °C. This sensor is mounted on the hull, 2 metres below the surface.

The SBE19+ CTD is returned to the manufacturer for servicing occasionally. During these events the sensors are also calibrated.

***Data Streams* - Sea Surface Temperature Sensors**

Up to ten vessels, generally those currently involved in the BoM's Volunteer Observer Fleet, will have hull contact sea temperature sensors fitted (model SBE38). Data streams will also include time and location information, the latter data generally being acquired from existing vessel GPS systems.

Additionally there are a number of other vessels that have been instrumented using a variety of sensors, by other organisations as well as the BoM. These include:

a. An installation comprising a SBE38 remote temperature sensor and a data collection and telemetry system will be completed on the Rottnest Island Ferry *Seaflyte* during October 2008.
b. A *Seabird* SBE45 thermosalinograph and associated SBE38 has been installed on *The Spirit of Tasmania 1*, by the Victorian Environmental Protection Agency. This system also has a *Wetlabs* FLNTU optical sensor to measure fluorescence and turbidity.
c. A *Seabird* SBE21 thermosalinograph and associated SBE38 will be installed on board the Gladstone to Heron Island Ferry by AIMS. This is currently scheduled for late 2008.
d. An *Everest* IR radiometer has been installed on the *Fantasea* (Whitsunday Islands Ferry) by AIMS. Note that unlike the other sea surface sensors in this facility, which measure the bulk SST, the IR radiometer will measure the skin temperature.
e. An SBE38 sea surface temperature sensor will be installed on the Antarctic resupply vessel *L'Astrolabe* by CMAR. It is intended that this data be ingested into the existing automatic weather station (AWS) data stream on board the vessel.

***Timeframes* - Sea Surface Temperature Sensors**

The SBE48 hull contact sensors and the L'Astrolabe SST data will be telemetered to the Bureau of Meteorology in Melbourne in near real time as an additional field in the AWS data stream once every three hours. The remainder of the SST data streams will be transferred to the Bureau of Meteorology once a day. After an automatic QC, the data will be available within minutes on the Global Telecommunications System (GTS) and daily automatically transferred to eMII.

Data Availability **- Sea Surface Temperature Sensors**

The data will be available at a number of sites, including eMII.

Uncertainty Values **- Sea Surface Temperature Sensors**

Volunteer Observer Ships for BoM

SBE48 (on VOS)	± 0.2 °C average bias

Seaflyte, L'Astrolabe, Heron Island Ferry, Spirit of Tasmania 1

SBE38	± 0.004 °C 95% c.i.
SBE21	± 0.001 S/m + 0.003 S/m per annum
SBE45	± 0.0003 S/m + 0.003 S/m per annum

Whitsunday Islands Ferry

Everest IR Radiometer:	± 0.5 °C
Location:	± 100 metres

Support for Uncertainty **- Sea Surface Temperature Sensors**

Everest Radiometer

Data from accuracy specification in manufacturer's datasheet.

SBE38 based installations.

See appendix C

Thermosalinographs, SBE21 and SBE45

See appendix C

SBE48 Hull Contact Sensors

The initial uncertainty of the SBE48 sensors themselves is only ± 0.002°C. However this is a minor contributor to the final error calculation. The bulk of the uncertainty is contributed by the method that the SBE48 utilises to acquire the seawater temperature. The method involves measuring the internal hull skin temperature of the vessel, and using this as an analogue for the external sea water temperature. This method provides great simplicity for installation, but has the drawback that a number of factors influence the temperature being measured by the SBE48. These include influences from heat sources mounted near to the SBE48 mounting location (such as ships engines or similar), and just the varying air temperature in the space where the SBE48 is mounted. In experiments undertaken on *RV Southern Surveyor* during 2008, errors greater than ± 0.5°C were observed if no mitigating strategy was undertaken. However it was found that if the hull plate immediately around the SBE48 installation point was insulated from the ambient air, then average bias is reduced to around ± 0.2°C, with a standard deviations of 0.12 °C.

The size of this bias may be different on different vessels. Factors that might improve performance would be:

1. Thinner hull plate on the vessel, (*RV Southern Surveyor* hull plate is 19mm)
2. Installation locations well away from heat sources and pipe penetrations,
3. Installation locations offering good potential for large areas (~ 1 m^2) of thermal insulation over and around the SBE48 sensor. (*RV Southern Surveyor* afforded insulation over an area of 1m x 0.4 m)

Conversely, the opposite of these conditions will degrade performance.

Spirit of Tasmania 1 Installation

The Victorian EPA installation is supported by the document: *IMOS Ships of Opportunity QA/QC: Spirit of Tasmania Underway system.* This comprehensive document describes the protocols to be followed for this system. It specifies regular annual calibration of instrumentation, and monthly comparisons via bottle samples to be analysed at MAFFRI.

***Data Streams* - Research Vessel Real Time Air-Sea Fluxes**

The research vessels *RV Southern Surveyor* and *RSV Aurora Australia* will be instrumented with complete meteorological suites. This consists of sensors for wind, air temperature and humidity, pressure, precipitation, long- and short-wave radiation. In addition sea surface temperature and salinity will be part of the data stream

***Timeframes* - Research Vessel Real Time Air-Sea Fluxes**

RV Southern Surveyor:

Once every six hours a data set is transmitted from the vessel to CMAR. The data are available immediately after reception.

RSV Aurora Australis:

It is proposed that data are transmitted once per day.

Both datasets are subsequently quality controlled by an automated system (with manual overview) at the BoM and then uploaded eMII.

Data Availability - Research Vessel Real Time Air-Sea Fluxes

RV Southern Surveyor:

Data is available from the CMAR web server. QC'd data are available from eMII.

RSV Aurora Australis:

QC'd data are available from eMII..

***Uncertainty Values* - Research Vessel Real Time Air-Sea Fluxes**

Pyranometer:	± 0.5% of reading. (5 W/m^2)
PIR:	± 1% of reading (5 W/m^2)
Optical Rain Gauge	± 5% of accumulation (from manufacturer)
Relative Humidity	± 1% or reading (95% c.i.) (HMT333)
Relative Humidity	± 3% or reading (95% c.i.) (HMP230)
Air Temperature	± 0.3°C
Siphoning Rain Gauge	± 1mm
Ultrasonic Wind Sensor	
Direction	± 3°
Speed	± 2%
Mechanical Wind Sensor	
Direction	± 4°
Speed	± 0.3 m/s or 1% (the larger of the two values)
Sea Surface temperature.	±0.002°C + 0.002°C per year 95% c.i.
Conductivity	±0.001 S/m + 0.004 S/m per year 95% c.i.

***Support for Uncertainty* - Research Vessel Real Time Air-Sea Fluxes**

Instruments to be calibrated on a yearly interval.

Radiometer data are sensitive to sensor maintenance. It is assumed that a regular (daily) calibration regime is followed during data collection.

Wind sensor uncertainty is a combination of the intrinsic sensor uncertainty, combined with a 2° uncertainty in installation orientation.

Siphoning Rain gauge is based on RM Young hardware, and a CSIRO designed data acquisition system. The uncertainty value is derived from the manufacturers' information., and recent calibrations of the instrument.

Facility 3. Southern Ocean Time Series (SOTS)

Data Streams

There are a number of different platforms that form the SOTS IMOS facility. These include a marine meteorology platform, the Pulse platform, and a high temporal resolution APEX float.

Timeframes

A limited data set will be telemetered in real time. More extensive data sets will be available after moorings have been retrieved.

Data Availability

Data will be discoverable on the eMII site.

Uncertainty Values

Surface data streams from ASIMET weather station

Surface barometric pressure:	± 0.5 hPa + 1.5hPa per annum
Surface atmospheric temperature:	± 0.05°C + 0.05°C per annum
Surface atmospheric RH :	± 1% + 1% per annum
Rain fall:	± 1 mm of rain accumulation
Rain fall rate:	± 1 mm/hour rainfall rate
Shortwave radiation:	± 2 W/m^2 + 2 W/m^2 per annum
Longwave radiation:	± 2 W/m^2 + 2 W/m^2 per annum
Sonic Wind speed:	± 2%
Sonic Wind direction:	± 2°
Licor PAR sensor:	± 5% + 2% per annum
Sea Surface temperature:	± 0.002° + 0.002° per annum
Sea Surface conductivity:	± 0.0003 S/m + 0.004 S/m per annum

Sub Surface data streams

Gas Tension Device	± 0.02 mbar per annum

Wetlabs FLNTU

Fluorescence	±1.5% + 1% per year
Turbidity	±1.5% + 1% per year

Optode O_2 Concentration	± 8uM/kg or 5% (whichever greater)

PMEL pCO_2 sensor

Sea surface pCO_2	± 2 micro atmospheres

APEX float

Temperature:	± 0.004 °C
Pressure:	± 2.4 dBar
Conductivity:	± 0.001 S/m
Salinity:	± 0.01 (PSU)
Dissolved Ox	± 2% + 0.5% per annum

Support for Uncertainty

ASIMET Meteorological Station

Uncertainties stated here are derived from data provided on the Woods Hole site at: http://frodo.whoi.edu/asimet/asimet_module_specs.html

Sea surface pCO_2

Uncertainty value based on discussion with the system designer, Dr Chris Sabine. The value of 2 microatmospheres is conservative, and has been verified by comparison to ship borne instruments during instrument deployment and recovery at previous installations. The instrument is routinely and automatically calibrated in-situ using a standard gas that is traceable to the WMO standards as used by atmospheric researchers.

http://www.pmel.noaa.gov/co2/moorings/eq_pco2/pmelsys.htm

Gas Tension Device

Data from the manufacturer's web site:

http://www.pro-oceanus.com/products_CO2.html

FLNTU

See Appendix A

Optode

See Appendix B

Facility 4. Australian National Facility for Gliders (ANFOG)

Data Streams

Gliders will be deployed to undertake targeted data acquisition programs. During a deployment, data are telemetered to ANFOG each time that the glider is at the surface. This dataset is a much reduced subset of the full data collected during each profile.

The period between these surfacings is controlled by the glider's dive and ascent trajectory, and the depth of the profile.

The mission parameters can be modified during the mission via iridium communications system.

Gliders from two different manufacturers are used. The *Slocum* from Webb Research Corporation, and the *Seaglider* from University of Washington. These two gliders provide similar data streams of comparable quality. The *Seaglider* is designed for longer missions, and has an increased depth range over the *Slocum.*

Timeframes

A small subset of data are available in real time each time the glider surfaces. Full data sets are available when the glider is recovered at the end of the deployment phase.

Data Availability

Subsets of real time data are available during missions at the IMOS website at: http://imos.org.au/anfog.html

Uncertainty Values

The CTD data is derived in both cases from a *Seabird Inc.* CTD. It is planned that these CTD will be calibrated on an annual schedule.

Seaglider **(**SBE41 + SBE43 dissolved oxygen sensor + BBFL2-VMT optical)

Temperature:	± 0.002 + 0.002°C (95% c.i.)
Pressure:	± 1 dBar (0.1% 0f 1000m range = 1 dBar)
Conductivity:	± 0.0003 S/m + 0.004 S/m per annum (95% c.i.)
Dissolved Ox	± 2% + 2% per 1000 hours
Fluorescence:	±1.5% + 1% per year
CDOM:	±1.5% + 1% per year
Turbidity:	±1.5% + 1% per year
Surface Location:	Uc < 10m radius (95%) (GPS)

Slocum **(**SBE41 + Aanderaa optode dissolved oxygen sensor + BBFL2-SLO optical)

Temperature:	± 0.002 °C + 0.002 °C (95% c.i.)
Pressure:	± 0.5 dBar (0.1% 0f 350m range = 0.4 dBar)
Conductivity:	± 0.0003 S/m + 0.004 S/m per annum (95% c.i.)
Dissolved Ox	± 8uM/kg or 5% whichever greater
Fluorescence:	±1.5% + 1% per year
CDOM:	±1.5% + 1% per year
Turbidity:	±1.5% + 1% per year
Surface Location:	Uc < 10m radius (95%) (GPS)

Support for Uncertainty

It is planned that the sensors on the gliders will be calibrated on an annual cycle. The *Seaglider* sensors will be serviced and recalibrated during the mandated re-batterying process at the manufacturer's premises. Recalibration of the *Slocum* sensors will be carried out either at Seabird or at an independent facility.

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

See Appendix A for discussion on optical sensors, and Appendix B for discussion on oxygen sensor calibration stability.

Facility 5. Autonomous Underwater Vehicle (AUV)

Data Streams

The Seabed based AUV has a standard suite of sensors. These include:

1. Stereo Still images
2. Water Temperature and Conductivity
3. Optical water parameters (Fluorometer for *Chl a* and CDOM, and turbidity)
4. Multibeam echo sounder seabed imagery

There are several operational data streams that are collected. These include positioning information from a USBL system, a forward looking sonar mainly for obstacle avoidance, an auxiliary pressure sensor for accurate vehicle depth determination, a Doppler Velocity Log (DVL) for vehicle speed determination, and bottom tracking, and a GPS unit for location at the start and end of transects.

Additionally, the AUV has the capability to operate as a platform to facilitate the deployment of users' novel instrumentation systems for specific missions. The uncertainty of the user's novel instrumentation cannot be quantified in this document.

Timeframes

Data are available at the conclusion of each mission.

Some data are available in near real time to the mission participants and to clients.

Data Availability

Data is freely available. The data sets are large in size (approximately 200 GByte per mission), and there are currently discussions as to how best to serve the data.

Uncertainty Values

Final Uncertainty values are yet to be determined, as the calibration protocols are currently being finalised.

Oceanographic Parameters.

From SBE37

Temperature:	± 0.002°C + 0.002°C per annum
Conductivity:	± 0.0003 S/m + 0.004 S/m per annum

From Wetlabs triplet instrument

Fluorescence	±1.5% + 1% per year
CDOM:	±1.5% + 1% per year
Turbidity:	±1.5% + 1% per year

Stereo Stills Images.

Using existing software tools and calibration methods, it is possible to get measurement errors below ± 1 mm.

Bathymetry

From Imagenex Delta T 837 multibeam system

Unclear of final calibration protocol that will be used. System accuracy will become apparent after full calibration of system via a patch test or similar procedure.

Navigational Parameters.

From Digiquartz pressure sensor

Pressure:	±0.02 % FS

Vehicle location

From Linkquest USBL system

Bearing from reference:	± 0.25 °
Slant range accuracy:	± 0.2 metre

Vehicle speed

From RDI DVL

Vehicle velocity: ±0.4% + 0.2 cm/sec (95% c.i.)

(RDI Workhorse Navigator 1200 kHz in bottom track mode)

Support for Uncertainty

It is a planned to calibrate the instruments that are most susceptible to calibration drift (SBE37 and Wetlabs Triplet) on an annual cycle.

Vehicle Speed

The RDI documentation states ± 0.2% + 0.1 cm/sec. At 1m/s this would calculate to 0.3cm/s, which is the same as the single ping standard deviation. A 95% c.i is usually simplified to a range of 2 standard deviation, so it might be proposed that the 95% c.i. for the DVL is 0.6 cm/sec

http://www.rdinstruments.com/datasheets/workhorse_nav_ds_lr.pdf)

Facility 6. Australian National Mooring Network (ANMN)

Data Streams

The Australian National Mooring Network comprises a broad program that is represented across all of the IMOS nodes. Moorings will be installed in Australian waters, from the inshore area to deep water locations.

Although there is a strong focus on physical moorings, there is also a parallel program of biogeochemical sampling and observations. This parallel program involves regular water samples being taken as part of the National Reference Station (NRS) effort. These water samples are then sent to central laboratories where they are analysed using a number of different techniques to determine salinity, dissolved oxygen, nutrients, TOC, silicate, phytoplankton and zooplankton. During the sampling, a CTD cast is also usually undertaken.

Timeframes

Timeframes for release of data vary and generally are driven by the particular logistics of accessing the mooring in question. There is a general philosophy to provide at least some data from each mooring in real time, and there are several techniques employed to accomplish this using several different telecommunications methods. Usually more complete data sets are physically retrieved from the instruments during scheduled servicing visits to the mooring installation, and these data sets are available after QC.

Release of biogeochemical datasets is driven by the amount of time it takes for collected samples to be sent to the necessary laboratories , and then for the data to be prepared and released.

Data Availability

Data are served from a number of locations, including eMII, and AIMS.

Uncertainty Values

The uncertainty values are presented below, grouped by sensor.

Physical Parameters

WQM	(National Reference Stations, GBROOS, SAIMOS, WAIMOS)
Temperature:	± 0.002 °C + 0.002 °C per year (95% c.i.)
Conductivity:	± 0.0003 S/m + 0.004 S/m per year (95% c.i.)
Pressure:	± 0.1% FS + 0.1% FS per year
Oxygen:	± 2% + 2% per 1000 hours operation
Fluorescence	±1.5% + 1% per year
Turbidity:	±1.5% + 1% per year
Real time clock:	± 5 seconds per month

SBE37	(GBROOS)
Temperature:	± 0.002 °C + 0.002 °C per year (95% c.i.)
Conductivity:	± 0.0003 S/m + 0.004 S/m per year (95% c.i.)
Pressure:	± 0.1% FS + 0.1% FS per year
Real time clock:	± 5 seconds per month

SBE39	(National Reference Stations, GBROOS, WAIMOS)
Temperature:	± 0.002 °C + 0.002 °C per year (95% c.i.)
Pressure:	± 0.1% FS + 0.1% FS per year
Real time clock:	± 5 seconds per month

RBR DR1050	(National Reference Stations, WAIMOS)
Pressure:	± 0.05% FS, yearly drift uncertain
Real time clock:	± 5 seconds per month

Aqualogger 520	(SEAMOS)
Temperature:	± 0.05 °C annual drift rates unknown
Pressure:	± 0.2% FS annual drift rates unknown
Real time clock:	unspecified

FSI NXIC CTD BIO (SAIMOS)

Temperature: ± 0.002 °C + 0.006 °C per year (95% c.i.)

Conductivity: ± 0.0005 S/m + 0.0006 S/m per year

Real time clock: ± 50 seconds per month

FSI NXIC CTD AUTO 7000M (SAIMOS)

Temperature: ± 0.002 °C + 0.006 °C per year (95% c.i.)

Conductivity: ± 0.0002 S/m + 0.0006 S/m per year

Time: ± 50 seconds per month

NOTE: The figures provided for FSI sensors are based directly on the manufacturer's specification sheet. Experience in the CMAR Calibration Facility supports the stated drift rates for the temperature channels. However observation of the calibration stability for a cohort of more than two dozen FSI instruments has indicated that the conductivity sensor drift is often around 0.02 S/m per year. Admittedly the instruments observed all utilise the older style "external field sensor" rather than the NXIC sensor, so the stability issues may not apply to these NXIC sensors. It will be valuable to follow a careful recalibration protocol with these new sensors to discover the stability of the calibration when used in the field. It is recommended that at least a subset of the instruments are calibrated on a yearly cycle so that knowledge of the sensor stability can be verified and quantified.

FLNTU (SAIMOS)

Fluorescence ±1.5% + 1% per year

Turbidity: ±1.5% + 1% per year

SBE19*plus* (SAIMOS, and CTD profiles at National Reference Stations)

Temperature: ± 0.002 °C + 0.002 °C per year (95% c.i.)

Conductivity: ± 0.0003 S/m + 0.0003 S/m per year (95% c.i.)

Pressure: ± 0.1% FS

It will be possible to correct the conductivity sensor on the SBE19*plus* by using the salinity bottle samples that are collected by the coincident biogeochemical sampling program for the National Reference Station work. For this reason a reduced uncertainty figure is suggested for these instruments.

SBE43	(SAIMOS, with SBE19+)
Oxygen:	± 2% + 2% per 1000 hours operation

Current Measurement

RDI 300kHz Workhorse	(SEAMOS)
Velocity:	± 0.5%
Tilt:	± 0.5° for tilt
Compass orientation:	± 2°

RDI 75kHz Long Ranger	(SEAMOS)
Velocity:	± 1%
Pressure:	± 5 m
Tilt:	± 0.5°
Compass orientation:	± 2°

RDI 300kHz Workhorse	(GBROOS)
Velocity:	± 0.5 %
Tilt:	± 0.5°
Compass orientation:	± 2°

RDI 150kHz Quartermaster	(GBROOS)
Velocity:	± 1%
Pressure:	± 5 m
Tilt:	± 0.5°
Compass orientation:	± 2°

Nortek 190 kHz Continental	(GBROOS)
Velocity:	± 1%
Pressure:	± 0.5%
Tilt:	± 0.2°
Compass orientation:	± 2°
Real time clock:	± 5 seconds per month

Meteorological

WXT520 Weather Station	(National Reference Stations, GBROOS, FAIMMS)	
Barometric Pressure	± 1 hPa	
Air Temperature	± 0.4 °C	
Relative Humidity	± 3% ± 5%	up to 90%RH 90% to 100%RH
Wind Speed	± 0.3 m/s or 3% ± 5%	up to 35 m/s for speeds > 35 m/s
Wind Direction	± 3°	
Rainfall	± 0.01 mm	

Passive Acoustics

CMST – DSTO designed sea noise logger.

Hydrophone sensitivity:	± 1 dB over frequency range
System frequency response:	± 1 dB over frequency range (10 Hz to anti-aliasing filter frequency) Calibrated to dB relative to 1 μPa at 1 metre
Clock drift:	± 0.5 s

The frequency of the anti aliasing filter is adjustable in a range from 1 kHz to 15 kHz

A 7.5 kHz pinger is used during data collection to generate a fiducial mark in the logged data of each co-located system. This will permit alignment of the separate logger clocks during data processing.

Biogeochemical Sampling	(National Reference Stations)
Salinity	± 0.000 2 S/m (95% c.i.)
Nutrients	± 0.2 uM up to 10uM ± 2% over 10uM
Dissolved Oxygen	± 0.01 ml/l + 0.5%
TCO2	± 2 umol/kg
Alkalinity	± 2 umol/kg
Picophytoplankton	± 5 % (flow cytometry)
Phytoplankton	± 12% counts for dominant species
Pigments	± 5 % (mg/m^3 for individual pigments)
Zooplankton	± 29/√N, where N is value reported (organisms m^{-3})

Water Clarity - Secchi Disk Measurements (National Reference Stations)

Measurement of the Secchi depth can be affected by a number of factors, (as well as the parameter being inferred – suspended particles or water clarity). These other factors include: different operators, varying surface light conditions, taking readings at different times of day, using Secchi disks of different sizes, and the water surface conditions. Several of these can be controlled for (eg maintaining the same operator, using a standard size disk throughout IMOS, and always reading at a standard time of the day). Water surface conditions may be more problematic, and should be recorded routinely. Some studies have been undertaken to quantify the variability in Secchi readings due to these factors:

Interoperator variability	± 5 %
Water surface factors	- 15 %

(Decrease in observed Secchi depth in disturbed water surface relative to calm conditions)

Solar Radiation (GBROOS)

Kipp and Zonen radiometers will be installed as part of the GBROOS program, to measure both long and short wave radiation. It is planned that the instruments will be swapped with fresh instruments at regular periods, and the instruments will then be returned to AIMS for comparison with laboratory instruments used as standards. Unfortunately at this stage the full uncertainty of the radiation measurements from these sensors has not been calculated.

Support for Uncertainty

Physical Parameters

WQM, SBE37, SBE39

Published *Seabird* and *Wetlabs* specifications. See appendix C

Aqualogger 520

Published specifications

http://www.aquatecgroup.com/download/datasheet/aqualogger/AQUAlogger520.pdf

Dissolved Oxygen, SBE43

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

Also at: http://www.seabird.com/technical_references/IOS43Article-MarApr2008.htm

SBE19plus

These CTD instruments will be used to obtain data at National Reference Station locations during biogeochemical sampling trips. The instruments will be able to be post calibrated for conductivity via the bottle samples that are taken for the biogeochemical effort. The pressure sensor can be compensated for offset drift in real time by looking at the surface pressure reading, and subtracting this value from the pressure data. In this manner the uncertainty for these two channels are reduced over what would be expected for an instrument that is deployed or operates unattended.

Current Measurement

Manufacturer's specifications

Passive Acoustics

Discussions with Rob McCauley of CMST.

Meteorological

Vaisala specifications:

Vaisala Weather Transmitter WXT520 Users guide (M210906EN-A)

Zooplankton

The procedure for acquiring the zooplankton sample requires a special net to be dropped through the water column for a defined period of time, before it is brought back to the surface, thereby sampling 17 m^3 of water. This sample is then concentrated down to 100ml for transport to the laboratory. The counting process entails taking a subsample of 1 ml and enumerating all the zooplankton present. The aim is to count at least 300 zooplankton organisms in the sample, so if the sample shows low levels of organisms making it difficult to identify 300 organisms, the sample volume counted is increased (to 2.5ml or greater). The resultant counts are then scaled up to estimate the abundance of each organism from the sampling location. Hence final reported values (in organisms per metre cubed is arrived at by the following:

Organisms = counts/ml x 100ml / 17 m^3 (organisms/m^3)

An estimate of the confidence interval at the 95% level is given by $\pm 2/\sqrt{N}$ where N is the number counted. As the numbers reported are scaled up from the counted values in the manner described above, the uncertainty can be defined as the following:

Uncertainty = $\pm 2/\sqrt{(\text{Reported Value} \times 17/100)} \times 100/17$

Or Uncertainty = $\pm 28.5/\sqrt{(\text{Reported Value})}$

Biogeochemical

Salinity

Cowley, R., 1999. *Hydrochemistry Operations Manual*. 236, CSIRO Marine Research, Hobart, Tasmania.

Alkalinity

A.G. Dickson, J.D. Afghan and G.C. Anderson, Reference materials for oceanic CO2 analysis: a method for the certification of total alkalinity, *Mar. Chem.* **80** (2003), pp. 185–197

Nutrients

Discussion with Dave Terhell and Alicia Navidad, CMAR hydrochemistry section.

Also see:

WOCE (1991), *WOCE Hydrographic Programme Operations Manual*, WHP Office Report, WHPO 91-1, Woods Holes, Mass.,USA.

It is noted that further work is currently in progress to quantify the uncertainties in nutrient determination.

Dissolved Oxygen

SCRIPPS, *Oxygen titration manual SIO/STS* version: 05-JAN-2001,

TCO2

Discussions with Dr Tilbrook. Based on analysis of duplicate samples, and certified reference material.

Picophytoplankton

References relating to the repeatability and the accuracy of flow cytometry analysis

Zubkov, M. V., M. A. Sleigh, P. H. Burkill, and R. J. G. Leakey. 2000. Bacterial growth and grazing loss in contrasting areas of North and South Atlantic. *J. Plankton Res*. 22:685-711

D.P. Evenson, L.K. Jost, D. Marshall, M.J. Zinaman, E. Clegg, K. Purvis, P. de Angelis and O.P. Claussen. 1999. Utility of the sperm chromatin structure assay as a diagnostic and prognostic tool in the human fertility clinic. *Human Reproduction*, Vol. 14, No. 4, 1039-1049.

http://aem.asm.org/cgi/ijlink?linkType=ABST&journalCode=plankt&resid=22/4/685

Phytoplankton

The value provided above was arrived at after discussion with P. Bonham, and after a review of previous results for triplicate samples.

Counting precision is estimated to be $\pm 2/\sqrt{N}$, for the 95% confidence interval, where N = the number counted. For phytoplankton, the technique to be used is to count 300 of the dominant species. This equates to a counting precision of approximately ±12%. While counting the dominant species, the minor species are also counted. As the resultant numbers will be lower than the 300 arrived at for the dominant species, the uncertainty for the minor species will be correspondingly higher.

In addition to counts or number of organisms per litre, an estimate of biomass for each species will be calculated using estimated geometry and volume of the organism class.

HPLC Pigments

The calibration of the HPLC is checked at the start of each run using single point reference pigments. Correct operation is confirmed if the measured concentration of the reference is found to agree within 5% of pigment stated value, hence this is a measure for the expected variability of the instrument when measuring real samples.

Reporting a pigment concentration is often controlled by the limit of detection (LOD) for that pigment, or more precisely the limit of quantitation in a sample (LOQ). The LOD is the lowest concentration that a pigment is detectable when a reference pigment is measured, and is based on a signal to noise level of 3. The LOQ is based on what expected pigment levels are discernible in real samples. This latter is a larger value (due to many complicating factors when real samples are measured), and is therefore based on a signal to noise level of 10. The LOQ is different for each pigment, as the HPLC sensitivity varies across the spectrum. A table detailing the LOD and LOQ for each of the pigments that will be reported as part of this IMOS facility are given below:

Pigment LOD and LOQ calculations

Reference wavelength was 436 nm
LOD based on S:N = 3 and LOQ based on S:N = 10
Values based on 4 litres filtered and an extract volume of 4 mL

Pigment	Rel. LOD (ug/L)	Rel. LOQ (ug/L)
Chlorophyll C3	0.005	0.017
Chlorophyll C2	0.001	0.006
Chlorophyll C1	0.001	0.006
Chlorophyllide a	0.004	0.014
Phaeophorbide a	0.034	0.113
Peridinin	0.004	0.013
19- Butanoyloxyfucoxanthin	0.002	0.007
Fucoxanthin	0.002	0.007
Neoxanthin	0.001	0.005
Prasinoxanthin	0.002	0.007
Violaxanthin	0.001	0.004
19- Hexanoyloxyfucoxanthin	0.002	0.007
Diadinoxanthin	0.001	0.005
Alloxanthin	0.002	0.006
Diatoxanthin	0.002	0.007
Zeaxanthin	0.004	0.012
Lutein	0.002	0.007
MV Chlorophyll b	0.007	0.021
DV Chlorophyll a	0.003	0.010
MV Chlorophyll a	0.003	0.010
Phaeophytin b	0.003	0.010
Phaeophytin a	0.025	0.085
B,e-carotene	0.002	0.007
B,B-carotene	0.002	0.007

The procedure to be followed for IMOS sampling specifies that two to four litres shall be filtered for each sample, with the larger volumes being required for the tropical samples.

Secchi Disk

LARSON G. L. ,BUKTENICA M. W. Variability of Secchi disk readings in an exceptionally clear and deep caldera lake. *Arch. Hydrobiol*. Volume 141, Number 4, pp 377-388

Facility 7. Australian Coastal Ocean Radar Network (ACORN)

Data Streams

There are two distinct types of instrumentation used in this facility. One is the *WERA* Phased Array system, and the other is the *CODAR* compact radar antenna system.

The *WERA* system feeds data to a software package called *Helzel*, where surface currents are derived. Additionally, a separate software package *Seaview* is used to generate data products describing RMS wave height and directional wave spectra.

The *CODAR* system uses the *Seasonde* package to create data products. This system generates surface current values, but does not provide RMS wave height or directional wave spectra.

Although the raw data files are different between the systems, the final data product for surface currents will have a common format across the ACORN facility. The area under observation is gridded, and a single surface current vector is assigned to each grid. These current vectors are a representation of the average surface current for the single grid.

Timeframes

Data collection and processing requirements dictate that the data from the *CODAR* system are available one hour after acquisition. Data from the *WERA* systems is available 10 minutes after collection.

Data Availability

Data will be stored on the eMII server.

Uncertainty Values

The two systems do not provide identical data streams. The *WERA* system provides surface currents, as well as RMS wave height and directional wave spectra. The *CODAR* system provides surface current data only.

Surface currents:

In both systems, a single current vector is derived for each grid. These vectors are specified as being representative of the average surface current for the relevant grid.

Uncertainty = ± 10cm/second for each orthogonal component, (for quality flag = 1)

Data points are tagged with a quality flag. A value of 1 indicates good data with uncertainties as specified above. Flag values of 2, 3 and 4 indicate increasing levels of uncertainty in the data. The actual values of the uncertainty at these lower quality tagged data points is not specified.

Wave information

RMS Wave Height	= ± Value not yet resolved
Directional wave spectra	= ± Value not yet resolved

Support for Uncertainty

CODAR

Website providing specifications:

http://www.codaros.com/seasonde_gen_specs.htm

WERA

Website providing specifications:

http://www.seaviewsensing.com/technology_software_spec.html

Facility 8. Australian Acoustic Tagging and Monitoring System (AATAMS)

Data Streams

Several curtains and arrays of listening stations will be deployed and maintained. These listening stations will record data from acoustic tags that are attached to fish and other species of interest. The data stream generally consists of records noting the presence of the tag, and the time and date it was heard by a listening station.

Some listening stations have a temperature logger associated with them, and the temperature is logged at regular intervals.

Some of the tags are capable of measuring and transmitting temperature and pressure values in addition to their ID to the listening stations. These data are coded and require a slope value and an intercept value before meaningful data can be calculated.

Data presented by IMOS will generally be raw data, uncorrected for clock drift, and with unprocessed tag pressure and temperature values. Where available the correction values and calibration coefficients necessary for correction and calibration will also be accessible to enable researchers to process these data should they need to.

Timeframes

To gain access to the data the listening stations need to be recovered from the sea, and downloaded. The period between data retrievals is variable, but is generally around once every 6 months.

Data Availability

Data will be available on eMII

Uncertainty Values

The data indicates the time and date of the presence of a tag within range of the acoustic listening station. Initial uncertainties therefore centre on the drift of the internal clock in the listening station, the imprecision of the location of the listening station, and the receiving range of the station.

The effects of clock drift can be mitigated by an analysis of the absolute clock error. If the clock error at the start and the completion of the deployment are recorded, then it is possible at a later stage to remove the clock error by applying a linear correction to the times that are recorded. In this case the uncertainty will be in the order of several seconds.

Geolocation imprecision of the listening stations will vary from location to location. The uncertainty will more likely be larger when deploying to locations where the water is deeper, as there is generally less control on the final location of the anchor. Another factor is the amount that local water currents act to move the listening station around from a static location.

Uncertainty also arises when there are a large number of tags in the vicinity of a listening station. This may translate to either a) false positive tag identifications (i.e. a tag is shown as being heard, but that tag was not physically in the area). Additionally there is the possibility that a tag is within the listening station range, but due to a high number of other tags communicating with the listening station in the same period the tag is not heard properly, and is therefore not recorded as being in the listening station's range (a "false negative"). The likelihood of both these events can be indicated by looking at the all the data recorded by the listening station at that epoch, and judging the traffic load on the listening station. There are no robust protocols readily available to allow a user to calculate the rate or probability for these false negatives and false positives.

The receiving range of a listening stations is an important parameter when analysing tag data. Unfortunately this range can vary due to a number of (mostly) environmental factors. An investigation is planned as part of the work for AATAMS to quantify the range of the stations, how that varies from the specifications, and what environmental factors control the range.

Listening Station Temperature.

Some of the listening stations are equipped with a *minilogger* temperature sensor. The accuracy specification for these sensors is ± 0.3°C

Tag Temperature and Pressure Sensors.

Some acoustic tags have the capability to transmit the temperature and pressure to the listening station. As described above, these data points are coded, and require knowledge of the intercept and slope before meaningful temperature and pressure values can be extracted. If this is followed however, the specification is as follows:

Tag Temperature:	± 0.5 °C
Tag Pressure	± 5% of FS

There is no published information on the calibration drift of either the listening station temperature loggers, or the tags that transmit temperature and pressure data.

Facility 9. Facility for Automated Intelligent Monitoring of Marine Systems (FAIMMS)

Data Streams

Currently the majority of the data streams are water temperature and conductivity. The water temperature is measured using *Seabird* SBE37, SBE39, and a suite of MEA2173 thermistor strings. Although the thermistor string absolute accuracy is not high, there is good matching between thermistors in each string. The plan is to deploy thermistor strings in associated with a higher accuracy *Seabird* instrument, and use the *Seabird* data to provide a correction to the thermistor data and improve the overall accuracy.

Timeframes

Data are telemetered back in near real time via mobile telephone technology.

Data Availability

Data are available from the AIMS website.

Uncertainty Values

SBE37

Temperature:	± 0.002 °C + 0.002 °C per year (95% c.i.)
Conductivity:	± 0.0003 S/m + 0.004 S/m per year (95% c.i.)
Pressure:	± 0.1% FS + 0.1% FS per year
Real time clock:	± 5 seconds per month

SBE39

Temperature:	± 0.002 °C + 0.002 °C per year (95% c.i.)
Pressure:	± 0.1% FS + 0.1% FS per year
Real time clock:	± 5 seconds per month

Thermistor strings	± 0.01°C

(thermistor data corrected by co-located *SBE37* or *SBE39)*

Support for Uncertainty

The specification for MEA thermistor string is 0.006°C agreement between individual within the string. If the string is deployed in close proximity to a calibrated SBE37 or SBE39, the thermistor string data can be corrected by the using the *Seabird* data, and the overall accuracy of the thermistor will be an addition of the *Seabird* uncertainty, plus a value to account for the intrastring variability. At a first approximation, this uncertainty would be:

> 0.002°C (for *Seabird* Uc) + 0.006°C (for thermistor intrastring variability)
> Which can be combined for a value of ± 0.01°C

The uncertainty values for Seabird instruments are based on a yearly recalibration schedule, with recalibrations occurring at Seabird or at another calibration facility of similar capabilities.

Facility 11. Satellite Remote Sensing (SRS)

Data Streams

Data sets are acquired from satellites via ground receiving stations located in several locations. These locations are: Hobart (TERSS), Townsville (AIMS), Alice Springs, Darwin, Perth and Melbourne. Two distinct sets of data will be provided, a sea surface temperature data set, and an ocean colour dataset. Data will be available as images (tiffs or jpeg), and as numeric netCDF files.

Timeframes

Data are collected during every satellite pass, approximately 4 times each day for each satellite. Once collected, the data are automatically processed, and data products are available within 30 minutes

Data Availability

Data is served from CSIRO Black Mountain and CSIRO Hobart. There are a variety of sophisticated methods that can be used to access the data. These methods are being written and will be released during the second half of 2008.

There are two distinct forms of data. The first is image based datasets, comprising of either jpeg images or tiff images displaying colour coded data over a geographic area.

The data will also be available in numeric format, as either netCDF files, or hdf files.

Uncertainty Values

Data uncertainty is dependent on the satellite that originally acquired the data.

Sea Surface Temperature (°C)

AVHRR	± 0.5°C
MODIS:	± 0.4°C
ATSR:	± 0.25°C

Chlorophyll (mg/m^3)

(MODIS):	± 35%

Support for Uncertainty

Extensive investigation has been undertaken to ground truth the algorithms that are used to translate the spectral information gathered by the satellites and convert it to the final data products. The uncertainties provided above are based on these investigations.

Sea Surface Temperature

Barton, I. J., and Pearce, A. F. (2006). Validation of AATSR SSTs in Australian waters. In: *Second Working Meeting on MERIS and AATSR Calibration and Geophysical Validation (MAVT-2006), Frascati, Italy (European Space Agency, (Special Publication) ESA SP, 615)* .

Ocean Colour

Barbini, Roberto, Colao, Francesco, Fantoni, Roberta, Fiorani, Luca, Okladnikov, Igor G. and Palucci, Antonio(2005) Comparison of SeaWiFS, MODIS-Terra and MODIS-Aqua in the Southern Ocean, *International Journal of Remote Sensing,* 26:11,2471 — 2478

Werdell, P. J., S. Bailey, G. Fargion, C. Pietras, K. Knobelspiesse, G. Feldman, and C. McClain (2003), Unique Data Repository Facilitates Ocean Color Satellite Validation, *Eos Trans. AGU*, 84(38), doi:10.1029/2003EO380001.

Appendix A. Fluorescence and Backscatter Turbidity Sensor Considerations

Fluorometers

The calibration of fluorometers is undertaken by sequentially measuring a series of known concentrations of a fluorescent solution, and recording the output of the fluorometer. The fluorescent material is often formazin, or rhodamine. However the calibration is generally scaled so that the fluorometer output is calibrated to indicate a biological equivalent such as “fluorescence signal equivalent to fluorescence of extracted *chlorophyll a*”.

The current generation of fluorometers has a response that is generally relatively stable. The company that is supplying the majority of the instruments used throughout IMOS reports that anecdotally their fluorometers (and for that matter their other optical sensors) appear to drift around 1.5% in the first year of operation as the sensor components age, and in subsequent years the drift rates are further reduced to around 1% change per annum.

Of course, as with all optical instruments calibration stability is critically dependent on optical windows being kept clean. If biological growth is allowed to build up on the surface of the fluorometer sensing window, this matter will greatly influence the data recorded. It is recommended that a cleaning protocol be followed with fluorometers so that they are cleaned once every 24 hours when in use.

The relationship between a *chlorophyll a* concentration and the fluorometer output would hold up in the field, however usually researchers are not interested in the “level of *chlorophyll a* that would give the same fluorescence as this signal I am seeing in the field”. Usually a biological parameter is sought, such as biomass estimates. Unfortunately the relationship between the biology and fluorescence can be highly variable, and a direct conversion from ug/l of “*chlorophyll a* equivalent signal” from a calibrated fluorometer reading does not easily convert to a ug/l value of biomass.

If a relationship between fluorescence and biomass (or some other biological parameter) is desired, it is essential to take in situ samples of the biomass that is being measured. These samples would then need to be quantitatively examined ultimately via HPLC, spectrophotometry or microscopical counting techniques to determine the biological parameter of interest, and so tie this value back to the fluorometer reading. In this way, a series of calibration points may be obtained that will permit the fluorometer to be used to obtain biological data. Samples need to be taken at various times of the day, and ambient PAR needs to be recorded as well, as the phytoplankton take 20-30 minutes to adjust their fluorescence response to a change in PAR. The retrieval of phytoplankton biomass, as chlorophyll a, from in-situ sampling during the day and applying this to fluorometer datasets is not a simple procedure.

There are several other caveats that also need to be considered. Different species have differing fluorescence signatures, and so as the assemblage of organisms in the field of view changes the combined fluorescence response will also vary. Additionally, the fluorescence response of a particular organism can change over time. And of particular importance, the phenomena of 'photochemical quenching' will seriously change the fluorescence response from an organism. An organism that has been exposed to sunlight will have a greatly reduced (up to 70%) fluorescence response, compared to the same organism that has not been exposed to sunlight. Sample calibration techniques (such as that outlined above) need to take this into account. It is considered that in-situ light levels below 70 uE will reduce, but not eliminate, the photochemical quenching problem. Phytoplankton cells must be kept in the dark for a minimum of 30 minutes to become fully dark adapted, and only this full dark adaptation will give the best relationship between extracted chlorophyll a and fluorescence.

Backscatter Turbidity Sensors

Turbidity sensors can give a different set of issues.

Turbidity sensors are calibrated by applying a series of solutions with different turbidities to the sensor being calibrated. Generally the series of solutions is made up using formazin to create the turbidity signal. Instruments calibrated in this way are able to provide an output that reads in "Nephelometric Turbidity Units" or NTU. Similarly to fluorometers, the instruments themselves are reasonably stable, and the calibration to NTU does not change markedly over time.

However there are at least two issues which need to be considered when using turbidity sensors. The first is that they are calibrated to NTU, and this is not directly related to any physical properties of a sample later measured by the sample. The relationship between the sample properties and the value in NTU are affected by difference in the size, reflectivity, refractive index, and shape of the particles in the sample, and often these parameters will be different to that of the Formazin that was used to calibrate the turbidity in the laboratory.

The second consideration is that backscatter turbidity sensors from different manufacturers (or even sometimes different models from the same manufacturer) may have a different response to suspended material in the field. To illustrate; say two different models of turbidity sensor both read 100 in a 100 NTU reference solution, and also 50 in the 50 NTU reference solution. However it is probable that when placed in a sample that contains an amount of environmental suspended material, one may read 45 and the other 53. This discrepancy will be caused by a variety of factors, including different optics between the instruments, different nephelometric angles used, and/or differing light source characteristics. While the numbers obtained are different, neither is necessarily wrong. The difference is caused by the fact that the instruments are calibrated to read NTU, and the backscatter response of environmental suspended material can be different to the response of formazin.

Appendix B. Calibration of Dissolved Oxygen Sensors

Aanderaa Optode

Aanderaa have a policy of not undertaking a calibration of each optode sensor. Instead, a calibration is undertaken on one sensor that is typical of the batch of similar sensors. This batch calibration is then supplied for all of the sensors within that batch.

The ramification of this is that the calibration is not optimal for each individual sensor in the batch, as there are inter-sensor variability that is not covered in the batch calibration. Because of this, the uncertainty of an Optode sensor fresh from Aanderaa is given as:

Accuracy = ±8 uM/kg or 5% (whichever is greater)

The reason that Aanderaa follows this policy is that the calibration process is complex, time consuming and therefore expensive, and they judge that the batch calibration provides a majority of their clients with a suitable data quality, at a significant cost benefit.

The optode sensor itself is however capable of achieving much higher accuracy if it is calibrated precisely. There are a number of researchers who require this higher accuracy data, and therefore some groups will calibrate the sensors after delivery. If this process is followed, the uncertainty can be reduced to around:

Accuracy = ± 0.4uM/kg

We do not have sufficient information on the long term stability of the optode calibration to make an informed comment as to sensor drift. Data from the comparison with HOTS data indicate that both the SBE43 and the Optode agreed well, with drift rates that were arguably similar. On the basis of this limited evidence, it is proposed that the drift rate of a calibrated optode be considered to be similar to the SBE43, at 2% per annum. This value can be refined once a representative dataset has been acquired.

Seabird SBE43

The SBE43 is a different technology to the optode. Seabird individually calibrate each SBE43 sensor prior to despatch.

The stated accuracy of the SBE43 is:

Accuracy = ± 2% of saturation + 2% drift per 1000 hours of operation.

There are reports of recalibration of SBE43 sensors that have been mounted on ARGO floats showing drift rates of 0.1% per annum.

References

Seabird Inc. Application Note AN64.
(http://www.seabird.com/application_notes/AN64.htm)

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

Appendix C. Recalibration Periods for Seabird Sensors.

This information has been gleaned from the last ten years of calibration history at the CMAR Calibration facility. In essence, conductivity sensors are often the sensor which drives the recalibration period, as they are the most susceptible to calibration shifts.

Temperature sensors

The facility has calibrated a range of Seabird sensors, including SBE3, SBE19, SBE19+, SBE21, SBE37 and SBE39. In nearly every case, it is possible to provide a calibration with uncertainties less than ± 0.002 °C.

Examining the change in calibration values, it is apparent that the temperature calibration of an instrument shifts by less than 0.002 °C per annum. Additionally, the drift is highest in the first years of life of the sensor, and afterwards the drift rate reduces, to around 0.000 5 °C per annum. Usually the drift is of the form of an offset over the range of the sensor.

The accuracy of data acquired using an **SBE48** sensor needs to be considered in a different manner. This sensor is calibrated and in itself is accurate to ± 0.002 °C. However it is designed to be used as a "hull contact sensor". That is, rather than the sensor being in direct contact with the water that is being measured, it is mounted instead on the inside of the hull of a suitable ship, below the water line. In this manner it attempts to measure the water temperature through the vessel's hull plate. There are very good logistical reasons to follow this path, however the extra errors introduced by measuring through the ships hull can be quite large, and will vary from ship to ship. See *Sea Surface Temperature Sensors* on page 24 for more information.

Conductivity sensors

The facility has calibrated SBE4, SBE19, SBE19+, SBE21 and SBE37 conductivity sensors. Conductivity sensors are more vulnerable (than Seabird temperature sensors) to calibration shifts occurring. This is mostly due to the reliance on strict dimensional stability of the internal conductivity cell. The internal volume of the cell can vary after use, due to factors such as slight bio-fouling or chemical coating on the borosilicate glass, or problems with the fouling on the electrodes. To minimise this, Seabird (and indeed other conductivity sensor manufacturers) go to lengths to reduce the susceptibility of conductivity sensors to bio-fouling.

Hence the calibration shift of a Seabird conductivity cell is dominated by its deployment history, rather than intrinsic electronics or sensor drift. A sensor that has been used in an area of minimal bioactivity will exhibit a minimum of drift, whilst a sensor that has been exposed for a lengthy period in a biological active area may experience a larger drift.

As the calibration shift is generally driven by dimensional change, the shift is usually proportional to the conductivity signal, rather than an offset.

It is difficult to precisely quantify the magnitude of possible calibration drifts. Drift rates have been observed to range from 0.005 S/m per annum for one instrument, down to 0.0001 S/m for another instrument. (Values at the 5 S/m calibration point). Generally the magnitude of the drift is towards the lower end of this range. Seabird provide estimated drift rates for their SBE4 cells of 0.0003 S/m per month, equating to 0.0036 S/m per annum. Discussions with technical staff at Seabird indicate that 95% of conductivity sensors fall well within this drift rate, but the remaining small percentage might exceed it. The usual factors behind instruments with high drift rates are related to difficult long deployments as moored instruments in high productivity locations, leading to bio-fouling driven calibration change.

Pressure Sensors

Seabird do not manufacture their own pressure sensors generally, but utilise a variety of pressure sensors from other specialised manufacturers. Hence the uncertainties for the pressure channels are based around the OEM specifications. The usual accuracies for strain gauge style sensors is ± 0.1% FS + 0.1% FS per annum. A quartz based sensor (Digiquartz) is available for some instruments. At a significant cost increase, these sensors offer improved accuracies of ± 0.02% FS + 0.025% FS per annum.

Seabird's integrated sensors

Seabird manufacture a number of products that are incorporated into instruments marketed by third parties. Of particular interest to IMOS are the SBE41 CTD package (used in ARGO floats, and gliders), and the CTD package that is used in the *Wetlabs* WQM product. These Seabird offerings perform similarly to other instruments in the Seabird range, (such as the SBE37), and recalibration information based on the SBE37 may be considered to apply to these integrated sensors as well.

Model	Instrument type	$T_{initial}$ °C	$T_{per\ annum}$ °C	$C_{initial}$ S/m	$C_{per\ annum}$ S/m	$P_{initial}$ % of FS	$P_{per\ annum}$ % of FS
SBE3	Temperature	±0.001	+0.002				
SBE4	Conductivity			±0.0003	+0.004		
SBE19+	CTD	±0.005	+0.002	±0.0005	+0.004	±0.1%	0.1%
SBE21	TSG (1)	±0.01 (1)	+0.002	±0.001	+0.004		
SBE37	Moored CTD	±0.002	+0.002	±0.0003	+0.004	±0.1%	0.05%
SBE39	Moored Temperature	±0.002	+0.002			±0.1%	0.05%
SBE38	Temperature	±0.001	+0.002				
SBE45	Micro TSG	±0.002	+0.002	±0.0003	+0.004		
SBE48	Temperature	±0.002	+0.002				
SBE911	CTD (2)					0.015%	0.02%

Table C.1 Published *Seabird* accuracies. (From *Seabird Inc.* datasheets)

Notes:

1. The relatively low accuracy of the SBE21 temperature reflects the normal requirement and installation of this instrument, where the sea temperature is usually measured with a remote temperature probe located in the inlet pipe at the vessel hull. The SBE21 temperature probe is used to convert in situ conductivity readings from the SBE21 into salinity readings.

2. The SBE911 is the highest quality CTD system offered by Seabird. This system has a built in pressure sensor for which the specifications are included in this table. The CTD system utilises external paired SBE3 sensors for measuring temperature, and external paired SBE4 sensors for measuring conductivity. The specifications for SBE3 and SBE4 sensors are described separately in this table.

Appendix D. Acronyms

AAD	Australian Antarctic Division
ADCP	Acoustic Doppler Current Profiler
AIMS	Australian Institute for Marine Science
ASIMET	Air-Sea Interaction METeorology
ATSR	Along Track Scanning Radiometer
AUV	Autonomous Underwater Vehicle
AVHRR	Advanced Very High Resolution Radiometer
BoM	Bureau of Meteorology
CDOM	Chromophoric (or Coloured) Dissolved Organic Matter
CMAR	CSIRO Marine and Atmospheric Research
CMST	Centre for Marine Science and Technology (Curtin University W.A.)
CPR	Continuous Plankton Recorder
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTD	Conductivity, Temperature, Depth (Oceanographic instrumentation)
DVL	Doppler Velocity Log
EAC	East Australian Current
GDAC	Global Data Assembly Centre
GODAE	Global Ocean Data Assimilation Experiment
GPS	Global Positioning System
GTS	Global Telecommunication System
GTSPP	Global Temperature-Salinity Profile Program
HOTS	Hawaii Ocean Time Series
IMOS	Integrated Marine Observing System
ISO	International Organization for Standardization

MODIS	Moderate Resolution Imaging Spectroradiometer
NCRIS	National Collaborative Research Infrastructure Strategy
NTU	Nephelometric Turbidity Units
NXIC	Non eXternal Inductive Conductivity sensor
PSU	Practical Salinity Units
QC	Quality Control
SCAR	Scientific Committee on Antarctic Research
SOOP	Ship Of Opportunity
TERSS	Tasmanian Earth Resources Satellite Station
TSG	ThermoSalinoGraph (Instrument used to measure temperature and salinity, usually installed on ships and recording continuously)
USBL	Ultra Short Base Line (underwater location system)
VOS	Volunteer Observing Fleet
WMO	World Meteorological Organization
XBT	eXpendable BathyThermograph (Ship based temperature profiling system)

Conclusion

While this document strives to be comprehensive, it is possible (due to the broad reach of IMOS and the number of people involved) that there are some IMOS elements that have been overlooked. I apologise if this is the case. Additionally, the nature of uncertainty and accuracy can be an inexact study, particularly in fields where there is limited information on long term calibration stability. Therefore there may be aspects of this document that will provoke discussion.