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1. Preface

The original Special Publications 9 Handbook – **The Australian Tides Manual** – was published in 1984 and a revised web enabled version followed in 2004. As the title suggests, it provided operating procedures to be followed by operators of tide gauges on the Australian "National Network" – those stations that provide data for tide predictions at standard ports and secondary ports. In the twenty years since it was published, there have been a number of changes in measurement technology, communications and procedure, which now makes a new version of SP9 necessary.

Like the original SP9, this book is written for the Australian user. As various governments worldwide define legal boundaries differently and have different procedural guidelines for tide gauge maintenance, datum control etc., many of the procedures which are described herein may not be appropriate elsewhere.

This document brings together in a single, user-friendly form, a large number of existing sources of information on the measurement of tides and tidal currents. To some extent it is intended to enable the reader to quickly find the most relevant and up–to–date information.

This document contains numerous links to documents in html and PDF (Adobe reader required) formats, such links are blue and underlined. If the user already has Reader on their computer the document will be opened automatically, but otherwise, they will be prompted to obtain a (free) copy from Adobe.

2. Introduction

Our ability to predict the tidal levels and currents through coastal waterways is of great importance to a number of human activities. The beneficiaries of this information include commercial and recreational users, the Navy and a host of others. Sea level monitoring also provides key data for coastal authorities responsible for the determination of property boundaries and for planners and engineers in the construction of waterfront buildings, bridges, and jetties.

It may be argued that it is no longer necessary to continuously monitor sea level for tidal prediction. Indeed, the greater parts of the tidal fluctuations are regulated so closely by clockwork-like astronomical variations that the tides can be predicted with a high degree of precision for many years into the future. Nonetheless, the monitoring of sea level and currents remains an essential task, even in tide prediction, which is only as good as the data on which it is based, and is continuously improved as the data set lengthens. This was recognized in the 1984’s when on 21 August 1984

> “Australia has agreed to participate in a Sea Level Pilot Project in the Pacific Region, sponsored by the Intergovernmental Oceanographic Commission of UNESCO and the World Meteorological Organisation, as part of the titled Integrated Global Ocean Services System (IGOSS).”

The Sea Level Pilot Project expanded to become the Global Sea Level Observing System (GLOSS) in 1990.

One reason for this is that water level and currents are controlled by transient environmental factors as well as astronomical motions, and accurate records of both are often required in retrospect for legal, scientific, environmental, maritime safety, and planning purposes. From a broader perspective, we might consider that the global ocean, so closely tied to climate, is very sparsely sampled and so we must do all in our power to maintain the best possible record of its variability at our shorelines.

Over the past several decades, sea level monitoring has taken on a new and important role in climate prediction, particularly for the El Niño Southern Oscillation (ENSO) and the estimation of long-term sea level variability. In the early 1990's, the advent of reliable satellite altimeter data combined with numerical models gave rise to the belief among some that conventional tide gauges would soon become obsolete. However, this has not proven to be the case. Tide gauges have proven to be the most reliable and accurate source of coastal sea level data and have even turned the tables on satellite altimeters, providing evidence of drift in the latter technology.

3. Tides, Sea Level and Water Currents

3.1 Basic Theory

A brief introduction to the tidal forces is contained in "Our restless Tides", by the National Oceanographic and Atmospheric Administration (NOAA) in the United States. The approach is fairly conventional, with basic graphics. An example of one such graphic is from "Our Restless Tides" NOAA:

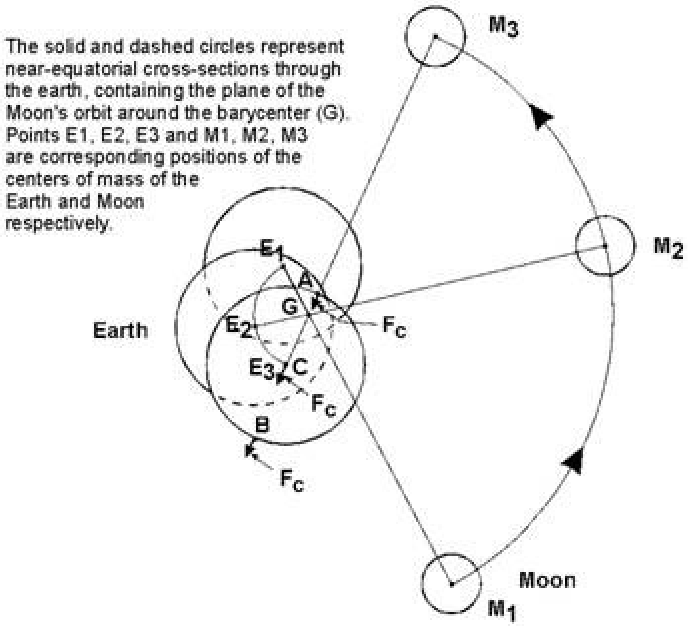

Figure 1 - Tidal forces

Figures such as Fig. 1 serve an important purpose, but there are alternative approaches that some may find preferable, particularly with the easy availability of web-based animation software. A very informative on-line tutorial "Introduction to ocean tides" is available (after you register) through "Meted", a cooperative online learning group. Another online introduction to tides that uses animated images is that of Professor M. Tomczak or Hawaii University .

Most introductions, including Our Restless Tides and Professor Tomczak's website, explain tides in terms of a balance between gravitational and centrifugal forces. Alternatively, introducing the concept of the "tidal potential" many of the complexities (e.g. Fig 1.) of the force balance can be avoided. The Canadian Tidal Manual (Forrester, 1983), discusses both approaches. This text requires slightly more advanced mathematical knowledge, but only by understanding the tidal potential can one understand the theoretical basis for the harmonic method of tidal analysis. It is more than twenty years old, but the theory has not gone out of date.

Finally, Pugh (1987) and Pugh (2004) have chapters on tidal theory written in a modern, textbook style.

3.2 Tidal Terminology

The National Tidal Unit (NTU) hosts the comprehensive NTU glossary with an emphasis on Australian terms (for example, the tidal datums favoured in Australian jurisdictions). The Australian Hydrographic Office (AHO) glossary, the Manly Hydraulics Laboratory (MHL; NSW Dept of Commerce) glossary, and the Maritime Safety Queensland (MSQ; Queensland Department of Transport) site contain a number of pertinent definitions in an Australian context. The Land Information New Zealand (LINZ) site contains a concisely worded, but limited selection of tidal definitions, and NOAA's tidal glossary defines tidal terms in the context of US usage. It also defines a number of oceanographic terms, such as "Kuroshio Current". The International Hydrographic Organisation (IHO) Hydrographic Dictionary, is a large compendium of all sorts of hydrographic and oceanographic terminology, including tidal.

3.3 Analysis and Prediction

The purpose of tidal analysis is to represent the water level or current time series by a set of harmonics, or sine waves, each of them having a specific amplitude and phase. The set of amplitudes and phases are known as the tidal constants. The official predictions created by the NTUfor the Australian National Tide Table uses up to 112 (given that there is at least one year of observations available for analysis). The definitions of four of the major constants are given in Table 1, these four constants can be used to classify the tidal character of a site (see section 1.3.3 Tidal Classification). There are two main methods for analysis: the harmonic method, and the response method. As the latter is used almost exclusively as a tool of scientific research, only the harmonic method will be discussed.

Table 1 - Major Tidal Constants

Constant	Definition
Major Diurnal Constants	
O^1	Principle Lunar diurnal constituent
K^1	Principle Lunisolar diurnal constituent
Major Semi-Diurnal Constants	
M^2	Principle Lunar semidiurnal constituent arising from the Earth with respect to the Moon
S^2	Principle Lunisolar semidiurnal constituent arising from the Earth with respect to the Sun

3.3.1 Tidal analysis

The harmonic method is based on the concept of the tidal potential. It is difficult to find books that set out in detail the process of analysis for the tidal constants, which are based on simultaneous linear regression for each of the amplitudes and phases (which may number over 100). Forrester (1983) and Pugh (1987) both contain a brief overview. The Manual for Tidal Heights Analysis and Prediction (Foreman, 1977) is essentially the operating manual for the "Foreman package" of tidal analysis and prediction and is one of the best practical guides. The PSMSL site presents some of the finer points of tidal analysis in the "Task-2000" discussion, and refers the reader to the analysis method outlined in Murray (1964) which described the current PSMSL practice (which is also the basis for present-day NTU practice). The International Oceanographic Commission website "Ocean Portal", which is devoted to the dissemination of ocean-related information, describes a number of tidal packages and invites the reader to review them.

Prospective tidal analysts should be aware that a set of constants derived using one analysis package may not provide accurate results with all prediction packages. This problem was discussed in Interpretation of tidal constituent Sa as well as in the Task-2000 report.

3.3.2 Tide prediction packages

Given a set of amplitudes and phases for a particular port from an analysis, the prediction of sea level is much simpler than the analysis that created them. The Scripps website listed above lists dozens of software packages that perform this function. Most generally contain a limited default set of constants for ports in the region covered, and it is also fair to say that most or all of those on the Scripps site are limited in the total number of constants they can accept (and hence limited in accuracy). For tidal information at Australian regional ports, AusTides, from the AHO contains information for over 680 Primary (Standard) and Secondary ports in Australia, Papua New Guinea, Solomon Islands, Antarctica and Timor-Leste. This information includes but is not limited to: predictions for high and low water for each day of the year for over 680 ports with tidal curves and predictions at each port location presented graphically at 10, 20, 30 and 60 intervals.

3.3.3 Tidal classification

The characteristic features of tides, such as whether there are two or only one high and low per day, vary widely around Australia. Various classification schemes have been developed, and one of the most common of these is the "form factor", F, defined by F = (K1 + 01)/(M2 + S2) (c.f. Table 1). The ANTT describes the classification of tidal types as follows:

"All tides are composed of both semi-diurnal and diurnal components, the latter introducing inequality in successive heights of high or low water and also in the times. When this diurnal inequality reaches a certain limit, it becomes more informative to list the average heights of the higher and lower high and low waters rather than the average spring and neaps values. The division between diurnal and semi-diurnal tides is arbitrary. In these tables the following criterion is used:

When (K1 + 01)/(M2 + S2) is less than or equal to 0.5, the tide is considered to be semi-diurnal. When (K1 + 01)/(M2 + S2) is greater than 0.5, the tide is considered to be diurnal. In some areas these formulae are unsatisfactory and a more detailed study of the harmonic constants is necessary to determine tidal characteristics".

3.3.4 Analysis of tidal currents

Tidal currents are analysed in terms of their separate (east-west and north-south) components. An introduction to tidal currents can be found on the NOAA website, and the NOAA glossary gives further detailed definitions, such as the meaning of "rotary" versus "rectilinear" currents. Many users find it useful to distinguish between the terms "tidal currents" and "tidal streams", with the latter being used to imply the major axis of flow denoted on nautical charts. Forrester (1983) and Pugh (1987) give additional details.

3.3.5 Long term sea level variability

Permanent continuous tide gauge installations are vital for monitoring long-term sea level changes. The Department of Environment has a dedicated webste on coastal Australia and include a section on sea level rise.

3.4 Environmental Effects on Sea Level

Water levels at the coast are governed by environmental (weather related, ocean wave, etc.) effects as well as by the astronomical tides. Perhaps the most familiar and dramatic example along the coasts of Australia is the storm surge, a large volume of water driven up to the coast by the combined effects of wind and atmospheric pressure. The effects of wind and atmospheric pressure are described in Section 2.3 of the IOC (Intergovernmental Oceanographic Commission) Training

Manual Vol. I (1985). This section also discusses the difference between tropical and extra-tropical surges.

3.4.1 Weather-related effects

The appendices of the NSW Coastline Management Manual contain descriptive reviews of coastal processes and the effects on beaches of storms and other weather-related events. The climate-related information is primarily focused on NSW, but the majority of the information is more general. Forrester (1983) (Chapter 4) describes wind set-up of sea level at the coast, wind-driven currents, atmospheric pressure effects, storm surges, seiches, precipitation, and runoff, written for the purposes of the tidalist. Pugh (1987) also covers most of those topics. Some illustrations and discussion of coastal processes can be found in Chapter 4 of Shelf and Coastal Oceanography by Prof. M. Tomczak.

A storm surge can, under certain conditions, become a free wave known as a coastally trapped wave (CTW) or continental shelf wave. In Australia such waves were intensively studied in the 1980's as part of the Australian Coastal Experiment, which focused on the continental shelf of southeastern Australia (Freeland et al.). However, the largest and most prevalent CTWs in Australia occur along the southern Western Australia coast and along the Great Australian Bight.

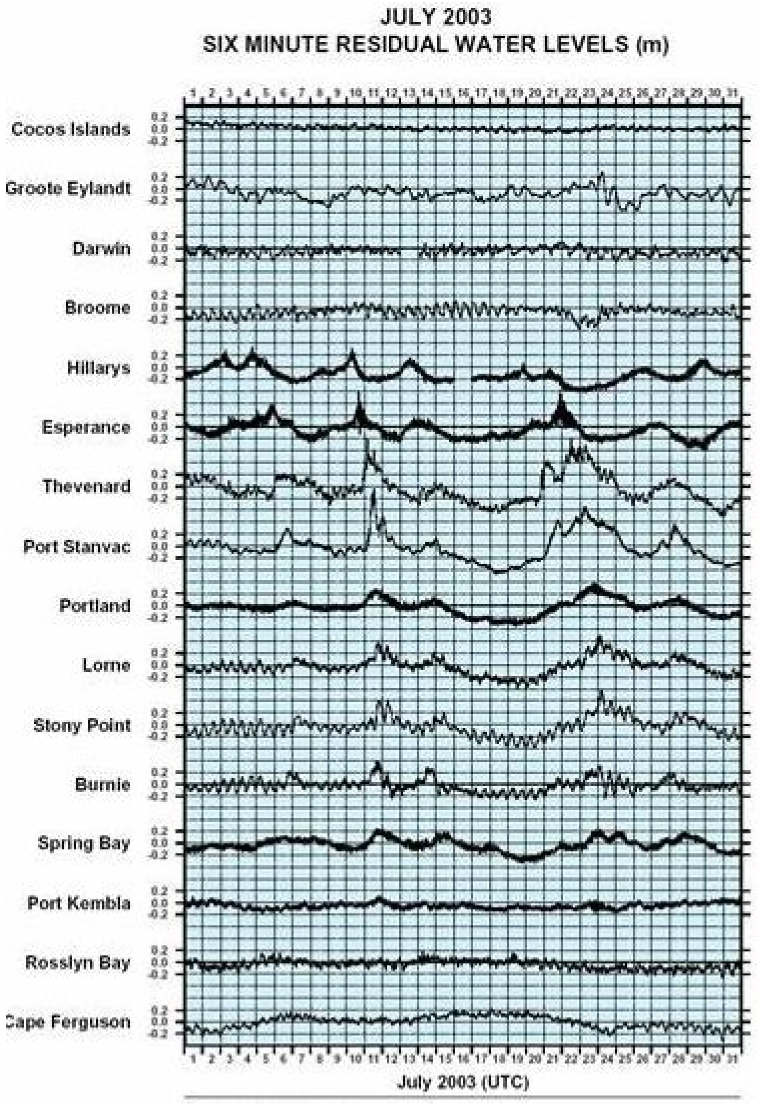

Figure 2 - An example of sea level residuals based on data from SEAFRAME stations of the Australian Baseline Array.

The effect of CTWs on coastal sea level is clearly visible in Fig. 2. A typical case begins somewhere in the vicinity of Hillarys, WA on 10 July. Onshore winds with peak gusts of 25 m/s (about 50 knots) drove water forward onto the shelf, sending sea levels at the tide gauge to about 30 cm above the predicted tidal value and initiating a CTW. CTWs travel along coastlines over the continental shelf. In the southern hemisphere the direction of travel is such that the coastline is to the left of the wave, so the CTW propagated southwards from Hillarys. It was evidently reinforced over the following days by onshore or north-westerly winds. The wave rounds the southwest corner of Australia, then turns to the east, successively raising sea levels by a half-metre or so at Esperance, Thevenard, Port Stanvac (Adelaide), Portland, and Lorne, finally entering Bass Strait a day or two after leaving Hillarys. A second CTW appears to be generated in the Bight itself on the 21st, with large residuals observed first at Esperance, and then stations to the east.

3.4.2 Shallow water effects

As the tide enters shallow waters, the tides associated with one or another of the major components (table1) often interact to produce "compound tides". Another effect is in the lagging of the tide wave through friction

"Ports which are situated in shallow water may have distorted tidal profiles, and this distortion may take many forms. In some cases, the distortion takes the form of a short period of rising tide and a long period of ebb, and at some places this can take the extreme form of a bore, particularly at spring tides. At other ports, the shallow water effects may cause double high or low waters, or perhaps a stand of tide lasting several hours; again the effect can vary considerably between spring and neap tides." Murray (1964).

An introductory-level discussion is contained in Forrester (1983). Many, but not all shallow water effects on tides can be accounted for by use of the full 112-constituent derived from harmonic analysis.

When tidal waters flow into coastal lagoons, or other partially impounded water bodies, the return flow frequently takes on a different character. For example, the flood currents are often more vigorous when the rise of water level in the lagoon is more rapid than when it falls. The connection of the lagoon to the ocean often takes the form of a long, narrow channel, which acts like a low-pass filter, reducing the amplitude of the higher tidal frequencies and the tidal effects within the lagoon. The time of high and low waters in the lagoon is also phase-lagged behind that of the ocean. The more restricted the connecting channel, the longer the hydrodynamic turn-over time, or residence time, within the lagoon. More restricted lagoons also tend to have greater salinity variations due to river input, which fluctuate with rainfall, and they also tend to be more prone to problems with sedimentation, pollution, and eutrophication. Consequently, there have been many instances of channel deepening and widening worldwide. These frequently have led to improved water quality, fish breeding, and other positive effects; however, careful study is required to predict the full ecological consequences in advance.

Tsunamis are well-known for their destructive impacts on many coastal areas. These also are essentially shallow-water phenomena since the generating wave is barely discernible in the open ocean. Recordings of tsunami are rare in Australian waters, but not unknown (see the Geoscience Australia website for more information). IOC Vol.1 states:

"A tsunami is a wave generated by seismic activity and as such falls outside the two categories of forces responsible for normal sea level changes, tides and the weather. Not all submarine earthquakes produce tsunami. The important element is a vertical crustal movement which displaces the sea bed. The tsunami wave characteristics will depend on the amplitude of the displacement and the dimensions of the sea bed involved. Horizontal displacements of the seabed will be relatively ineffective. The waves travel at a speed given by (water depth • gravitational acceleration)^{½}. Amplitudes in deep water are small, probably not more than 1 metre. The Pacific Ocean and its coastlines are the most vulnerable to tsunami because of the seismically active surrounding plate boundaries. As the wave approaches shallow coastal waters its amplitude increases and there are multiple reflections and refractions which combine to give very large local amplitudes. A network of reporting tide gauges in the Pacific enables warnings of tsunami arrival to be given some hours in advance."

4. Vertical Datums

A height system is a coordinate system used to define the height of a point above or below a reference surface. Its definition varies according to the reference surface chosen (e.g. geoid) the path along which the height is measured (e.g. plumbline). A height datum is the practical realisation of a height system (c.f. AVWS Technical Implementation Plan).The diagram below illustrates some of the various vertical datums in use within Australian waters and on land. The terms on the diagram are explained in Table 2.

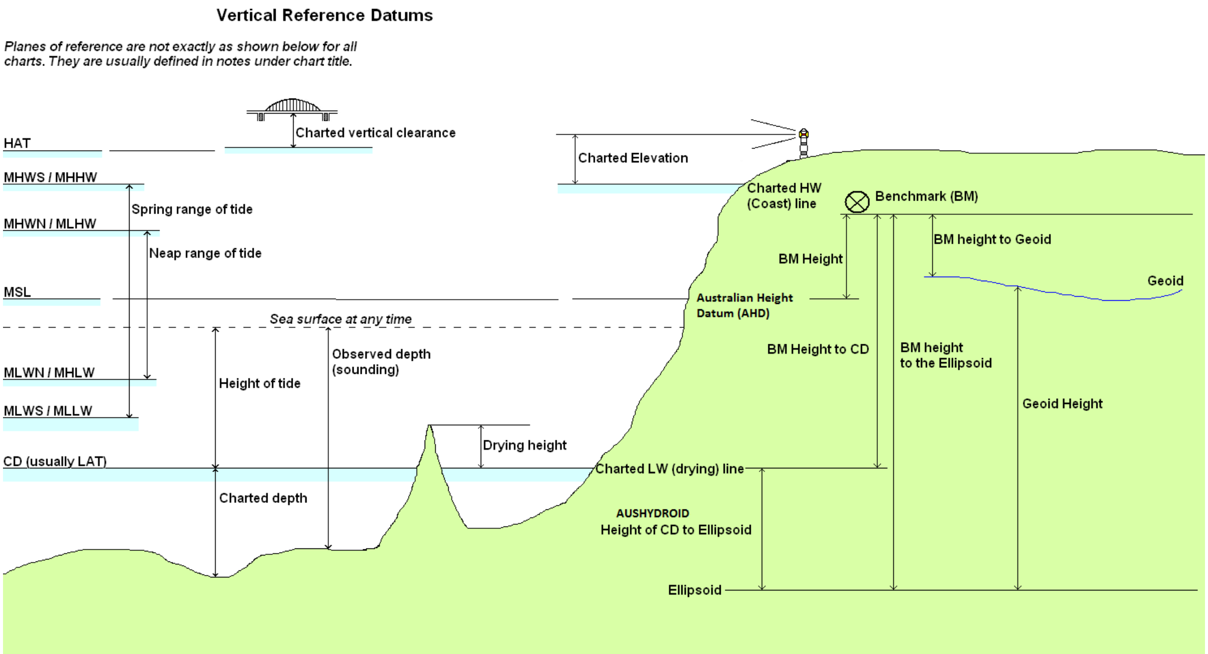

Figure 3 Vertical Reference Datums

Table 2 - Tidal Planes

Plane/Level	Purpose	definition
HAT	Landward limit of the tidal interface. Chart datum for high tide (Clearances). Limit of landward extent of tidal water under normal atmospheric circumstances.	Highest Astronomical Tide: the highest level of water which can be predicted to occur under any combination of astronomical conditions.
MHWS (and MHHW)	Tidal datum for cadastral (boundary) purposes for some jurisdictions (e.g. New Zealand, Queensland)	Mean High Water Springs (MHWS): the average of all high water observations at the time of spring tide over a period of time (preferably 19 years). Applicable in semi-diurnal waters only. Mean Higher High Water (MHHW): the mean of the higher of the two daily high waters over a period of time (preferably 19 years). Applicable in mixed and diurnal waters.
MHW	Common law datum for cadastral (land boundary) purposes. Used in Australia unless amended by legislation (as in Queensland for example). Frequently used as the coastal limit on topographic mapping.	Mean High Water (MHW): the average of all high waters observed over a sufficiently long period.
MSL	Average limit of the tides.	Mean Sea Level (MSL): the arithmetic mean of hourly heights of the sea at the tidal station observed over a period of time (preferably 19 years).
MLWS (and MLLW)		Mean Low Water Springs (MLWS): the average of all low water observations at the time of spring tide over a period of time (preferably 19 years). Applpicable in semi-diurnal waters only. Mean Lower Low Water (MLLW): the mean f the lower of the two daily low waters over a period of time (preferably 19 years). Applicable in mixed and diurnal waters.

Plane/Level	Purpose	definition
MLW	Has been used as the limit of Australian States as the definition of “low water”	Mean Low Water (MLW): the average of all low waters observed over a sufficiently long period.
LAT	Chart low water datum Baseline for the purposes of defining Australia’s maritime boundaries in compliance with the UN Convention on the Law of the Sea.	Lowest Astronomical Tide (LAT): the lowest tide level which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions.
AUSHYDROID	Facilitate GNSS Surveying method to chart datum	Defines the surface separation between the National Ellipsoid[1] and Chart datum.
Australian Height Datum (AHD)	National Vertical datum for Australia and refers to Australian Height Datum 1971 (AHD71; Australian mainland) and Australian Height Datum (Tasmania) 1983 (AHD-TAS83)	AHD71 is a surface that passes through approximate MSL realised between 1966 and 1968 at 30 tide gauges around the coastline. AHD-TAS83 is based on MSL at two tide gauges. Section 4.3 provides additional information
Ellipsoidal height (geodetic height) “h”	Facilitate GNSS Surveying methods across land/sea.	distance of a point from the ellipsoid measure along the perpendicular from the ellipsoid to this point, positive if upwards or outside of the ellipsoid
Geoid	Facilitate GNSS Surveying methods across land/sea	A hypothetical model surface that coincides with mean sea level and is perpendicular , at every point, to the direction of gravity.

[1] http://www.ga.gov.au/scientific-topics/positioning-navigation/geodesy/geodetic-datums

4.1 Tidal Datum Epoch for LAT and HAT

The tidal datum epoch (TDE) is the interval recommended for the calculation of datums. It is normally longer than 18.6 years in order to include a full lunar nodal cycle. The Tides and Sea Levels Working Group (TSLWG) recommended that a 20-year TDE, 1992-2011 inclusive, be adopted for the determination of Lowest Astronomical Tide and Highest Astronomical Tide (LAT and HAT).

This TDE is to be known as LAT (1992) and HAT(1992).

Use of the tidal planes outside of navigation should consider other influence for water level exceedance.

Some States and Territories are moving to a epoch 2010-2029 (20 years) inclusive epoch for HAT determinations (HAT2029).

Internationally, there are different but equivalent ways of defining the epoch. For example, to account for slow variations of sea level relative to land, NOAA intends to re-compute the U.S. National TDE (NTDE) every 20-25 years. (The "current" epoch is the 19-year period ending 31 December 2001) The NTDE is used in the US for the computation of not only LAT and HAT, but also mean sea level and most other tidal datums. The NOAA site and on implementation information.

4.2 Tidal Planes and Levels

The terms “tidal planes”, “tidal datums”, and “tidal levels” will be used interchangeably, although some authors draw a distinction - for example, a “plane” implies a two-dimensional surface extending over a given region.

4.2.1 Harmonics-based definitions

The following definitions, based on the tidal harmonics, are taken from the ANTT. The harmonic definitions can be considered convenient simplifications. The Intergovernmental Committee on Surveying and Mapping (ICSM), Tidal Interface Working Group (TIWG), in 2003 produced a 103-page compendium of terms related to the legal definition of the land-sea boundary in Australia. It can also be found as a summary. In the following, Z0 represents the mean sea level, and the other symbols are the usual harmonic constants.

For semi-diurnal ports:

Mean High Water Springs: MHWS = $Z_0 + (M_2 + S_2)$

Mean High Water Neaps: MHWN = $Z_0 + |M_2 - S_2|$

Mean Low Water Springs: MLWS = $Z_0 - (M_2 + S_2)$

Mean Low Water Neaps: MLWN = $Z_0 - |M_2 - S_2|$

For diurnal ports:

Mean Higher High Water: MHHW = $Z_0 + (M_2 + K_1 + O_1)$

Mean Lower High Water: MLHW = $Z_0 + |M_2 - (K_1 + O_1)|$

Mean Higher Low Water: MHLW = $Z_0 - |M_2 - (K_1 + O_1)|$

Mean Lower Low Water: MLLW = $Z_0 - (M_2 + K_1 + O_1)$

4.2.2 Observations-based definitions

The harmonic-based definitions are not universally accepted, in part because they assume that M2, S2, O1, and K1 are the dominant four components, which is not always the case. For this reason, many authorities (e.g., MSQ and NOAA) adhere strictly to observation-based definitions of the tidal planes. The list of standard terms in the table 2 gives observation-based definitions from the Australian Hydrographic Office tidal glossary. Variations of the definitions may apply in current legislation.

4.3 The Australian Height Datum

Table 2, mentions the AHD which is described in detail in the GDA94 Technical Manual. For convenience, several key paragraphs are reproduced below:

On 5 May 1971 the then Division of National Mapping, on behalf of the National Mapping Council of Australia, carried out a simultaneous adjustment of 97,230 kilometres of two-way levelling. Mean sea level for 1966-1968 was assigned the value of zero on the Australian Height Datum at thirty tide gauges around the coast of the Australian continent.

The resulting datum surface, with minor modifications in two metropolitan areas, has been termed the Australian Height Datum (AHD) and was adopted by the National Mapping Council at its twenty-ninth meeting in May 1971 as the datum to which all vertical control for mapping is to be referred. The datum surface is that which passes through mean sea level at the thirty tide gauges and through points at zero AHD height vertically below the other basic junction points.

The AHD is an imperfect realisation of mean sea level because some of the tide gauges used for its definition were not well sited; the mean sea level determination was for a limited period and a particular epoch and no allowance was made for sea surface topography. The difference between AHD and mean sea level, which may be of the order of several decimetres, is not significant for conventional propagation of AHD, which is relative to existing AHD bench marks, but may be important if connecting AHD to a recent determination of mean sea level, or when working on-shore over large areas for environemental studies (e.g. for flood or storm modelling), Lidar Surveys and Hydrography.

The AUSGeoid2020 model provides the offset between the Australian Height Datum (AHD) and GDA2020 ellipsoidal coordinates. It was determined from gravity data and GNSS-levelling derived heights (Brown, 2018). The model enables GNSS users to obtain AHD heights without having to connect to a physical benchmark. However, due to local biases and distortions in the AHD levelling data, the AUSGeoid model can only be determined with an accuracy of 6-13 cm across Australia. AUSGEOID2020 is not designed for use offshore.

4.3.1 The Australian Vertical Working Surface

A user requirements study found the Australian Height Datum (AHD) and AUSGeoid are not capable of meeting some users accracuy needs due to the aforemention limitations (AVWS Technical Implementation Plan).. The Australian Gravimetric Quasigeoid (AGQG) model is a gravity model that provides the offset between the GRS80 ellipsoid and (approximately) the geoid.

Global Navigation Satellite System (GNSS) dervied ellipsoidal heights (h) can be converted to AVWS heights by subtracting the height anomaly (ζ) provided by the AGQG model. This is advantageous since GNSS ellipsoidal heights are relatively cheap and easy to obtain in comparison to large-scale levelling campaigns. AVWS heights can be computed directly from GNSS without needing to connect to survey mark infrastructure. Since the model is determined using just gravity data is does not contain the distortions and local biases present in the AHD. The AGQG2017 model has been determined with an accuracy of 4-8 cm. The model will continue to be improved as more gravity data are acquired.

AHD remains the only legal height datum.

5. Tide Gauge Heirarchy

This edition introduced the adoption of hierarchy of continouse operated tide gauges (COTG). It is similar to the hierarchy used for continouse operated reference stations (CORS), see reference 9.2(h). Australia has three tiers of tide gauges In operation. With the tiers in order of intent of use of the tide gauge.

5.1 Tier 1 COTG

Tier 1 COTG require high accuracy gauges connected with first order levelling to a CORS to support sea level research at local, national and global scale. These sites are established and maintained to support the International GLOSS program. The IOC site (ref 9.2 J) providesguidelines for all COTG contributing data to IOC. Data from Tier 1 COTG sites should be submitted to IOC for global sea level science and research purposes (e.g. tsunami monitoring).

5.2 Tier 2 COTG

Tier 2 COTG require high accuracy tide gauges and are usually established by national,state or territory agencies for the purpose of defining and maintaning a significant port datum. or scientific research. These sites for the primary national tide gauge network and are also known as Standard ports.

Note that Tier 1 COTG sites are generally a subset of these Tier 2 locations, providing a tie between the national and international network. Data from Tier 2 should be made available to the relevant national, state or territory jurisdiction for the purpose of national hydroid realisation and improvement.

5.3 Tier 3 COTG

Tier 3 COTG require accurate tide gauges usually established by national,state, territory government and /or commerical agencies for the purpose of defining and maintaning a port datum, often supporting real-time applications. These stations add to the densification of the national hydroid realisation, improvement and network.

5.4 Summary of recommendations for COTG

Table # provides a summary of the recommendations provided in this manual.

Recommendation	Tier 1	Tier 2	Tier 3
Foundation:			
Mounted on buidling or similar structure	■	■	□
Single pylon driven to resistance	X	X	■
Monumentation:			
Stainless steel or galvansized mild steel mounts attached to builidng or structure	■	■	□
Interference:			
Minimise wave/stilling well/ environment sources	■	■	■
Long-term site tenure	■	■	■
Power:			
Ensure continuous operation of tide gauge	■	■	■
Ensure continuous operation of all communication devices	□	□	■
Communications			
Support remote control and data access	■	■	■
Reliable and continuous, with a latency of less than 2 seconds from tide gauge to end user(when used for real-time applications)	■	■	■
Sensors			

Primary water level: 0.0005 m over a range of 0 - 15 m	■	■	■
Sampling rate between 6-15 mins or 1 mintute or less for tsunami warning	■	■	■
Timing accuracy must be better than 1 minute or less than for more frequentt sampling rates	■	□	□
Individually calibrated tide gauge instrument	■	■	□
Annual calibration/checks of tide gauge	■	■	■
Continuous logging of data	■	■	■
Ability to store at least 60 days of raw data	■	■	□
Ability to store at least 30 days of raw data	□	□	■
Continuous raw data streaming, RTCM at 1hHz	■	□	□
Dual water level gauge installation	■	■	□
Backup water level	■	■	□
Levelling: +/ - 0.001 m. This must be maintained for a minimum period of twelve months between re - levelling	■	■	□
Additional Instrumentation			
Continuse Operating Reference Stations (CORS) GNSS – installed as close as practical (within 5 km) of Tide gauge	■	■	□
Pressure measurement accuracy better than ± 0.01 hPa	■	■	□
Air and SeaTemperature: 0.1° C over a range of - 10 to +55° C	■	■	□
Realtive Humidity measurement to better than ± 2%	■	■	□
Wind Speed: 0.5 m/s over a range of 0 to 50 m/s.	■	■	□
Wind Direction: 5° over a range of 0 to 360°	■	■	□

Reliability:			
Require complete, continuous time series dataset for post-processing	■	■	□
Short communication outages tolerated	■	■	X
Ensure continuous stram of data to support real-time services	□	□	■
Metadata:			
Complete and current site log on BoM website	■	■	□
Readily available site metadata	■	■	■

Legend

■ Strongly Recommended X Not Recommended
□ Recommended N/A Not Applicable

5.5 Network Design

The key parameters in the design of the COTG network are:

- Distance between the COTG;
- Connection to the reference frame and / or national geodetic datum; and
- Effect of a station outage on service delivery

Typical COTG network interstation distancs are as follows:

Tier 1 COTG: not closer than 500 kilometres for island groups and not less than 1000 kilometres along continental coasts. Preference has been given to islands in order to maximize exposure to the open ocean.

Tier 2 COTG: 80 to 500 kilometres

Tier 3 COTG: 20 to 80 kilometres

Co-location of Tier 1 or Tier 2 COTG with equivalent CORS, meteorological or research infastracture is encourged where possible.

6. Instruments

6.1 Tide Gauges

6.1.1 Types of Water Level Sensors

The main types of water level sensors in use in standard ports in Australia are the microwave (radar), acoustic and pressure sensors. Also used, but less common are laser ranging and ADCP current meters. The IOC Training Volumes provide a very comprehensive source of information on tide gauge types (see links below). Bear in mind that there are substantial gaps in time between the three manuals, published in 1985, 1994, 2002 and 2006 so that the latest manual is far more up to date than the original.

The pros and cons of the main types are given in IOC Vol. III, Table 2.1. This table has been updated in IOC Vol IV Table 3.1 describes the merits and drawbacks of each tide gauge technology, including radar gauges. Several studies have been undertaken since 2006 that evaluate the major tide gauge types in use, copies of these can be found on the PSMSL website Tide Gauge Experiences.

IOC Vol. V was released in 2017 and is just on radar gauges. The radar instrument is a freestanding, portable unit which sends a microwave pulse downward through free air and measures the return time. Radar gauges are easy to operate with no parts in the water and give a direct measurement of water level with no dependency on air temperature. Descriptions of radar type gauges are given in IOC Vol IV. The radar sensor can also be setup to operate within a stilling well. A cable must be installed down the centre of the well to guide the microwave pulse.

Figure 4 - Typical Microwave radar sensor used at many Australian Ports. This particular unit is a Vega Pulse 63 on a wharf in Gladstone harbour.

Descriptions of pressure-type tide gauges (including bubbler systems) are given in SP9 1984, IOC Training Manual Vol. I Section 2.4 and Vol. III Section 2.2.

Descriptions of acoustic tide gauges are given in IOC Vol. II and IOC Vol. III.

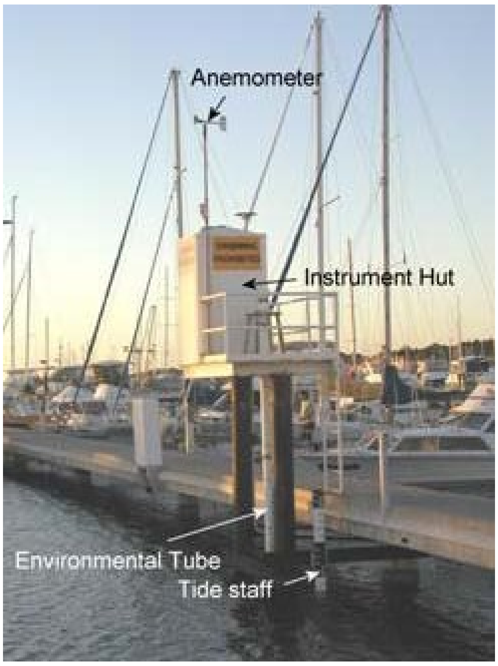

Figure 5 - Tide gauge at Hillarys, Western Australia.

Figure 4 is a "SEAFRAME" station, one of thirteen installed by NTU to monitor long-term sea level changes around Australia. The water level is measured be sending an acoustic pulse down a small pipe within the environmental tube.

These instruments measure return time, sending an acoustic pulse down a 13 mm (internal diameter) ABS sounding tube. The return travel time through the air between a transmitter/receiver and the water surface below is converted to sea level. A calibration hole, drilled into the tube at a set distance from the transmitter, causes a secondary reflection which is used to correct the sound velocity (which changes with temperature and other factors). Most acoustic instruments are very lightly damped in comparison to the 1:10 ratio of float gauges. For example, the acoustic instruments of the Australian Baseline are damped only 1:3. The mechanical damping is replaced by digital filtering of the return signals. A pulse is sent down the tube every second for three minutes. The arithmetic mean of the return times is then recorded. The standard deviation of the levels is also recorded, as it is used to eliminate outliers and can be related to the significant wave height (SWH), both of which can be of significant advantage.

Descriptions of float gauges are given in IOC Training Manual Vol. 1 Section 3.2, Vol. II Section 2.1 and Vol. III Section 2.3.

The most recent newcomer to the field of sea level measurement is the laser ranging wave gauge (LRWG). These were developed for application to wave measurement but are also capable of application to measuring water level. For a comparison of the LRWG and other sensor types see the Canadian Hydrographic comparison of sensors. The ability to measure sea level and wave heights with one instrument makes the EWS and LRWG attractive options for port operations.

Figure 6 - Laser wave ranging gauge in operation at Hay Point.

The instrument is a WTS-1 non-contact laser from Harbour and Marine Engineering. Photo is courtesy of North Queensland Bulk Ports.

6.1.2 Recording Devices

Modern tide gauge installations automatically record the water level data. For a mechanical system such as a float device, the distance travelled by the float was, until recently, usually recorded directly on a chart recorder, but nowadays more commonly is converted to an electrical pulse for recording on a digital medium. Acoustic systems use a transducer to convert the acoustic wave to an electrical signal.

6.1.2.1 Chart recorder operating procedures

As chart recorders are nearly obsolete at Australian ports, we refer the reader, if necessary, to Vol. 1 of the IOC training manuals, and SP9 1984, which contains a check sheet for operational water level checks to the tide staff.

Figure 7 - A chart recorder

6.1.2.2 Digital recorder operating procedures

Chart recorders are gradually being replaced by some form of shaft encoder coupled with a digital recording device. A pulley attached to the float (see diagram below) causes the encoder shaft to rotate in response to vertical motion of the float.

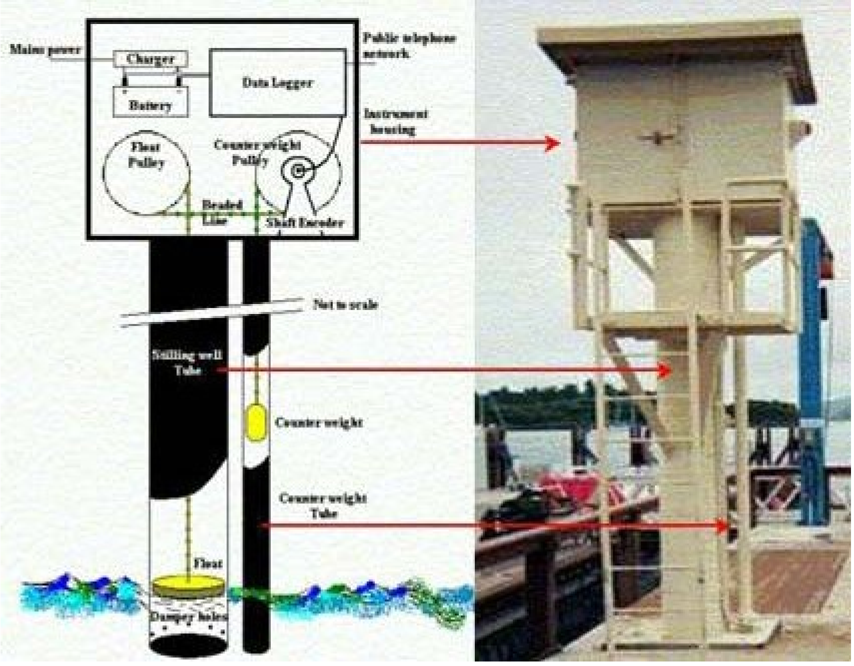

Figure 8 - Diagram of tide gauge with shaft encoder and data logger, from the Queensland EPA website.

There are many types of shaft encoder; however they all convert the vertical displacement of the float to a digital or analog electrical signal. Some employ a quadrature device that picks up the motion of a rotating disk and sends out two digital pulses, out of phase by 90°. This requires a second device to interpret the edges of the pulses “increase or decrease of voltage” as either upwards or downwards motion. Another type uses a transducer to send out a 16 bit parallel code which again requires interpretation by an electrical sensor. Other types include potentiometers “voltage level output” and counters “these send out a “motion” pulse plus an “up/down” signal”.

Figure 9 - An incremental shaft encoder

The operating procedures for digital recording devices are outlined in SP9 1984, in which may be found a check sheet for operational water level checks to the tide staff.

6.1.3 Tide Gauge Specification

6.1.3.1 Precision, accuracy and resolution

Accuracy and precision are frequently confused, despite having quite distinct technical definitions. A simple way to think of the difference is in terms of a target. Consider a cluster of five arrows shot into a small area above and to the right of the bulls-eye. The archer's accuracy would be measured by the distance from the bulls-eye to the centre of the cluster, while his or her precision would be measured by the tightness of the cluster. Precision is a measure of repeatability, or how closely repeated measurements of the same quantity agree with each other. Accuracy is a measure of reliability - how close are the measured values, as a whole, to the true or accepted value?

Resolution is usually defined as the smallest interval of change that can be measured by a particular instrument.

6.1.3.2 Requirements for accuracy and placement

Tide gauges used for standard port predictions in Australia have the same requirement for accuracy as tide gauges on the GLOSS network, i.e., one centimetre accuracy in all weather (see IOC Vol. III Section 1.3). Likewise, it is important that should an instrument be replaced, there should be a period of overlap in which the two operate in parallel to ensure accuracy and to pinpoint the mean level. The GLOSS implementation plan suggests that the period be one decade, but acknowledges that this will be impractical.

Many tide gauges, such as the SEAFRAME instruments operated as part of the Australian Baseline Array, are intended to monitor sea level trends over the longest possible period of time. Compared to the port and storm surge gauges, these are subject to more rigorous requirements in accuracy and precision, as well as datum control.

6.2 Calibration

6.2.1 Tide gauge calibration

From the 1984 Special Publication 9 on tide gauges:

Many tide records show unexplained jumps in datum, bad overlaps on charts, time errors, and other discrepancies which have no connection with the tidal movement which the gauge is required to monitor.

The fact that a gauge is in error is not necessarily a reflection on the attention of the operator. No gauge is perfect or trouble-free and errors are to be expected from time to time. Our main concern is that the user of the records should be able to see at once whether any correction to the records is necessary.

Perhaps the main requirement to enable the tide gauge records to be correctly processed is the availability of independent checks. From these checks the performance of the gauge can be assessed and any necessary corrections made before putting the records into the national data base. It is therefore most essential that accurate and true comparisons be made between the gauge time and a standard clock and also between the recorded height and the height as read from the tide staff.

The preceding words from SP9 1984 are still true, except that the independent checks now often take the form of a second instrument, either temporarily or permanently installed alongside the primary gauge.

Figure 10 - Calibrating an Aquatrak sensor in a calibration rig.

A description of stilling well test calibration and maintenance may be found in IOC Training Manual Vol. 1 Section 3. A description of the Van de Casteele test may also be found in the IOC Training Manual Vol. I Section 3.2. These checks should be carried out yearly or more often if biological fouling of the sensors is a problem, and always after a change of any of the components of the system.

Figure 11 - Biological fouling is a real problem, especially in near shore tropical waters.

The picture shows a side view of the circular copper plates normally bolted to the bottom of the acoustic sensor, and the brass damping cone that sits just above them inside the environmental tube. The tide gauge is located in Kiribati, and shows the accumulation of about five years' growth. Photo credit: Allan Suskin.

There must be frequent independent water level checks, with time and height recorded. The tide staff and TGBM, and its supporting marks must be re-surveyed at least yearly and at any change to the board.

Precise datum control for pressure gauges is outlined in IOC Vol. II

6.2.2 Verification of field barometers

1. For stations with a pressure sensor the barometer height will need to be surveyed by a licensed surveyor to an accuracy of at least 0.1 m. A new survey will only be required if the barometer is relocated.
2. The reference barometer and test barometer should be mounted at the same height.
   For most electronic barometers placement on a common surface is sufficient. If however the barometer under test is a Mercury in glass barometer, place the reference barometer on the same level as the cistern. In the case of mechanical digital aneroid barometers the datum level is the centre of the dial.
3. Where possible, plan instrument verification to have the least impact on scheduled metrological messages by minimising this disruption to sensors in the 10 minutes preceding observation times.

Ambient Single point verification

1. For verification of a pressure sensor at ambient conditions you will require, a traceable calibrated reference barometer and temperature sensor.
   Ideally the reference barometer should have an uncertainty of at least a third of the manufacturer's specification of the unit to be tested. i.e. for a test barometer with a specification of 0.3 hPa the reference should have an uncertainty of 0.1 hPa.
2. Ensure the reference and test barometers are stabilised at the same temperature.
   Allow the reference barometer a minimum of 15 minutes to stabilise to near the same temperature as the test barometer. If the two barometers have been exposed to considerably different temperatures, i.e. >15° C difference, for a moderate length of time, allow up to 60 minutes before performing the verification.
3. Record the start time of the test and the serial number for the reference and test barometers
4. Record the pressure as measured by the reference barometer
5. record the temperature
6. Record the pressure as measured by the instrument under test.
7. Apply any temperature correct corrections to the reference or test barometers.
   For electronic barometers temperature corrections are seldom applied, however these are essential for Mercury in glass and mechanical digital aneroid barometers. They should be supplied with the instrument from the manufacturer. Often for mechanical digital aneroid is there is an operational window ±2°C or ±5°C around the calibration temperature.
8. Repeat steps 7 to 10 five times the minimum of two minutes between each measurement.
9. Calculate the difference between the reference barometer and the test barometer.
10. Calculate the average of the five results.
11. Calculate the roots sum square of the uncertainty of the reference barometer and the manufacturer's accuracy specification for the test barometer.
12. Also calculate the roots sum square of the uncertainty of the barometer and three times the manufacturers accuracy specification for the test barometer.
13. If the specification for the test barometer is unknown then use the appropriate value from the list below:-

Barometer	Estimated Accuracy

Professional quality • electronic digital • mercury in glass • mechanical digital aneroid	0.3 hpa
Low Cost barometer/AWS	0.5 hPa
Dial Aneroid	0.7 hPa

14. If the calculated difference from step 13 is less than the value calculated at step 14 then the barometer can be considered to be in calibration and no adjustment needs to be made.
15. If the calculated difference from step 13 is greater than the value calculated at step 14 but less than value calculated at step 15. Then the barometer is considered to be out of calibration but may be adjusted according to the manufacturer's method for adjustment.
16. If the calculated difference from step 13 is greater than the value calculated at step 15, then the barometer is considered to be faulty and should be returned for service.
17. Record the adjustment made and repeat steps 6 through to 18 to confirm the barometer is within calibration.

Sample Test Record

Date	15/5/2018	**Time**	5:00		
Reference Serial Number	A12345	**Test Barometer Number**	B45612		
	Reference hPa	**Test Barometer hPa**	**Temperature °C**	**Temp Correction hPa**	**Difference hPa**
Test 1	1012.3	1012.3	20.1		0.0
Test 2	1012.3	1012.4	20.1		0.1
Test 3	1012.2	1012.3	20.2		0.1
Test 4	1012.3	1012.4	20.1		0.1

Test 5	1012.2	1012.3	20.2		0.1
Average					0.08
Uncertainty	0.12	0.3			
Pass Threshold					0.32
Fail Threshold					0.53

Multipoint Verification

1. To undertake a multipoint verification across a range of pressures the following is required.
    a. a traceable calibrated reference barometer
    b. temperature sensor
    c. a hand held hydraulic pressure pump
    d. T piece and pipes
    e. record sheet
2. Ideally the reference barometer should have an uncertainty of at least a third of the manufacturer's specification of the unit to be tested. i.e. for a test barometer with a specification of 0.3 hPa the reference should have an uncertainty of 0.1 hPa.
3. Ensure the reference and test barometers are stabilised at the same temperature.
   Allow the reference barometer a minimum of 15 minutes to stabilise to near the same temperature as the test barometer. If the two barometers have been exposed to considerably different temperatures, i.e. >15° C difference, for a moderate length of time, allow up to 60 minutes before performing the verification.
4. Connect the main shaft of the T-piece to the hand pump and ensure the hand pump is set at half volume.
5. Connect the reference and test instruments to the cross piece of the T using the appropriate pipes.
6. Record the start time of the test and the serial number for the reference and test barometers
7. Record the pressure as measured by the reference barometer
8. Record the temperature
9. Record the pressure as measured by the instrument under test.

10. Apply any temperature correct corrections to the reference or test barometers.
For electronic barometers temperature corrections are seldom applied, however these are essential for Mercury in glass and mechanical digital aneroid barometers. They should be supplied with the instrument from the manufacturer. Often for mechanical digital aneroid is there is an operational window ±2°C or ±5°C around the calibration temperature.
11. Repeat steps 27 to 30 three times the minimum of two minutes between each measurement.
12. Wind the hand pump out half way to reduce the pressure, and repeat steps 27 to 30
13. Wind the pump out fully, and repeat steps 27 to 30
14. Return the pump to the original position, and repeat steps 27 to 30
15. Wind the pump half way in, and repeat steps 27 to 30
16. Wind the pump all the way in, and repeat steps 27 to 30
17. Return the pump to the original position, and repeat steps 27 to 30
18. Calculate the difference between the reference barometer and the test barometer.
19. Calculate the average of each set of results.
20. Calculate the roots sum square of the uncertainty of the reference barometer and the manufacturer's accuracy specification for the test barometer.
21. Also calculate the roots sum square of the uncertainty of the barometer and three times the manufacturers and accuracy specification for the test barometer.
22. If the calculated difference from step 39 is less than the value calculated at step 40 then the barometer can be considered to be in calibration and no adjustment needs to be made.
23. If the calculated difference from step 39 is greater than the value calculated at step 40 but less than value calculated at step 41. Then the barometer is considered to be out of calibration but may be adjusted according to the manufacturer's method for adjustment.
24. If the calculated difference from step 39 is greater than the value calculated at step 41, then the barometer is considered to be faulty and should be returned for service.
25. Record the adjustment made and repeat steps 27 through to 39 to confirm the barometer is within calibration.
26. Sample Test Record

Date	15/5/2018	**Time**	5:00		
Reference Serial Number	A12345	**Test Barometer Number**	B45612		

	Reference hPa	Test Barometer hPa	Temperature °C	Temp Correction hPa	Difference hPa
Test 1	1012.3	1012.3	20.1		0.0
	1012.4	1012.2	20.1		-0.2
	1012.3	1012.2	20.2		0.1
Average					-0.033
Test 2	975.1	975.4	20.1		-0.3
	975.2	975.4	20.2		-0.2
	975.2	975.5	20.2		-0.3
Average					-0.266
Test 3	890.2	890.5	20.2		-0.3
	890.3	890.7	20.1		-0.4
	890.2	890.5	20.1		-0.3
Average					-0.333
Test 4	1010.3	1010.4	20.1		-0.1
	1010.2	1010.3	20.0		-0.1
	1010.2	1010.2	20.1		0.0
Average					-0.066
Test 5	1041.7	1041.4	20.2		0.3
	1014.6	1041.3	20.2		0.3
	1014.6	1041.2	20.2		0.4
Average					0.333
Test 6	1089.5	1090.1	20.2		0.6
	1089.6	1090.1	20.2		0.5
	1089.6	1090.3	20.2		0.7
Average					0.60
Test 4	1011.4	1011.4	20.1		0.0
	1011.3	1011.4	20.0		-0.1
	1011.2	1011.3	20.1		-0.1
Average					-0.066
Uncertainty	0.12	0.3			
Pass Threshold					0.32

Fail Threshold					0.53

Ambient Verification table

Date		**Time**			
Reference Serial Number		**Test Barometer Number**			
	Reference hPa	**Test Barometer hPa**	**Temperature °C**	**Temp Correction hPa**	**Difference hPa**
Test 1					
Test 2					
Test 3					
Test 4					
Test 5					
Average					
Uncertainty					
Pass Threshold					
Fail Threshold					

Multipoint Verification Table

Date		**Time**			
Reference Serial Number		**Test Barometer Number**			
	Reference hPa	**Test Barometer hPa**	**Temperature °C**	**Temp Correction hPa**	**Difference hPa**
Test 1					
Average					
Test 2					
Average					
Test 3					
Average					
Test 4					
Average					
Test 5					
Average					
Test 6					
Average					
Test 4					

Average					
Uncertainty					
Pass Threshold					
Fail Threshold					

6.3 Current Meters

6.3.1 General References

Forrester (1983) contains a review of current meter practice relevant to hydrographers.

US Bureau of Reclamation Water Measurement Manual is a useful reference, particularly Chapter 10.

6.3.2 Types of Current Meter

Most current meters operate on one of the following principles: propeller or rotor with flow vane, acoustic Doppler, electromagnetic, or tilt. Manufacturer's websites are often the best source of up-to date information. The following list is a guide only and is not intended to promote any individual manufacturer.

The propeller-type current meter shown below is normally mounted inline in a moored array. The large cylinder contains the A/D conversion and recording electronics. A small red propeller sits above the cylinder. A large vane keeps the instrument facing into the current. The instrument as a whole is mounted on the gimballed vertical rod that is attached to the mooring riser.

Figure 12 - The Aanderaa doppler current meter

The Aanderaa doppler current meter meter is superficially similar to the propeller-type metre above, aside from the latter's vane, which is not required as the Doppler meter uses an acoustic Doppler method to measure water velocity at the instrument's depth. The Aanderaa document describes the Doppler principle, which is based on the change in frequency of reflected sound waves - the change in frequency is proportional to the relative speed of the reflecting particle or air bubble. A simple diagram of a moored array of two meters and a release is shown below. More information about this type of meter can be found in the manual. UCM also manufactures doppler current meters for currents in three dimensions. The manual describing the UCM-60 gives further information.

Acoustic Doppler current profilers (ADCPs) are designed to simultaneously measure currents at a range of distances or levels. A data sheet describes the range of modes in which such profilers can be operated. The diagram below shows a bottom-mounted instrument for vertical profile.

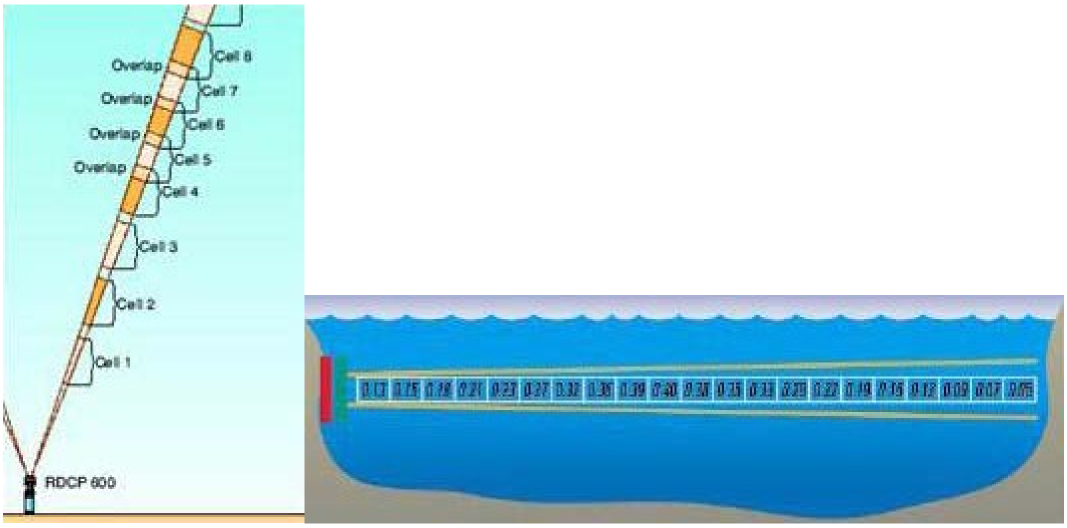

Figure 13 - A) Bottom-mounted ADCP instrument for vertical profile B) Side-viewing ADCP

A horizontal profiler of current is often required for straits and channels. In such cases, a side-viewing ADCP may be used. The range may be up to several hundred meters.

Most modern current meters and ADCPs come with a software interface for processing and visualisation, for example WinADCP. Electromagnetic current meters are able to detect the velocity of the surrounding water by setting up a magnetic field and measuring the voltage induced in a pair of electrodes by the water flowing past it. Additional description and theory can be found in the linked documents. The diagram below shows several different modes in which electromagnetic current meters may be deployed.

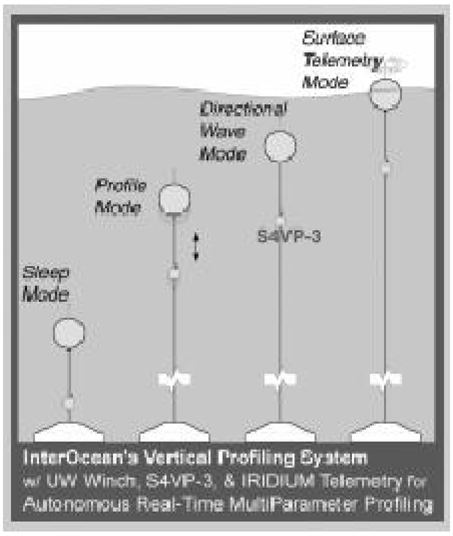

Figure 14 - InterOcean's Vertical Profiling System

There are a number of current meter manufacturers, and again their inclusion here is not intended as an endorsement. Manufacturers' brochures, such as the Aanderra are an invaluable source of information which can be applied to any system, not just that of the manufacturer.

6.3.3 Measurement System Defects

A discussion of the errors common to stilling wells and chart recorders is given in IOC Training Manual Vol. I (see Section 4.2), and a diagram of the amplitude attenuation as a function of wave height is shown in Figure 3.3 of the same volume.

A summary of possible systematic errors in the acoustic measurement system can be found in Section 2.1.1 of IOC Vol. III. The most serious problem commonly cited is with temperature gradients along the flight path of the acoustic pulse, as can happen, for example, when the sun shines only on the part of the "environmental tube" which encloses the inner sounding tube. Such errors can be quite substantial. These can be avoided to a large extent by providing even solar exposure of the environmental tube to the direct rays of the sun.

Section 2.4 of IOC Vol. III discusses possible sources of systematic errors in pressure gauges. One of these is barometric pressure, which can be avoided either by simultaneous air pressure monitoring, or by using a gauge vented to the atmosphere. With pressure gauges in deep water, changes in water temperature or salinity may need to be considered. Another problem discussed on Section 2.4 is that of datum control with pressure gauges, particularly in light of the general tendency of the transducers to drift. A means of overcoming this is given, by use of a second pressure gauge at approximate mean sea level.

1. Survey and Levelling

6.4 Site Selection for survey marks

The criteria set out in the establishment of the Australian Baseline Array provide a useful guide to the selection of sites for high precision tidal recording equipment. They may be found in the at section 11.1 of this document. Additional guidelines are given in IOC Training Manual Vol. I Section 3.1, updated in Vol. II Section 2.5.

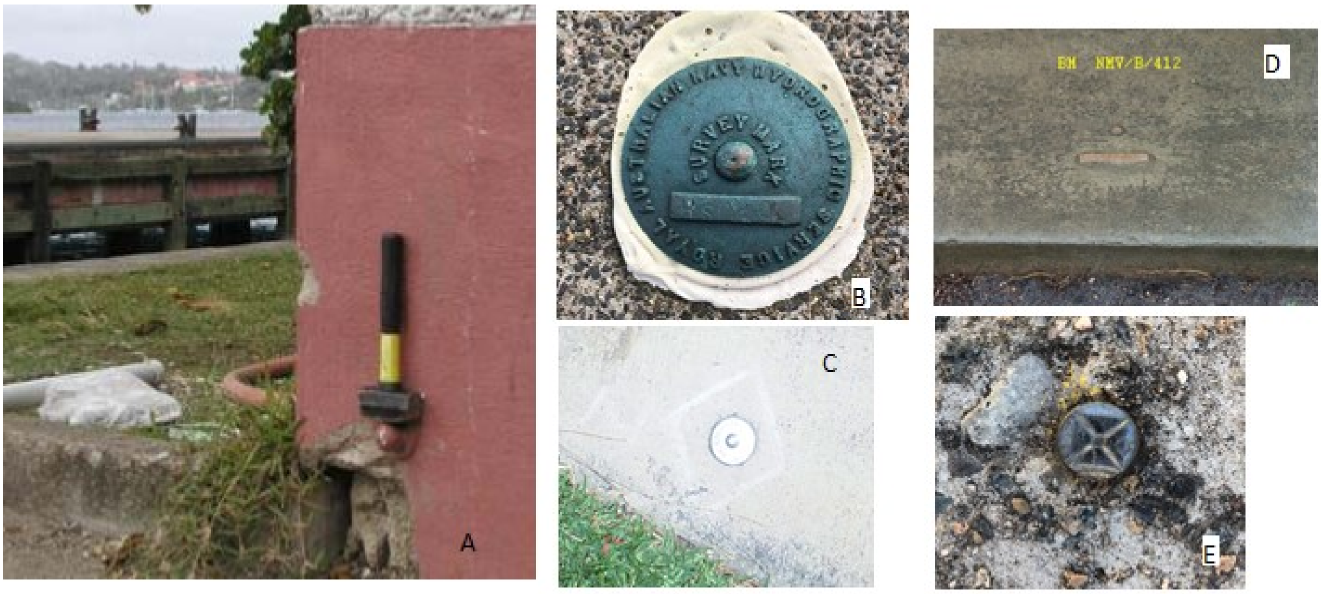

Figure 15 - Examples of a benchmarks a) conspicuous mark on building b) brass survey mark set in epoxy glue, c) irrigation water mark d) plain brass pin with brass label set in concrete and e) survey nail set in road often marked with yellow paint.

The tide gauge benchmark for the SEAFRAME at Port Vila known as "Van 14", installed by the Royal Australian Navy is shown above. The benchmark is the small knob on which the hammer is resting. A raised mark at the top of the knob is the precise level. A chunk of concrete below the benchmark fell off during a recent earthquake.

6.5 Levelling Procedures

This is a topic that has undergone tremendous change in the past decade due to improved technologies. For a thorough discussion of modern geodetic surveying procedures and definitions (including "class" as a measure of survey accuracy), the ICSM publication SP1, "Standard for Australian Survey Control Network" and associated guidelines are recommended. The Australian Height Datum (AHD) (see section 4.3).

A review of levelling for tide gauges was presented in the TSLWG document Tide gauge survey instructions, October 2003. Topics included in this document are:

1. Work to be carried out at each site
2. Calibration of automatic recorders

3. Tide gauge details sheets
4. Bench marking
5. Levelling to the zero of tide staffs
6. Connection to the National Levelling Survey
7. Photographic record of each site
8. Plan of gauge installation
9. Discussion with owners and operators
10. Notification to TSLWG
11. Tide gauge details form
12. Tide gauge calibration form
13. Photographic exposure record form

GEOSCIENCE AUSTRALIA
SPATIAL INFORMATION FOR THE NATION

Geodetic Connections to Tide Gauge at Thevenard

RESULTS OF OPTICAL LEVELLING

Bench Mark Name	AHD Ht (m) Aug 1991	AHD Ht (m) Mar 1992	AHD Ht (m) Apr 1994	AHD Ht (m) May 1995	AHD Ht (m) Jun 1995	AHD Ht (m) Jun 1999	AHD Ht (m) Sep 2002	Comments
BM 1153	2.9350	-	2.9351	-	-	-	-	Datum for AHD heights.
BM 1476	4.4787	4.4787	4.4787	4.4787	4.4787	4.4787	4.4787	Primary Coastal array BM.
BM 1478	4.7812	4.7813	4.7811	4.7814	4.7815	4.7828	4.7828	Coastal array BM.
BM 1479	11.7187	11.7189	11.7186	11.7185	11.7182	11.7184	11.7186	Coastal array BM.
BM 1487	15.9773	15.9780	15.9779	15.9779	15.9778	15.9780	15.9790	Coastal array BM.
5633/1581	4.211	-	4.212	4.212	-	-	-	Seaframe Sensor Recovery Mark
5633/1591	4.4977	4.4979	4.4500	4.4995	4.5001	4.4995	4.4999	Seaframe Sensor BM
5633/1680	-	-	-	16.5410	16.5410	16.5409	16.5422	Coastal array Pillar #

Note 5633/1680 levelled to top of 5/8" threaded stub that is 14mm above the surface of the pillar plate. Ratcliff B, email 2002.

Figure 16 - Log sheet example of successive levelling surveys.

Figure 13 above shows the recording sheet for successive optical levelling surveys at Thevenard, South Australia. The AHD benchmark is BM 1153. BM 1476 is the primary TGBM. The five surveys indicate that the TGBM has retained the constant value of 4.4787 with respect to the AHD benchmark.

In 2000, this subject was reviewed in detail in the IOC Training Manual Vol. III, Section 4, "Datums and datum connections at tide gauges". For convenience, the topics from Section 4 are listed below:

4.1 Some definitions (key terms such as Tide Gauge Benchmark defined)

4.2 Levelling between local benchmarks

4.3 Levelling between wider area marks

4.4 Geodetic fixing of tide gauge benchmarks 4.4.1 Introduction

4.4.2 Geodetic Coordinates of Tide Gauge Benchmarks and Monitoring of Vertical Land Movements at Tide Gauges

4.4.3 GPS measurements

4.4.4 DORIS Measurements

4.4.5 Absolute gravity measurements

4.5 Geodetic contact points

Section 4.1 describes the expanding use of Global Positioning System (GPS) benchmark arrays. Australian practice permits spirit levelling of the TGBM and its supporting recovery benchmarks to an array of GPS– heighted benchmarks.

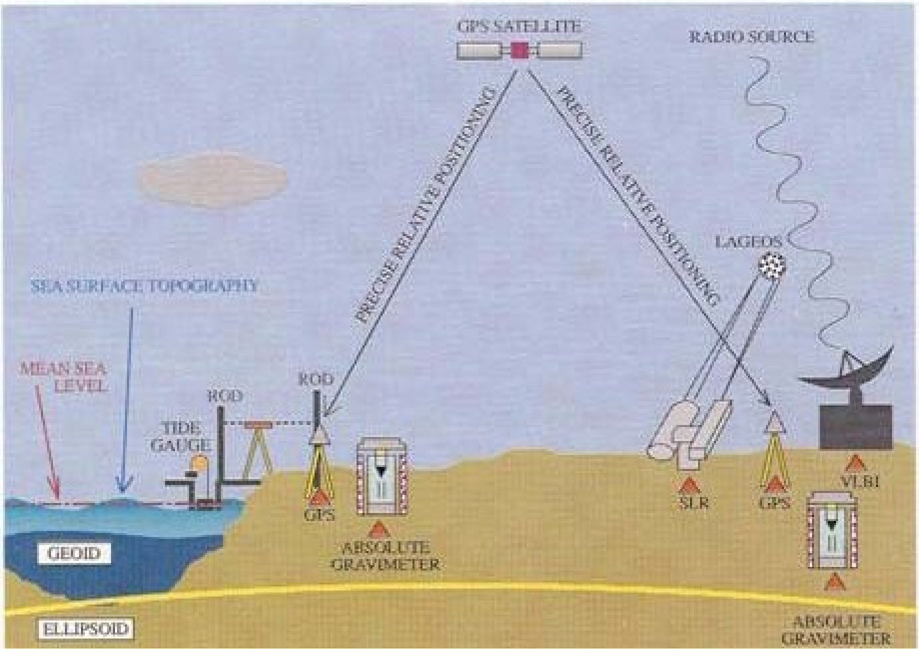

Figure 17 - Some technologies for measuring absolute level.

Many tide gauges are connected to Continuous GPS sites in order to identify vertical land movement in the sea level records.

7. Australian Ports

7.1 Standard Port Tidal Stations that have Permanent Operating Recorders

A standard port (also known as a "primary port", particularly in North America) is one for which sufficient data is available in order for a set of official predictions to be produced. By contrast, a secondary (or "subordinate") port is one for which predictions are required, but due to insufficient data, they may be less reliable. In some cases, at secondary ports, certain constants are inferred on the basis of relationships taken from the nearest standard port.

*Standard port: A place for which independent daily predictions are given in the tide or stream tables, from which corresponding predictions are obtained for other locations, known as secondary ports, by means of differences or factors.

Table 3 - List of Australian Standard Ports

Name	Sensor Type	Owner/ Operator
Eden	Radar/ Pressure	MHL
Newcastle	Radar/ Radar	NPC
Port Kembla	Acoustic/ Pressure	NTU
Sydney (Fort Denison)	Acoustic/ Radar	SPC
Yamba	Pressure	MHL
Centre Island†	No operating gauge	
Darwin	Acoustic/ Pressure	NTU
Name	**Sensor Type**	**Owner/ Operator**
Gove Harbour	No operating gauge	
Milner Bay	Acoustic	NTU
Queensland		
Abbott Point	No operating gauge	MSQ
Booby Island	Acoustic	AMSA
Brisbane Bar	Radar	MSQ
Bugatti Reef	No operating gauge	
Bundaberg	Radar	MSQ/DES
Cairns	Guided wire microwave	DES
Gladstone	Radar	MSQ
Gold Coast Seaway†	No operating gauge	
Hay Point	Radar	MSQ
Ince Point	Acoustic	AMSA
Jubilee Reef†	No operating gauge	
Karumba	Radar / Guided wire	DES/MSQ
Leggatt Island	No operating	
Lucinda	Radar / Guided wire	DES/MSQ
Mackay	Radar/ guiuded wire	DES

Mooloolooba	Radar	MSQ/DES
Mourilyan Harbour	Guided wire	MSQ/DES
Mornington Island†	Guided wire	DES
Noosa Head†	No operating gauge	
Port Alma	Guided wire microwave	DES
Poll Island	No operating gauge	
Name	**Sensor Type**	**Owner/ Operator**
Port Douglas	Acoustic / guided wire microwave	DES
Shute Harbour	No operating gauge	
Turtle Head	Acoustic	AMSA
Twin Island	No operating gauge	
Urangan	Radar	DES
Waddy Point	No operating gauge	
Weipa	Radar	DES/MSQ
South Australia		
Port Adelaide	Purge Bubbler / Radar	FP
Port Giles	Float / Radar	FP
Port Lincoln	Purge Bubbler / Radar	FP
Port Pirie	Purge Bubbler / Radar	FP
Thevenard	Acoustic/pressure / Radar	NTU
Victor Harbor	Float / Radar	FP/Transport SA
Wallaroo	Purge Bubbler / Radar	FP
Whyalla	Acoustic / Radar	FP/OneSteel
Tasmania		
Burnie	Acoustic	NTU
Devonport	Acoustic	Tasports
Georgetown	No operating gauge	

Hobart	Acoustic	Tasports
Spring Bay†	Acoustic/ Pressure	NTU
Stanley	No operating gauge	
Low Head	Acoustic	Tasports
Name	**Sensor Type**	**Owner/ Operator**
Victoria		
Geelong	Acoustic	Vic Channels Auth.
Melbourne	Acoustic	PoM
Port Philip Heads (Lonsdale)	Acoustic	PoM
Portland	Acoustic	NTU
Port Welshpool	Acoustic	Gippsland Ports
Lakes Entrance	Acoustic	Gippsland Ports
Western Port (Stony Point)	Acoustic	NTU/TOLL
Western Australia		
Albany	Radar	Albany Port
Bouvard (Dawesville)♈	Radar	DoT
Bremer Bay	Radar	DoT
Broome	Acoustic/Pressure	NTU
Bunbury	Radar	DoT
Busselton	Radar	DoT
Caddadup (Dawesville)♈	Radar	DoT
Cape Lambert	Float	Rio Tinto
Carnarvon	Radar	DoT
Derby Jetty	Radar	DoT
Esperance	Acoustic/Pressure	NTU

Esperance	Radar	DoT
Exmouth	Radar	DoT
Fremantle – Fishing Boat Harbour	Float / Radar	DoT
Name	**Sensor Type**	**Owner/ Operator**
Fremantle	Radar	Fremantle Ports
Geraldton	Radar	Geraldton Port
Harvey Estuary (Dawesville)♈	Radar	DoT
Jurien	Radar	DoT
King Bay	Radar	PPA
Mandurah	Radar	DoT
Mangles Bay	Radar	DoT
Onslow (Beadon Ck.)	Radar	DoT
Onslow (Onslow Salt)	Radar	Onslow Salt
Peel Inlet (Dawesville)♈	Radar	DoT
Perth (Barrack St.)	Radar	DoT
Point Sampson♈	Pressure	DoT
Port Hedland	Radar	PPA
Two Rocks	Radar	DoT
Useless Loop Jetty	Radar	Shark Bay Resources
Wyndham	Radar	DoT
Antartica		
Casey†	Pressure	AAD
Davis†	Pressure	AAD
Mawson†	Pressure	AAD
Australian Territories		

Cocos Island	Acoustic/Pressure	NTU
Macquarie Island†	Acoustic/Pressure	AAD
Norfolk Island	Float	MHL

†Ports marked with this symbol are "standard ports" in AusTides, but not ANTT.

♈ Ports marked with this symbol are not listed in AusTides or ANTT.

Acronyms:

AMSA: Australian Maritime Safety Authority

AAD: Australian Antarctic Division

DSITI: Department of Science, Information Technology and Innovation (Queensland)

DoT: Department of Transport (Western Australia)

FP: Flinders Ports Pty Ltd

MHL: Manly Hydraulics Laboratory

MSQ: Maritime Safety Queensland

NPC: Newcastle Port Corporation

NTU: National Tidal Centre (Bureau of Meteorology)

PoM: Port of Melbourne Corporation

PPA: Pilbara Ports Authority

SPC: Sydney Ports Corporation

All gauges listed in the table of standard ports are fitted with digital recording devices (there are no chart recorders).

8. Digital Data Handling

8.1 Storage and Archiving

Data to be archived should be corrected for documented instrumental and datum errors only. No gap-filling is to be applied to archived data - this is to be left to the individual later undertaking post-processing of the data.

"A sea level agency should aim to not only operate gauges to its best ability, but also to provide proper documentation, data processing and archiving functions. Documentation has already been alluded to in previous sections. All tide gauge operations (equipment change notes, calibration records, maps, photographs etc.) must be documented within an overall, preferably computerised system so that the information is not lost to future analysts. The tide gauge data themselves must be checked (and if necessary corrected) for their quality and properly documented before being passed to scientists in the wider community."

– IOC Training Manual Vol. III

8.2 Quality Control

Quality control of the data prior to archiving consists of several checks. If more than one gauge is in operation at the site, subtraction of the two time series may reveal abrupt changes in reference level (a gauge from a nearby port may also serve). Comparison with a tide staff, though less precise, is an equivalent check.

A second check consists of subtraction of a time series of predicted tides from the data. What remains are the tidal "residuals". Inspection of the residuals can reveal timing errors, datum shifts, out-of-range values, and other errors not apparent in the original data. If possible, such errors are to be resolved and removed from the data prior to archiving. If an error such as a datum shift is evident, but its exact location in time can not be identified, the problem must be fully documented in the metadata. The quality assessment practices vary between different institutions. The University of Hawaii's UHSLC QA system fully documents the quality assessment process and provides full metadata for their "research quality sea level data".

8.3 Post-processing

These procedures were described in IOC Training Manual Vol. II Section 5. A revised and updated version was presented in Vol. III Section 5, however the earlier volume contains some valuable details not included in the latter. Volume III also discusses tide analysis, filtering to remove tides, and the computation of extremes.

8.4 Data Exchange Formats

A protocol for data exchange was laid out in IOC Training Manual Vol. III Section 6. In Australia, the TSLWG (May 2004 report) has acknowledged the existence of several international formats and affirmed the need for a minimum set of metadata. These are: Identification (Station Name and Geographical Co-ordinates); Measurement Units; Details of Owner/Custodian and Contact details; Date of Supply; Quality Assessment;

Instrumentation. This information is sufficient to enable the user to seek further information from the data provider.

8.5 Data Banks

International sea level centres and information required to submit data to them, are listed in the IOC Training Manual Vol. II Section 6. The GLOSS station Handbook has a more comprehensive set of metadata for ports - for example see Fremantle. The Australian stations on the GLOSS database are listed below (note that the port numbers are active only if online).

Table 4 - Australian GLOSS Stations

Australian Gloss Stations				
061	Booby Is.	Australia	10º 36'S	141º 55'E
058	Brisbane (West Inner Bar)	Australia	27º 22'S	153º 10'E
040	Broome	Australia	18º 00'S	122º 13'E
059	Bundaberg	Australia	24º 46'S	152º 23'E
052	Carnarvon	Australia	24º 54'S	113º 39'E
278	Casey	Australia	66º 17'S	110º 32'E
047	Christmas Is.	Australia	10º 25'S	105º 40'E
046	Cocos Is. (Keeling)	Australia	12º 07'S	096º 53'E
062	Darwin	Australia	12º 28'S	130º 51'E
277	Davis	Australia	68º 35'S	077º 58'E
054	Esperance	Australia	33º 52'S	121º 54'E
053	Fremantle	Australia	32º 03'S	115º 43'E
148	Lord Howe Is.	Australia	31º 31'S	159º 04'E
130	Macquarie Is.	Australia	54º 30'S	158º 56'E
022	Mawson	Australia	67º 36'S	062º 52'E
124	Norfolk Is.	Australia	29º 04'S	167º 57'E
Australian Gloss Stations				
051	Port Hedland	Australia	20º 19'S	118º 34'E
055	Portland	Australia	38º 20'S	141º 36'E

056	Spring Bay	Australia	42º 33'S	147º 56'E
057	Sydney, Fort Denison	Australia	33º 51'S	151º 14'E
308	Thevenard	Australia	32º 10'S	133º 40'E
060	Townsville	Australia	19º 16'S	146º 50'E

9. Best practice for data collection and for publication

To comply with regulatory or other requirements, tide gauges on the national network must meet with certain standards for accuracy and reliability, as well as being subjected to regular maintenance schedules. This ensures the integrity of the database on which the tidal predictions are based.

In the following table 3 lists the recommendations that should be met for the official publication: Australian National Tide Tables and Austides. Recommnedations marked with an asterix (*) are records where a copy should be sent to the AHO. Requesting Authority must make direct arrangement with National Tidal Centre, Bureau of Meteorology or State Authority to provide AHo annually with

1. Daily High/Low predictions
2. 10 minute equal spaced predictions
3. Harmonic constants

9.1 A typical tide gauge installation

Consists of the following.

1. A data recording (short term storage) device. Tide gauges at all Australian primary ports use a digital recording device.
2. At least one water level sensor. Majority of Australian primary ports have a secondary sensor in case of failure with the main sensor.
3. A means of communicating the readings to users - a direct connection to the recorder, a broadcast, polled or on-demand interrogation device.
4. Some means of independently checking the height and time recorded (e.g. a tide staff, the operator to maintain a clock set to standard time)
5. A station height datum above/below which heights are measured, recorded, and stored.
6. A TGBM (tide gauge benchmark) of known elevation relative to the station height datum.
7. Several recovery benchmarks in the event the TGBM is damaged.
8. A clock set to a standard time zone for recording.
9. Performance specifications: station to comply with a given set of requirements, e.g. the GLOSS (Global Sea Level Observing System) requirements found in IOC Training Manual I Appendix 1.
10. Highly recommended (optional) instrumentations:
    a. Barometer
    b. Wind speed gauge and direction
    c. GNSS
11. Documentation in accordance with levelling procedures outlined in Section 5 below.

Table 5 Observation recommendations

Recommendations	Tier 1 and Tier 2	Tier 3
1. Observation Length (days)	365+	35+
2. *Tide Pole /gauge comparison[2]	After every service/event/adjustment or six monthly which ever is the least.	Beginning and end of deployment period when tide staff is not fixed to a permanent infrastructure.
3. *Levelling	maximum allowable misclosure of 2mm*√,(km) per SP1[3]	maximum allowable misclosure of 12mm*√,(km) per SP1[2]
4. Levelling frequency	12-24 months	Beginning and end of deployment period
5. *Bench Marks	Minimum of 3 survey marks and one mark must be connected to the National Levelling Network	
6. *GNSS	1) 1x24 hour (minimum) continuous GNSS observations to define the ellipsoidal height + 2) 1x 6 hour (minimum) continuous GNSS observations with an antenna change greater than 0.3m (compared to the 24 hr setup) as a redundancy check. 3) A third setup maybe required if the difference btween the 1st and 2nd setup is not within the AUSPOS 95% uncertainty.	Minimum of six hours on two consecutive UTC days to achieve SU<20mm for ellipsoidal height per SP1[4] with an antenna height change of >0.3m .

[2] Minimum of 25 hours during a calm day or water level checks taken to capture a minimum of two turns of the high and two turns of the low as well as two mid points.

[3] Guideline for Control Surveys by Differential Levelling Special Publication1

[4] Guidelines for Control Surveys By GNSS Special Publication1

7. GNSS Observation frequency	Continuous with data realtime fed to Geoscience Australia or every 12 monts with maintenance schedule	Minimum of once during deployment period preferred
8. *GNSS Tides Gauge (when Recommendations 3-7 can not e carried out due to safety)	N/A	Minimum of 2x 25 hours (beginning and end of deployment period).

10. Contact detail, Useful Links and Further reading

10.1 Contact detail

ICSM Tides and Sea Levels Working Group (TSLWG)

Secretary TSLWG
8 Station Street
Wollongong, NSW 2500
AUSTRALIA
Email: Hydro.RAC@defence.gov.au

10.2 References and Useful links

i. *Anonymous, 1994 Hydrographic Dictionary, International Hydrographic Organization, Special Publication No. 32, 1994*

ii. ANTT "AusTides"

iii. Australian Hydrographic Office Glossary

iv. Intergovernmental Committee on Surveying and Mapping

v. Canada Fisheries and Oceans glossary

vi. *Forrester, W.D., 1983 Canadian Tidal Manual, Department of Fisheries and Oceans, Ottawa. 138 pages*

Discusses many tide-related topics, such as how tides propagate as waves, the tide-generating potential (an alternate way of thinking about the forces behind tidal motions), the harmonic analysis of sea levels and tidal streams, environmental influences on sea level, and vertical datum control. Of particular relevance are chapters on the establishment of tide gauge sites (including levelling), transferring datums between two water level time series, and current meters. Unfortunately it is now more than twenty years old and some of the technology discussed is virtually obsolete in Australia. Chapters on tidal theory, tidal specification, tidal cycles, analysis and prediction, sea level observations, tidal terminology, and tables of harmonics

vii. Flinders Ports Pty. Ltd.

viii. FOREMAN 1977 Tidal Analysis and predcition Package

ix. Freeland et a. 1986 The Australian Coastal Experiment: A Search for Coastal-Trapped Waves

x. ICSM (Tidal Interface Working Group): Compendium of Terms (103 pages)

xi. ICSM SP1 Standard for Australian Surevy Control network

xii. ICSM Guideline for Continously Operating Reference Stations

xiii. Intergovernmental Oceanographic Commission (IOC)

xiv. IOC training manuals "Manual on sea level measurement and interpretation":

  a. Volume 1: Basic Procedures
  b. Volume 2: Emerging Technologies
  c. Volume3: Reappraisals and Recommendations as of the year 2000
  d. Volume 4: An update to 2006
  e. Volume 5: Radar Gauges
  f. Extreme environment for tide guage deployments.

xv. Land Information New Zealand glossary

xvi. Manly Hydraulics Laboratory

xvii. Manly Hydraulics Laboratory glossary

xviii. Maritime Safety Queensland (Home)

xix. Maritime Safety Queensland (Tides)

xx. *Murray, M.T., 1964 A general method for the analysis of hourly heights of the tide. International Hydrographic Review, 41(2), 91-101.*

xxi. National Tidal Centre

xxii. NOAA Publications

xxiii. NOAA glossary

xxiv. NOAA “Our Restless Tides”

xxv. Permanent Service for Mean Sea Level - Training Information

xxvi. Ports Australia - Members

xxvii. *Pugh, D.T. 1987 Tides, Surges, and Mean Sea-Level, John Wiley and Sons, Chichester, 472 pages.*

This book is out of print but still worth noting. There are useful chapters on observations (summarising the main methods for monitoring levels and currents), tidal forces, analysis and prediction, tidal dynamics, storm surges, shallow water dynamics, tidal engineering, mean sea level, geological processes, and biological processes associated with tides.

xxviii. *Pugh, D.T. 2004 Changing sea levels. Effects of tides, weather and climate. Cambridge University Press, 280pp.* Contains some of the material from

Tides, Surges, and Mean Sea-Level, but updated and with much new information.

11. Annexes

11.1 Site Selection Specifications for Tidal Station

Selection of appropriate sites for tidal stations is a critical precursor to the acquisition of accurate height recordings.

The TSLWG recommends that the following be taken into consideration with regard to the selection of the site for tidal height recording stations:-

1. Tectonic/geological stability of the site;
2. Stability of the supporting structure;
3. Proximity to existing or specially installed high stability benchmarks;
4. Exposure of the site to the tidal regime of the open ocean;
5. Minimum exposure to tidal streams or currents exceeding 0.5 knots;
6. Water column stability, i.e. minimum exposure to estuarine - river discharge effects;
7. Minimum exposure to wave energy;
8. Avoidance of proximity to headlands and harbours with restricted entrances;
9. Minimum subjection to siltation ;
10. Minimum subjection to marine growth;
11. Protection from vandalism;
12. Proximity to mains power and telephone; and
13. Ease of access:-
    a. For servicing the instrumentation: and,
    b. To high-precision level connection to stable benchmarks.

Attention to factors 1, 2, and 3 ensures that the height datum will be stable over a long time providing readings that can be used for many purposes well past the time at which they were made.

The environmental factors 4, 5, 6, 7, 8, 9, and 10 are important. Their application ensures that the recorded heights are truly representative of the tide.

Convenience is important, factors 12, and 13. Servicing tidal stations is an onerous task and any thing that makes it easier for the technicians will be appreciated.

Factors 11 and 12 contribute to maintaining a high level of serviceability from the station.

After considering all of the above factors, acceptance of a compromise will ensure that the best possible tidal readings will be obtained from the site selected.

11.2 Instrument Specification for High Precision sea Level Monitoring Stations

The following is the statement of user requirements upon which the selection of equipment for the Australian baseline sea level monitoring stations was based. These specifications are provided as a guide to the selection of high precision tidal recording equipment.

User Statement of Requirements

Instrumentation is required for the purpose of high precision monitoring of the sea level. It is expected that the equipment, supported by appropriate operating techniques, will be capable of measuring sea level change attributed to the Greenhouse Effect.

The purpose of this document is to specify the requirements of the complete Field Unit hereinafter referred to as the field unit.

The field unit shall be a stand - alone, unattended, data acquisition and data transmission device capable of acquiring, storing and reporting water level measurements from remote locations. Low power consumption and high reliability are important considerations in the design of the field unit.

Instrument Requirements

The sensor/measurement subsystem of the field unit provides for the measurement of water level and ancillary meteorological and atmospheric phenomena necessary to fulfil the primary mission requirements for tide and water level measurements.

The sensor/measurement subsystem is required to accommodate up to eleven ancillary measurements.

Three of these are expected to be provided by sensors that provide a digital or frequency output; the remainder will provide analogue output.

The field unit shall be able to operate with different site - specific combinations of sensor inputs and power sources as specified herein. All possible sensor/power combinations shall be accommodated by on - site actions, which include setting switches, installing cables, and entering parameters via a temporarily connected operator's terminal or the public switched telephone network.

The configuration of an individual field unit will depend on the information requirements of the TSLWG, as well as site - specific factors such as environmental conditions. However, the minimum configuration will consist of: -

Primary water level sensor

Seawater temperature

Air temperature

Barometric pressure

Wind speed and direction

Backup water level sensor

Resolution:

Primary Water Level: 0.0005 metres over a range of 0 - 15 metres.

Resolution: other sensors

Backup Water Level:	0.003 m over a range of 0 - 15 metres.
Temperature:	0.1 Deg. C over a range of - 10 to +55 Deg. C.
Baro. Pressure:	0.01 hPa over a range of 800 to 1060 hPa.
Wind Speed:	0.5 m/s over a range of 0 to 50 m/s.
Wind Direction:	5 Deg. over a range of 0 to 360 Deg.

Accuracy of the Primary Water Level Sensor:

Height	+/ - 0.005 metres.
Time	+/ - 1 minute per year.
Datum	+/ - 0.001 metres. This must be maintained for a minimum period of twelve months between re - levelling.

Sample interval:

User selectable within the range 1 to 60 per hour.

The default value will be 12 per hour for the Primary Water Level Sensor.

It is required that each sensor be capable of being sampled at its own individual sample rate.

Integration time:

User selectable within the range 1 to 10 minutes, at a nominal rate of two samples per second with a default value of one sample per second. This must also be settable for each individual sensor.

Calibration:

Capable of regular calibration in the field, automatic self - calibration is required for the Primary Water Level Sensor.

Timing:

The sensor/measurement subsystem must contain a calendar clock capable of generating year, month, day, minute and second with leap year correction. Time shall be resolved to at least one second. The sensor/measurement subsystem shall, at least once a day, re - initialise its calendar clock with time and date from the satellite telemetry module, (where fitted) which is required to be more accurate.

The sensor/measurement subsystem must be capable of recording a sample on the integral hour.

Watchdog Timer:

The sensor/measurement subsystem shall contain a watchdog timer that can restart the field unit without loss of current system parameters or stored data.

This timer shall start the field unit after a fixed time delay unless the timer is itself reset by a software controlled signal. The presence of the timer shall ensure that the field unit will always operate when power is available, and there is no damage to the field unit itself.

Communications:

Five communication ports (four serial and one telephone) shall be provided, one shall be dedicated to the Backup water level sensor and one dedicated to satellite telemetry. The other two serial ports will be available for parameter set - up, data collection and external modem.

A common protocol shall be used for the latter two serial ports and the telephone port. This protocol shall be selected from protocols currently in use and supported by multiple users in industry and the government.

Telemetry:

Telemetry will be by telephone modem and/or satellite transmission. Satellite transmission will be by use of one or more of the following systems: GOES, GMS, ARGOS and AUSSAT.

Transmitter and telephone modem must conform to the standards required by the appropriate licensing authority.

Data Storage:

On board back - up:

Type:	Digital.
Medium:	Solid - state memory.
Output:	RS232C compatible with downloading facility, software to be provided.

Memory retention:

Thirty (30) days minimum, obtained from the following representative configuration of sensors and measurement rates:

Primary water level sensor	12 measurements/hour
Six of the eleven ancillary sensors	1 measurement/hour
Backup water level sensor	12 measurements/hour

All data acquired by the field unit through automatic sensor sampling shall be stored as a sequence of individually identified data entries. These data entries shall be stored in chronological order as they are acquired. The acquisition date and time of each data entry, to nearest minute, shall be available for each data entry. This date and time may either be stored with the entry or obtained by computation. All memory not used for other purposes shall be available for storage. When the storage has consumed all available memory, the oldest data entries shall be discarded to provide space for new entries.

Other types of data entries that shall be stored include, primarily:

Field unit system parameters.

Field unit performance status.

The field unit data storage capacity shall be expandable, on - site, by field maintenance personnel. The capacity shall be expandable by at least 50 per cent.

Power:

The complete field unit must be run from an internal rechargeable sealed battery. The unit must also contain a power conversion module capable of powering the field unit from any one of the following sources:

External 12v batteries.

Solar panels.

Wind generators

Single connection to a commercial power service (216 - 288v, 40 Hz. to 60 Hz.).

This module must also be capable of charging the internal batteries when connected to any of the above sources. The internal battery compartment, whilst it may be contained within the same environmental enclosure as the rest of the field unit, must have its own sealed enclosure, which is vented directly to the outside atmosphere. The batteries shall be sealed, shall not emit corrosive fumes, and shall be resistant to explosion. They shall also be compatible with locally available types for replacement purposes.

Primary Water Level Sensor

The Primary Water Level Sensor shall consist of an Air Acoustic Sensor and two Correction Air Temperature Sensors.

Air Acoustic Water Level Sensor.

The air acoustic water level sensor shall be an Aquatrak Model 2010 - 10 - C or equivalent. This sensor shall use an active, air - acoustic, ranging technique to measure water level within a Government furnished protective well. The sensor shall have no active contact with the water e.g. (float). Passive (static) contact, such as a protective tubing or a signal duct, is acceptable. The sensor shall perform in the presence of disturbances or other biological fouling, joints in the protective well, and ambient acoustic noise.

The sensor shall measure water level in a protective well that:

Will be a 0.1 to 2 m diameter pipe open at the top and bottom.

May be fabricated from one or more lengths of pipe to the length required by the station conditions.

Will be vertical to within 5 degrees.

May not have smooth walls or specially fabricated joints.

The sensor shall sample the water level at a nominal rate of two samples per second and have a digital output proportional to the water level. A sample is defined as a single observation of water level. The sensor shall have a dynamic response capable of measuring to the specified accuracy with a water level change rates up to 0.3 m/sec.

The field unit shall measure water levels via the Primary water level sensor at selected times and selectable rates as defined above. Each measurement shall be associated with an acquisition date and time (time - tag) computed to the nearest full minute.

A measurement shall consist of a mean water level value, two data quality assurance parameters, and two air temperatures for correcting measurement errors caused by temperature profile variations along the acoustic path.

The mean water level and data quality assurance parameters values shall be computed from a selectable fixed number of sequential samples acquired from the sensor, acquisition of this sequence of samples shall start before the time indicated by the time - tag, and shall be such that the middle of the sequence occurs at the time indicated. Timing shall be synchronized so that one of the time tags will be on the integral hour.

To allow for the most flexible operation of these instruments over their expected life, as much as possible of the operation and computation should be done under software control. As an example, the mean water level computations could be made as follows:

1. Compute the mean of the acquired sample sequence.
2. Compute the standard deviation about the mean.
3. Count all samples (outliers) that differ from the mean by more than three times the standard deviation.
4. Remove the outliers from the sample sequence.
5. Recompute the mean water level.
6. Recompute the standard deviation.

The value computed in step 5 shall be stored as the mean water level. The standard deviation computed in step 6 and the outlier count in step 3 shall be stored as the data quality assurance parameters values.

The contractor will be required to define the algorithm that is proposed to compute the mean water level.

The Primary water level sensor must have been designed, manufactured, assembled and tested for the marine environment.

The Primary Water Sensor must have a demonstrated field history of satisfactory performance of at least 12 months in use in a national/international monitoring program.

Redundancy of Water Level Sensor and Data Logger

The field unit shall also record water level by acquiring serial data from a Backup water level logger, which shall use a pressure transducer to determine water level. This sensor will be mounted separately from the Primary water level sensor.

The Backup water level logger shall be capable of operating independently of any other component of the field unit. There shall be no other connection between it and the rest of the field unit.

The unit shall meet the following specifications:

Measure water level by sampling and processing water pressure.

Compute water level and data quality assurance parameters data by the same method as that used for the Primary water level sensor.

Automatically compensate for local barometric pressure.

Transmit water level and data quality assurance parameters data periodically or upon demand serially.

Contain a calendar clock with equal resolution and accuracy as that in the sensor/measurement subsystem of the field unit.

Range: 0 to 15m.

Accuracy: +/ - 0.015m.

Resolution: 0.003m.

Operate in the same environment as that defined for the Field Unit.

Pressure sensor shall withstand submersion to a depth of 30m without damage.

Operate for one year without service

Provide internal solid state data storage for the most recent 90 days of data.

Performance Monitoring

The field unit shall monitor its performance, non - invasively, shall encode the results into a status data set at the beginning of each hour, and shall store that set along with a time - tag.

Performance monitoring shall be done by a dedicated software task that is executed hourly and upon operator request. As a minimum, the following tests shall be performed:

Program memory check.

Random access memory check.

CPU check.

Telemetry interface check.

Battery voltage.

Charge rate (if external power is in use).

AC power - interruption (if AC power is used).

Other hardware/software checks, as required by system design.

The above tests shall also identify and record fault location, such as memory addresses and communication ports.

Interchangeability

All circuit boards, modules and sensors providing the same function(s) shall be completely interchangeable among the various modules and units without modification or adjustment.

Maintenance

The field unit shall be designed and constructed for reliable and simple maintenance and operation in the specified environment.

The design of the field unit and the maintenance program shall minimise the use of special facilities and test equipment. The contractor shall provide specialised test equipment which is designed to assist in the installation and check - out of the field units if they determine it is necessary to meet the required specifications, and is advantageous to the program. This equipment shall obtain power primarily from its own internal batteries or optionally from the power conversion module of the field unit.

Minimum Operating Periods

The field unit shall be capable of fully automatic and unattended operation at a remote site for an operating period of not less than one year without replenishment of expendables or preventative maintenance.

The internal battery shall operate the field unit without loss of performance or data during interruption and re - establishment of commercial AC power for a period of at least 10 days with the following representative configuration of sensors and measurement rates:

Primary Water Level Sensor - 12 measurements/hour. (includes level, data quality assurance parameters, and two correction air temperatures)

Backup Water Level Sensor - 12 measurements/hour. (including level and data quality assurance parameters)

Six of the eleven ancillary sensors - 1 measurement/ hour.

The field unit shall be able to repeat the ten day, no - power operation after recharging its internal batteries for a period no greater than 24 hours. Furthermore, the field unit shall be able to operate on this 10 day, no power, 24 hour recharge cycle with a full complement of 15 sensors (primary water, backup water, and eleven ancillaries) by adding more internal batteries in the field. The number of additional batteries required shall be determined by the contractor.

Operating Environment

The field unit will operate in the following climatic conditions:

Ambient Air Temperature:	- 10 to +55 deg. Celsius
Air Temperature Change:	20 deg. Celsius per hour

Water Temperature:	- 2 to +35 deg. Celsius
Salinity:	0 to 50 parts per 1000
Humidity:	0 to 100% condensing
Wind Speed:	0 to 50m/sec, with gusts to 60m/sec
Water Currents:	0 to 2.5m/sec
Shock/Vibration	Resistance: Resistant to 2g at 5 to 50 Hz.

Moderate sand and dust, salt spray and humid salt air:

Electromagnetic:

Capable of operating in an electromagnetic environment that includes commercial radio and television broadcast signals, UHF and marine radio transmission and reception and marine radar transmissions and stronger interference up to one volt per meter from several sources:

UHF Radio:	400 to 420 MHz.
VHF Radio:	30 to 170 MHz.
Radio Beacons:	280 to 300 KHz.
HF Radio:	0.5 to 30 MHz.
Radar:	S - band 2 to 4 GHz.
	C - band 4 to 8 GHz.
	X - Band 8 to 12 Ghz.

The field unit must have adequate protection against damage caused by indirect lightning strikes and static discharges, with particular attention to sensor lines, antenna leads and any power lines. Techniques such as opto - isolation, transformer coupling, surge diverters or combinations of these, in addition to adequate earthing and shielding techniques, shall be employed. An earth stud or terminal of adequate current carrying capacity shall be provided on the outside of the field unit for connection to an earthing system. All surge protection circuits should be directed to this point.

In addition the water level sensors, which are part of this field unit specification, will be exposed to turbidity, biological fouling and water borne marine life expected in the tidal areas of Australia and surrounding territories.

Construction of Field Unit

The field unit must be an integrated unit of modular construction and housed in an environmentally protective cabinet.

Integration need not extend to the sensors which may be remote from the field unit itself, however all sensor and communication signals shall enter the field unit through an interconnection sub - unit, which shall consist of four components:

Weather - proof entry.

Terminal block

Suppression circuits

Connector for cable to the sensor/measurement subsystem.

Water - proof plugs or water - proof cable glands shall be used to ensure the waterproof integrity of the unit. The terminal block shall have sufficient capacity (terminals and space) to connect cables from a full complement of sensors plus 20 per cent spare capacity. Suppression circuitry shall be provided for all terminals on this terminal block.

The connector shall provide connections for a full set of sensors plus 20 per cent spare capacity, all wiring between the connector and the terminal block shall be installed.

If the field unit has provision for cable connection or entry through its bottom surface, then feet shall be attached to that surface so that cables can connect or enter without undue bending when the enclosure is placed on a work - bench or floor.

Each component located within the enclosure shall be easy to install and remove. Access shall be provided for the connection of all cables internal to each enclosure. All internal controls and displays shall be visible, accessible and clearly marked when the cover is open.

Each enclosure shall be weather - proof when permanently attached covers, caps, or lids are closed. All spaces containing electronics shall be at least weather resistant when operating with the covers open.

Each enclosure shall have tabs or other provision for wall mounting.

The Barometric Pressure sensor if housed in the environmental cabinet must be vented to the outside by means of a static head connection.

Vertical reference

The Primary water level and Back up water level sensors will be referenced to a set of high stability benchmarks by direct levelling. Each sensor shall have a permanent reference point suitable for use with surveyor's levelling instruments. This point shall be both visibly distinct and physically accessible so that a high precision levelling staff may be held against it.

This point shall be located at a fixed, known distance from the sensor mounting holes (or pins). This fixed distance shall be the same for all sensors; thus, sensors can be replaced, on - site, without resurvey (levelling) to the local benchmark.

Ancillary Sensors

The field unit shall be capable of acquiring and storing input signals from a minimum of eleven sensors simultaneously. Eight input ports shall be provided for analogue voltage signals, and three input ports shall be provided for pulse stream of frequency signals. As well as the mandatory sensors already listed several other types of oceanographic and meteorological sensors may be utilised, typically:

Humidity	Water Current Speed
Rainfall (Tipping Bucket)	Water Current Direction

Water Conductivity Water Density

Not withstanding the specifications already stated, the Ancillary sensors will, where possible be selected from a range in accordance with Bureau of Meteorology specifications AS2659.

All cables necessary to interface the sensors, external power sources and antenna to the field unit are to be supplied.

Transport

The field unit will be subjected to the following conditions during transport to and from sites:

Temperatures: - 40C to +60C.

Humidity: 0 - 100% condensing.

Shock: 1 meter drop.

Vibration: 2g, 5 to 50 Hz.

As these field units will be manually handled and located in remote areas, they could be transported by one or more of the following means: air freight, truck, four wheel drive vehicles, all terrain vehicles, car, survey ship, launch, small boat, light aircraft, helicopter and human carrying. They should therefore be of a size and weight to meet any such carrying restrictions and be easily handled by preferably one but no more than two persons.

Mandatory Documentation

Software/Firmware documentation:

Program specifications:

User Manuals: and

Program Maintenance Manuals.

Technical Manuals (including circuit diagrams).

Field Unit;

Backup Data Logger: and

Each additional environmental sensor.

User Manuals

Field Unit;

Backup Data Logger; and

Each additional environmental sensor.

Test Reports for each component must be supplied.

11.3 Tide Gauge Survey Instructions

1. Work to be Carried Out at each Tide Gauge

In accordance with the procedures and recommendations contained in these instructions, carry out the following work:

1.1. Subject to the owners agreement calibrate each automatic recorder.

1.2. Complete "Tide Gauge Details" sheets for each tide gauge.

1.3. Inspect existing benchmarks and, where necessary, install additional or supplementary marks to bring the number of stable marks in the vicinity of each gauge to at least three.

1.4. Determine the difference in height between each of the tide gauge benchmarks and the zero of the tide staff and/or recorder at each installation.

1.5. If not already, and where reasonably possible, connect the tide gauge benchmarks to a level traverse of the national Levelling Survey.

1.6. Make a photographic record of each automatic recorder, the tide staff and nearby features.

1.7. Prepare a plan of each tide gauge installation.

1.8. If necessary, identify each gauge and the benchmarks on aerial photography.

1.9. Discuss with the owners and/or operators of the gauges any faults found with and possible improvements to each gauge and its records.

1.10. Send a copy of all documentation to the TSLWG as soon as possible after installation.

2. Calibration of Automatic Recorders

Automatic recorders may be calibrated in accordance with the following procedure:

2.1. Each gauge should be calibrated both before and after cleaning of the sensor or stilling well inlets unless inspection shows them to be clear.

2.2. Use the "Tide Gauge Calibration" forms provided to record the level of the sea inside the stilling well as indicated by the automatic recorder, the level of the sea outside the well as indicated by the tide staff, and the date and time of observation, and other relevant details, every 1/4 hour on the 1/4 hour, continuously for a period of the complete tide range including both the rising and falling tide, ideally at springs.

2.3. Clean the sensor or stilling well inlets and repeat the test.

2.4. Where the tide staff is not conveniently placed to enable observation of the recorder height and the tide staff height to be simultaneous, a temporary tide staff is to be established in a suitable position and its height is to be related to the existing tide staff.

2.5. A careful inspection of the tide staff should be made to see that it is firmly fixed and in a vertical position. If necessary, but only with the agreement and co - operation of the operator of the gauge, the tide staff should be firmly secured in a vertical position without disturbing the height of the tide staff zero. Any work carried out on the tide staff should be noted on both the tide gauge chart and the calibration record.

2.6. In exposed locations or in rough water the tide staff may be difficult to read without adequate stilling precautions. If necessary, a length of 1/2 inch diameter clear plastic tube, open at the top and fitted with a suitable notched plug at the lower end, may be fixed to the tide staff so that the water level in the tube can be read. It is essential to ensure that the tube does not become clogged and that there is sufficient opening at the lower end. It there is any wave movement on the outside, the water in the tube should show perceptible oscillation.

2.7. Record wind speed and direction and atmospheric pressure during the calibration period at 6 hourly intervals, unless readings are available from an nearby meteorological station

2.8. Make arrangements, if possible, with the owner or operator of the gauge for the supply to the Tides and Sea Level Working Group of a copy of at least that portion of the recorder chart and or digitally recorded readings covering the period of the calibrations.

3. Tide Gauge Details Sheets

3.1. In consultation with the owner and or the operator of the gauge and by personal inspection and observation complete the 4 pages of "Tide Gauge Details" in as much detail as possible.

3.2. These sheets serve as a permanent record of the tide gauge installation and it is important that as much information as possible be obtained and that the information is accurate.

3.3. If any information differs from previous records attempt to find out when the changes occurred and note. Do not destroy the old information.

3.4. With reference to environmental effects (Question 28) describe in detail any feature which may limit exposure of the gauge to open water (e.g. shallows narrows etc.).

4. Benchmarking

4.1. Inspect existing permanent benchmarks in the vicinity of each tide gauge and if these are inadequate in number and/or quality establish new permanent marks so that at least three marks of good quality and stability are available at each gauge.

4.2. New marks should be about l00 metres apart and away from any anticipated construction activity or other possible cause of disturbance.

4.3. Marks established as tide gauge benchmarks should preferably be constructed of brass rod set at least 150 mm into solid rock concrete foundations or other suitable structures the top of the rod protruding not more than 5 mm and indicated by a brass numbering plate. If no suitable rock or structure is available benchmarks are to be established in accordance with Part C "Recommended Marking Practices" of the ICSM Special Publication 1 "Standards and Practices for Control Surveys Version 1.7

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4.4. The identification number allocated to each new benchmark is to be legibly stamped on the brass numbering plate.

4.5. Each new benchmark is to be fully described in the field level book and a Permanent benchmark Record is to be prepared for each new mark on the forms provided.

4.6. Benchmarks established during the level observations from the tide gauge benchmarks to National Levelling, Survey traverses shall be constructed in accordance with the above Schedule.

4.7. Supply a copy of all Permanent Benchmark Records to the State Survey Authority.

5. Levelling to the Zero of Tide Staffs

5.1. The differences in height between all tide gauge benchmarks and the zero of the tide staff is to be determined in accordance with section 6.1 and 6.2 below.

5.2. A diagram showing the differences in height between the tide gauge zero and the tide gauge benchmarks is to be prepared for each gauge.

5.3. Information relating to any change in the position of the tide staff or damage to it in recent years should be sought from the gauge owner or operator and included in the report on the tide gauge.

5.4. Check the graduations on the tide staff itself for accuracy and note any anomalies.

6. Connection to the National Levelling Survey

6.1. If the tide gauge benchmarks have not already been connected to a traverse of the National Levelling Survey such a connection shall be carried out to class LC in accordance with Part B Best Practice Guidelines for Surveys and Reductions sub section 2.4 Differential Levelling of the ICSM Special Publication 1 "Standards and Practices for Control Surveys Version 1.7 September 2007

6.2. All levelling is to be checked and a summary completed before leaving the site of the survey.

6.3. The levelling summary should be submitted to the State Survey Authority for incorporation into the National Levelling Survey adjustment.

6.4. An Ellipsoidal height should be available on at least one of the TGBM’s. If not, attempts should be made to observe an “Absolute” ellipsoidal height with GPS see 2.6.14 of ICSM Special Publication 1 “Standards and Practices for Control Surveys Version 1.7 September 2007. Heights to be entered into the tide gauge meta-data sheet.

7. Photographic Record of the Tide Gauge

7.1. Two photographs of each tide gauge benchmark shall be taken. One photograph shall be a close - up of the actual mark and the other shall show the detail of the area surrounding the mark.

7.2. Two photographs of the tide gauge recorder hut shall be taken, from different directions.

7.3. Two photographs of the tide staff shall be taken, one a close - up of the tide staff and the other, if possible, showing both the tide staff and the recorder hut.

7.4. Two photographs showing the recorder inside the hut shall be taken from different positions.

7.5. Two or more photographs shall be taken from a considerable distance and shall show the tide gauge installation in relation to other prominent local features.

7.6. A record of the exposures in their correct sequence is to be kept on the photography record sheet provided.

7.7. On completion of a film it is to be labelled with the names of the photographed tide gauges on both the wrapping paper and the cassette or container.

8. Plan of the Gauge Installation

8.1. The position of the recorder, the tide staff and all benchmarks shall be shown on a large scale plan of the area.

8.2. A suitable map of the area can usually be obtained from local authorities. Where such plans or maps are unobtainable a sketch shall be prepared showing the recorder hut, the tide staff, the benchmarks and other local features in their proper relative positions and identify their location on aerial photography as described below.

8.3. The automatic recorder and all benchmarks shall be identified on aerial photography by pricking their positions on the photos with a fine needle and by suitable annotation.

Where an identification is in doubt, an easily identifiable point nearby shall be identified. The photo annotation shall refer to this nearby point as the "Photo Reference Point" and shall indicate its bearing and distance from the recorder and the benchmarks.

8.4 The plan of tide gauge installation should be included with the Tide Gauge Details sheets.

9. Discussion with Owners and Operators

9.1. The owners of the gauges should be advised well in advance by letter that the survey party from a designated organisation will be visiting each gauge. A few days before the party is expected to arrive at each gauge the party leader shall try and contact the operator by telephone to let him know when to expect the party.

9.2. Any faults in the gauge or the records shall be discussed with the owner and or operator but no adjustments are to be made without the agreement of the owner or operator.

10. Tides and Sea Level Working Group

10.1. Supply a copy of the Tide Gauge Details sheets, plan of installation, annotated aerial photograph (if applicable) and height connection diagram (see paragraph 5.3) to the TSLWG as soon as possible after installation.

10.2. If any changes occur to the details provided or the gauge is removed, the TSLWG should be informed immediately.

Tide Gauge Details

In addition to details of the site, type of gauge, owner and operator, the “Tide Gauge Details” form requests technical details of the gauge, the frequency and method of connection to benchmarks, and environmental effects, the last referring in particular to any impediment to the exposure of the gauge to open water which may reduce the accuracy of the records obtained. This information is required to facilitate comparison and interpretation of the tide gauge records.

Operators are invited to refer to the committee any difficulties encountered in completing the form any suggestions as to how it might be improved.

Station Number		***Name***			
Latitude		***Longitude***		***Horizontal Datum***	
1 : 100, 000 Map Name		***Number***			
M.G.A. Northing		***M.G.A. Easting***			

Site description	
Operator's Name	
Address	
Telephone	
Type of Recorder	
Makers Name	
Date of manufacture	
Serial Number	
Range of Gauge	
Commencement of Operation	
Period for which continuous records are available	
Period of intended operation of gauge	
Frequency of recorder chart change	
Frequency of height check	
Frequency of time check	
Method of height check	
Method of time check	
Tide staff graduations	
Chart height scale	
Chart time scale	
Type of record	
Records stored at	

Float operated gauge:	
Diameter of float	
Diameter of well	
Height of inlet above the sea bed	
Specifications and configuration of inlet/s	
Pressure operated gauge: (Strain gauge, gas purge, etc)	
Type of sensor/s	

Depth of sensor/s below gauge zero	
Distance of sensor/s from recorder	
Method of pressure transmission	

Pulse flight time operated sensor (downward looking radar or acoustic pulse sensor)	
Type of Sensor/s	
Height of sensor above gauge zero	
Distance of sensor from recorder	

Are water density, temperature and salinity measured? If yes, how often:	

Recorder Calibrated:	
Period	
Method	

Environmental effects on gauge	

Description of benchmarks	
Height of benchmarks in metres:	
Above tide staff zero	
Above recorder zero	
Above Australian Height Datum	
Above Hydrographic chart datum	
Above the Ellipsoid	
Above Low Water Datum	
Above Other Datum (Specify)	

A.H.D. height in metres of:	
Tide Staff Zero	
Recorder Zero	

Levelling Section (A.H.D. connection)		
Number		
Levelling by		
Level Books		
Levelling Date		
Ellipsoidal height in metres of:		
Tide Staff Zero		
Recorder Zero		
Ellipsoidal Heights Information (SP1)		
ITRF Epoch (MMM/YYYY)		
ITRF Height above BM	***is***	
ITRF Height above TGZ is		
Length of GPS Observations		
Method of determination		

Reference to Ellipsoid (preferably the Australian Datum at the date of Survey)	
Name of Ellipsoid	
Date of Survey	
Field Record ID	
Elevation calculation record id	
List of elevation control marks with elevation	
Nature of elevation calculation (constrained or unconstrained to elevation control marks)	

Other relevant details	

Issue		***Prepared By***		***Date***	

Name:			Number:		
Date	**Standard Time**	**Recorder Time**	**Recorder (m)**	**Staff (m)**	**Weather Conditions**
Observer				**Time Zone**	

Record of Exposures: Film/cassette/digital media have been labelled thus: -

Name of Station	
Date of Photography	
Log of Exposure	

Signature of Surveyor..

11.4 Interpretation of the Tidal Constituent Sa

A comparison of the Doodson numbers in the IOS (UK) and IOS (Canada) prediction programs revealed a difference in the interpretation of the constituent Sa that has the potential to degrade the accuracy of tidal predictions in Australia. The former program is used by the former National Tidal Facility Australia, the National Tidal Centre, Bureau of Meteorology and the Transport Department of West Australia while the latter program is used by the Hydrographic Office RAN and a significant number of other Australian organisations.

Constituent Sa, which represents the seasonal variation (with period of about one year) in mean sea level is quite significant in Australian waters. It may have an amplitude of up to 0.4 metres but generally is in the order of 0.1 metres.

The Doodson numbers for Sa used in the IOS (UK) program (Reference A Table 4) are 0 0 1 0 0 0. Those used in the IOS (Canada) (Reference C, Appendix 4) are 0 0 1 0 0 -1. The former set involves only the mean longitude of the sun and its rate of change. The latter set also involves the mean longitude of the solar perigee and its rate of change. The effects of the difference in the last number are calculated in Annex A. While the effect on the speed of the constituent is almost negligible, the effect on our programs calculation of the initial phase of Sa is large giving rise to inaccurate tidal predictions.

Source of Constituent Constant	IOS (UK)	Difference	IOS (Canada)
Constituent name	Sa		Sa
Interpretation Doodson numbers	0 0 1 0 0 0		0 0 1 0 0-1
Speed (degrees/hour)	0.0410686	0.0000019	0.0410667
Period (mean solar days	365.24254		365.24995
Phase in degrees at time origin	(0000 GMT 1/1/76)		
	278.78841	-77.472360	357.26077
Phase in degrees at	(0000 GMT 4/4/84)		
	9.54387	-77.33048	86.874358

It is not particularly important which Doodson numbers are used for the constituent as long as those used in the prediction program are the same as those used in the tidal analysis.

The effect of the differing Doodson number on the accuracy of past predictions was demonstrated by test predictions for a year using Sa with Doodson Numbers 0 0 1 0 0 0 and 0 0 1 0 0 1. Using a typical amplitude of 0.1 m, the difference in tidal height varied from zero to 0.13 m.

There are two ways to deal with the difference in interpretation

1. Include details of the Doodson number for Sa in the metadata accompanying tidal constituent constants
2. Modify analysis and prediction programs to use the IOS (UK) interpretation i.e. the Doodson number for Sa is 0 0 1 0 0 0

It would be prudent to implement both.

References

A: "The Fine Resolution of Tidal Harmonics" by M. Amin 1975.

B: "The Harmonic Development of the tide generating Potential" by A.T. Doodson 1921.

C: "Manual for Tidal Heights Analysis and Prediction" MGG Foreman. IOS (Canada) 1977.

11.5 Ellipsoidal Height Measurements at Offshore Locations

Overview

The measurement of sea level at an offshore location is typically undertaken using moored oceanographic sensors including pressure gauges, and temperature and salinity sensors. Sea level data derived from these sensors is relative to the gauge zero, often located at significant depth. In order to transform this sea level to become relative to an international or national datum (e.g. the International Terrestrial Reference Frame, ITRF), and expressed on an ellipsoid, simultaneous GNSS measurements of sea level at the offshore site must be undertaken. This process is undertaken regularly by the Australian Integrated Marine Observing System (IMOS) in order to derive data at key locations comparable with satellite altimetry (see Watson et al. 2011). In this case, GNSS equipped buoys (Figure 17) are deployed over an array of moored oceanographic sensors, typically for multiple periods of ~48 hours duration. Post processed sea level data is obtained with respect to the ITRF and directly comparable with other ellipsoidal based data that use the same datum.

Hardware

The hardware required consists of a floating platform, typically a buoy of some description, equipped with a geodetic grade GNSS receiver (e.g. Figure17). Data acquisition is typically undertaken at 1 Hz at both the buoy, and at a nearby reference GNSS station if differential carrier phase based processing is being undertaken. The height of the GNSS antenna above the water surface must be accurately determined. Significant changes in the orientation of the platform with respect to the vertical may introduce systematic error, and in the case of large structures (e.g. large offshore buoys or boats used as the floating platform), may require additional measurement and correction (see Watson, 2005 for review).

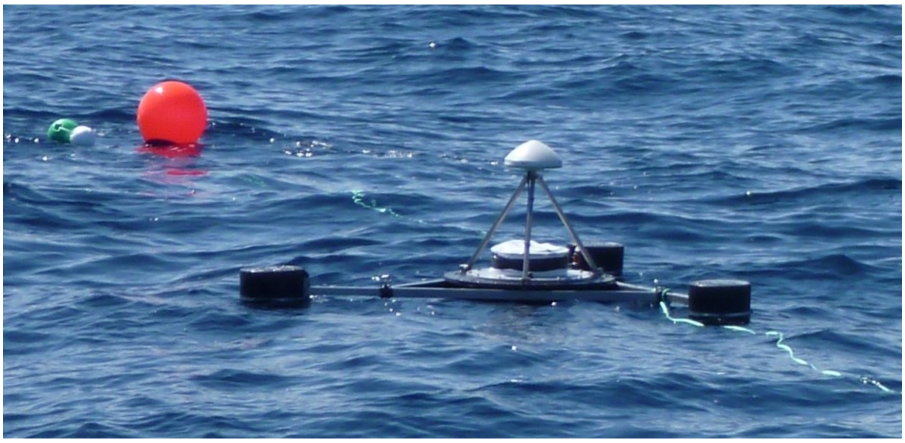

Figure 18 The IMOS GPS buoy used by Watson et al. (2011)

A number of commercial providers produce off the shelf GNSS equipped buoys (e.g. 'HydroLevel Buoy' by Axys Technologies http://www.axystechnologies.com/). A larger number of providers produce GPS equipped 'wave-rider' buoys for computing directional wave spectra (e.g. 'DWR-G by Datawell http://www.datawell.nl). Note these are not designed for estimating accurate ellipsoidal sea surface height.

Processing

Two processing strategies are available for GNSS buoy data. Differential carrier phase based techniques require additional data from a static land based GNSS reference site operating at the same data rate as the GNSS buoy. Processing may be undertaken in a number of commercial and research orientated packages that support kinematic processing. The alternate mode of processing is known as kinematic Precise Point Positioning (kPPP). This technique doesn't require a land based reference station, but requires a minimum data span of several hours and slightly more sophisticated software that is not supported by as many commercial providers.

Processing of GNSS buoy data is typically undertaken post-collection, however provided a communication link is available, real time processing is readily possible on the buoy or at a shore based location in the case of the differential carrier phase based technique (known as Real Time Kinematic, RTK, processing).

Processing of the GNSS buoy data yields epoch-by-epoch estimates of sea surface height relative to the chosen datum and expressed on a chosen ellipsoid. GNSS time series of sea level may then be filtered to remove wave effects and compared against offshore tide gauges to derive the required offsets to transform the mooring sea level onto the datum imposed by the GNSS buoy time series (see Watson et al. 2011 for further detail).

Accuracy

Accuracy of the GNSS derived estimates of sea level is affected by a range of variables, only some of which are unique to the ocean GNSS buoy environment. In the case of the IMOS buoys used for scientific purposes, the RMS of the difference between mooring sea level and the filtered GNSS sea level is at the 2 cm level. With a sufficiently long acquisition of data over multiple days, the error about the mean difference (mooring – GNSS sea level), is at the cm level. Typical swell experienced at the IMOS deployment locations is 1-2 m, with deployment locations typically ~20 km from the coast. The main factors that influence the accuracy of the technique are briefly mentioned below:

GNSS Related factors:

1) In the case of differential carrier phase based processing, proximity to land based GNSS reference station(s) is important (preferred < 25 km).
2) Duration of the GNSS buoy deployment (preferred > 24-48 hours)
3) Sea state at the time of the GNSS buoy deployment (large waves can cause loss of lock to the GNSS signals), and high dynamics associated with rougher conditions make kinematic processing problematic.
4) Water level to GNSS antenna separation (easy to determine for a custom buoy but more challenging if a larger platform or boat is used).

Tide gauge factors:

1) Quality of the pressure sensor (i.e. low drift, high resolution etc).
2) Ability to determine a dynamic height correction based on temperature and salinity through the water column (requires appropriate sensors).
3) Ability to remove atmospheric pressure from pressure gauge time series (requires access to observed data or meteorological models interpolated to the measurement location).

References

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