Quality Assurance and Quality Control by Variable

Summary

This is a working document designed to summarise the current status of quality assurance and quality control (QA/QC) procedures across IMOS from the perspective of the ocean variables we are measuring. This has not been done before now, and it is expected to take some time to complete (hence the description as a 'working document'). For the purpose of this document, QA and QC are defined according to the IODE Quality Management Framework (2013). QA is the quality management that is focused on providing confidence that quality requirements will be fulfilled and involves the systematic monitoring and evaluation of the processes associated with the generation of a product or service. QC is defined as the process of monitoring the output of quality assurance activities to improve products and services so that quality requirements and/or standards are met.

The purpose of this document is to highlight gaps, identify priorities, and to provide an evidence base for use by the IMOS community in considering whether or not the QC procedures that we have evolved are as effective and efficient as they need to be for a sustained observing system.

This document includes:

1. An Introduction which explains the background to variables being measured within IMOS and platforms and technologies being used.

2. A section on International Context, covering
   2.1 Essential Ocean variables (EOVs) in the Global Ocean Observing System (GOOS)
   2.2 QC within the relevant global networks (e.g. Argo)
   2.3 The International Quality controlled Ocean Database (IQuOD) project, and
   2.4 The US-IOOS Quality Assurance of Real-Time Ocean Data (QARTOD) project.

3. A summary of the current QA/QC procedures of IMOS variables

4. Appendices with a table indicating the existence of written protocols (A1), a summary table of key issues and recommendations per variable (A2), and a list of acronyms (A3).

General points emerging from this review include:

1) QA/QC across IMOS facilities per variable is inconsistent (after taking into account sensor type and instruments), particularly when there are several facilities (and organisations) undertaking QC using different standards.

2) Some facilities used different Quality Flags (QF) for the same variable (i.e. SST).
3) The lack of a written document outlining QA/QC protocols in some facilities makes it very difficult to understand and assess their QA/QC processes. This includes QC procedures that have their methodology in several peer reviewed papers but is not compiled into a single document. (See table in Appendix 1).
4) Calibration of sensors is inconsistent, with similar sensors sent to different places for their calibration.
5) For some facilities (e.g. gliders) manual QC is lost when data is re-processed, and becomes a time consuming exercise to re-do.
6) Data from additional sensors used in some facilities (e.g. SOTS velocity and acoustic data) has not been delivered to AODN and discussion is needed if these data are to be available through the AODN.
7) Some EOVs need analysis of data to obtain data on an EOV (passive and active acoustics).
8) Some near real time (NRT) data is not QC'd with some variables having little to no QC (waves)
9) QC for some facilities (biologging) is outsourced to partner organisations
10) Visual validation done of the automated/semi-automated QC from the Matlab toolbox by Facilities/subfaciltities that use it needs improvement.
11) New QA/QC procedures have been developed or are being developed by some facilities and are leading in their field (Acoustic tracking, Autonomous Underwater Vehicle imagery, Radar)
12) Centralisation for the QA/QC of some variables, such as nutrients and phyto-zooplankton has worked well, ensuring all data are treated the same and facilitating the identification of issues.

The review suggests the following recommendations:

- That all facilities without a written protocol produced one that includes the QA/QC procedures for all variables derived from this facility. The protocol will be made available on the IMOS or the AODN website so they can be easily accessible.
- The possibility of centralising QA/QC for some variables should be discussed as a way to solve inconsistencies in the data sets, such as sensor based observations from moorings and SOOP.
- Publication of the data in a peer review journal (such as the phytoplankton and zooplankton databases) is good practice and should be encouraged. This gives confidence in the data and also opens the opportunity for non-IMOS data contributions.
- Implementing and developing a set of standard automated test similar to QARTOD for near real-time QC could be a good approach for NRT data streams not currently QC'ed and in general
- Availability of the calibration results from sensors through the AODN website, and the addition of target accuracies, error estimates per measurement (particularly needed for the reanalysis/data assimilation community), uncertainty flags and the elimination of biased errors where possible will improve confidence
- Given we now have more than 7 years of experience with various sensors and combined with a rich history of calibration stability and sensor issues from the IMOS community

updating the document "IMOS Data Streams and their Uncertainties" to incorporate knowledge learnt form practical experience will be very valuable.

- Defining a more rigorous process to get user feedback, which will help improve our systems
- A written report of results from some Task Teams (TT) such as the O2, radiometry and acoustic tracking TT's are essential and expected. They represent important steps to improve our QA/QC procedures for those variables.

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1. Introduction

IMOS is funded by Australian Government as a national collaborative research infrastructure. As such its requirements have been set by the scientific community. Science and implementation plans were written to set out the rationale for measuring particular variables at particular time and space scales in particular places. These plans then informed investment in a portfolio of observing platforms and technologies to take the required observations. IMOS science and implementation plans have been refined and developed over the years in response to changing socio-economic drivers, new scientific knowledge, and technological development. All plans were subject to international peer review in 2009-10. There is a single national plan supported by six more detailed plans for the open ocean and five sub-regions collectively covering Australia's shelf and coastal oceans. The full package of documentation (650 pages in total) can be found here.

Development of IMOS science and implementation plans from 2009 to present has been concurrent with revitalisation of the Global Ocean Observing System (GOOS) since the Ocean Obs'09 conference. In particular, the Framework for Ocean Observing has strongly influenced IMOS science and implementation planning in terms of defining requirements, assessing 'readiness', and focusing on essential ocean variables (EOVs).

The process of developing and refining science questions under major themes of research has led to IMOS observing 30 variables, of which 21 are directly measured, 4 are derived measurements, 3 are relative estimates and 2 could potentially be derived – see Table 1. These variables are being observed/estimated using 26 different platforms and technologies (called Facilities within IMOS) – see Table 2.

Many variables are measured by multiple Facilities (up to 18 for temperature), whereas some are measured by only one (e.g. nekton biomass). Virtually all Facilities measure multiple variables (up to 17 at National Reference Stations). This multi–use approach is seen to be a strength of IMOS as it increases both scientific effectiveness and operational efficiency.

Because of the way in which IMOS was developed, QC is largely done by Facility and the organisation that hosts the Facility. Over the years there has been discussion as to whether or not this is the most effective and efficient approach, and it is now time to focus on this issue at the whole-of-program level. The physics, biogeochemistry, and biology & ecosystems panels of GOOS are placing significant emphasis on the identification and specification of EOVs (see next section). So the timing is good from this perspective. Other international efforts referenced will include:

- QC within the relevant global networks (e.g. Argo)
- The International Quality Controlled Ocean Database (IQuOD)
- The US-IOOS Quality Assurance for Real Time Oceanographic Data (QARTOD) project.

As a first step, this report documents current QC procedures by variable (i.e. cross-Facility).

The Australian Ocean Data Network AODN Ocean Portal enables discovery, access and downloading of data by parameter (physical, chemical, biological), and is now backed by a controlled vocabulary service. It will be important for IMOS to ensure that work on EOVs is synchronised with the parameter vocabularies.

Table 1: The variables required to address key science questions across IMOS.

Science themes	Variables	Sea Surface Temperature	Subsurface Temperature	Subsurface Salinity	Surface/subsurface currents	Sea Surface Height	Sea State (wave parameters)	Ocean surface vector stress (wind parameters)	Heat flux/radiation	Dissolved oxygen	Carbonate System (pCO2)	Carbonate System (pH)	Carbonate System (TIC)	Suspended particulates (TSS)	Carbonate System (Alkalinity)	Macronutrient concentration	Chlorophyll a/ fluorescence	CDOM	Phytoplankton species	Phytoplankton Biomass	Zooplankton Species	Zooplankton Biomass	Nekton Species	Nekton Biomass	Top Predators species	Top predators – population	Benthos (% coverage of species)	Detritus (flux)	Ocean Colour	Primary productivity
Multidecadal Ocean Change	Global Energy Balance	■	■	■	■	■		■	■																					
	Global Hydrological Cycle	■	■	■	■	■			■																					
	Carbon Budget	■	■	■	■			■	■	■	■	■	■	■	■	■	■	■	■	■		■		■				■	■	■
	Global Circulation	■	■	■	■	■		■		■																				
Climate Variability and Weather	Inter-annual (ENSO, IOD)	■	■	■	■	■		■	■	■	■																			
	Intra-seasonal (MJO, Cyclones, ECL's)	■	■	■	■	■		■	■	■	■																			
Boundary Currents and Inter-basin Flows	Fluxes (Mass, Heat, Salt)	■	■	■	■	■		■																						
	Drivers	■	■	■	■	■		■																						
	Dynamics	■	■	■	■	■		■																						
Continental Shelf Processes	Eddy-Shelf interactions	■	■	■	■	■		■																						
	Upwelling/ Downwelling	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■									■	■
	Shelf Currents	■	■	■	■	■		■																						
	Wave Processes				■	■	■	■																						
Ecosystem Responses	Circulation and nutrient fluxes	■	■	■						■	■	■	■	■	■	■	■	■	■	■	■	■							■	■
	Productivity	■	■	■						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Trophic connections									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Distribution and abundance	■	■	■						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■

Table 2: How variables required to IMOS science questions are delivered by IMOS facilities. Blue = directly measured variable; Red = derived variable; Orange = could be derived; Green = relative estimate.

How facilities deliver variables across IMOS		Sea Surface Temperature	Subsurface Temperature	Subsurface Salinity	Surface/subsurface currents	Sea Surface Height	Sea State (wave parameters)	Ocean surface vector stress (wind parameters)	Heat flux/radiation	Dissolve oxygen	Carbonate System (pCO2)	Carbonate System (pH)	Carbonate System (TIC)	Suspended particulates (TSS)	Carbonate System (Alkalinity)	Macronutrient concentration	Chlorophyll a/ fluorescence	CDOM	Phytoplankton species	Phytoplankton Biomass	Zooplankton Species	Zooplankton Biomass	Nekton Species	Nekton Biomass	Top Predators species	Top predators – population	Benthos (% coverage of species)	Detritus (flux)	Ocean Colour	Primary Productivity
	Argo	Blue	Blue	Red	Red	Orange				Blue																				
Ships of Opportunity (SOOP)	XBT	Blue	Blue																											
	Sea Surface Temperature	Blue																												
	Air-Sea Fluxes	Blue						Blue	Red																					
	Biochemistry (pCO2)	Blue		Red							Blue																			
	Cont. Plankton Recorder																Green		Blue	Green	Blue	Green								
	Bioacoustics																					Orange		Orange						
	Tropical RV/Temperate MV	Blue		Red													Red													
Deep water Moorings	Air-sea fluxes	Blue			Yellow		Blue	Blue	Red	Blue	Blue																			
	Deep water arrays		Blue	Red	Blue																									
	Southern Ocean Timeseries		Blue	Red			Blue			Blue			Blue	Blue	Orange	Blue	Red	Orange	Blue	Green		Yellow		Yellow				Blue		
Ocean Gliders	Seagliders	Blue	Blue	Red	Red					Blue					Orange		Red	Red												
	Slocum Gliders	Blue	Blue	Red	Red					Blue					Orange		Red	Red												
	Auto. Underwater Vehicle		Blue	Red	Orange												Red	Red									Red			

Table 2 cont: How variables required to IMOS science questions are delivered by IMOS facilities. Blue = directly measured variable; Red = derived variable; Orange = could be derived; Green = relative estimate.

How facilities deliver variables across IMOS		Sea Surface Temperature	Subsurface Temperature	Subsurface Salinity	Surface/subsurface currents	Sea Surface Height	Sea State (wave parameters)	Ocean surface vector stress (wind parameters)	Heat flux/radiation	Dissolve oxygen	Carbonate System (pCO2)	Carbonate System (pH)	Carbonate System (TIC)	Suspended particulates (TSS)	Carbonate System (Alkalinity)	Macronutrient concentration	Chlorophyll a/ fluorescence	CDOM	Phytoplankton species	Phytoplankton Biomass	Zooplankton Species	Zooplankton Biomass	Nekton Species	Nekton Biomass	Top Predators species	Top predators – population	Benthos (% coverage of species)	Detritus (flux)	Ocean Colour	Primary Productivity
Moorings	National Reference Stations	Blue	Blue	Red	Red		Blue	Blue		Blue		Orange	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue	Blue								
	Shelf Arrays		Blue	Red	Red		Blue			Blue																				
	Acidification Moorings	Blue		Red						Blue	Blue	Blue																		
	Passive Acoustics																								Orange	Green				
Ocean Radar	WERA				Red		Orange	Orange																						
	CODAR				Red																									
Animal Tagging	Acoustic Tagging																						Blue		Blue	Orange ?				
	Biologging	Blue	Blue	Red																					Blue	Orange ?				
	Wireless Sensor Networks	Blue	Blue	Red				Blue																						
Satellite Remote Sensing	Sea Surface Temperature	Blue																												
	Sea Surface Height				Red	Blue																								
	Ocean Colour															Blue	Red	Red	Blue	Red									Red	Orange
	Repeat Hydrography	Blue	Blue	Red	Red					Blue	Red	Blue	Blue	Blue	Blue	Blue	Red													
	Tide Gauges					Blue																								
	Wave buoys						Blue																							

2. International Context

2.1. Essential Ocean variables (EOVs) in the Global Ocean Observing System (GOOS)

In developing IMOS science and implementation plans there was good guidance available for open ocean physics via the ocean Essential Climate Variables (ECVs) of the Global Climate Observing System (GCOS). The International Ocean Carbon Coordination Project (IOCCP) and the former GOOS Panel for Integrated Coastal Observations (PICO) also provided guidance in their areas of focus. However, it is only very recently that the 'new' GOOS panels (which in concept cover physics, biogeochemistry, and biology & ecosystems, from open-ocean to coast) have begun defining a comprehensive set of EOVs in a systematic fashion. This is still very much a work in progress, but it may be useful to begin comparing this emerging set of EOVs with those being measured by IMOS and other GOOS Regional Alliances (e.g. US IOOS).

In the table below, the 30 IMOS EOVs have been compared with 11 GCOS physics ECVs (6 surface ocean, 2 surface atmosphere and 3 sub-surface ocean) now being reviewed by the Ocean Observations Panel for Climate (OOPC), the 8 EOVs identified by IOCCP with its broadened biogeochemistry mandate, and the 7 'first cut' biological EOVs identified by the newly formed Biology & Ecosystems panel.

GOOS Panel EOVs (11+9+7 = 27)	**IMOS EOVs (29)**
Physics Panel/OOPC	
1. Sea surface temperature (SST)	1. Sea Surface Temperature
2. Sea surface salinity (SSS)	*(gap just starting to be addressed)*
3. Sea surface height	2. Sea Surface Height *(tide gauge network sits outside IMOS)*
5. Sea state (Significant wave height, wave period, wave direction, maximum wave height, swell, directional spectrum, whitecap fraction)	3. Sea state (wave height, spectrum, period)
6. Sea ice	*(identified gap)*
7. Surface currents	5. Surface currents
8. Ocean surface vector stress (Equivalent neutral winds, stress equivalent neutral winds, scalar stress)	6. Ocean surface vector stress (Wind parameters: velocity and stress)
8. Heat flux/radiation	7. Heat flux/radiation
9. Subsurface temperature	8. Subsurface temperature
10. Subsurface salinity	9. Subsurface salinity
11. Subsurface currents	10. Subsurface velocity
BGC Panel/IOCCP	
1. Dissolved Oxygen	11. Dissolved oxygen
2. Inorganic macro nutrients	12. Macronutrient concentration
3. Carbonate System (DIC, Total Alkalinity, pCO2, pH (at least 2 of 4))	13. Carbonate system (pCO2, pH, alkalinity, TIC)
4. Transient tracers	
5. Suspended particulates (POM, POC, PON, POP, PIC)	17. Suspended particulates (PON, POC, PIC, TSS)
6. Nitrous oxide	
7. Carbon isotope	
8. Dissolved organic carbon	18. CDOM
9. Ocean Colour	19. Ocean colour
	20. Chlorophyll fluorescence

Biology & Ecosystems Panel	
1. Phytoplankton biomass and diversity (Presence/Absence/Relative Abundance, Diversity/Taxonomy ,Genomic information, Pigment concentration (chlorophyll a, b, HPLC pigments), Spectral reflectance (ocean color, Primary productivity) (different methods)	21. Phytoplankton biomass and diversity (Relative Abundance, Taxonomy , Pigment concentration (chlorophyll a, b, HPLC pigments), Spectral reflectance (ocean color, Primary productivity) (different methods)
2. Zooplankton biomass and diversity	22. Zooplankton biomass and diversity
3. Marine turtles, birds, mammals abundance and distribution	23. Top Predators species 24. Top predators – population
4. Live coral cover	*(AIMS Long Term Monitoring Program)*
5. Seagrass cover	25. Benthos (% coverage of species)
7. Macroalgal canopy	(Benthos see above)
6. Mangrove cover	*(not currently in scope for IMOS)*
7. Fish abundance and distribution	26. Nekton Species 27. Nekton Biomass
	28. Detritus (flux)
	29. Primary Productivity

This simple comparison indicates that, at first glance, 22 of 29 IMOS EOVs are consistent with those emerging from the panels.

IMOS is not currently observing eight of the 27 emerging GOOS EOVs. Some of these differences are identified gaps, some are deliberate positioning around other programs or are currently out of scope, and some provide food for thought about future priorities. Not too much should be read into the Biology & Ecosystems EOVs at this stage as they are very preliminary.

The work being done on EOV specification by the GOOS panels will be very helpful in this context. IMOS may also be able to contribute to the work of the panels as we have built up some very substantial data collections in areas where EOVs are just being defined or are under consideration. These data holdings may prove useful in testing the utility of candidate EOVs.

2.2. QC within the relevant global networks (e.g. Argo)

From inception, IMOS was designed to contribute to and benefit from the Global Ocean Observing System (GOOS), and many of the facilities operated by IMOS are embedded and contribute data to important global networks. The table below indicates the IMOS facility and the global network to which it contributes.

IMOS Facilities/Sub-Facilities		Relevant global networks
Argo		Argo
Ships of Opportunity (SOOP)	XBT	Ships Observations Team (SOT)
	Sea Surface Temperature	Group for High Resolution Sea Surface Temperature (GHRSST) Shipboard Automated Meteorological and Oceanographic System Initiative (SAMOS)
	Air-Sea Fluxes	Shipboard Automated Meteorological and Oceanographic System (SAMOS)
	Biochemistry (pCO2)	Surface Ocean CO_2 Atlas (SOCAT), Global Ocean Acidification Observing Network (GOA ON)
	Cont. Plankton Recorder	Sir Alister Hardy Foundation for Ocean Science (SAHFOS), Southern Ocean CPR (SO-CPR), Global Alliance of CPR Surveys (GACS)
	Bioacoustics	CLimate Impacts on Oceanic TOp Predators (CLIOTOP)
	Tropical RV/Temperate MV	iQAM
Deep water Moorings	Air-sea fluxes	OceanSITES
	Deep water arrays	OceanSITES
	Southern Ocean Time series	OceanSITES, The International Ocean Carbon Coordinating Project (IOCCP)
Ocean Gliders	Seagliders	Everyone's Gliding Observatories (EGO)
	Slocum Gliders	Everyone's Gliding Observatories (EGO)
Auto. Underwater Vehicle		N/A
Moorings	National Reference Stations	N/A
	Shelf Arrays	N/A
	Acidification Moorings	Global Ocean Acidification Observing Network (GOA ON), Surface Ocean CO_2 Atlas (SOCAT)
	Passive Acoustics	N/A
Ocean Radar	WERA	Group on Earth Observation, GEO Global High Frequency (HF) Radar Network Component
	CODAR	Group on Earth Observation, GEO Global High Frequency (HF) Radar Network Component
Animal Tagging	Acoustic Tagging	Ocean Tracking Network (OTN)
	Biologging	Marine Mammals Exploring the Oceans Pole to Pole – MEOP, Sea Mammal Research Unit – SMRU, Southern Ocean Observing System – SOOS, Ocean Tracking Network – OTN

Wireless Sensor Networks		Coral Reef Ecological Observation Network (CREON)
Satellite Remote Sensing	Sea Surface Temperature	Group for High Resolution SST (GHRSST)
	Sea Surface Height	AVISO Satellite Altimetry Data
	Ocean Colour	International Ocean Colour Coordinating Group (IOCCG)

Other useful resources that could inform IMOS include SeaDataNet, Copernicus Marine Environment Monitoring Service and others.

2.3. International Quality controlled Ocean Database (IQuOD)

The objective of IQuOD is to construct a climate-quality ocean temperature database (later moving to other variables), with a consistent quality control (QC) standard. The database will be continually updated into the future – see http://www.iquod.org/index.php/home

The IQUOD project members will initially refine and agree on a common set of QC methods and apply them to the historical database (all records that are publicly available). IQuOD Member countries/organisations are pooling resources to apply these QC methods to historical archives being assembled, duplicate checked and labelled with errors. The hope, once the historical archive is assembled, is to continue adding to the database into the future.

The 'IQUOD standard' database, with consistent quality control that is continually updated, will be invaluable for data assimilation, anthropogenic warming estimates, ocean heat content and sea level change estimates.

2.4. The US-IOOS Quality Assurance of Real-Time Ocean Data (QARTOD) project

The key objective of QARTOD is to sustain a process for establishing QA/QC procedures that will:

- Establish authoritative QA/QC procedures for 26 of the **U.S. IOOS core variables**, as necessary, including detailed information about the sensors and procedures used to measure the variables
- Produce written manuals for these QA/QC procedures
- From the list of individual QA/QC procedures and guidelines developed, define a baseline set of QA/QC procedures that can be used for certification of RCOOS data providers
- Facilitate QA/QC integration with Global Ocean Observing System (GOOS) and other international ocean observation efforts
- Engage the Federal Agencies and IOOS Regions that are part of, contribute to, US IOOS who will use the established QA/QC procedure
- Work efficiently, without duplication of effort, to facilitate the implementation of common QA/QC procedures amongst US IOOS Partners.

Real-Time Quality Control Manuals have been produced for:

- Real-Time Quality Control of Dissolved Nutrients Observations
- Real-Time Quality Control of Wind Data
- Real-Time Quality Control of Water Level Data
- Real-Time Quality Control of In-Situ Surface Wave Data
- Real-Time Quality Control of Ocean Optics Data
- Real-Time Quality Control of High Frequency Radar Surface Current Data
- In-situ Temperature and Salinity Data
- Dissolved Oxygen Observations in Coastal Oceans
- In-Situ Current Observations

Other QARTOD Quality Control Manuals

- Manual for Oceanographic Data Quality Control Flags

3. Current status of QC in IMOS variables

The following tables show the QA/QC procedures used per variable by the different IMOS facilities. Colours used in the tables shown in the following sections have the same meanings as in Table 1 i.e.

Blue = directly measured variable;

Red = derived variable;

Orange = could be derived;

Green = relative estimate.

1. Sea surface temperature

2. Sub surface temperature

These variables include near-real time data and delayed mode data and different levels of QC are applied.

		Sea surface temperature	Subsurface temperature	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Argo				Argo Quality Control Manual for CTD and Trajectory Data, includes near real-time tests. . Global OI mapping done by the GDACs help identify major sensor faults within 2-3 days.	Argo Quality Control Manual for CTD and Trajectory Data. Rigorous QC by experts. Data are eligible for DMQC after 12 months.	Sensors are compared to ship-based hydrographic and nearby recently deployed float data to diagnose any sensor drift and offsets on delayed mode QC. Consistency with satellite altimetry is checked regularly to detect sensor drifts.	Follows international convention
Ships of Opportunity (SOOP)	XBT			Automated test of similar scope to Argo, independent from the Cook book	Follows CSIRO's Quality Control Cook book for XBT (report 221)	Several processes used as described in the Cook book	The Cook book is used for Australia, and for a subset of data run on the lines that fall under the SOT network. There are many other XBT data (Navy data) that do not get QC'd – hence the need or an ongoing iQUOD type activity

		Sea surface temperature	Subsurface temperature	QC procedures near-real time	QC procedures delayed mode	QA	Comments
	*Sea Surface Temperature			Automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	There is no delayed mode QC. Manual QC was performed prior June 2013. Manual QC involved: visual inspection using the IDL program samos_vidat_v002.pro (/flurry/home/rverein/IMOS_QC/) to review of flags assigned by the automated QC system and for visual data examination to ensure the data consistency	Documented at http://imos.org.au/sst_data.html and in Beggs et al. (2012) and http://imos.org.au/sst_instrumentation.html Hull contact temp SBE 48 sensor tested when installed. SBE 48 sensors calibrated every 2-3 years and calibration coefficients entered into instrument access programs. SBE 38 sensors calibrated yearly. Biases differ according to vessels, location of sensor, etc. The RV Investigator ISAR has been compared with 33 other ship-borne SST radiometers, and its calibration blackbody compared to the NPL reference blackbody,	• SAMOS QC slightly modified to fit BOM purposes, applied once for near-real time with no further QC. BOM own QC flags are used. • Independent routine QC/QA of the IMOS ship SST observations is performed by NOAA/NESDIS using their on-line In Situ Quality Monitor (iQuam2).
	*Air-Sea Fluxes			Automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	There is no delayed mode QC. Manual QC was performed prior June 2013	No information provided but in "IMOS Data Streams and their uncertainty document" suggests yearly with radiometer maintained daily	QC based on SAMOS but slightly modify to fit BOM purposes, applied once for near-real time with no further QC. They use their own QC flags
	Biochemistry (pCO2)			No near-real time QC	QC at CSIRO by Marine National Facility for R/V Investigator and the IMOS facilities own protocol	Calibrated yearly, accuracy given in pCO2 QC protocol, although no QC manual is produced by MNF	QC procedure from MNF is robust, however, there is no written protocol for QC of this and other environmental variables
	*Tropical RV/Temperate MV			TRV Basic QC done that is automated and includes range of acceptable/non-acceptable values TMV has its own QC by Vic EPA.	TRV: No extra delayed mode QC TMV: delayed mode QC includes calibration offsets (sensor to sample), and sensor drifts due to bio-fouling	TRV: Sensors re-calibrated every year by manufacturers. Uncertainty values provided by manufacturers, with allowances for sensor drift. Compare underway system data with CTD samples, TMV: Annual calibration in CSIRO, monthly servicing of equipment, other procedures outline in their protocol	TRV: BoM also QC the TRV data using their own system but the data is only deliver to GTS for BoM purposes. TMV: Very clear and detailed protocol

		Sea surface temperature	Subsurface temperature	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Deep water Moorings	Deep water arrays			N/A	Processing and quality control of the data are completed using Matlab routines developed in CSIRO, with some routines aligned with the IMOS toolbox and sharing the same algorithms. Data are also visually inspected by experts during the process and before submission of data.	Immediately after retrieval of each mooring, Seabird, Star Oddi, and some Nortek DW Aquadop instruments are placed in a well-mixed calibration bath on board the ship	
	Southern Ocean Timeseries			N/A	CSIRO QC which aligns with WOCE protocols.	Calibration before and after	No detailed protocol, all in peered review papers and others
Ocean Gliders	Seagliders			No near-real time QC	QC through automated standard tests. Has written protocol on the treatment of data	Calibration after one year deployment Calibration and other pre-processing and corrections applied to data	
	Slocum Gliders			No near-real time QC	QC through automated standard tests. Has written protocol on the treatment of data	Calibration after one year deployment, Calibration and other pre-processing and corrections applied to data	
Auto. Underwater Vehicle				N/A	No QC		Environmental data are not QC

		Sea surface temperature	Subsurface temperature	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Moorings	National Reference Stations			Near real-time (NRT) data only available in Maria Island (MAI), North Stradbroke Island (NSI), Yongala (YON), and Darwin (DAR) NRS. Some of the relevant IMOS toolbox routines are implemented in NRT at YON and DAR	Data QC using IMOS Matlab toolbox and CTD uses the IMOS guidelines as well. QC is mostly automated and semi-automated, supervised (tuned / validated) by a technician (only rarely by an expert in oceanography). See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series	Annual calibration Monthly CTD checks and water sampling collected	Issues with lack of validation of automated QC from Toolbox has resulted in some bad data not being flagged. This relates to data from WQM Calibration of sensors have been performed either locally, at the CSIRO facility or at the manufacturers, and is dependent on the needs and sub-facility. According to new definitions of SST, 5-10m temperature is regarded as “foundation” SST. Most moorings only measure temperatures below 20 m, and none measure the skin SST. Buoys that usually measure within the top 1m (Yongala, Darwin & Beagle)
	Shelf Arrays			NRT data available only in QLD&NT. Automated QC done with own code that borrows from Matlab toolbox	Data QC using IMOS Matlab toolbox and CTD uses the IMOS guidelines as well. QC is mostly automated and semi-automated, supervised (tuned / validated) by a technician (only rarely by an expert in oceanography). See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series	Annual calibration Deployment and post-recovery CTD checks are made in a calibration bath.	Issues with lack of validation of automated QC from Toolbox has resulted in some bad data not being flagged. This relates to data from WQM Calibration of sensors have been performed either locally, at the CSIRO facility or at the manufacturer’s, and is dependent on the needs and sub-facility.
	Acidification Moorings			Automatic QC	Temperature corrected based on pre and post deployment calibrations, although no corrections have been necessary to date	Sensor calibrated pre and post-deployment at NATA test facility	

		Sea surface temperature	Subsurface temperature	QC procedures near-real time	QC procedures delayed mode	QA	Comments
	Biologging			No QC	Done by MEOP. A location AC will be implemented within IMOS in the near future	Done by MEOP	MEOP is doing the QC data. It includes a standard set of tests, adapted from Argo standard quality-control procedures, is first run to remove bad profiles, spikes, and outliers. Temperature and salinity adjustments are then determined, which vary from tag to tag, and they are applied identically to all profiles from a given tag
Wireless Sensor Networks				In house procedures, no protocol written. Automated QC and sometimes manual QC if there is something evidently wrong	N/A		QC done on a data stream by data stream basis by the facility (i.e. the hard and soft limits vary for each data stream) with values are constantly tweaked during the manual QC.
Satellite Remote Sensing	Sea Surface Temperature			International Group for High Resolution Sea Surface Temperature (GHRSST) "GDS 2" file formats provide QC flags ("l2p_flags" and "quality_level") and uncertainty estimates ("sses_bias" and "sses_standard_deviation"). See http://imos.org.au/sstdata0.html.	International Group for High Resolution Sea Surface Temperature (GHRSST) "GDS 2" file formats provide QC flags ("l2p_flags" and "quality_level") and uncertainty estimates ("sses_bias" and "sses_standard_deviation"). See http://imos.org.au/sstdata0.html..	Satellite SST data is validated with drifting buoys, moorings, Argo and SOOP SST. See http://imos.org.au/sstdata_validation.html. Gridded data are provided at quality level 2 (worst),3, 4 and 5 (best) based on GHRSST guidelines. See http://imos.org.au/sstdata0.html .	

It is important to consider the spatial scale of the observations at which each platform measures this variable. Some platforms observe throughout the water column, other ones at one point in the water column, and others only at the surface.

Key points:

1. Sub-facilities follow their own protocol for QA/QC, with few linked to international programs (e.g. Argo, XBT)
2. Some QA/QC procedures are more robust than others, with some facilities not doing any QC (AUV) for this variable.
3. QC for some facilities (biologging) will be/is outsourced
4. Most of the moorings (shelves, deepwater and NRS) use similar QC procedures that include or are aligned to the IMOS toolbox

5. SST from ships of opportunity has different QC applied, depending on the agency processing the data, i.e. BoM will do an automated QC and apply its own QC flagging system while AIMS TRV will do basic QC and apply the IMOS QC flags.
6. Some near real-time data is not QC (e.g. gliders, some moorings, some SOOP BGC)
7. While there are some facilities with written protocols, there are many that don't.

Issues:

1. QC results produced by the toolbox need visual validation by the NRS and Shelves moorings sub-facilities in order to avoid bad data not being flagged.
2. A separate issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, however, this is being corrected.
3. The consistency of the QC'ed SST data from the different vessels (SOOP SST, TMV, TRV and SOOP BGC) is variable, including the QF (quality flags). This can lead (has led) to some confusion from people downloading and using the data. Additionally, there is variation in the temporal frequency of the data delivered, with TMV facility delivering data at very high temporal frequencies (1 second) in comparison to other SST data from BOM (SOOP SST) or AIMS (TRV) (10 seconds).
4. While there are written protocols for some facilities, it does not include the QA/QC of all the variables derived from the facility as this is dependent of the organisation that performs the QC. For example, SOOP BGC has a written protocol for the BGC variables but there is no written documentation on the MNF QC protocol for the physical variables from this facility. This is being corrected.
5. There is currently limited knowledge within IMOS of the QC work performed at MEOP, there is a preliminary strategy in place should MEOP stop QC'ing the biologging data, but this needs to be fully formed.

Recommendations

1. The Australian National Mooring Network Steering Committee (ANMN SC) has agreed to re-process the relevant mooring datasets and improve the QC performed on them. There needs to be improvement on the visual validation of Toolbox QC results as well as more guidance and agreement on a standard use of the Toolbox. A task team (TT) will be proposed to develop a document that would try to describe a consistent methodology on how to QC a mooring dataset with the toolbox.
2. Centralising the calibration of sensors, where possible, will be a good strategy for consistency in the QA. In addition, documenting the process by the calibration provider is also needed.
3. It is important that all facilities have a written document on their QA/QC protocols and make them available. This will facilitate the querying of the QA/QC procedures and give users confidence in the data.
4. The AODN is currently harvesting the MEOP QC data (which includes IMOS), some thought should be given if the outsourcing of the QC is the best strategy for IMOS regarding the QA/QC of these data sets, and some involvement from IMOS should be discussed with MEOP.

5. Discussion is needed on how to handle the QA/QC and file formatting of the SST data from SOOP, TRV, NMF and TMV in order to provide a consistent data set that is not dependent on the agency that processes the data. Centralising the QC to one agency could be one way to solve this issue.
6. It would be beneficial to update the document “IMOS Data Streams and their Uncertainties” that reflects the current situation, sensors and processes

3. Sub surface salinity

		Subsurface Salinity	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Argo			Argo Quality Control Manual for CTD and Trajectory Data, includes near real-time tests	Argo Quality Control Manual for CTD and Trajectory Data. Rigorous QC by experts. Data are eligible for DMQC after 12 months. Where target accuracy is not achieved, the estimated accuracy is captured in the error fields for each observation. Salinity data with errors larger than 0.05 psu are deemed uncorrectible and are flagged as bad data.	Sensors are compared to ship-based hydrographic data and nearby Argo float data to determine if any sensor drift or offset occurs and it can be corrected through delayed mode QC. To identify drift and to permit the correction of the drift in the conductivity sensors, the conductivity data from the floats are compared to existing climatological databases, and compared to nearby floats. A thermal lag correction is also applied which is dependent on the CTD pump rate and float ascent rate.	Argo's target accuracy is 0.01 psu.
Ships of Opportunity (SOOP)	Biochemistry (pCO2)		No near-real time QC except on RTM Wakmatha where data go through range checking and have a QC procedure applied (e.g, ensuring adequate flow).	QC at CSIRO Marine National Facility for R/V Investigator and the facility's own protocol.	Calibrated yearly, accuracy given in pCO2 QC protocol, although no written QC manual is produced by MNF. However, Investigator sensor is maintained and checked regularly against calibrated CTD sensors and bottle samples. Aurora Australis and Wakmatha calibrated yearly, and checked against salinity samples.	No written protocol for QC of this and other environmental variables from MNF
	Tropical RV/Temperate MV		TRV Basic QC done that is automated and includes range of acceptable/non-acceptable values. TMV has its own QC by Vic EPA.	TRV: No extra delayed mode QC TMV: delayed mode QC includes calibration offsets (sensor to sample), and sensor drifts due to bio-fouling	TRV: Sensors calibrated every year by manufacturer. Uncertainty values provided by manufacturers, with allowances for sensor drift. Underway system data compared with CTD samples TMV: Annual calibration in CSIRO, monthly servicing of equipment, other procedures outline in their protocol	TRV: A new tool has been developed at AIMS to improve QC procedures, known as the Data Visualization and Quality Control tool. TMV: Very clear and detailed protocol
Deep water Moorings	Deep water arrays		N/A	Processing and quality control of the data is completed using Matlab routines developed by CSIRO, with some routines aligned with the IMOS toolbox and sharing the same algorithms. Data are also visually inspected by experts during the process and before submission of data.	Immediately after retrieval of each mooring, Seabird, instruments are placed in a well-mixed calibration bath on board the ship. Offsets and drifts are applied as needed, though this is rare with well prepared SBE37s'.	

		Subsurface Salinity	QC procedures near-real time	QC procedures delayed mode	QA	Comments
	Southern Ocean Timeseries		N/A	Facility's own procedure, aligned with WOCE protocols.	PSAL Derived from conductivity and temperature using EOS-80. SBE16 and SBE37Derived from Pressure, Temperature (IPTS68) and Conductivity using PSS 1978 equations.	
Ocean Gliders	Seagliders		No near-real e QC	Automated standard tests. Has written protocol on the treatment of data	Calibration after one year deployment, weight distribution and balance done in lab before every mission	
	Slocum Gliders		No near-real time QC	Automated standard tests. Has written protocol on the treatment of data	Calibration after one year deployment, weight distribution and balance done in lab before every mission	
Auto. Underwater Vehicle			N/A	No QC		Environmental data are not QC
Moorings	National Reference Stations		NRT data only available in MAI, YON, and DAR. Automated QC done in YON and DAR with AIMS code that borrows from Matlab toolbox. No automated QC on MAI and NSI	Data QC using IMOS Matlab toolbox and CTD uses the IMOS guidelines as well. QC is mostly automated and semi-automated, supervised (tuned / validated) by a technician (only rarely by an expert in oceanography). See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series	Calibration roughly once a year.	• There are issues with the WQM, which has been unreliable for many measurements including salinity (conductivity), although recently there has been an improvement in its performance, i.e. good comparison between bottle salinity and WQM measurements, as in published results of Feng et al. (2015). However, there is still a need to systematically assess this. • Issues with lack of validation of automated QC from Toolbox has resulted in some bad data not being flagged. This relates to data from WQM . • There has been issues with sub-facilities not keeping conductivity data, which will allow a better assessment on the data • Calibration of sensors have been performed either locally, at the CSIRO facility or at the manufacturer's, and is dependent on the needs and sub-facility.

		Subsurface Salinity	QC procedures near-real time	QC procedures delayed mode	QA	Comments
	Shelf arrays		NRT data available only in QLD&NT. Automated QC done with own code that borrows from Matlab toolbox	Data QC using IMOS Matlab toolbox and CTD uses the IMOS guidelines as well. QC is mostly automated and semi-automated, supervised (tuned / validated) by a technician (only rarely by an expert in oceanography). See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series.	Calibration roughly once a year	Same issues as above
	Acidification Moorings		Automated QC	QC at CSIRO using the facility's own protocol, with bottle samples (from NRS sampling) used to check the salinity calibrations and corrections applied where necessary.	Calibration pre and post-deployment	
Animal Tagging	Biologging		No QA/QC	Done by MEOP. A location AC will be implemented within IMOS in the near future	QA/QC to be done by MEOP	MEOP QC data includes a standard set of tests, adapted from Argo standard quality-control procedures, is first run to remove bad profiles, spikes, and outliers. Temperature and salinity adjustments are then determined, which vary from tag to tag, and they are applied identically to all profiles from a given tag
Wireless Sensor Networks			Own procedures, no protocol written. Automated QC and sometimes manual QC if there is something evidently wrong	N/A	Bounds checking using soft and hard limits. Checks against historical data where this is available Checks against reference sensors	QC done on a data stream by data stream basis (i.e. the hard and soft limits vary for each data stream) with values are constantly tweaked as we do the manual QC.

Key points:

1. Sub-facilities follow their own protocol for QA/QC, with few linked to international programs (e.g. Argo, XBT)
2. Some QA/QC procedures are more robust that others, with some facilities not doing any QC for this variable (AUV).
3. QC for some facilities (biologging) is outsourced
4. Most of the moorings (shelves, deepwater and NRS) use similar QC procedures that include or are aligned to the IMOS toolbox
5. Some near real-time data is not QC (gliders, some moorings, some SOOP BGC)
6. While there are some facilities with written protocols, there are many that don't.

Issues:

1. QC results produced by the toolbox need visual validation by the NRS and Shelves moorings sub-facilities in order to avoid bad data not being flagged.
2. A separate issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, however, this is being corrected.
3. Some ANMN sub-facilities did not extract the raw conductivity data (from which salinity is derived) to make sure spikes are not an instrument issue, the data will be re-processed to add it
4. There is a general lack of information on the calibration results.
5. Some protocols indicate the calculations used to derive salinity, while many do not state it.
6. While there are written protocols for some facilities, it does not include the QA/QC of all the variables derived from the facility as this is dependent of the organisation that performs the QC, i.e. SOOP BGC has a written protocol for the BGC variables but there is no written documentation of the QC protocol undertaken by MNF for the physical variables for this facility
7. There is currently limited knowledge within IMOS of the QC work performed at MEOP, there is a preliminary strategy in place should MEOP stop QC'ing the biologging data, but this needs to be fully formed.

Recommendations

1. The Australian National Mooring Network Steering Committee (ANMN SC) has agreed to re-process the relevant mooring datasets and improve the QC performed on them. There needs to be improvement on the visual validation of Toolbox QC results as well as the use of the Toolbox. A task team (TT) will be proposed to develop a document that would try to describe a consistent methodology on how to QC a mooring dataset with the toolbox.
2. Centralising the calibration of sensors, where possible, will be a good strategy for consistency in the QA. In addition, documenting the process by the calibration provider is also needed to improve confidence in the data
3. It would be highly beneficial for all facilities to have a written protocol and make them available. This will facilitate the querying of the QA/QC procedures and give users confidence in the data.
4. The AODN is currently harvesting the MEOP QC data (which includes IMOS), some thought should be given if the outsourcing of the QC is the best strategy for IMOS regarding the QA/QC of these data sets, and some involvement from IMOS should be discussed with MEOP. Similar to ANMN, conductivity needs to be stored if reprocessing is needed in the future.
5. It would be beneficial to update the document "IMOS Data Streams and their Uncertainties" that reflects the current situation, sensors and processes

4. Surface/subsurface currents

		Surface/subsurface currents	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Argo	Argo		Position data are QC'd as per Argo manual	Consistency is checked with float timing information and past positions	Limited to date, largely through global synthesis products.	Average velocity is derived from float dive and surfacing positions. Change of sat localisation from Service Argos to GPS has seen a major accuracy increase.
Deep water Moorings	Deep water arrays		N/A	QC of the ADCP data (equivalent to the application of the IMOS Teledyne QC procedures). These tests examine the diagnostic variable output from the RDI ADCP instruments (echo amplitude, correlation magnitude, percent good, error velocity and velocities). The IMOS side---lobe test is also applied. Data are also visually inspected by experts during the process and before submission of data.	Inter comparison with other instruments, ocean models and surface currents are used to verify the acoustic measurements. Several parameters are looked at to ensure the heads are working during deployment ADCP are currently not calibrated, though generally tidal analyses can be used to identify any major amplitude or direction drifts; interbeam and correlation information allows single beam failures to be detected.	Undertake their own QC but it is aligned with IMOS QC toolbox.
Ocean Gliders	Seagliders		Not Qc	UCUR and VCUR are depth-mean velocities of the seawater over all the water that the glider travels through between surfacing. The values are approximate estimates derived from engineering parameters.	Velocity estimation calculated using the two GPS positions taken after the glider resurfacing	These current estimations are not very accurate because their calculation relies on many simplifications and assumptions
	Slocum Gliders		Not QC	UCUR and VCUR are depth-mean velocities of the seawater over all the water that the glider travels through between surfacing. The values are approximate estimates derived from engineering parameters	Velocity estimation calculated using the two GPS positions taken after the glider resurfacing	These currents estimations are not very accurate because their calculation relies on many simplifications and assumptions
Moorings	National Reference Stations		NRT data only available from Yongala and Darwin	IMOS Matlab toolbox for QC for moorings and CTD uses the IMOS guidelines as well. See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series	Calibration of ADCP for current speed is not required, however, ADCP compass calibration and other physical measurements made by the instrument do require calibration. Pre-deployment checks are made for compass and tilt,	Automated and semi-automated QC applied.
	Shelf Arrays		NRT data available only in QLD&NT. Automated QC done with own code that borrows from Matlab toolbox	IMOS Matlab toolbox for QC for moorings and CTD uses the IMOS guidelines as well. See https://github.com/aodn/imos-toolbox/wiki/QCProcedures#moored-time-series	Calibration of ADCP for current speed is not required, however, ADCP compass calibration and other physical measurements made by the instrument do require calibration. Pre-deployment checks are made for compass and tilt,	Automated and semi-automated QC applied.
Ocean Radar	WERA		Not QC	QC developed by the facility, however, the documentation was not transferred when the facility moved to UWA. The current leadership is developing new QC procedures and now has a preliminary	Periodic and extensive calibrations of all the radar electronic components, performed every 3 months	There is no international QC standard procedure for WERA, but QARTOD is providing RT QC manuals, to which IMOS has contributed. Signal-to-Noise Ratio (SNR) is accepted as a proxy for data quality both for

				manual for offline QC describing procedures that can also be applied in RT model		WERA and SeaSonde radial currents. WERA radars (Doppler peak width, separation of 1st and 2nd order for radials; GDOP or GDOSA for vector maps) are considered valid proxies for data quality.
	CODAR		Not QC. The current leadership is developing new QC procedures.	No specific QAQC procedures were developed at JCU for SeaSonde radars. QA procedures also include some periodic calibrations but were not documented in the logs since the beginning. The current leadership is developing new QC procedures.	Periodic and extensive calibrations of all the radar electronic components, performed every 3 months	There are QC procedures developed by the radar community with new ones being proposed, but they're not universally accepted. The CODAR QC complies with the best-practices. Signal-to-Noise Ratio (SNR) is accepted as a proxy for data quality both for WERA and SeaSonde radial currents. Additional metric is either specific to SeaSonde systems (MUSIC peak width, single VS dual solution for the radials; geometry of the intercepting beams –or GDOP- and GDOSA for the vectors)
Satellite Remote Sensing	Sea Surface Height		Estimated from calibrated satellite data, see below under SSH	Estimated from calibrated satellite data, see below under SSH		Geostrophic surface current velocity is estimated using sea surface height anomaly calculated from SRS SSH and tide gauges.

Each observing platforms observes velocity at different scales and regions. For example, radars will estimate surface velocity at a local scale while satellites will be estimating at broadscale. Moorings will be measuring in a depth binned manner throughout the water column, except for the surface. Gliders provide a depth average estimate as the glider travels through between surfacing.

Key points:

1. There is no universal agreement on the QA/QC approach for radar currents within the radar group and the scientific community is split between the two major technologies.
2. QC procedures developed in house for WERA but not SeaSonde. Currently tests are being performed on a new data format for ocean radar currents, that is being developed within the international HF radar community. Similarly, tests are being performed for the near real-time and offline quality-control procedures, in accordance with the IOOS (Integrated Ocean Observing System) "Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data".
3. SSH linked internationally to contribute calibrated and validated SSH data from which surface currents are derived
4. The Matlab toolbox is used for QC of the data for moorings by the different sub-facility leaders.

Issues:

1. Bonney Coast and GBR radars not optimized to monitor the regions.
2. Calibration of ADCP for current speed is not required, however, ADCP compass calibration and other physical measurements made by the instrument do require calibration.

Recommendations:

1. ADCPs can be acoustically calibrated and there is suggestions for the CSIRO facility to purchase the necessary acoustic equipment to calibrate ADCP acoustically
2. Discussion may be needed about the utility of the Bonney Coast and GBR radars and how to improve them
3. ADCP QA checks to ensure the data outputs are consistent and sensible are highly valuable. A facility or prescribed method to undertake a check of current speed/compass integrity would be recommended.

5. Sea Surface Height

		Sea Surface Height	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Satellite Remote Sensing	Sea Surface Height		Follow standard procedure	Follow standard procedure for the mooring and GPS processing with a step in the data processing for the satellite calibration processes	Fine checks are carried out around the time of the satellite overflight	The sub-facility contributes a continuous absolute bias data stream, or time series, to the Ocean Surface Topography Science Team (OSTST), vital to deliver final 'calibrated and validated' Geophysical Data Records (GDRs) to the global oceanographic community. It directly contributes to the calibration and validation of the Jason-series satellite altimeters within the framework of the OSTST

Sub-facility contributes internationally to deliver calibrated and validated SSH data. The only one in the southern hemisphere.

Key points:

1. The facility does not follow a fixed protocol, however, they follow a standard procedure for the mooring and GPS processing with a step in the data processing for the satellite calibration purposes. Fine checks are carried out around the time of the satellite overflight (~10 days).

Recommendation:

1. While the facility follows standard procedure to calibrate satellite SSH, providing some written documentation would be beneficial as an information source

6. Sea State (wave height, spectrum, period)

		Sea state	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Deep water Moorings	Southern Ocean Timeseries		N/A	CSIRO QC procedures based on inter-comparison of wave height from the different sensors	No information given	No protocol written
Moorings	National Reference Stations		Acceptable on board processing for statistical analysis and error detection allows NRT QC	No QC performed.	Pre-deployment checks on ADCP made	• Most research users of wave data would prefer to start from the raw data. • It is currently expected that users use their own software or that provided by the manufacturers to satisfy themselves of the integrity of the data. The manufacturer provides both on board (for NRT data) and post deployment software.
	Shelf moorings		Acceptable on board processing for statistical analysis and error detection allows essential NRT QC	There is an experimental Nortek AWAC at One tree east (GBROTE) mooring, data it flagged as experimental and there is a need to remove mooring motion from it	Pre-deployment checks on ADCP made	
Ocean Radar	WERA		Not QC	Data processing involving temporal and spatial averaging is being set up to improve the data.	The WERA radar system needs to be optimise for waves or currents, and currently it is used for currents.	The optimization of the wera systems for wave would require a major work. Data not available in portal, just through the thredds server

Key points:

1. QC of wave data from SOTS is done in CSIRO and involves sensor inter-comparison
2. There is essential manufacturer QA/QC for the IMOS wave data from moorings in NRT and delayed mode. Some data are considered experimental only.
3. There are no written protocols available for the QA/QC of these data in most facilities. Manufacturers and QARTOD protocols are available
4. The radar facility is looking at improving the wave data and has produced a report, although the radar set up was specifically designed for currents

Issues:

1. Rudimentary or not QC

Recommendations:

1. Given the increase interest in wave data, it may be important to start considering QC these data set and provide a written protocol of the QA/QC procedures. It is important to consider the purpose for the use of these data as QC requirements may vary.

NOTE: Radar wave spectrum data are available through thredds

7. Ocean surface vector stress (wind parameters: speed, direction and stress)

		Ocean surface vector stress	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Air-Sea Fluxes		BoM automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	No further QC	Acoustic wind velocity and direction measurements are validated by design and calibration is not needed. Pre-deployment verification is needed for functionality	
Deep water Moorings	Air-sea fluxes		BoM automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	No further QC	No information provided but in "IMOS Data Streams and their uncertainty document" it suggests that wind sensor uncertainty is a combination of the intrinsic sensor uncertainty, combined with a 2° uncertainty in installation orientation. Yearly calibrations suggested	Literature on CFD modelling of flow around the buoy and its impact on accuracy should be referenced as well as differences between dual sensors.
Moorings	National Reference Stations		Rudimentary near real time QC	No further QC		Wind sensors are replaced with new so no re-calibrations
Ocean Radar	WERA		N/A	N/A		Wind data is output from model. However comparing it with in situ data, the radar wind information matches quite well all the temporal scales with high spectral coherence
Wireless Sensor Networks			Wind velocity data is QC's by using an upper limit only due to the natural variability. Averages over 10 and 30 minutes are undertaken. Wind direction is smoothed but not QC because of the difficulty of that data stream	N/A		

Key points:

1. Wind velocity data only, QC in BoM, using the same automated QC used for all other variables, namely: SST, Air-sea fluxes, and others.
2. Rudimentary QC is undertaken in all other facilities.

Recommendations:

1. QARTOD manuals suggest that expert QC should be considered for both speed and direction of winds, along with comparisons with other observations such as Satellite. This could be a possibility to improve the data we are currently serving.
2. There is also the potential to use remote sensing scatterometer data/and or reanalysis data to detect major errors.

8. Heat flux/radiation

NOTE: Sensible and latent heat fluxes have traditionally been estimated through bulk formulae with the aid of the observations of SST, near surface air temperature and humidity, surface winds, waves, and surface air pressure.

		Heat flux/radiation	QC procedures near-real time	QC procedures delayed mode		Comments
Ships of Opportunity (SOOP)	Air-Sea Fluxes		BoM automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	No further QC	No information provided but the document "IMOS Data Streams and their uncertainty" it suggests that wind sensor uncertainty is a combination of the intrinsic sensor uncertainty, combined with a 2° uncertainty in installation orientation. Yearly calibrations suggested	Parameters measured are: wind speed and direction, air temperature, air humidity, air pressure, precipitation, solar radiation (down welling short-wave), infrared radiation (down welling long-wave), sea surface temperature (at 1m depth), and sea surface salinity.
Deep water Moorings	Air-sea fluxes		BoM automated test is based on the system developed by the Center for Ocean-Atmospheric Prediction Studies (COAPS) SAMOS http://coaps.fsu.edu/woce/docs/qchbook/qchbook.htm#intro	No further QC	No information provided but the document "IMOS Data Streams and their uncertainty" it suggests that wind sensor uncertainty is a combination of the intrinsic sensor uncertainty, combined with a 2° uncertainty in installation orientation. Yearly calibrations suggested	Parameters measured: wind direction and speed, relative humidity, air pressure, air and water temperature, sunlight and precipitation, as well as oceanographic measurements including salinity and conductivity

QA/QC of air-sea fluxes are done by BoM for both SOOP and SOFS using the same automated QC system.

9. Dissolved oxygen

		Dissolved oxygen	IMOS QC procedures near-real time	QC procedures delayed mode	QA	Comments
Argo			The quality control procedures on the near real-time data are limited and automatic.	QC procedure for oxygen databased on a modified approach from Takeshita et al. 2013 through a comparison of Argo float data to the climatology CARS 2009. Oxygen correction coefficients are estimated for a linear regression of float vs climatological percent oxygen saturation. The MATLAB GUI that has been developed allows the assessment of the correction with various modifications (gain only, gain and offset, offset only terms, winter months and ascent rate filters, mixed layer and deep layer filters).	To verify the climatology-based QC procedure corrected float data are compared to calibrated oxygen profiles taken on deployment of several floats when available. Calibration protocols using air O2 measurements need to be incorporated in the future to account for dynamic errors of sensors.	Strict QC procedures have yet to be agreed upon and implemented for dissolved oxygen by Argo data centres. The current Argo quality control procedures are specified in the Argo quality control manual for dissolved oxygen concentration available here: http://archimer.ifremer.fr/doc/00354/46542/ REF: Takeshita et al, 2013. A climatology-based quality control procedure for profiling float oxygen data. JGR. 118, 5640-5650.
Deep water Moorings	Air-sea fluxes		N/A	There is no documentation on the QC, it follows WOCE protocols. The only documentation available is the sensors' calibration history.	Sensors are calibrated by CSIRO using and CSIRO calibrations using the Winkler method. Sensor drift is also checked, characterised and corrected pre and post deployment calibration. Cross check with other sensors, with uncertainty estimated.	• Two different O2 sensors deployed. Sea Bird SBE43 Clark cell oxygen sensors along with Aanderaa 3975 (3830 with adaptor) Optode. • Sensor failure has been far more common in the data set for SBE43 electrodes than Aanderaa or SBE63 Optodes., with SBE43 showing a higher sensor drift. However, this sensor is still useful for comparison The SBE43 data has also shown that the optode data can take 0-2 weeks to stabilise once put into the water. Within certain accuracy the SBE43 is still a very useful sensor.
	Southern Ocean Timeseries		N/A	Similar to the above, QC is conducted by CSIRO, follows WOCE protocols	Similar to the above	
Ocean Gliders	Seagliders		No QC for near real time	This parameter is visually checked and manually flagged for QC		
	Slocum Gliders		No QC for near real time	Careful QC conducted on data.	Improvement of dissolved oxygen data made by recomputing dissolved oxygen data with time shifted bphase data and temperature data from the fast response CTD	• The raw parameters from the optodes are only available for datasets where gliders were deployed after mi-2011, which prevent the facility to improve the oxygen data of datasets anterior to mid-2011. • There is a method to back-calculate the phase measured by the optode which will allow this correction for Slocum

						glider missions, since 2008. However, the facility has not yet correct the data for the oldest missions (before 2011), where only the oxygen concentration and oxygen saturation are available.
Moorings	National Reference Stations		NRT data only available in MAI, DAR and YON	Measurement of dissolved oxygen using modified winkler titrations for water samples are needed to check the quality of the data but these data are only collected at Maria Island and more recently Rottnest Island. Moored WQM oxygen sensors: SBE43 sensors are used in IMOS WQM's. There is limited QC done on the data	The CTD sensors are calibrated intermittently at CSIRO, Hobart. The WQM sensors are calibrated before deployments	• The SBE43 used in CTD is a fast response, but suffer from a high failure rate and variable drift. • Without bottle calibration data, the NRS CTD profiles are of limited use. AIMS Townsville has the capability to do Winkler titrations • For the moored WQMs occasional sensor failure and lack of calibration water samples at most sites make these data difficult to use. • There is a suggestion of problems with oxygen calibration from CSIRO, that could be 10-15 uM out.
	Acidification Moorings		No QC for NRT	QC performed in CSIRO	Moored optical oxygen sensors are calibrated pre and post deployment using high quality winkler titrations. Sensors are checked for sensor drift over time, which is typically very low	• QC is to a high standard • Optical sensors are accurate and show low drift

Key points:

1. QA/QC undertaken by facility.
2. Issue with high failure rate of the O2 sensors in WQM and CTD in the ANMN facility
3. Moored optical oxygen sensors used in acidification moorings show low and linear drift with time and deliver an accuracy of about 0.5% or better.

Issues

1. WQM O2 sensors and CTD SBE43 sensors suffer from high failure and winkler titrations are needed to cross check the WQM and CTD data.
2. Winkler titrations for cross checking sensors are only carried out in MAI and ROT due to the equipment needed to conduct them. The lack of these titrations on other NRS makes their data difficult to use, although there is potential for Qld NRS to do titrations with AIMS equipment.

Recommendations:

1. That a report is produced by the O2 Task Team giving recommendations for sensors available, uses, target accuracies and precisions required (e.g. Future Oceans EOV[1]s) and options and recommendations for calibration and maintenance for O2 sensors.
2. That optical oxygen sensors are used on NRS with 6-12 monthly calibrations and data processing using well defined and available techniques.
3. A fast response sensor like the Seabird SBE63 or Aanderaa 4330F sensors may be needed for a profiling CTD. Initial tests at Maria Island using bottle samples provide a way to ensure the sensors can be used for profiling prior to purchasing a number for other NRS CTD's.

10. Carbonate System (pCO2, pH, Total. Inorg. Carbon, Alkalinity)

		pCO2	pH	Total. Inorg. Carbon	Alkalinity	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Biochemistry (pCO2)					pCO2 data is calibrated daily using a zero and span gas and the calibrations applied in real time	Data is carefully QC in CSIRO for pCO2. After completion of the quality control checks, the measured mole fractions are corrected to final values using measurements of four CO2-in-air standards made every 3 hours when the system is operating at sea.	A number of parameters are used to establish that the system is functioning correctly.	• Data are QC post-cruise. • QC to a high standard • A protocol for QC is available for this facility.
Deep water Moorings	Air-sea fluxes					N/A	pCO2 sensor is from PMEL NOAA, they perform the QA/QC for this data		These data are not in the portal
	Southern Ocean Time series					N/A	TCO2 and TAlk samples analysed using techniques developed for measurements in ocean waters on CO2/CLIVAR sections	The accuracy of the methods used are checked against certified reference material from SIO	TCO2 and alkalinity analyses do follow the most up to date measurement protocols.
Moorings	National Reference Stations					N/A	TCO2 and TAlk samples analysed using techniques developed for measurements in ocean waters on CO2/CLIVAR sections.	The accuracy of the methods used are checked against certified reference material from SIO	• Protocol very well described. • Data is from water samples. • pH is not derived from this facility
	Acidification Moorings					At each measurement of pCO2, a zero and span gas is used to calibrate the sensor response and determine the CO2 value.	QC performed by CSIRO. .	All sensors are calibrated before and after deployments. . pCO2 sensors are calibrated at each measurement point using a zero and span gas. Diagnostic parameters are checked and any parameters that are questionable and can influence the final pCO2 value are flagged along with pCO2. pH is calibrated on the total pH scale with calibration data calculated from total dissolved inorganic carbon and total alkalinity samples. The sensors are preconditioned in seawater prior to deployment	The pH sensors have been tested at Maria Island and data for the past 12 months and tests indicate these data are now ready for deployment on other moorings

IOCCP have defined these variables collectively as ‘the carbonate system’ – need to measure 2 of 4
Key points:

1. Data from all facilities are QA/QC to a good high standard, all linked to international standards
2. pH is delivered only by one sub-facility

Recommendations

1. Deliver pH data to AODN where available and consider implementation on SOOP and CO2/acidification moorings
2. A written protocol from SOTS consolidating all their QC for all their variables is necessary

NOTE: SOTS methods are the same as used elsewhere in IMOS. The new protocols referred to are part of a larger update and have not changed compared to earlier methods. The only difference is the reference and pH, TCO2 and alkalinity for SOTS and elsewhere, the latest protocols are

11. Macronutrient concentration

		Macronutrient concentration	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Deep water Moorings	Southern Ocean Timeseries		N/A	Follows GO-SHIP protocols. http://www.go-ship.org/HydroMan.html. Nutrients collected are Si, NO3 and PO3. There is also a sensor for NO3	Follows GO-SHIP procedures, analyses are carried out by MNF/CSIRO hydrochem group	There are issues with the NO3 sensor because of biofouling and it is not recommended for use at fixed point sites.
Moorings	National Reference Stations		N/A	They have their own NRS BGC manual and protocol where they set the detection limits based on Go-SHIP. QA/QC is centralised in Hobart CSIRO	Method detection limits and precision for nutrients are determined for each run using standards. Accuracy is determined using KANSO reference material of nutrients in seawater (RMNS).	

Key points:

1. Currently very sparse nutrient observations based on water samples.
2. Bio-fouling issues with NO3 sensor when moored.

Issues

1. Satlantic ISUS NO3 sensor appears to be good in profiling mode such as Argo, maybe gliders. This can open up the potential to have more observations at larger scales.

Recommendations:

1. The centralization of nutrient analysis in Hobart is a good approach as it makes the data consistent.

12. Ocean colour
13. Chlorophyll a/ fluorescence

		Ocean Colour	Chlorophyll a concentration	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Cont. Plankton Recorder			N/A	Phytoplankton Colour Index is estimated and has 4 levels depending on the greenness of the silk.	Methods described in peer review publication	• Although the phytoplankton colour assessment is done 'by eye', there is very close agreement between CPR analysts on the estimated colour of silks. • Phytoplankton colour index has proven to be a good index of phytoplankton biomass (chlorophyll) estimate fluorometrically and from satellite (see Richardson et al. (2006) for more information).
	Tropical RV/Temperate MV			TRV Basic QC done that is automated and includes range of acceptable/non-acceptable values. TMV has its own QC by Vic EPA.	TRV: No extra delayed mode QC TMV: delayed mode QC includes calibration offsets (sensor to sample), and sensor drifts due to bio-fouling. Scale factor and the offsets for the variables (fluorescence, turbidity and salinity) are applied.	TRV: Sensors calibrated every year by manufacturer. Uncertainty values provided by manufacturers, with allowances for sensor drift. TMV: regular cleaning of the sensors to minimise fouling. Salinity and chlorophyll-a samples taken during service as a calibration check. Annual calibration to assess long-term drift	TRV: DALEC radiometer on board for in situ validation of ocean colour TMV: Very clear and detailed protocol
Deep water Moorings	Air-sea flux			N/A	PAR sensor data is QC by BOM using their automated QC program. WQM data is QC by CSIRO.	Wet Labs provide a calibration for the sensors output to Chlorophyll-A (ug/l) equivalent, CSIRO calibration lab provides a calibration for the sensor output to Fluorescein solution concentration (ug/l).	• Surface photosynthetically active radiation and surface UV are measured, to help assess light available for phytoplankton production. • Sensors include Wetlabs FLNUTS sensor, LiCor PAR sensor, Wetlabs ECO PAR sensor.
	Southern Ocean Timeseries			N/A	No more information provided	Wet Labs provide a calibration for the sensors output to Chlorophyll-A (ug/l) equivalent, CSIRO calibration lab provides a calibration for the sensor output to Fluorescein solution concentration (ug/l).	The relationship between Fluorescein concentration and Chlorophyll-A concentration is not provided by Wet-Labs.

Ocean Gliders	Seagliders			No QC for near real time	Measured as fluorescence. QC done using calibration coefficients. Data QC on the bio-optical data stream flags only the most obvious of outliers as bad data, thus QC for this parameters is manual.	Sensors are sent overseas for calibration. There is a standard performance test procedure for pre- and post-deployment on glider ecopucks.	• Serious effort needs to be made to interpret bio-optical data streams from gliders. • Additionally, there is an issue with manual QC, in that when data are reprocessed the manual QC flags are removed during the re-processing so QC needs to be re-done again manually • The last BOWG suggested that having a calibration facility in Australia will help reduce the time spent sending instruments overseas. • The BOWG produced a document for QA, however it is not clear if this has been applied. The document does not seem to be available online.
	Slocum Gliders			No QC for near real time	Measured as fluorescence. QC done using calibration coefficients. Sensors are sent overseas for calibration. There is a standard performance test procedure for pre- and post-deployment on glider ecopucks. Data QC on the bio-optical data stream flags only the most obvious of outliers as bad data, thus QC for this parameters is manual.	Sensors are sent overseas for calibration. There is a standard performance test procedure for pre- and post-deployment on glider ecopucks.	• Serious effort needs to be made to interpret bio-optical data streams from gliders. • Additionally, there is an issue with manual QC, in that when data are reprocessed the manual QC flags are removed during the re-processing so QC needs to be re-done again manually • The last BOWG suggested that having a calibration facility in Australia will help reduce the time spent sending instruments overseas. • The BOWG produced a document for QA, however it is not clear if this has been applied. The document does not seem to be available online.
Auto. Underwater Vehicle				N/A	Not QC	No QA	
Moorings	National Reference Stations			NRT data only at MAI, YON, DAR and NSI	Detail protocol for the collection of samples and the HPLC analysis for Chl-a concentration. WQM measures fluorescence and phytoplankton (pigments)	Calibration is not centralised so each subfacility will get their sensors calibrated at different places. Experimental project being undertaken to improve the data collection and interpretation	• Conversion from fluorescence to CHl-a is difficult • An experimental project undertaken by CSIRO to help interpret the observations collected by the WQM fluorescence sensors is

					samples are collected to check the WQM sensor performance		underway. This is done by calibrating and converting fluorescence to Chla from the WQM using different algal cultures. This has been done in MAI and NSI and will be expanded to all NRS. • CSIRO WA are devoting some efforts on the instrument response to low concentrations. • SARDI implementing local low range Chl-a calibrations
Satellite Remote Sensing	Ocean Colour			n/A	DALEC from Solander has currently minimal QC but will include similar checks to Lucinda in the future. At LJCO several routines from the toolbox are used to QC the data from WQM.	A radiometry TT has been created and will deliver a report on the laboratory absolute calibrations and inter-comparison, relative intercomparison and field inter-comparison at LJCO and recommendations as to how radiometry should be organised / developed in IMOS for the future	This facility provides the in-situ observations for validation of Ocean colour from satellites

Key points:

1. QA/QC undertaken by facility
2. Conversion from fluorescence to Chl-a concentration can be difficult
3. In situ HPLC Chl-a conc. provides Chl-a concentration with high accuracy at the NRS
4. An experimental project to calibrate and convert fluorescence data from WQM using algal cultures is currently underway, and there are other regional efforts, particularly in WA and SA to implement low Chla calibrations and instrument response
5. Calibration is not centralised within the ANMN
6. There is a radiometry TT underway to look at calibrations and sensor inter-comparisons

Issues:

1. The is a lot of work needed for the WQM to calibrate and convert fluorescence to Chla
2. Many facilities do not have a detail protocol written
3. The WQM fluorescence conversion using algal cultures is experimental, results have not been published and converted data has not been given to AODN
4. An issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, this has recently been corrected.

Recommendations

1. That results from the project to convert fluorescence from WQM to Chl-a be published and a detailed protocol written. This project will help the conversion by considering the regional differences as well as sensor differences. It will be helpful if this project includes all WQM and not only the NRS ones (i.e. Lucinda, SOTS and other shelf moorings).

2. Discussion is needed to clarify if results from the experimental project to convert WQM fluorescence to Chl-a data is to be used to process all WQM fluorescence data (including historical data).
3. That recommendations from the radiometry TT are implemented once the TT is finished.
4. Centralising calibration of sensors will be ideal and more efficient
5. All facilities should have written protocols available
6. Bottle pigment samples could be used to calibrate the WQM data in situ, and maybe needed because of site variations in the community composition.

14. CDOM

15. Suspended particulates (PON, PIC, POC, TSS)

		CDOM	Suspended particulates	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Deep water Moorings	Southern Ocean Timeseries			N/A	PON, POC and PIC are collected with the sediment trap and analysis follows JGOFS protocols	Follows JGOF protocols	PON, POC and PIC is collected in this facility. This is consistent with the subvariables for the Suspended particles EOVs from IOCCP The facility has a backscatter sensor, which could be converted into a TSS or POC units. However, it is not being done and it would have very limited validity. The backscatter sensor is currently being used as a control on the phytoplankton ce signal
Ocean Gliders	Seagliders			No QC for near real time	Data QC on the bio-optical data stream flags only the most obvious of outliers as bad data, thus QC for this parameters is manual.	Pre and post deployment calibrations and tests done. The facility has slowly compiled a 'climatology' for bio-optical parameters from glider missions around Australia and used it to help in the assessment of extreme values A document has been prepared this year to describe the calculation of a particle backscattering coefficient (BBP, m-1)	• There is an issue with manual QC, in that when data are reprocessed the manual QC flags are removed during the re-processing so QC needs to be re-done again manually •
	Slocum Gliders			No QC for near real time	Data QC on the bio-optical data stream flags only the most obvious of outliers as bad data, thus QC for this parameters is manual.	Pre and post deployment calibrations and tests done. A document has been prepared this year to describe the calculation of a particle backscattering coefficient (BBP, m-1)	Same comments as above
Moorings	National Reference Stations			N/A	CDOM is measured with the Ecotriplet. This sensor will not be used anymore because of the instruments have yielded very inconsistent data and the issues have been difficult to diagnose.	Annual calibrations are performed by the manufacturer Wetlabs Calibration by the manufacturer may not be appropriate to Australian waters and require more frequent pre- and post-deployment local calibrations. TSS and CDOM measured from water samples	• TSS and CDOM are currently measured from a pooled sample spaning from 0-50m. This does not make the data very useful so there will be a change implemented with TSS and CDOM measured from a sample at the surface. • There are plans to measure CDOM from water samples at the NRS to help satellite validation. • TSS is collected but there has been trouble with the blank (control) samples. This is currently under investigation
Satellite Remote Sensing	Ocean Colour			N/A	CDOM and TSS are measured at LJCO with CDOM fluorescence measured with a WETLabs WETStar fluorometer, particulate and dissolved spectral absorption and attenuation coefficients using a	No information given but follows similar procedures of NRS for water samples	Water samples in LJCO have been collected, however, these data are not in the AODN yet, but will be delivered soon. The samples are QC and analysed as per NRS by CSIRO team

					WETLabs AC-S and, total backscattering coefficients using a WETLabs BB9 radiometer. Lucinda Jetty Coastal Observatory (LJCO) data are processed in two steps, first all data including BB9 and Wetstar are applied two QC, min / max check and rate-of-change check. These conditions are flagged with bit masks, and is converted to IMOS compliant QC.		

Key points:

1. The water samples collected at Lucinda and the NRS are QC and analysed as per NRS protocol by CSIRO team.
2. There is no written protocol for LJCO and Gliders for these variables

Issues:

1. There are issues with measuring the TSS from the pooled sample collected at NRS, this is currently under review to resolve the issues.
2. Data from water samples taken at LJCO are currently not delivered to AODN, although there are plans for the delivery of these data soon.
3. There is an issue with manual QC from gliders, in that when data are reprocessed the manual QC flags are removed during the re-processing so QC needs to be re-done again manually
4. There are issues with the filters used for the collection of TSS samples from IMOS (see NOTE below)

Recommendation:

1. The change from the pooled sample to the stratified samples in will allow the use of the CDOM and TSS samples for satellite validation purposes.
2. A protocol on the QA/QC should be available for all facilities
3. Data from LJCO water samples should be delivered to AODN

NOTE: There has been some discussion around the collection of the TSS samples; IMOS TSS samples are collected on pre-weighed GF/F filters and the TSS is split into an organic and inorganic fraction, with protocols for TSS analysis for the remote sensing community is to use GF/F filters. AIMS in their non-IMOS work (MMP) collect TSS on a membrane filter which cannot be used to separate the inorganic and organic fractions. There are also issues with contaminated blanks. Further discussion ensued and it was decided that a comparison between filters types and blanks analysis will be undertaken

16. Phytoplankton biomass and diversity

		Phytoplankton divesity	Phytoplankton Biomass	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Cont. Plankton Recorder			N/A	All phytoplankton identification has been standardised to the correct current classification as given by the World Register of Marine Species (WoRMS) There is a detailed protocol they use for flagging data.	Protocol that considers data entry measures, taxonomic measures, naming conventions and ID rules. ID rules from SAHFOS	The CSIRO database holds all the raw data, for example original species names and ambiguous records, from these datasets, and researchers can request further information from the corresponding author if required Their protocol also includes plastics
Deep water Moorings	Southern Ocean Timeseries			N/A	All phytoplankton identification has been standardised to the correct current classification as given by the World Register of Marine Species (WoRMS)	None indicated but may follow similar rules as the NRS	
Moorings	National Reference Stations			N/A.	Detailed protocol for the collection and analysis of samples that include same sample analysis by two different analysts for QC purposes.	Same as for CPR, but follows Sedgwick Rafter square for ID rules	Phytoplankton (pigments) samples are collected to check the WQM sensor performance. This type of variable is done with water samples that need to be analysed in lab.

Key Points:

1. All the phytoplankton data is managed centrally making these data consistent.
2. Regular taxonomic training and comparison of our identification with overseas labs also increases consistency
3. In addition, the publication of the phytoplankton database in Nature Scientific Data was an opportunity to get the IMOS and other data in a consistent and standard way. It should be encouraged for other data sets.

17. Zooplankton biomass and diversity

		Zooplankton diversity	Zooplankton Biomass	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Cont. Plankton Recorder			N/A	ID done is guided by the library of taxonomic keys the facility has assembled. It follows procedures described in Richardson et al 2006.	There is a detailed protocol they use for flagging data..	A suite of taxonomic guides is used for identification, with the main one being the online guide "Diversity and Geographic Distribution of Marine Planktonic Copepods", which summarizes the taxonomic literature over the past 130 years and is regularly updated
	Bioacoustics			N/A	In-house tools developed to assist with data management and help identify and prioritise subsets of data for post-processing. Data cleaned from background and intermittent noise. Defined metrics for data quality.	Vessels are calibrated according to the procedures recommended in the ICES CRR 144 document (Foote 1987). In the case of ES60 systems, the calibration data is pre-processed to eliminate the possibility of bias of up to +/- 0.5 dB. At a minimum vessels will ideally be calibrated annually	• The bio-acoustic data has the potential to deliver information on biomass and to a certain extent species. However, the data needs to be analysed before that information can be estimated from observations and it requires in depth knowledge of acoustic data. • It is likely that expert user would like to have access to the raw data
Moorings	National Reference Stations			N/A	Dry weight analysis undertaken for biomass following standard procedures. Species ID keys used to identify organisms. The ID of these observations are carried out by the same lab that does SOOP CPR and thus both data sets are consistent.	There is a detailed protocol they use for flagging data.	A taxonomic key for Australian zooplankton was created from this and the CPR datasets
Deep water Moorings	Southern Ocean Timeseries			N/A	No QC	No QA	Some SOFS and FluxPulse moorings have had a 4-frequency acoustic water column profiler which provides information on zooplankton and fish abundances and their vertical diel migrations.

Key Points:

1. The management of the zooplankton data from SOOP and ANMN into a central laboratory makes these data consistent.
2. A taxonomic key for Australian zooplankton was created from these data sets as a collaboration between IMOS, UTas and CSIRO and is available online http://www.imas.utas.edu.au/zooplankton/home
3. Bioacoustic data is QC to international standards following the ICES WGFAST recommendations
4. Bioacoustic data will need analysis to estimate zooplankton biomass
5. Regular taxonomic training and comparison of our identification with overseas labs increases consistency
6. The zooplankton data set has been published in Ecology

Issues:

1. There is an multifrequency acoustic system in SOTS, however, the data has not been given to AODN

Recommendations:

1. Serious discussion is needed on extra data sets from sensors added by facilities but not integrated to IMOS

18. Nekton Species
19. Nekton Biomass

		Nekton Species	Nekton Biomass	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Ships of Opportunity (SOOP)	Bioacoustics			N/A	In-house tools developed to assist with data management and help identify and prioritise subsets of data for post-processing. Data cleaned from background and intermittent noise. Defined metrics for data quality.	Vessels are calibrated according to the procedures recommended in the ICES CRR 144 document (Foote 1987). In the case of ES60 systems, the calibration data is pre-processed to eliminate the possibility of bias of up to +/- 0.5 dB. At a minimum vessels will ideally be calibrated annually	• The bio-acoustic data has the potential to deliver information on biomass and to a certain extent species. However, the data needs to be analysed before that information can be estimated from observations and it requires in depth knowledge of acoustic data. • It is likely that expert user would like to have access to the raw data
Animal Tagging	Acoustic tagging			N/A	QC includes the 1) identification of false tag detections, 2) distance test, 3)velocity test, 4) species distribution test and 5) distance from release location test. Additional QC tests are carried out on the tag metadata: 1) validation of the species name, 2)comparison of release date, 3) comparison of release location	All data from the Animal Tracking Facility's arrays are typically serviced and uploaded on an annual basis; all collaborating projects have their own servicing schedule. Information related to the receiver, tags, species ID is entered into the database by researchers at the onset of the project and is updated once receivers are downloaded or tags are released	• Data from this sub-facility includes IMOS as well as contribution from other parties. False detection QC procedures have been published in the scientific literature • The full QC procedure is being finalised and has been successfully applied to all data available in the animal tracking database • A scientific publication is in preparation for publication

Key points:

1. Both facilities have good QA/QC procedures
2. Bio-acoustic data is QC to international standards.
3. The acoustic animal tracking facility is the first to set standards for these observations, with false detection analysis. Information has been peered review and published and can be found here: https://animalbiotelemetry.biomedcentral.com/articles/10.1186/s40317-015-0094-z

20. Top Predators species
21. Top predators – population

		Top Predators species	Top predators – population	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Moorings	Passive Acoustics				The data is scrutinised for notable events and to assess data quality.	The passive acoustic moorings are typically serviced every 10-12 months, with the duty cycle giving an 11-12 month duration. On recovery the instruments are calibrated post deployment and check everything is working.	Data is currently supplied in its raw format only, although a software product CHORUS has been made available to facilitate analysis of these datasets
Animal Tagging	Acoustic Tagging				QC includes the identification of false tag detections using several different approaches and the protocol is available in the IMOS facility website.	All data from the Animal Tracking Facility's arrays are typically serviced and uploaded on an annual basis; all collaborating projects have their own servicing schedule. Information related to the receiver, tags, species ID is entered into the database by researchers at the onset of the project and is updated once receivers are downloaded	• Data from this sub-facility includes IMOS as well as contribution from other parties. The false detection QC was applied to all the data available in the animal tracking database. • False detection QC procedures have been published in the scientific literature
	Biologging			No QC	No QC, but they are discussing ways to QC the accuracy of the spatial information. See avobe		

Key points:

1. Data is QC in both the passive acoustic moorings and the animal acoustic tagging facilities. Animal movement and presence/absence information can be extracted from these data, however, population information will need different techniques.
2. There is no written QA/QC protocol for passive acoustic. A software product, CHORUS, to analyse the IMOS Passive Acoustic data sets has been provided by Curtin.

Recommendations:

1. That all facilities write a protocol for QA/QC that is publicly available

22. Benthos (% coverage of species)

		Benthos (% coverage of species)	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Auto. Underwater Vehicle			N/A	Optical imagery is delivered as individual high resolution, colour corrected images (geotiffs) and also in processed form, as mosaics and 3D seafloor reconstructions. Specialised software Squidle used for annotations	Each of the high resolution imaging missions are typically flown at a fixed altitude above the seafloor. All data products are precisely georeferenced using state-of-the art terrain-aided navigation algorithms. Standard annotation scheme (CATAMI) was adopted but proved to be too restrictive	• Two reviews of the benthic monitoring program were conducted this year with recommendations for improvement of the program given. • Reviews for the entire program looked at improving the workflow as well as improving diagnostics and robustness in the tools required for retrieving data from the vehicles, converting the data to account for issues with lighting, computing geo-referenced information for the imagery, generating integrated mosaics and 3D structural models and uploading the data to online archives.

While there is no written protocol for QA/QC, two reviews of the program had been undertaken to look at issues with the sampling design, standardise annotation software development and uptake of the data.

Key points from the review:

1. Annotation happens outside the AODN through the software Squidle. The updated Squidle+ software will be able to handle larger data sets with flexible annotation. Members of the community agreed to upload their annotated data.
2. CATAMI has been too restrictive, so a flexible annotation scheme will be implemented.
3. There has been discussions with AODN to support closer integration with Squidle and the AODN portal and to facilitate the inclusion of additional data sources as part of the NeCTAR Ocean Sciences cloud.

Recommendations from the review relevant to QA/QC:

1. That the IMOS AUV Facility steering committee review the campaign planning and design of dives at sites around the country to ensure that a consistent methodology is adopted and that future data collected by the facility can be compared and conclusions drawn on a national basis to support the broadscale objectives of the program.
2. That the facility should accelerate the transition to higher resolution imagery to improve description of benthos.
3. That the next generation of online annotation tools be designed to support flexible classification schemes.
4. To form a scientific steering committee with representation from the major groups involved in this work helps to set priorities for the IMOS Integrated Benthic Monitoring program, secure ship time, assist with fieldwork and lead the analysis of the resulting data streams

23. Detritus (flux)

		Detritus (flux)	QC procedures near-real time	QC procedures delayed mode	QA	Comments
Deep water Moorings	Southern Ocean Timeseries		N/A	Sinking particles to estimate carbon fluxes are collected with the SAZ sediment trap. QA/QC follows JGOFS protocols.	Follows JGOFS protocol	The SAZ sediment trap mooring collects sinking particles to quantify carbon fluxes,

Key points:

1. Follows international convention for QA/QC. This is the only facility that collects these observations.
2. No written protocol

APPENDIX 1

Table: Indication of how facilities undertake QA/QC per variable and if written protocols are available. Purple written international protocol that is available online, Green: Written protocol in development, Grey: written organisation protocol, Yellow: incomplete protocol written or lacks detail, Pink: no written protocol but procedures can be found in literature; Blue: QC but no written protocol; Red: no QC. * No written protocol, but use the IMOS Matlab toolbox;

How facilities deliver variables across IMOS		Sea surface temperature	Sub surface temperature	Subsurface salinity	Surface/subsurface currents	Sea Surface Height	Sea state (wave parameters)	Ocean surface vector stress (wind parameters)	Heat flux/radiation	Dissolved oxygen	Carbonate system (pCO2)	Carbonate system (pH)	Carbonate system (TIC)	Carbonate system (Alkalinity)	Suspended particulates	Macronutrient concentration	Chlorophyll a/fluorescence	CDOM	Phytoplankton diversity	Phytoplankton Biomass	Zooplankton diversity	Zooplankton Biomass	Nekton diversity	Nekton Biomass	Top Predators species	Top predators – population	Benthos (% coverage of species)	Detritus (flux)
	Argo	Purple	Purple	Purple						Grey																		
Ships of Opportunity (SOOP)	XBT	Purple	Purple																									
	Sea Surface Temperature	Purple																										
	Air-Sea Fluxes	Grey						Grey	Grey																			
	Biochemistry (pCO2)	Yellow		Yellow							Grey																	
	Cont. Plankton Recorder																Grey		Grey	Grey	Grey	Grey						
	Bioacoustics																					Purple		Purple				
	Tropical RV/Temperate MV	Grey		Grey													Grey											
Deep water Moorings	Air-sea fluxes	Grey					Blue	Grey	Grey	Grey	Purple						Grey											
	Deep water arrays		Grey	Grey	Grey																							

	Southern Ocean Timeseries																											
Ocean Gliders	Seagliders																											
	Slocum Gliders																											
	Auto. Underwater Vehicle																											
Moorings	*National Reference Stations																											
	*Shelf Arrays																											
	Acidification Moorings																											
	Passive Acoustics																											
Ocean Radar	WERA						Experimental	Experimental																				
	CODAR																											
Animal Tagging	Acoustic Tagging																											
	Biologging																											
	Wireless Sensor Networks																											
Satellite Remote Sensing	Sea Surface Temperature																											
	Sea Surface Height																											
	Ocean Colour																											

APPENDIX 2. KEY POINTS, ISSUES AND RECOMMENDATIONS PER VARIABLE

Variable	Key Points	Issues	Recommendations
Sea surface temperature **Subsurface Temperature**	Sub-facilities follow their own protocol for QA/QC, with few linked to international programs (e.g. ARGO, XBT)		
	Most of the moorings (shelves, deepwater and NRS) use similar QC procedures that include or are aligned to the IMOS toolbox	QC results produced by the toolbox need visual validation by the NRS and Shelves moorings sub-facilities in order to avoid bad data not being flagged.	The Australian National Mooring Network Steering Committee (ANMN SC) has agreed to re-process the relevant mooring datasets and improve the QC performed on them. There needs to be improvement on the visual validation of Toolbox QC results as well as more guidance and agreement on a standard use of the Toolbox. A task team (TT) will be proposed to develop a document that would try to describe a consistent methodology on how to QC a mooring dataset with the toolbox.
		A separate issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, however, this is being corrected.	Centralising the calibration of sensors, where possible, will be a good strategy for consistency in the QA. In addition, documenting the process by the calibration provider is also needed.
	QC for some facilities (biologging) will be/is outsourced	There is currently limited knowledge within IMOS of the QC work performed at MEOP, there is a preliminary strategy in place should MEOP stop QC'ing the biologging data, but this needs to be fully formed.	The AODN is currently harvesting the MEOP QC data (which includes IMOS), some thought should be given if the outsourcing of the QC is the best strategy for IMOS regarding the QA/QC of these data sets, and some involvement from IMOS should be discussed with MEOP.

Variable	Key Points	Issues	Recommendations
	While there are some facilities with written protocols, there are many that don't.	While there are written protocols for some facilities, it does not include the QA/QC of all the variables derived from the facility as this is dependent of the organisation that performs the QC. For example, SOOP BGC has a written protocol for the BGC variables but there is no written documentation on the MNF QC protocol for the physical variables from this facility. This is being corrected	It is important that all facilities have a written document on their QA/QC protocols and make them available. This will facilitate the querying of the QA/QC procedures and give users confidence in the data.
	SST from ships of opportunity has different QC applied, depending of the agency processing the data, i.e. BoM will do an automated QC and apply its own QC flagging system while AIMS TRV will do basic QC and apply the IMOS QC flags.	The consistency of the QC'ed SST data from the different vessels (SOOP SST, TMV, TRV and SOOP BGC) is variable, including the QF (quality flags). This can lead (has led) to some confusion from people downloading and using the data. Additionally, there is variation in the temporal frequency of the data delivered, with TMV facility delivering data at very high temporal frequencies (1 second) in comparison to other SST data from BOM (SOOP SST) or AIMS (TRV) (10 seconds).	Discussion is needed on how to handle the QA/QC and file formatting of the SST data from SOOP, TRV, NMF and TMV in order to provide a consistent data set that is not dependent on the agency that processes the data. Centralising the QC to one agency could be one way to solve this issue.
	Some QA/QC procedures are more robust that others, with some facilities not doing any QC (AUV).		
	Some near real-time data is not QC (gliders, some moorings, some SOOP BGC)		
			It would be beneficial to update the document "IMOS Data Streams and their Uncertainties" that reflects the current situation, sensors and processes

Variable	Key Points	Issues	Recommendations
Subsurface salinity	Sub-facilities follow their own protocol for QA/QC, with few linked to international programs (e.g. ARGO, XBT)		
	While there are some facilities with written protocols, there are many that don't.	While there are written protocols for some facilities, it does not include the QA/QC of all the variables derived from the facility as this is dependent of the organisation that performs the QC, i.e. SOOP BGC has a written protocol for the BGC variables but there is no written documentation of the QC protocol undertaken by MNF for the physical variables for this facility	It would be highly beneficial for all facilities to have a written protocol and make them available. This will facilitate the querying of the QA/QC procedures and give users confidence in the data.
	QC for some facilities (biologging) is outsourced	There is currently limited knowledge within IMOS of the QC work performed at MEOP, there is a preliminary strategy in place should MEOP stop QC'ing the biologging data, but this needs to be fully formed.	The AODN is currently harvesting the MEOP QC data (which includes IMOS), some thought should be given if the outsourcing of the QC is the best strategy for IMOS regarding the QA/QC of these data sets, and some involvement from IMOS should be discussed with MEOP. Similar to ANMN, conductivity needs to be stored if reprocessing is needed in the future.

Variable	Key Points	Issues	Recommendations
	Most of the moorings (shelves, deepwater and NRS) use similar QC procedures that include or are aligned to the IMOS toolbox	QC results produced by the toolbox need visual validation by the NRS and Shelves moorings sub-facilities in order to avoid bad data not being flagged.	The Australian National Mooring Network Steering Committee (ANMN SC) has agreed to re-process the relevant mooring datasets and improve the QC performed on them. There needs to be improvement on the visual validation of Toolbox QC results as well as the use of the Toolbox. A task team (TT) will be proposed to develop a document that would try to describe a consistent methodology on how to QC a mooring dataset with the toolbox.
		A separate issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, however, this is being corrected.	Centralising the calibration of sensors, where possible, will be a good strategy for consistency in the QA. In addition, documenting the process by the calibration provider is also needed to improve confidence in the data
		Some ANMN sub-facilities did not extract the raw conductivity data (from which salinity is derived) to make sure spikes are not an instrument issue, the data will be re-processed to add it	
		There is a general lack of information on the calibration results.	
	Some near real-time data is not QC (gliders, moorings, SOOP BGC)		
	Some QA/QC procedures are more robust that others, with some facilities not doing any QC for this variable (AUV).		

Variable	Key Points	Issues	Recommendations
		Some protocols indicate the calculations used to derive salinity, while many do not state it.	
			It would be beneficial to update the document "IMOS Data Streams and their Uncertainties" that reflects the current situation, sensors and processes
Surface/subsurface currents	There is no universal agreement on the QA/QC approach for radar currents within the radar group and the scientific community is split between the two major technologies.	Bonney Coast and GBR radars not optimized to monitor the regions.	Discussion may be needed about the utility of the Bonney Coast and GBR radars and how to improve them.
	QC procedures developed in house for WERA but not SeaSonde. Currently tests are being performed on a new data format for ocean radar currents, that is being developed within the international HF radar community. Similarly, tests are being performed for the near real-time and offline quality-control procedures, in accordance with the IOOS (Integrated Ocean Observing System) "Manual for Real-Time Quality Control of High Frequency Radar Surface Current Data".		
	SSH linked internationally to contribute calibrated and validated SSH data from which surface currents are derived		
	The Matlab toolbox is used for QC of the data for moorings by the different sub-facility leaders.	Calibration of ADCP for current speed is not required, however, ADCP compass calibration and other physical measurements made by the instrument do require calibration.	ADCPs can be acoustically calibrated and there is suggestions for the CSIRO facility to purchase the necessary acoustic equipment to calibrate ADCP acoustically

Variable	Key Points	Issues	Recommendations
			ADCP QA checks to ensure the data outputs are consistent and sensible are highly valuable. A facility or prescribed method to undertake a check of current speed/compass integrity would be recommended.
Sea Surface Height	The facility does not follow a fixed protocol, however, they follow a standard procedure for the mooring and GPS processing with a step in the data processing for the satellite calibration purposes. Fine checks are carried out around the time of the satellite overflight (~10 days).	There is no written documentation of their protocol	While the facility follows standard procedure to calibrate satellite SSH, providing some written documentation would be beneficial as an information source
Sea state (wave parameters)	Wave data from SOTS is done in CSIRO, QC is sensor intercomparison	Rudimentary or not QC	Given the increase interest in wave data, it may be important to start considering QC these data set and provide a written protocol of the QA/QC procedures. It is important to consider the purpose for the use of these data as QC requirements may vary.
	There is essential manufacturer QA/QC for the IMOS wave data from moorings in NRT and delayed mode. Some data are considered experimental only.		
	There are no protocols available for the QA/QC of these data in most facilities. Manufacturers and QARTOD protocols are available		
	The radar facility is looking at improving the wave data and has produced a report,		

Variable	Key Points	Issues	Recommendations
	although the radar set up was specifically designed for currents		
Ocean surface vector stress (wind parameters)	Wind velocity data only, QC in BoM, using the same automated QC used for all other variables, namely: SST, Air-sea fluxes, and others.		
	Rudimentary QC is undertaken in all other facilities.	No written protocols except for BoM	QARTOD manuals suggest that expert QC should be considered for both speed and direction of winds, along with comparisons with other observations such as Satellite. This could be a possibility to improve the data we are currently serving.
			There is also the potential to use remote sensing scatterometer data/and or reanalysis data to detect major errors.
Heat flux/radiation	QA/QC of air-sea fluxes are done by BoM for both SOOP and SOFS using the same automated QC system.		
Dissolved oxygen	QA/QC undertaken by facility.		That a written report is produced by the O2 Task Team giving recommendations for sensors available, uses, target accuracies and precisions required (e.g. Future Oceans EOV[1]s) and options and recommendations for calibration and maintenance for O2 sensors.
	Issue with high failure rate of the O2 sensors in WQM and CTD in the ANMN facility	WQM O2 sensors and CTD SBE43 sensors suffer from high failure and winkler titrations are needed to cross check the WQM and CTD data.	That optical oxygen sensors are used on NRS with 6-12 monthly calibrations and data processing using well defined and available techniques.

Variable	Key Points	Issues	Recommendations
	Moored optical oxygen sensors used in acidification moorings show low and linear drift with time and deliver an accuracy of about 0.5% or better	Winkler titrations for cross checking sensors are only carried out in MAI and ROT due to the equipment needed to conduct them. The lack of these titrations on other NRS makes their data difficult to use, although there is potencial for Qld NRS to do titrations with AIMS equipment	A fast response sensor like the Seabird SBE63 or Aanderaa 4330F sensors may be needed for a profiling CTD. Initial tests at Maria Island using bottle samples provide a way to ensure the sensors can be used for profiling prior to purchasing a number for other NRS CTD's.
Carbonate system (pCO2, pH, TIC, Alkalinity)	Data from all facilities are QA/QC to a good high standard, all linked to international standards		
	pH is only delivered by one sub-facilities		Deliver pH data to AODN where available and consider implementation on SOOP and CO2/acidification moorings
	No protocol written for SOTS		A written protocol from SOTS consolidating all their QC for all their variables is necessary
Macronutrien t concentration	Currently very sparse nutrient observations based on water samples.		The centralization of nutrient analysis in Hobart is a good approach as it makes the data consistent.
	Bio-fouling issues with NO3 sensor when moored.	Satlantic ISUS NO3 sensor appears to be good in profiling mode such as Argo, maybe gliders. This can open up the potential to have more observations at larger scales.	
	No protocol written for SOTS		A written protocol from SOTS consolidating all their QC for all their variables is necessary
Ocean Colour Chlorophyll	QA/QC undertaken by facility	Many facilities do not have a detail protocol written	All facilities should have written protocols available

Variable	Key Points	Issues	Recommendations
fluorescence	Conversion from fluorescence to Chl-a concentration can be difficult	The is a lot of work needed for the WQM to calibrate and convert fluorescence to Chla	Bottle pigment samples could be used to calibrate the WQM data in situ, and maybe needed because of site variations in the community composition
	An experimental project to calibrate and convert fluorescence data from WQM using algal cultures is currently underway, and there are other regional efforts, particularly in WA and SA to implement low Chla calibrations and instrument response	The WQM fluorescence conversion using algal cultures is experimental, results have not been published and converted data has not been given to AODN	That results from the project to convert fluorescence from WQM to Chl-a be published and a detailed protocol written. This project will help the conversion by considering the regional differences as well as sensor differences. It will be helpful if this project includes all WQM and not only the NRS ones (i.e. Lucinda, SOTS and other shelf moorings).
			Discussion is needed to clarify if results from the experimental project to convert WQM fluorescence to Chl-a data is to be used to process all WQM fluorescence data (including historical data).
	Calibration is not centralised within the ANMN	An issue with moorings is that not all sub-facilities send their instruments to a central place for calibration, this has recently been corrected	Centralising calibration of sensors will be ideal and more efficient
	In situ HPLC Chl-a conc. provides Chl-a concentration with high accuracy at the NRS		
	There is a radiometry TT underway to look at calibrations and sensor intercomparisons		That recommendations from the radiometry TT are implemented once the TT is finished.

Variable	Key Points	Issues	Recommendations
CDOM **Suspended particulates (PON, PIC, POC, TSS)**	The water samples collected at Lucinda and the NRS are QC and analysed as per NRS protocol by CSIRO team.	There are issues with measuring the TSS from the pooled sample collected at NRS, this is currently under review to resolve these issues.	The change from the pooled sample to the stratified samples in NRS will allow the use of the CDOM and TSS samples for satellite validation purposes.
		There are issues with the filters used for the collection of TSS samples from IMOS	Discussion is needed to resolve this issue
		Data from water samples taken at LJCO are currently not delivered to AODN, although there are plans for the delivery of these data soon.	Data from LJCO water samples should be delivered to AODN
	There is no written protocol for LJCO and Gliders for these variables		A protocol on the QA/QC should be available for all facilities
		There is an issue with manual QC from gliders, in that when data are reprocessed the manual QC flags are removed during the re-processing so QC needs to be re-done again manually	
Phytoplankton diversity **Phytoplankton biomass**	All the phytoplankton data is managed centrally making these data consistent.		
	Regular taxonomic training and comparison of our identification with overseas labs also increases consistency		

Variable	Key Points	Issues	Recommendations
	In addition, the publication of the phytoplankton database in Nature Scientific Data was an opportunity to get the IMOS and other data in a consistent and standard way. It should be encouraged for other data sets.		
Zooplankton diversity **Zooplankton biomass**	The management of the zooplankton data from SOOP and ANMN into a central laboratory makes these data consistent.		
	A taxonomic key for Australian zooplankton was created from these data sets as a collaboration between IMOS, UTas and CSIRO and is available online http://www.imas.utas.edu.au/zooplankton/home		
	Bioacoustic data is QC to international standards following the ICES WGFAST recommendations		
	Bioacoustic data will need analysis to estimate zooplankton biomass	There is an multifrequency acoustic system in SOTS, however, the data has not been given to AODN	Serious discussion is needed on extra data sets from sensors added by facilities but not integrated to IMOS
	Regular taxonomic training and comparison of our identification with overseas labs increases consistency		
	The zooplankton data set has been published in Ecology		
	Both facilities have good QA/QC procedures		

Variable	Key Points	Issues	Recommendations
Nekton species **Nekton biomass**	Bio-acoustic data is QC to international standards.		
	The acoustic animal tracking facility is the first to set standards for these observations, with false detection analysis. Information has been peered review and published and can be found here: https://animalbiotelemetry.biomedcentral.com/articles/10.1186/s40317-015-0094-z		
Top predator species **Top predator population**	Data is QC in both the passive acoustic moorings and the animal acoustic tagging facilities. Animal movement and presence/absence information can be extracted from these data, however, population information will need different techniques.		
	There is no written QA/QC protocol for passive acoustic. A software product, CHORUS, to analyse the IMOS Passive Acoustic data sets has been provided by Curtin.		That all facilities write a protocol for QA/QC that is publicly available
Benthos (% coverage of species) *** This facility has undergo an internal review**	Annotation happens outside the AODN through the software Squidle. The updated Squidle+ software will be able to handle larger data sets with flexible annotation. Members of the community agreed to upload their annotated data.		That the IMOS AUV Facility steering committee review the campaign planning and design of dives at sites around the country to ensure that a consistent methodology is adopted and that future data collected by the facility can be compared and conclusions drawn on a national basis to support the broadscale objectives of the program.

Variable	Key Points	Issues	Recommendations
	CATAMI has been too restrictive, so a flexible annotation scheme will be implemented.		That the facility should accelerate the transition to higher resolution imagery to improve description of benthos.
	There has been discussions with AODN to support closer integration with Squidle and the AODN portal and to facilitate the inclusion of additional data sources as part of the NeCTAR Ocean Sciences cloud.		That the next generation of online annotation tools be designed to support flexible classification schemes.
			To form a scientific steering committee with representation from the major groups involved in this work helps to set priorities for the IMOS Integrated Benthic Monitoring program, secure ship time, assist with fieldwork and lead the analysis of the resulting data streams
Detritus flux	Follows international convention for QA/QC. There is only one facility that collects these observations.	No written protocol	A written protocol for this facililty that compiles all the QA/QC

APPENDIX 3 LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
AIMS	Australian Institute of Marine Science
ANMN	The Australian National Mooring Network
ANMN SC	The Australian National Mooring Network Steering Committee
AODN	Australian Ocean Data Network
AUV	Autonomous Underwater Vehicle
BGC	Biogeochemistry
BOM	Bureau of Meteorology
BOWG	Bio-optical Working Group
CATAMI	Collaborative and Annotation Tools for Analysis of Marine Imagery
CDOM	Colored Dissolved Organic Matter
CLIOTOP	CLimate Impacts on Oceanic TOp Predators
CLIVAR	Climate Variability and Predictability
COAPS	Center for Ocean-Atmospheric Prediction Studies (COAPS)
CPR	Continous Plankton Recorder
CREON	Coral Reef Ecological Observation Network
CSIRO	
CTD	Conductivity, Temperature, Depth
DAR	Darwn Station
ECV	ocean Essential Climate Variables
EGO	Everyone's Gliding Observatories
EOV	Essential Ocean variables
EPA	Environment Protection Authority
FLNTU	Fluorescence, optical turbidity
GACS	Global Alliance of CPR Surveys
GBR	Great Barrier Reef
GCOS	Global Climate Observing System
GDRs	Geophysical Data Records
GHRSST	Group for High Resolution Sea Surface Temperature
GOA-ON	Global Ocean Acidification Observing Network
GOOS	Global Ocean Observing System
GPS	Global Positioning System
GTD	Gas Tension Device
GTSPP	Global Temperature Salinity Profile Programme
ICES	International Council for the Exploration of the Sea
IOCCP	International Ocean Carbon Coordination Project
IQuOD	International Quality controlled Ocean Database
JCU	James Cook University
JGOFS	Joint Global Ocean Flux Study
LJCO	Lucinda Jetty Coastal Observatory

MAI	Maria Island Station
MEOP	Marine Mammals Exploring the Oceans Pole to Pole
MMP	Marine Monitoring Program
MNF	Marine National Facility
NecTAR	National eResearch Collaboration, Tools and Resources
NRS	National Reference Stations
NRT	Near Real Time
NT	Northern Territory
OOPC	Ocean Observations Panel for Climate
OSTST	Ocean Surface Topography Science Team
OTN	Ocean Tracking Network
PAR	Photosynthetically active radiation
PIC	particulate inorganic carbon
PICES	North Pacific Marine Science Organization
PICO	Panel for Integrated Coastal Observations
POC	particulate organic carbon
PON	particulate organic nitrogen
QA	Quality Assurance
QARTOD	Quality Assurance of Real-Time Ocean Data
QC	Quality Control
QF	Quality Flags
QLD	Queensland
RCOOS	Regional Coastal and Ocean Observing Systems
ROT	Rottnest Station
SAHFOS	Sir Alister Hardy Foundation for Ocean Science
SAMOS	Shipboard Automated Meteorological and Oceanographic System
SIO	Scripps Institution of Oceanography
SMRU	Sea Mammal Research Unit
SOCAT	Surface Ocean CO_2 Atlas
SO-CPR	Southern Ocean CPR
SOFS	Souther Ocean Flux mooring
SOOP	Ships of Opportunity Program
SOOS	Southern Ocean Observing System
SOTS	Southern Ocean Time Series
SRS	Satellite Remote Sensing
SSH	Sea Surface Height
SST	Sea Surface Temperature
TIC	Total Inorganic Carbon
TMV	Temperate Merchant Vessel
TRV	Tropical Research Vessel
TSS	Total Suspended Solids
TT	Task Teams
US-IOOS	United States - Integrated Ocean Observing System
UWA	University of Western Australia

WOCE	World Ocean Circulation Experiment
WoRMS	World Register of Marine Species
WQM	Water Quality Monitor
XBT	Expendable Bathy Thermograph
YON	Yongala Station