Article

A COHERENT TIDAL DATUM FOR THE TORRES STRAIT

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Abstract

The Torres Strait is a complex waterway to the north of Australia linking the Arafura and Coral Seas. Sea level data from 13 islands were provided with the intention of validating the GPS extension of AUSGeoid98 to the Torres Strait. A comparison between the Australian Height Datum (AHD) determined from the AUSGeoid98 model and Mean Sea Level (MSL) identified differences of up to 1.57m. A coherent tidal datum was established with a seasonal adjustment to the long-term level from Thursday Island. The seasonally adjusted MSL from this study should be considered as an approximation of AHD in the Torres Strait.

Résumé

Le détroit de Torres est une voie navigable complexe au nord de l'Australie, qui relie les mers d'Arafura et de Coral. Les données sur le niveau de la mer de 13 îles ont été fournies dans l'intention de valider l'extension du GPS d'AUSGeoid98 au détroit de Torres. Une comparaison entre le système de référence australien (AHD) déterminé à partir du modèle de AUSGeoid98 et le niveau moyen de la mer (MSL) a mis en évidence des différences allant jusqu'à 1,57m. Un zéro des marées cohérent a été établi avec une correction saisonnière du niveau à long terme, à partir de Thursday Island. Le MSL corrigé des variations saisonnières de cette étude doit être considéré comme une approximation du AHD dans le détroit de Torres.

Resumen

El Estrecho de Torres es un canal complejo al norte de Australia, que conecta los Mares de Arafura y Coral. Se proporcionaron datos del nivel del mar de 13 islas, con la intención de validar la extensión GPS de AUSGeoid98 al Estrecho de Torres. Una comparación entre el Plano de Referencia Australiano (AHD) determinado a partir del modelo AUSGeoid98 y el Nivel Medio del Mar (MSL) identificó diferencias de hasta 1,57m. Se creó un Datum de Mareas coherente con un reajuste de nivel estacional a largo plazo a partir de la Isla Thursday. El MSL reajustado estacionalmente a partir de este estudio debería ser considerado como una aproximación del AHD en el Estrecho de Torres.

Introduction

The Torres Strait is unique in the way that tides and weather driven forces interact across and along the Strait. The Strait is a topographically very complex, shallow, body of water that links the Coral Sea to the east with the Arafura Sea to the west (Wolanski, 1994). The amplitude and phase of the tide changes rapidly through the strait, mostly along the shallow and constricted centreline (Saint-Cast, 2008). The strait enables movement of water between the two seas while the tidal phase of the two water bodies is incoherent within the strait (Wolanski et al, 1988). To the east the tide is chiefly semi diurnal and to the west it is predominantly diurnal (Easton, 1970). This creates a region of interaction in the Strait between diurnal and semi-diurnal tides that is very complex (Saint-Cast, 2008). This tidal incoherency can result in large differences in level of up to 6m (Wolanski et al, 1988).

There is very little long term sea level information from the region in general. Historically the focus has been on the shipping lanes in the southern regions of the strait for maritime safety purposes. Over time, datum information was adopted independently for each island without links between the islands or between the islands and mainland Australia. Island connections to the Australian Height Datum (AHD) would allow for the integration of existing tide gauge data, elevation models, topographic mapping imagery and simplify island management activities such as coastal development. Connection to AHD will also allow a coherent datum for storm surge modelling, sea level rise studies and Hydrographic surveys.

This paper presents the results of harmonic analysis of sea level data collected through a field study undertaken with the initial aim of establishing GPS connections to the AHD across islands in the Torres Strait and to further the knowledge of tidal dynamics within the Torres Strait region. Connecting to AHD proved problematic, hence connection to a coherent tidal datum, and to a seasonally adjusted mean sea level as an approximation of AHD is investigated here.

Methods

Sea level data recorded at thirteen island sites across the Torres Strait between the period of 27 May to 30 June 2008 were provided by Griffith University. The methods used to collect and transform this data from raw pressure to sea level referenced to a levelled tide staff datum are given in the Griffith University report “Torres Strait Tidal Survey” (Zier et al, 2009).

To classify the tidal characteristics of the project sites, they were divided into three groups based on their collective location (*see Figure 1*). The sites in the Coral Sea form the eastern group; those close to PNG form the central northern group and the sites north of Cape York, the central southern group.

The form factor was calculated for each site as the ratio of the major diurnal constituents to the major semi-diurnal constituents as: K1+O1/M2+S2. The form factor is defined in the Australian National Tide Tables (ANTT) as; a site is considered to be semi-diurnal if the ratio is less than 0.5 and diurnal if the ratio is greater than 0.5 (Australian Hydrographic Service RAN, 2009).

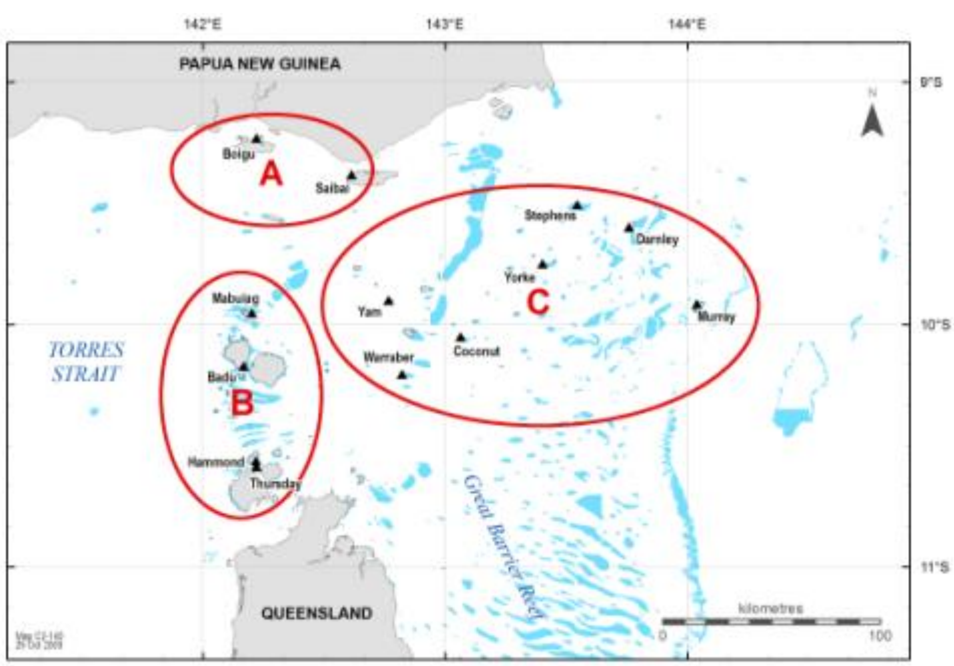


Fig . 1 / Project site grouping (A) Northern central sites (B) Southern central sites and (C) Eastern sites.

The sea level data consisted of two and five minute averaged levels (for three sites) referenced to the zero of each tide gauge. Hourly levels were then extracted from this sea level data. This data was initially transformed via a regression from the tide gauge (zero) datum to the datum (zero) of a tide staff. The tide staffs were installed close to the tide gauges and connected to local benchmarks via levelling surveys. The times and heights of high and low water were extracted from the hourly levels with the intention of doing datum transfers between the Thursday Island data and the Hammond Island, Badu Island, Mabuiag Island and Yam Island data. The transfer consisted of regression analysis between the reference site and the secondary site.

The hourly sea level readings referenced to tide staff zero were then analysed using the "Foreman Tidal Package" (Foreman M., 1977). As part of the harmonic analysis procedure, the tidal constituents from a nearby site with a long data set was used to infer the shallow water effects as the data-sets here were only 35 days in length. Analysis of such a short data-set will not identify some tidal constituents hence these must be inferred from a nearby site with a long data-set (Pugh, 1996). There were two sites used as base inference sites.

Thursday Island tidal constituents were used for the Central Southern sites while Twin Island Constituents were used as the inference constituent set for the Eastern and Central Northern sites. These inference tidal constituents were supplied by the National Tidal Centre (National Tidal Centre, 2009).

The constituent set from the analysis formed the basis for calculating Lowest Astronomical Tide (LAT) and tidal planes including Highest Astronomical Tide (HAT). Tidal predictions were generated for the Tidal Datum Epoch (TDE) 1992 to 2011 and LAT and HAT levels were determined from these tide predictions. The difference between LAT and the zero of the data was used to adjust HAT and the Mean Water Level (MWL) of the raw data to a LAT datum. This new datum then becomes the tidal datum for each site and is referred to as "LAT 2008". The Highest Astronomical Tide calculated in this paper is also referred to as HAT2008. The methods used to calculate the diurnal and semi-diurnal tidal planes were based on the simplified formulae (*see Table 1*) used in the ANTT (Australian Hydrographic Service RAN, 2009).

The Australian Height Datum (AHD) is defined as MSL at 32 tide gauges around Australia over the period 1966 to 1968 (Brown, 2010). So in the absence of a levelled AHD value and in this case where the AUSGeoid98 model introduces large errors, AHD can be represented by long term MSL at a particular site. A suitable MSL value was calculated by applying an offset to the MWL of the sea level data. The offset used was essentially the difference between MWL at Thursday Island (this project) and the published Thursday Island long term MSL. The Thursday Island tide gauge was set to the well established (LAT) datum at that site. Hence the shift from the short term MWL to the long term MSL was observed directly there.

Semi-diurnal Planes	**Simplified Formulae**
MHWS	Z0+(M2+S2)
MHWN	Z0+abs(M2-S2)
MLWN	Z0-abs(M2-S2)
MLWS	Z0-(M2+S2)
Diurnal Planes	
MHHW	Z0+(M2+K1+O1)
MLWH	Z0+abs(M2-(K1+O1))
MHLW	Z0-abs(M2-(K1+O1))
MLLW	Z0-(M2+K1+O1)

***Table 1**. Simplified formulae used to calculate tidal planes from the Australian National Tide Tables, 2009 (Australian Hydrographic Service RAN, 2009).*

Included in the offset was the difference between the calculated LAT and the current LAT provided by the National Tidal Centre for Thursday Island (0.23m). The seasonal correction at Thursday Island was assumed to be the same across the study region and applied accordingly.

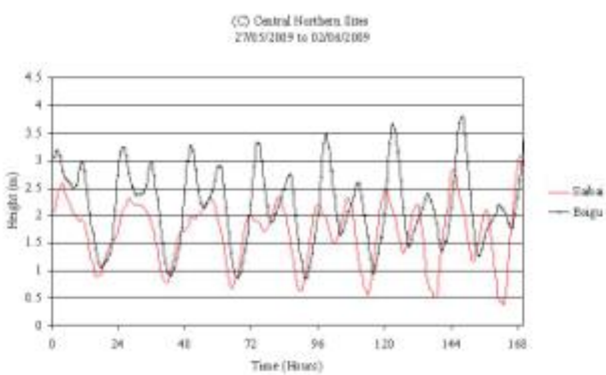
The methods used to calculate HAT carry an unknown level of uncertainty because of the shortness of the data sets that the calculations are based upon. The definition of HAT (PCTMSL, 2009) assumes an observed data-set of sufficient length. In this context "sufficient length" should be long enough to include the nodal factors, that is, greater than 18.6 years. In our case, the observed data was only 35 days in length.

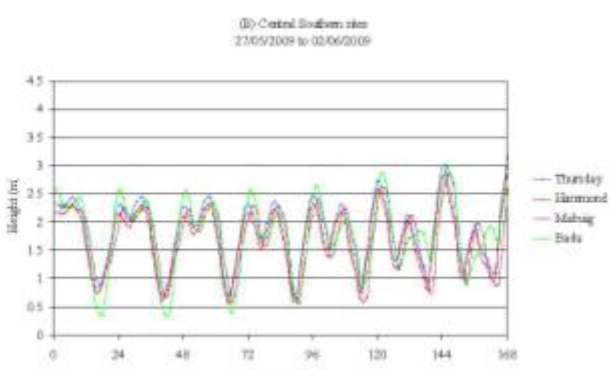
However at Thursday Island there is an observable indication of this difference and the data from all sites were recorded over the same sampling period. This has allowed an offset to be applied to all sites.

Connections from the tide staffs to local, island based, primary survey and recovery marks were established by Griffith University (Zeir et al, 2009). With LAT datum now established for each site relative to tide staff zero's, it is possible to extend the LAT2008 datum to the local bench marks. The Department of Natural Resources and Water (DNRW) followed up the benchmark levelling work of Griffith University with GPS determinations of primary and recovery benchmark Ellipsoidal heights. The benchmarks were then connected to the AHD via the Ausgeoid98 model. For further details on the AUS-Geoid98 model see Featherstone et al, 2006.

Results

The observed sea levels for the first seven days of the 35 day sampling period are presented for the three groups in *Figure 2*. The tidal dynamics are generally coherent within each group with some notable exceptions. Within the eastern group, tidal dynamics are similar during the spring tide but some small differences are apparent during the neap period. Of the central southern sites, one site shows a different dynamic with respect to the other sites in the group.





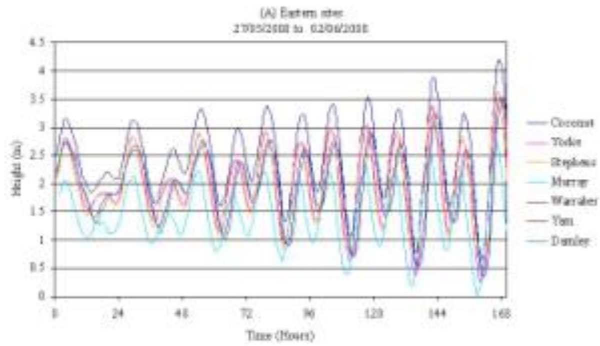


Figure 2 *The first seven days of sea level data set to an arbitrary datum and divided into three groups, (A) Eastern sites; Coconut, Yorke, Stephens, Murray, Warraber, Yam and Darnley Islands (B) Central Southern sites; Thursday, Hammond, Mabuiag and Badu Islands and (C) Central Northern sites; Saibai and Boigu Islands.*

From *Figure 2*, the level at Badu Island converges on day 6 and 7 away from the levels of the other sites in the Central Southern group. This happens at the time of the inequality and it appears that another high tide peak converges with the following high tide at Badu before this happens at the other sites. The tidal dynamics of the two central northern sites differ considerably and reflect the change from being semi-diurnal in the east (in the Coral Sea) to being dominantly diurnal in the west of the Torres Strait in the Gulf of Carpentaria (Saint-Cast, 2008).

The regression (tidal transfer) between the reference site of Thursday Island and the other central (north and south) islands was significant to Hammond Island as evidenced by an R^2 value greater than 0.99, see *Table 2*. This was not the case however with regressions to other sites in these two groups. The regressions from the eastern reference site of Yam Island to the other five sites has revealed that Warraber Island has similar tidal dynamics to Yam Island with an R^2 value of greater than 0.99 see Table (3). This close relationship was not evident with regressions to the other eastern group islands.

Site	Ratio	R^2
Thursday Island (reference site)	1.0	1.0
Hammond Island	0.997	0.995
Badu Island	1.148	0.946
Mabuiag Island	0.999	0.973
Boigu Island	1.160	0.9247
Saibai Island	0.923	0.890

Table 2. *Tidal transfer between Thursday Island and Hammond Island, Mabuiag Island and Badu Island.*

Site	Ratio	R^2
Yam Island (reference site)	1.0	1.0
Coconut Island	1.093	0.985
Darnley Island	1.012	0.965
Murray Island	0.828	0.966
Stephens Island	1.075	0.944
Warraber Island	1.000	0.997
Yorke Island	1.059	0.974

Table 3. Tidal transfer between Yam Island and Yorke Island, Warraber Island, Stephens Islands, Murray Island, Darnley Island and Coconut Island.

MSL from the analysis is presented in *Table 4* and *Figure 4*; there were five sites where the published (Australian Hydrographic Service RAN, 2009) MSL varied considerably from these. A range of between 1.78m at Murray Island to 2.28m at Coconut Island is evident in the project MSL.

For each site the adjusted MSL, along with seasonal constituents Sa (annual) and Ssa (semi annual) from the closest site where published values (Australian Hydrographic Service RAN, 2009) are available were included in the constituent list. Some sites have published seasonal constituents and were used accordingly (see *Table 4*). As justification for the choice of the seasonal constituents used in this analysis, modelled seasonal annual constituent "Sa" were supplied by the Australian Maritime College (Mason, 2009) (not presented here).

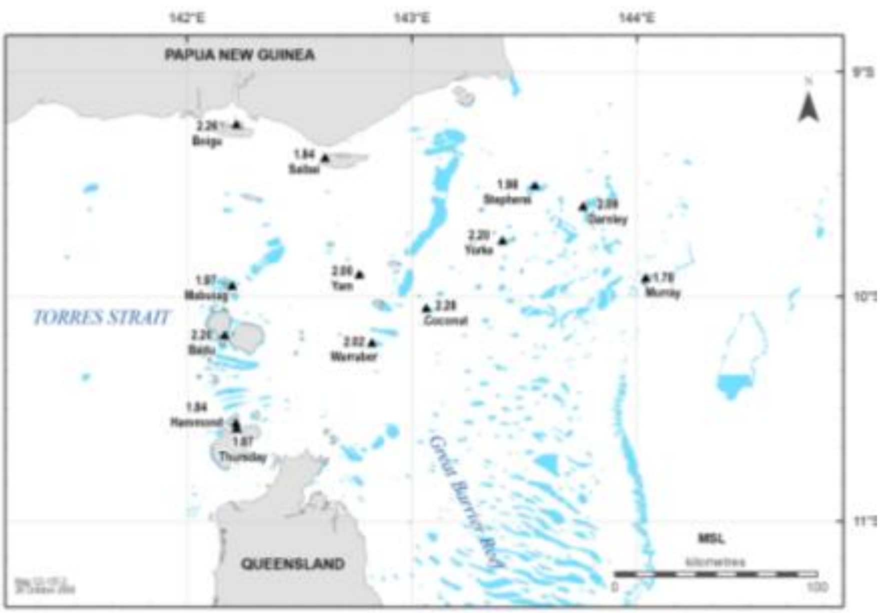


Figure 3 *MSL based on the project data. In metres above LAT2008.*

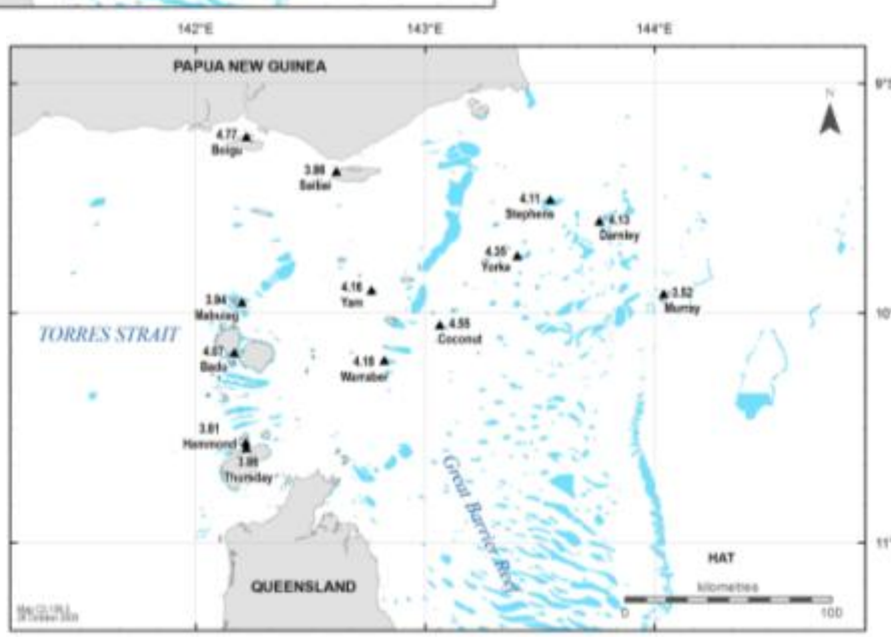


Figure 4 *HAT2008 calculated from tide predictions for the period 1992 to 2011 derived from the project data. In metres above LAT2008.*

Some notable differences are evident between the two sources of Sa. Boigu Island has a published magnitude of Sa that is around 10 cm higher than the modelled Sa and a phase difference of over 10 degrees. A recalculated HAT was 0.09m (not listed here) lower using the modelled Sa. There are no published seasonal constituents for Saibai Island, those from Yam Island were used for Saibai Island and the same effect of reducing HAT was noted when the modelled Sa (magnitude and phase) was used.

The phase of the modelled Sa was considerably different for the Eastern sites of Yam Island and Stephens Island. A re-analysis of HAT with the modelled phase revealed a small drop of 0.02m-0.04m (not shown here) so the published Sa phase was used here. The Seasonal constituents for Yam Island were used for the remaining Eastern sites as the Yam constituents fall within the modelled amplitude of Sa.

Site	M2 Amp. Phase	S2 Amp. Phase	O1 Amp. Phase	K1 Amp. Phase	Sa Amp. Phase	Ssa Amp. Phase
Badu Is	0.453 124.9	0.269 340.6	0.369 140.6	0.633 202.7	0.113 322.8	0.011 4.7
Boigu Is	0.452 156.5	0.447 51.5	0.271 161.0	0.591 225.8	0.261 308.7	0.049 293.1
Coconut Is	0.715 333.9	0.442 323.3	0.172 163.2	0.408 206.6	0.077 339.9	0.028 42.6
Darnley Is	0.720 309.9	0.368 291.6	0.161 160.5	0.353 199.8	0.077 339.9	0.028 42.6
Hammond Is	0.342 57.5	0.343 342.6	0.248 146.8	0.509 205.0	0.113 322.8	0.011 4.7
Mabuiag Is	0.375 59.5	0.424 7.5	0.210 153.0	0.500 213.1	0.113 322.8	0.011 4.7
Murray Is	0.571 291.9	0.303 267.6	0.141 155.5	0.300 194.0	0.077 339.9	0.028 42.6
Saibai Is	0.386 29.4	0.537 24.0	0.197 171.41	0.514 225.3	0.077 339.9	0.028 42.6
Stephens Is	0.748 314.2	0.371 297.9	0.164 154.5	0.349 200.3	0.093 330.4	0.017 47.3
Thursday Is	0.359 62.3	0.337 343.2	0.252 144.8	0.532 204.4	0.113 322.8	0.011 4.7
Warraber Is	0.614 349.7	0.444 338.8	0.174 163.7	0.432 211.8	0.077 339.9	0.028 42.6
Yam Is	0.577 1.2	0.475 354.6	0.177 168.1	0.455 216.8	0.077 339.9	0.028 42.6
York Is	0.728 320.0	0.404 308.4	0.165 163.0	0.374 204.1	0.077 339.9	0.028 42.6

Table 4. *Tidal Constituents as Amplitude (m) and Phase (degrees). Sa and Ssa taken from ANTT (Australian Hydrographic Service* ***RAN, 2009) for Boigu Island, Stephens Isles, Thursday Island and Yam Island. Badu Island, Hammond Island and Mabuiag Island Sa and*** *Ssa from Thursday Island. Coconut Island, Darnley*

The calculated project HAT2008 levels were generally close to the ANTT published levels with four sites being lower by between 4 cm and 13cm and four sites being higher by between 23 cm and 41 cm. The remaining five sites have no published HAT levels. It should be noted that the ANTT HAT levels are rounded to one decimal place whereas the project HAT2008 levels are to two decimal places.

Figure 4 presents HAT2008 levels relative to LAT2008 based on the project data, the highest HAT2008 values are at Boigu Island and Coconut Island. The project HAT2008 of 3.86m for Thursday Island is the same as the HAT given in the ANTT for Thursday Island. HAT2008 and MSL at Stephens Island were very close to the published levels verifying the removal of erroneous data that resulted from the tide gauge bottoming out on a low tide (not presented here - see Metters, 2009).

Central Southern Group					Central Northern Group	
Datum Level	Thursday Island	Hammond Island	Badu Island	Mabuiag Island	Boigu Island	Saibai Island
TGBM	PM 10078 6.375	PM 145548 4.459	PM 164065 4.959	PM 89051 8.312	PM 140483 4.136	PM 173502 4.598
Top of Ramp	na	4.05	5.046	4.891	4.560	4.349
HAT2008	3.86 (3.86)	3.81 (3.75)	4.07	3.85 (Talab 3.9)	4.77 (4.9)	3.86
MSL	1.87 (1.87)	1.84	2.20	1.93	2.26 (2.45)	1.84 (1.71)
Island Datum	0.00	0.04	0.536 (ISLW)	0.294	0.074	-0.248
LAT2008	0.00	0.00	0.00	0.00	0.00	0.00

Eastern Group			
Datum Level	Yam Island (Iama)	Sue Island Warraber)	Coconut Island (Poruma)
TGBM	PM 146546 4.666	PM 146550 4.752	PM 156559 5.008
Top of Ramp	4.358	4.559	4.335
HAT2008	4.16 (4.2)	4.18 (4.16)	4.55 (4.2)
MSL	2.00 (1.96)	2.02	2.28 (1.99)
Island Datum	-0.124	0.009	-0.163
LAT2008	0.00	0.00	0.00

Eastern Group				
Datum Level	York Island (Masig)	Stephens Island (Ugar)	Darnley Island (Erub)	Murray Island (Mer)
TGBM	PM 146543 4.364	PM 164053 4.615	PM 146551 5.009	PM 164054 5.499
Top of ramp	4.615	4.632	4.556	not levelled
HAT2008	4.35	4.11 (4.1)	4.13 (3.9)	3.52 (3.1)
MSL	2.20	1.98 (2.00)	2.09 (1.82)	1.78 (1.44)
Island datum	0.115	0.122	0.17 (ISLW)	0.034
LAT2008	0.00	0.00	0.00	0.00

Table 5*. Connections from LAT2008 to Island datum, MSL, HAT2008, bench mark at the top of each boat ramp and TGBM. HAT value in brackets from the Queensland Tide Tables 2010 (QTT, 2010) for Thursday Island only. Hammond Island transferred from Thursday Island. Warraber transferred from Yam Island and the remainder from the Australian National Tide Tables (ANTT, 2009). MSL in brackets from the ANTT (ANTT, 2009). All values are in metres.*

The vertical distance between LAT2008 and HAT2008 to primary bench marks are given in Table (5). A complete list of the Griffith University connections, other historic surveys, connections to the ellipsoid, tidal constituents and tidal planes are given in Metters, 2009. The vertical separation between local benchmarks is consistent using both GU levelling surveys and the DNRW ellipsoidal determinations (Metters 2009). This verifies the levelling survey work. However the connections from the tide gauges to the benchmarks cannot be verified directly.

Site	Height above MSL	Height above AHD	Difference MSL-AHD
Thursday Island	3.518	3.613	-0.095
Hammond Island	2.094	2.122	-0.028
Badu Island	2.759	3.258	-0.497
Mabuiag Island	6.382	7.656	-1.274
Boigu Island	1.876	2.706	-0.83
Saibai Island	2.071	2.793	-0.722
Yam Island	2.666	4.232	-1.566
Sue Island	2.732	3.204	-0.472
Coconut island	2.158	2.524	-0.366
York Isles	2.515	2.895	-0.38
Stephens Island	2.635	2.89	-0.255
Darnley Island	3.09	3.953	-0.863
Murray Island	3.719	4.681	-0.961

Table 6*. Difference between the Project MSL and Australian Height Datum for one benchmark at each site.*

A comparison of the AHD determinations with project MSL reveals large differences (see *Table 6*). Of the thirteen sites only two give a close relationship with less than 0.1m difference and nine sites were different by up to 1.0m. The difference between MSL and AHD were considerable at Yam Island by -1.57m and Mabuiag Island by -1.27m difference.

The change in tidal dynamics from east to west in the strait is seen in the form factor for each site. The Eastern sites have a form factor generally less than 0.5 with the exception of Warraber Island and Yam Island, both of which are close to 0.5. Hence the Eastern sites are generally semi-diurnal (refer *Figure 5*). The form factor of the central sites ranges from 0.89 at Mabuiag Island to 1.39 at Badu Island and these can be considered to be more diurnal in nature.

Discussion

The sea level data of this project, although short in length enabled a sound basis for establishing a coherent tidal datum across thirteen islands in Torres Strait.

The datum transfer from Thursday Island to Hammond Island and from Yam Island to Warraber Island is useful in verifying the results of the tidal analysis. The tidal regime is similar at Hammond and Thursday Islands and this is clarified with a high R^2 of greater than 0.99 from the regression between the two sites. The tidal regime is also very similar at Yam Island and Warraber Island with a high R^2 also greater than 0.99. HAT2008 levels of 3.81m and 4.18m derived from project tidal constituents were very close to the transferred HAT levels of 3.75m and 4.16m at Hammond Island and Warraber Islands respectively. For the islands north of Hammond Island, the tidal regime differed by more than 5 % of Thursday Island. Islands to the east of Warraber Island expressed a tidal regime that differed by 1.5% to 5.4% that of Yam Island.

The similarity in tidal dynamics at Hammond Island and Yam Island is also confirmed with similar form factors at each site. This is also the case between Yam Island and Warraber Island (see *Figure 5*). The large variance in form factors within the south central and eastern groups confirms that tidal transfers could not be used. The form factor of the two northern central sites are the same, however the tidal dynamics are clearly different as seen in *Figure 2(c).*

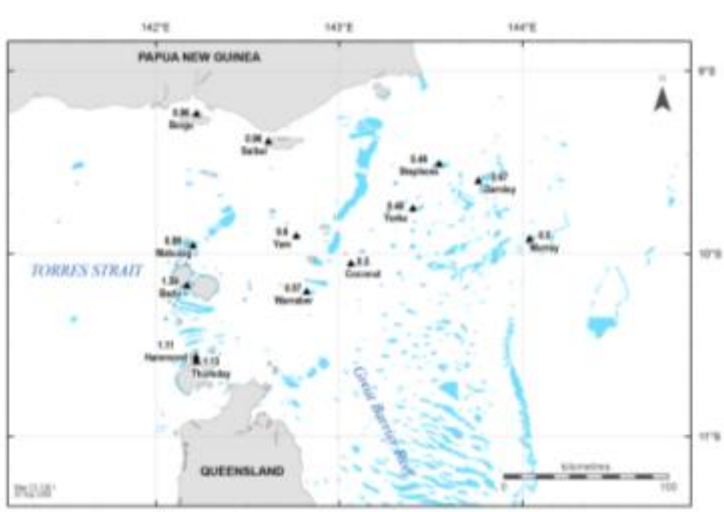


Figure 5. *Tidal form factor (as K1+O1/M2+S2) for the project sites*

The tidal planes and particularly MSL have been derived from short data-sets of 35 days. This data length is sufficient to incorporate most tidal cycles but does not account for longer tidal cycles such as the 18.6 year nodal cycle. An offset was applied in view of accounting for this unknown difference between the MSL derived from these short data-sets and MSL derived from a long dataset. The levels of MSL and HAT2008 derived from the project data after adjustment for seasonal and long-term factors varied by more than 10 cm from published values for five out of the eight published sites. This difference reflects the difference between the LAT2008 datum and the datum of the published sites.

The seasonal constituents Sa and Ssa cannot be verified directly for most of the project sites as there just isn't enough sea level information available from the region. In order to determine the seasonal or annual component of sea level from observed data there must be one year or more of sea level readings. There is more than one year of readings available for Thursday Island. For the other islands in this project where there are published seasonal constituents, the data that formed the basis of these constituents was less than one year in length and in some cases snippets of data from different years were joined to make up one year (personal communication with the National Tidal Centre). The modelled seasonal constituents reduced the level of HAT. If you consider that one of the main uses of HAT is as a reference point for development work including floor levels, it would be better to use a higher estimate of HAT rather than a lower estimate. A higher HAT will give some tolerance to allow for potential increases in sea level and HAT (through sea level rise etc). A lower HAT will increase the risk of inundation and flooding through building floor levels being too low.

Considerable difference was seen between the project MSL and AHD determined via AUSGeoid98 at many of the island sites. The MSL-AHD difference also varied between sites within the strait. Also notable is a general gradient in the difference increasing from South to North and to the Northeast. At Thursday and Hammond Islands, MSL was within 0.1m of AHD. There were six sites with a MSL-AHD difference of greater than 0.5m which exceeds the accuracy of AUSGeoid98 of ±0.5m (Featherstone et al., 2001). There are two possible causes of these anomalies; firstly the inability of the AUSGeoid98 to represent AHD (MSL) in the north of Australia where there is a known gradient in the AUSGeoid98 towards the North of Australia of 0.5m (Brown, 2010). The other possible cause of these anomalies lies in the adjustment to a long term MSL. MSL was derived from short term data-sets and the offset applied to adjust it to an approximation of a long term MSL may not be appropriate for application to all of the islands. MSL has a range of between 1.78m at Murray Island to 2.28m at Coconut Island. The actual (but unknown) difference between this short term mean level and the long term MSL will very likely differ from this difference at Thursday Island. These two factors suggest that connecting to the AHD with GPS from the Torres Strait islands warrants further investigation. The overall objective of this project is to establish a datum that is coherent within the strait. With the difference between AHD and MSL in mind and the coherent nature of the project data, it is recommended that MSL derived here be used as an alternative to AHD in Torres Strait.

This study verifies the dynamic nature of the tide in the Torres Strait. The form of the tide can change over short distances in the Strait as evidenced by the difference in the tidal dynamics between Boigu Island and Saibai Island which are only 45 kilometres apart. Of particular interest is the change from a semi-diurnal tide in the Coral Sea to dominantly diurnal in the southern central section. The observation of Easton (Easton, 1970) of a change from semi diurnal in the East of the strait to being predominantly diurnal to the West of the strait is verified here. The form factor of sites to the east in the Gulf of Carpentaria, and to the south east on the north east coast of Queensland extends this change in dynamics. Just to the west of the strait the form is 1.47 at Goods Island and 1.54 just south at Weipa. In the south east of the Gulf of Carpentaria, the form factor is a much larger 6.48 at Karumba. The form factor at ports on the north east coast of Queensland is around 0.5.

There is a considerable difference in height along the strait where the maximum difference in sea level height at any one time for the project period was 3.3m (not presented here) between Darnley Island and Badu Island. Although not as large as the 6m difference claimed previously (Wolanski et al, 1988), it demonstrates the difference in phase of the two water bodies that the strait connects (Wolanski,et al, 1988 and Saint-Cast, 2008). This difference has implications for safe shipping transit through the strait.

Tidal planes including HAT2008 were calculated and referenced to LAT2008 and to the local benchmarks. This will enable local authorities to revise the local knowledge of tidal planes (particularly HAT) for use in coastal development and inundation mitigation. If HAT and the tidal planes presented in this report are to be used for purposes such as storm surge and sea level rise mitigation, coastal development and maritime safety, then it is recommended that an arbitrary level of error be applied. Where the accuracy of HAT is important for these purposes, it is recommended that these data-sets be extended to a more suitable length through long term installations of tide gauges. Long term installations will also be needed to verify the LAT2008 datum and MSL from this project.

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References

Australian Hydrographic Service RAN, 2009. Australian National Tide Tables 2009, Department of Defence, Australian Hydrographic Publication 11.

Brown, N., 2010. AUSGeoid09; Converting GPS heights to AHD heights. Ausgeo news, issue 97,online at: www.ga.gov.au/ausgeonews.

Easton, A.K., 1970. The tides of the continent of Australia. Horace Lamb Center for Oceanographic research, AdelaideResearch Paper no. 37.

Featherstone, W.E. and Sproule, D.M., 2006. Fitting AUSGeoid98 to the Australian Height Datum using GPS-levelling and least squares collocation; Application of a cross-validation technique. Survey Review, 38(301) 573-582.

Foreman, M.G.G., 1977. (revised 1996). Manual for tiheights analysis and prediction. Pacific Marine Science Report 77-10, Institute of Ocean Sciences, Patricia Bay, 58 pp. (ftp for postscript).

Mason, L., 2009. In SEA (2009), Probabilistic Assessment of Extreme Ocean Water Levels and Inundation Hazard in Torres Strait. Prepared for Torres Strait Regional Authority by Systems Engineering Australia Pty Ltd, in preparation.

Metters, D., 2009. Torres Strait Tidal Survey Datum Analysis. Maritime Safety Queensland unpublished internal report.

National Tidal Centre, Bureau of Meteorology, 2009. Tidal planes and constituents for Thursday Island and Twin Island supplied under the National Tidal agreement.

Permanent Committee on Tides and Mean Seal Level (PCTMSL), Australian Tides Manual: Special Publication 9 (SP9), on-line at: http://www.icsm.gov.au/icsm/tides/SP9/index.html.

Pugh, D.T. 1986 (revised 1996). Tides, Surges and Mean Sea Level, John Wiley and Son 472 pp.

Maritime Safety Queensland, Queensland Tide Tables 2010. Department of Transport and Main Roads, Queensland Government.

Saint-Cast, F., 2008. Multiple time scale modelling of the Torres Strait-Australia. Continental Shelf Research 28, 2214-2240.

Wolanski, E., Ridd, P.,Inoue,M., 1988. Currents through Torres Strait. Journal of Physical Oceanography 18, 1535- 1545.

Wolanski, E., 1994. A review of the physical oceanography of Torres Strait in: Physical oceanographic processes of the Great Barrier Reef. CRC press Inc. Florida.

Zier, et al., 2009, "Torres Strait Tidal Survey", unpublished report on a research project by the Queensland Dept. of Natural Resources and Griffith University.

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