Article

GPS Techniques in Tidal Modelling

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Abstract

With advances in processing techniques, and the associated improvement in positioning accuracies, it is apparent that deriving estimates of water level from GPS height observations is becoming accepted as a viable alternative to traditional tidal solutions. This paper outlines GPS techniques providing high-accuracy solutions that are of potential use in tidal modelling, describes a trial of alternative GPS systems, and presents data examples from actual survey projects. Within the discussion the concept of accuracy versus precision is defined, with special emphasis on the problem of vertical datums.

Résumé

Avec la progression des techniques de traitement et l'mélioration associée dans les exactitudes du positionnement, il est évident que les estimations de niveau d'eau dérivées des observations de hauteur du GPS sont progressivement acceptées en tant qu'alternative viable aux traditionnelles solutions de marée. Cet article decrit les techniques GPS qui fournissent des solutions de grande exactitude susceptibles d'être utilisées dans la modélisation des données, décrit un essai de systèmes GPS alternatifs, et présente des exemples de données à partir de projets hydrographiques concrets. Dans le cadre de la discussion, les concepts d'exactitude et de précision sont définis l'un par rapport à l'autre, et l'accent est placé en particulier sur le problème des systèmes de référence verticale.

Resumen

Con el avance de las técnicas de procesamiento y el mejoramiento asociado en la exactitud en posicionamiento, es aparente que el derivar estimaciones del nivel del agua basado en observaciones de las altura con GPS esta siendo aceptado como una alternativa viable para las soluciones de mareas tradicionales. Este artículo se refiere a las técnicas de GPS que proporcionan soluciones de alta exactitud que son de uso potencial en el modelación de la marea, describe una prueba de sistemas GPS alternativos, y presenta ejemplos de datos de un proyecto de levantamiento real. Dentro de la discusion se define el concepto de exactitud versus precisión, con especial énfasis en el problema de los datum verticales.

Introduction

Hydrography is the science that deals with the measurement of the physical properties of bodies of water and their littoral land areas. Within this science, special emphasis is usually placed on elements that affect safe navigation, and hydrographic surveys are conducted to collect the source data required for the compilation of nautical charts and associated publications.

The measurement of water depth, as with all survey observations, is subject to measurement errors. In planning a hydrographic survey, an error budget will be calculated in order to quantify and assess the error components. The purpose of the survey will drive the accuracy requirements, and the error budget will be used to determine whether the proposed solution will meet the specifications. One of the largest components of the hydrographic error budget is the tidal uncertainty.

This paper outlines a traditional approach to tidal reduction, describes the typical accuracies required, and outlines some of the difficulties of the approach.

The theory of using GPS as an alternative method of deriving tide is introduced, and this includes a brief description of the different GPS techniques. The concept of accuracy versus precision is discussed in relation to the definition of tidal datums.

In order to assess the performance of GPS for tidal modelling a trial was organised, and a number of GPS systems were installed on a survey vessel. The trial is described here, the results are presented, and some of the technical and logistical problems are discussed. Examples of GPS derived tides are presented from other survey projects that have been undertaken.

Finally, some concluding remarks are made, with suggestions for further investigations.

Traditional Techniques

The traditional method of tidal reduction is to record the rise and fall of the tide using a gauge. In situations where a survey is conducted in the immediate vicinity of the instrument, this technique remains, arguably, the most reliable. The challenge, however, is to translate the observations recorded at a gauge to a survey area that is at a remote distance from this location. Tidal errors will increase with distance from a gauge, and the problem is to quantify and to control these errors.

The accuracy requirements for a bathymetric survey are often specified in terms of a percentage of water depth. Hydrographic surveys, for nautical charting, usually follow the criteria defined in the International Hydrographic Organisation (IHO) S-44 publication (International Hydrographic Organisation, 1988). These criteria are given below:

Special Order: 0.25metres + 0.75% of depth
Order 1: 0.5 metres + 1.30% of depth
Order 2&3: 1.0 metres + 2.3 % of depth

These figures are given for the 95% confidence level. Using these criteria, the resultant Depth versus Accuracy graph for shallow-medium water depths is shown in Figure 1.

Figure 1: IHO S44 accuracy specification versus depth.

Special Order surveys are usually limited to port areas and their approaches, and it is the Order 1 specification that is most applicable to offshore continental shelf areas such as the North Sea. From the specification given above it may be seen that an

Figure 2: BA5058 co-tidal chart.

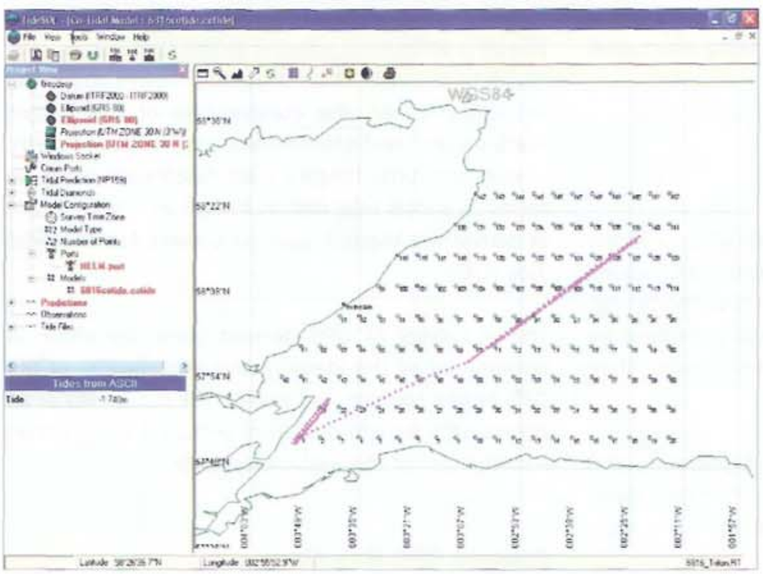

Figure 3: Digital version of B5058, illustrating model grid nodes and vessel track.

accuracy of approximately 0.8m (95%) is required in a water depth of 50m.

Extrapolation of tides from a gauge to the survey area is typically achieved using either a hydrodynamic model or a co-tidal chart. In the North Sea, Admiralty co-tidal publications BA5057/5058/5059 are widely used for this purpose (Figure 2).

The co-tidal chart presents contours of Mean Spring Range (MSR) and Mean High Water Interval (MHWI). Gardline have produced a digital model of this chart, which allows interpolation of MSR and MHWI values from a series of "nodes" that surround the vessel location. If desired, a weighted mean may be derived by combining data from a number of ports. The seamless digital model allows the smooth interpolation of tidal values as a vessel transits a large survey area (Figure 3).

When the co-tidal approach is used for tidal modelling, knowledge of the accuracy of the co-tidal chart is required in order to compile the error budget. The accuracy of BA5058 varies with location, but is usually quoted as:

Mean Spring Range: 0.5metres
Mean High Water Interval: 30 minutes

The influence of these factors on the modeled tidal height is a function of tidal range and period, and will vary across a large survey area. Experience has shown that generally these are conservative estimates, but it is also true that in some instances the model may not be sufficient to meet survey requirements. On these occasions, it is possible to make local improvements to the model by deployment of one or more tide-gauges at the survey area. Collection of tidal information for a one-month period is sufficient to enable harmonic analysis to extract the major tidal constituents, and these may then be used to quantify, and potentially also improve, the accuracy of the co-tidal model (Figure 4).

Unfortunately, the deployment of tide-gauges in offshore areas is accompanied by significant risk of loss, typically of the order of 30-40%. It is not vi-

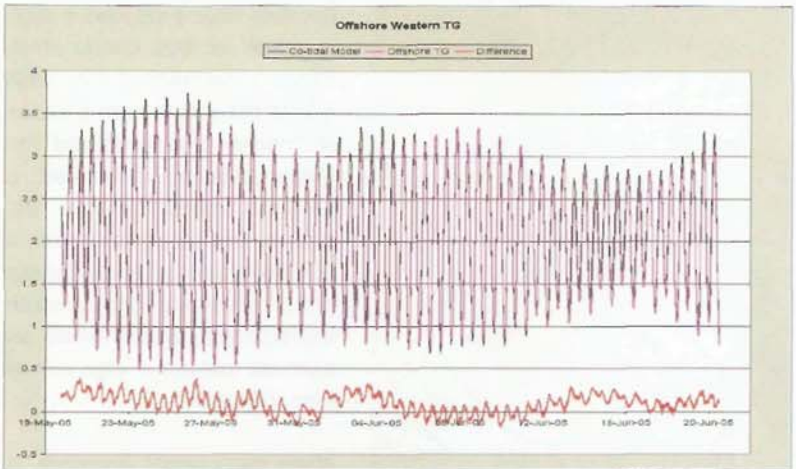

Figure 4: Comparison of offshore tide-gauge and equivalent tides derived from on-shore gauge and co-tidal model.

able, therefore, to deploy a number of gauges for the period of an extensive survey with an expected duration of several months. Hence, there are major cost and logistical advantages in seeking alternative tidal strategies.

GPS Techniques

In the near-shore environment certain GPS solutions have become widely used and accepted techniques for horizontal control and for use in tidal modelling. These solutions are limited by the requirement for close proximity to a reference station, hence their restriction to near-shore surveys.

In recent years, advances in GPS techniques and processing algorithms suggest that other GPS methods may deliver height solutions of sufficient accuracy for use in tidal modelling.

However, before considering this in detail, it is necessary to refine our concept of accuracy by introducing the distinction between accuracy and precision. These are not unfamiliar terms in the field of positioning, and the importance of the distinction is often discussed in relation to geodetic datums. Thus, a GPS receiver is capable of delivering a position of high precision or repeatability, but if the user has incomplete or erroneous knowledge of the appropriate geodetic datum transformation, then the final coordinate could be of low accuracy.
In an analogous situation, GPS derived heights may be very repeatable or precise, but in order for them to be useful as tides, detailed knowledge of the relationship between the GPS height and the tidal datum is required. Only with this knowledge can the GPS derived tides be described as accurate.

However, notwithstanding this comment, precise GPS observations may provide useful information on tidal range and period, even with incomplete knowledge of absolute datum. In this respect GPS offers potential to be used as an aid to the traditional approach by helping to identify scale and phase errors in a co-tidal model.

The GPS solution is referred to the GPS datum, and height is reported as an ellipsoidal height above the WGS84 ellipsoid (the complexities of the current "GPS datum" and ellipsoid are not discussed here). In contrast, tidal heights have historically been referred to a local tidal datum, known as Chart Datum, or derivatives thereof, such as Lowest Astronomical Tide (LAT).

The suitability of GPS derived tides, therefore, is determined by the stability and repeatability of the GPS height solution, but also by the availability of an appropriate transformation of vertical datum and an assessment of the associated error.

Current GPS Solutions

High-accuracy GPS positioning techniques that are potentially suitable for GPS tides may be divided into four categories.

Real-Time Kinematic (RTK)
RTK is established as an acceptable method for deriving GPS tides. The RTK method relies on real-time transmission of carrier phase observations from a local reference station. The method is capable of producing high precision GPS height observations, but is limited in range, and therefore ideally suited to local near-shore surveys, such as harbour and port approaches.

In coastal studies, the integration of land-based and offshore survey data is increasingly important, and the adoption of the land-based vertical datum for use offshore is a simple method to achieve this integration. The RTK method is most suited to this approach, as derived GPS heights will be referred to the height of the onshore reference station, at which the precise height in the desired vertical datum may be derived.

An extension of the RTK method, which overcomes some of the logistical problems associated with operating within limited range of a reference station, is Network RTK. These are usually commercial networks to which a user may subscribe.

Post-Processed Kinematic (PPK)

PPK, as the name implies, is not a real-time solution. The technique involves the post-processing of data collected on the survey vessel, with data acquired at one or more reference stations. If precise positioning is not required in real-time, then this method offers significant advantages. If a public GPS service exists which can supply appropriate reference station data, then the PPK method obviates the need to establish local reference stations.

The RTK and PPK techniques generally give a height solution with centimetre-level precision when working within approximately 10km of a reference station. Typically, the maximum quoted range to a reference station is 20km.

Globally Corrected GPS (GcGPS)

The RTK and PPK techniques are only suitable for work in close proximity to reference stations. In order to potentially overcome these limitations, a number of commercial operators now offer a high-accuracy Globally Corrected GPS (GcGPS) service. These systems have global coverage, based on large investment in infrastructure to support the service. There are four major commercial systems available today:

Fugro: Starfix HP
Fugro: Skyfix XP
C&C Technologies: C-Nav
Veripos: Veripos Ultra

Two distinct approaches are employed to derive these high-accuracy solutions. Skyfix XP C-Nav and Veripos Ultra systems are largely based on a similar technique, whereby a network of monitoring stations determines satellite orbit and clock corrections, and these corrections are broadcast to the user.

The Starfix HP service is more analogous to the familiar Differential GPS (DGPS) service, as reference stations are used to derive corrections for GPS observables, which are then processed and optimised as a high-accuracy Wide-Area DGPS (WADGPS) solution.

Typically, these systems claim a vertical accuracy of better than 30cm (2DRMS).

Precise Point Positioning (PPP)

The final high-accuracy GPS technique discussed, is the Precise Point Positioning (PPP) method. This is a post-processed solution, which in contrast to the PPK method, does not require data from reference stations. The technique uses precise GPS orbit and clock corrections in conjunction with raw GPS data logged on the survey vessel. In this respect the method is similar to the real-time GcGPS technique. However the PPP method is unique in that neither a real-time correction service, nor reference station data is required for the solution. The user, however, does require access to the Internet in order to download the precise orbit and clock parameters, and there is some delay before this information is published.

The software tested on these trials was TerraPOS, produced by Terratec of Norway. Accuracy specifications are dependant not only on GPS geometry but also on the duration of the observation period. Figures of 40cm (2VRMS) are quoted for a 1-hour period, reduced to 8 cm (2VRMS) with 24 hours of data. To process data from a high-dynamic environment, such as a vessel at sea, raw GPS data should be recorded at a frequency of 1Hz.

GPS Dynamic Positioning Trials

In order to investigate the performance of the different GPS techniques described above, a small trial was organised so that systems could be compared under the same (or very similar) set of operational conditions.

The trial took place in March 2007, at Great Yarmouth, Norfolk, UK, and utilised the Gardline near-shore survey vessel, MV *Confidante* (Figure 5). The

Figure 5: Near-shore survey vessel MV Confidante.

following systems were employed for the trial:

- 2 x RTK systems
  - A local system established in the port area especially for the trials.
  - A Network RTK system, part of the Leica Smart-Net system.

- 4 x GcGPS systems
  - Starfix HP
  - Skyfix XP.
  - C-Nav.
  - Veripos Ultra.

- 2 x Reference Stations
  - A local station, established on Gardline premises as RTK base station.
  - A local station, established on Gardline premises as PPK base station.

- 2 x Permanent Tide-Gauges, both operated by the Great Yarmouth Port Authority
  - A gauge at the river mouth.
  - A gauge at the first river crossing (Haven Bridge).

- 1 x Temporary Tide-Gauge
  - Deployed offshore during trials.

In order to attempt identical site conditions for each of the GcGPS systems, a temporary scaffold mounting was installed on the starboard side of the vessel (Figure 6). This arrangement was used for installation for all GcGPS antennae. In practice it was found that one system (nearest to the bridge superstructure), did suffer from some masking, but this did not detract significantly from the trials.

The temporary RTK system comprised a pair of TopCon Hyper RTK receivers, with UHF data link, and the reference station was established on a Gardline building within the port area.

The second RTK receiver was a Leica GX1230 receiver, used in conjunction with the national Smart-Net service, operated by Leica in conjunction with the Ordnance Survey (OS). This service uses the OS network of GPS base stations (OS Net) and real-time corrections are delivered using GSM or GPRS technology.

The second reference station was established on another Gardline building, and this was occupied

Figure 6: GPS antennae installations onboard MV Confidante.

with a Trimble MS750 dual-frequency receiver. This station was configured to log data at 1 Hz.

The purpose of the trials was not to compare or contrast specific systems, but to investigate the performance of generic system types with respect to the precision of the height information. Overall accuracy of the systems, a function of vertical datum transformations, was not investigated.

It was the intention to log data from all the systems continuously for four days; two of which were to be spent offshore. Unfortunately, poor weather intervened and offshore "dynamic" trials had to be severely curtailed. Real-time position information was acquired using the standard Windows tool, Hyperterminal, to log NMEA-0183 datagrams at a frequency of 1 Hz. In addition, each GPS system logged raw data, in their own proprietary format.

Data Processing and Results

Position solutions, whether acquired in real-time or by post-processing of raw GPS data, were processed in the same manner. In general, the position solution was either the NMEA GGA datagram recorded using Hyperterminal, or a similar text file output by one of the GPS post-processing packages.

It will be noted that no attempt has been made in the trials to compensate the GPS height solutions for vessel motion. In a highly dynamic offshore environment this obviously introduces additional noise into the measurements that requires appropriate smoothing and/or filtering. The procedure adopted was simple in concept:

- Data, logged at a 1-second epoch, was initially processed using a 2-minute Median filter. The Median value was chosen in preference to the Mean in order to attempt to mitigate the influence of isolated outliers.
- Median values were smoothed with a 10-minute filter.

Due to lack of motion data, it is possible for small biases to enter the processed solution. Generally, heave motion should have a zero mean, but using a simple mean for observations subject to pitch and roll motion will introduce small errors, dependent on the antenna height above the centre of motion. In these trials these potential errors are assumed to be insignificant.

Results from these trials are presented in the Figures that follow.

Figure 7. GPS height derived from the four GcGPS systems over a 5-day period. Note that individual systems are not identified, but labelled from A to D. What is clear from this display is that similar precision has been attained by all systems.

Figure 8. A 3-day period of data, as the vessel was alongside the quay, and within a short distance of one of the permanent tide-gauges. The GPS data has been arbitrarily shifted to match the tide-gauge datum. This data confirms precision of all the systems within manufacturers specifications.

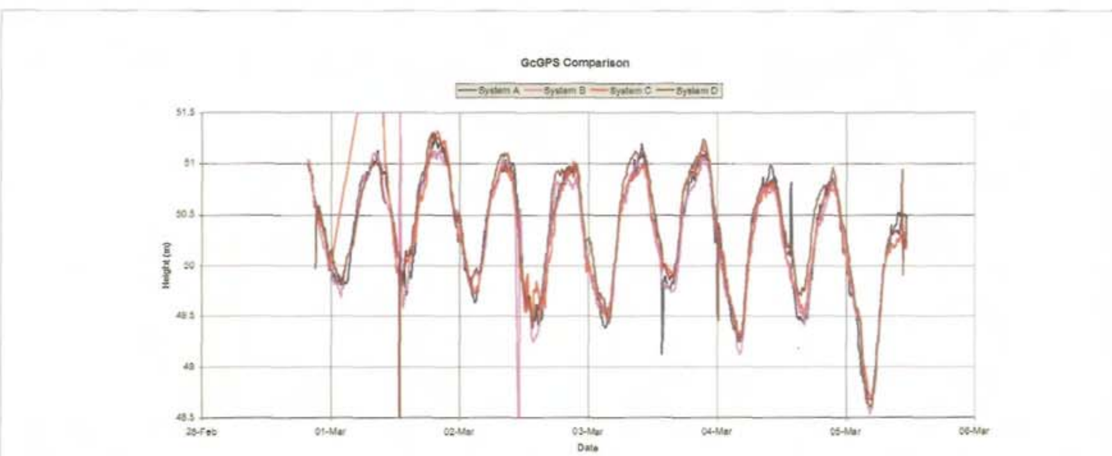

Figure 7: GcGPS ellipsoidal height comparison.

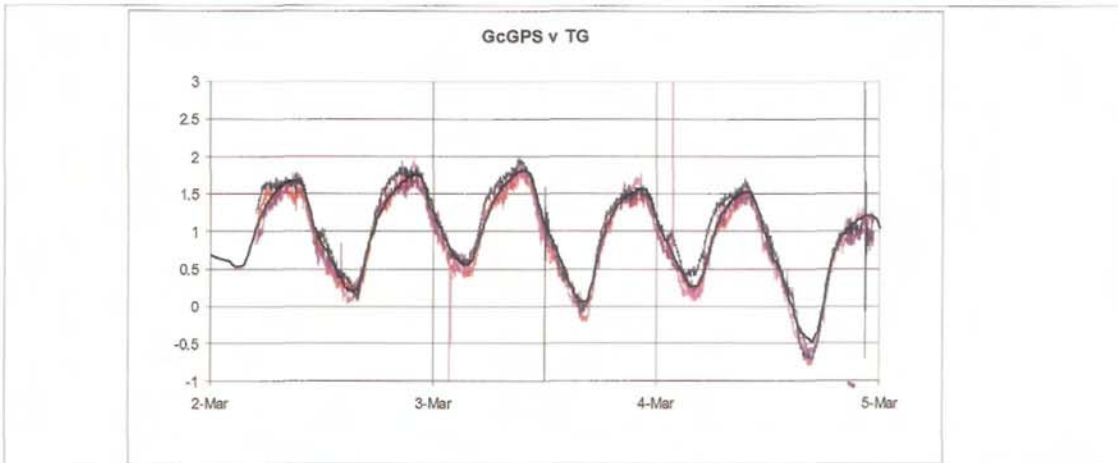

Figure 8: GcGPS heights versus tide-gauge.

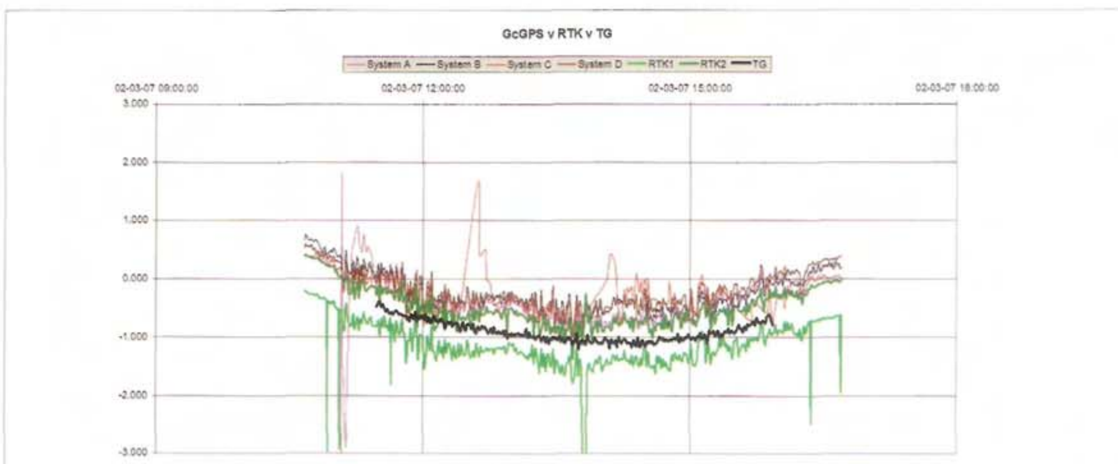

Figure 9: GcGPS heights versus RTK heights versus tide-gauge.

Figure 9. A 7-hour period of data obtained whilst the vessel was offshore. This includes data from the two RTK systems and the temporary tide-gauge. The tide-gauge data has been arbitrarily translated for comparison with the GPS data. This data has a number of points of interest:

- One of the GcGPS systems shows periods of outages. This was caused by antenna masking, mentioned earlier, as the vessel was heading in one direction, and does not reflect on the performance of that particular system.
- The GcGPS solutions agree closely with the RTK solutions.
- Although absolute accuracy was not a goal in this trial, it is interesting to note that one of the RTK systems closely matches the GcGPS data, and one shows a difference of approximately 0.5m. The Leica system, part of a permanent national network, was the RTK system that agreed with the GcGPS data, and the temporary system shows the height discrepancy.
- Within all the GPS systems, there is a slight undulation apparent in the data at about 1300 hours. This undulation is not evident in the tide-gauge data. A second, less pronounced, undulation is also seen at about 1400 hours. This feature is interpreted to be the result of the survey vessel steaming up and down a survey line within the tidal regime, and thus the measured tidal signature is slightly different to the gauge data recorded at a fixed location. It had been the intention to deploy the temporary tide-gauge at one end of the survey line, and collect data between this gauge and the permanent gauge at the river mouth. Logistical problems precluded this deployment.

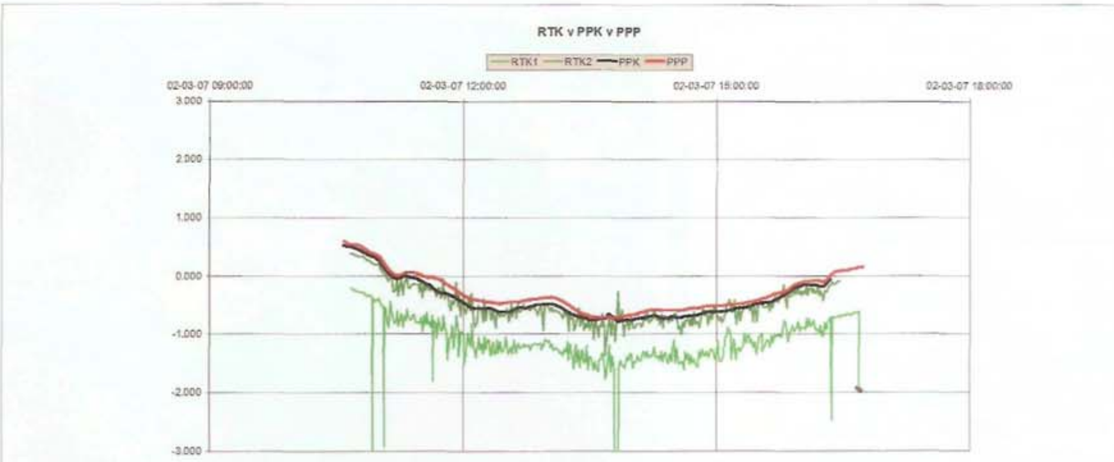

Figure 10: RTK heights versus tide-gauge.

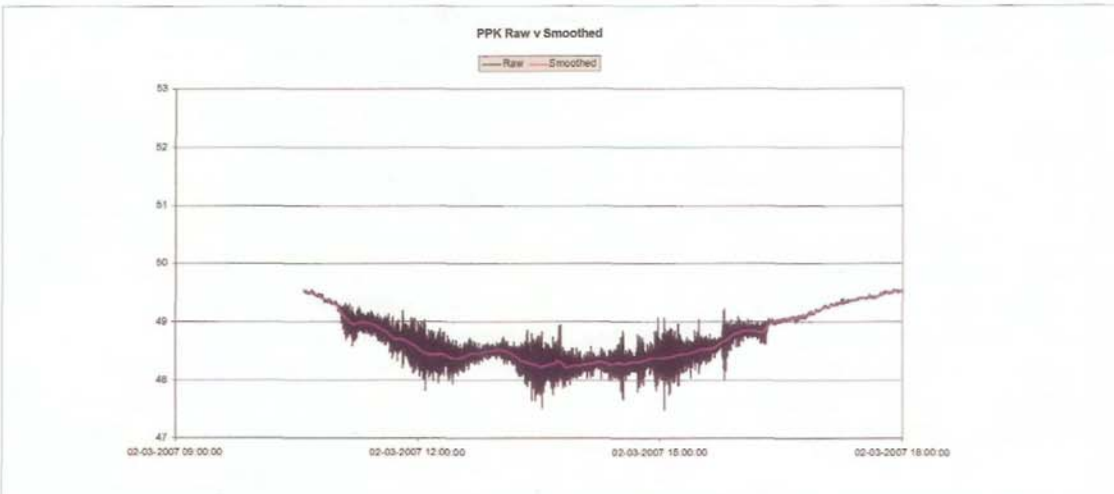

Figure 11: PPK raw height versus smoothed height.

Figure 10. A comparison of the 7-hour RTK solution versus the post-processed solutions. Dual-frequency GPS data was logged on the vessel every second. This data was post-processed with data from the Gardline reference station, also logged at 1Hz, hence a PPK solution was derived every second. The PPK solution is shown in black on the graph.

The Precise Point Position solution (PPP) was derived using TerraPOS software. The same dual-frequency data used in the PPK processing was used to derive this solution. The PPP solution is shown in red on the graph.

The post-processed solutions in this graph appear much more stable that the real-time GPS solutions, but this is due to a slightly different processing sequence, and these datasets have been subject to higher levels of smoothing compared to the real-time data. A comparison of the raw and smoothed PPK solutions is shown in Figure 11.

GPS Accuracy - The Datum Problem

The trials conducted in Great Yarmouth suggest that GcGPS could be a viable aid in tidal modelling. The issue of absolute accuracy has not been discussed, but based on data presented here, the precision appears to be within the manufacturers quoted specifications.

Without addressing the datum problem, a GPS derived tide may still be useful as an aid to traditional tidal modelling, but would have limited value if used in isolation. The GPS tidal curve may be arbitrarily moved to match a conventional tidal curve, and this could be used to provide confirmation (or not) of co-tidal range and time differences.

The vertical datum for GPS height information is the geodetic reference ellipsoid. To have real value in tidal modelling a transformation into a tidal datum is required. The geodetic framework is a precise mathematical model, but the concept of a tidal datum is an irregular, disparate surface, based not on mathematics, but empirical analysis of historical data. A transformation, therefore, between the two datums is not a trivial matter.

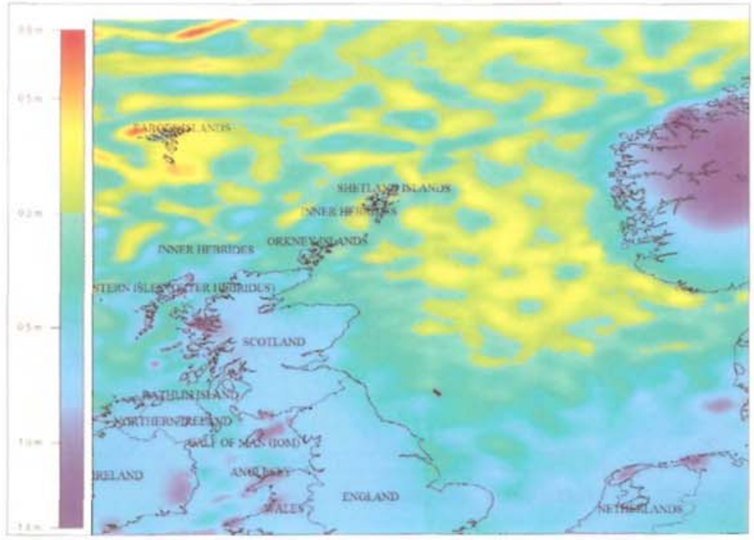

Figure 12: Mean Sea Surface (KMS04) compared to geoid (EGM96) in the North Sea.

The relationship between different vertical reference datums is the subject of on-going research. In the UK, the Integrated Coastal Zone Mapping project (ICZMap), investigated the problem of integrating land and hydrographic survey data (Adams, 2004). This highlighted the desirability of a uniform vertical reference frame, and subsequently the UKHO has commissioned a research project to investigate the feasibility of a Vertical Offshore Reference Frame (VORF) for use in UK waters (Adams et al, 2006).

Notwithstanding the complexities of the issues, the transformation of GPS heights into a tidal datum can be achieved with some success in a simple three-stage procedure.

1. Reduce the GPS antenna height, relative to the ellipsoid, to the Vessel Water Line. Usually two static measurements are required for this;
   - GPS antenna height relative to the vessel reference point.
   - Water line relative to the vessel reference point.
2. After this correction we have a measurement of instantaneous sea level above the geodetic ellipsoid. The next stage is to transform into a tidal datum, and the obvious choice is Mean Sea Level. A global geoid model could be used as an approximation of MSL, and the most recent model that is readily available is EGM96. This model has been used in the examples here. In future work this will be replaced by a Mean Sea Surface (MSS) model. The latest version that is readily available is KMS04, however this is shortly to be replaced by KMS06, recently renamed DNSC07. In the North Sea area this model should offer significant improvements. Figure 12 illustrates the difference between EGM96 and KMS04, which can attain levels of 50 cms in this area.
3. The final stage is the transformation from MSL to the required tidal datum. Nautical charts have traditionally been related to a local tidal datum, known as Chart Datum, which in the UK usually approximates to Lowest Astronomical Tide (LAT). The local nature of these individual datums gives rise to the problem of integrating these into a national (or international) model. In the future, within UK waters, the VORF project will potentially provide the necessary tools to resolve this issue. In the absence of such a model, an effective solution is to use the co-tidal approach. The co-tidal chart is used in the traditional approach to translate tides from a local port to the survey area. In this process the tidal datum is implicitly translated. The same method, therefore, may be used merely to translate the datum.

Further Studies

Further studies continue into the use of GPS for tidal monitoring. In the near-shore environment, RTK and PPK solutions routinely provide accurate and reliable data for tidal reduction. In these littoral areas, where the fusion of land and hydrographic survey data is important, the datum problem may be overcome by the adoption of the vertical land datum for use at sea. In the UK, Ordnance Datum Newlyn (ODN) is frequently used for this purpose (Figure 13).

In the offshore environment, GcGPS systems continue to be evaluated. The evidence at the moment suggests that performance within system specification, as achieved on the trials and illustrated in Figures 7 and 8, is difficult to achieve with 100% reliability.

Figure 13: RTK surveying in near-shore area; soundings reduced to land datum (ODN).

It is acknowledged, however, that system specifications do not quote figures with 100% reliability, and no attempt has been made to quantify a "reliability" figure.

Of more importance is to investigate the reasons for the observed GPS outages. Possible causes include poor GPS geometry, multi-path or other local interference, or perhaps excessive vessel motion as a result of poor weather. Figures 14 and 15 contrast the same system in periods of contrasting weather conditions. In these images the blue data represents the raw GPS height, and the spread of data is indicative of the vessel motion. The purple curve represents the smoothed data. At this stage no firm conclusions are drawn from this data, as other influences, such as satellite geometry have not been investigated.

Figure 16, from a different dataset, is included to show the influence of poor geometry, in periods of both good and bad weather. The red curve indicates the satellite geometry, as reported by the VDOP figure. The large spikes in the VDOP values clearly influence the height solution, and the system appears to take some time to recover from the outages.

Periods of poor geometry still occur periodically, even in areas such as the North Sea. Figure 17 illustrates predicted GPS geometry from a day in June 2007. The outage in the early morning, particularly evident in the geometry plot, persisted for a number

Figure 14: GcGPS data; good weather, good reliability?

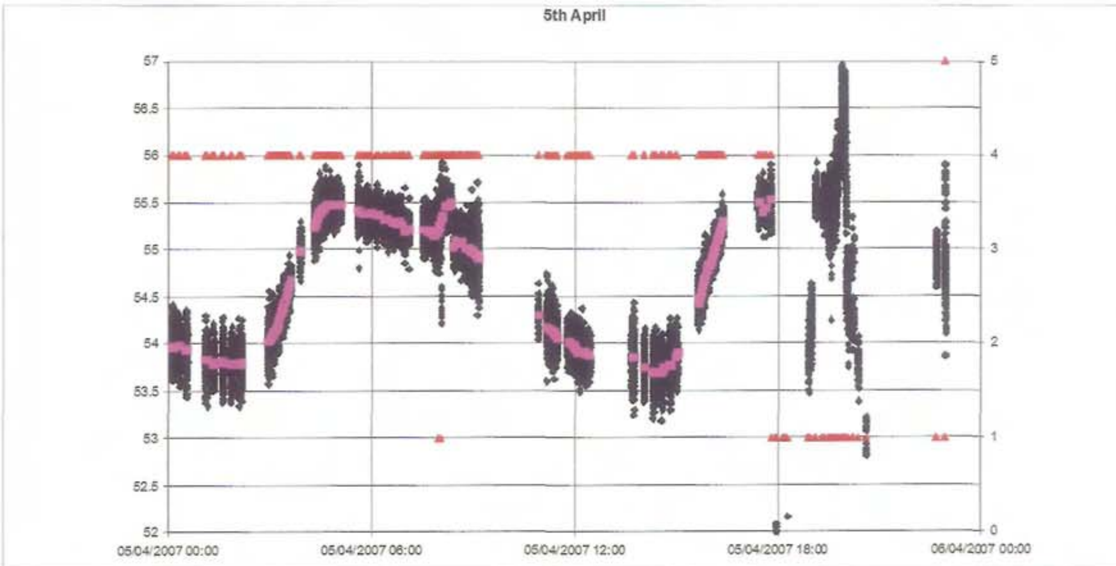

Figure 15: GcGPS data; poor weather, poor reliability? GPS mode (red) falls from 4 to 1 when solution fails.

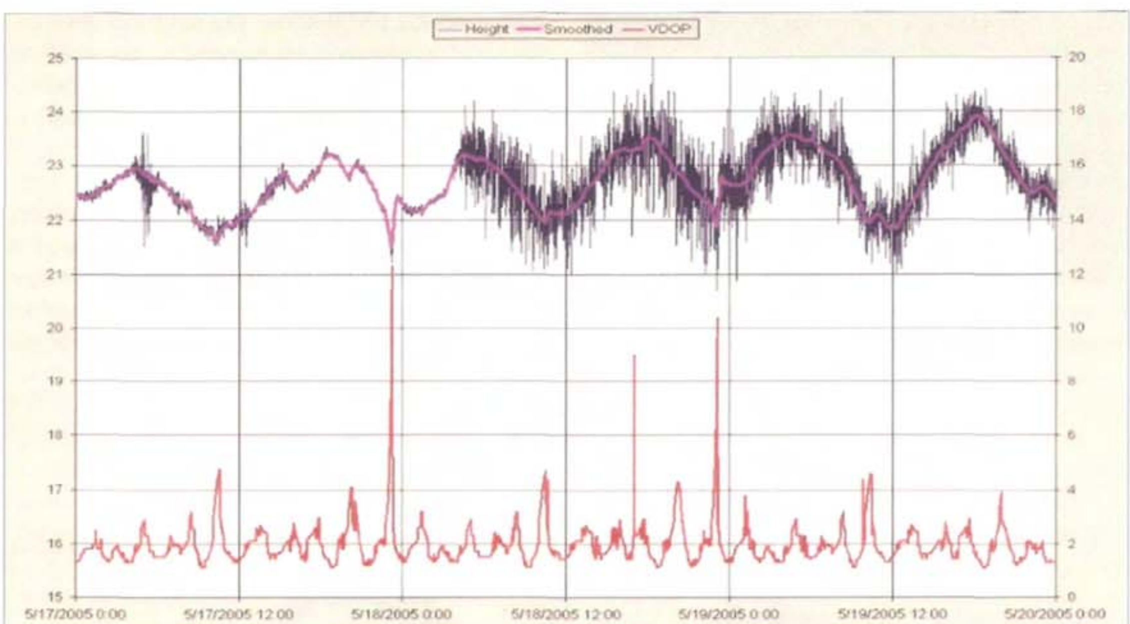

Figure 16: GcGPS data with 1 metre jumps in height solution; VDOP (red) indicates periods of poor geometry.

of weeks. GcGPS data for this period has yet to be analysed, although Gardline vessels did report minor difficulties with DGPS solutions.

Conclusions and Suggestions for Future Work

A number of high accuracy GPS techniques exist which may potentially be used in tidal modelling. In the near-shore environment RTK and PPK solutions are accepted methods. Trials suggest that GcGPS systems may provide the necessary precision when working offshore, and that the post-processed PPP technique could be viable if a real-time solution is not required.

GcGPS data acquired in the offshore environment has not managed to replicate the reliability obtained in the near-shore trials. Further work is necessary to identify the causes of GPS outages.

Analysis of offshore data is more problematic, as generally there are no benchmark systems with which to evaluate results. Deployment of offshore tide-gauges would be a suitable baseline system, but due to risk of loss this rarely commercially viable. Where a suitable survey grid is proposed, analysis of bathymetric mis-ties may provide information on tidal precision.

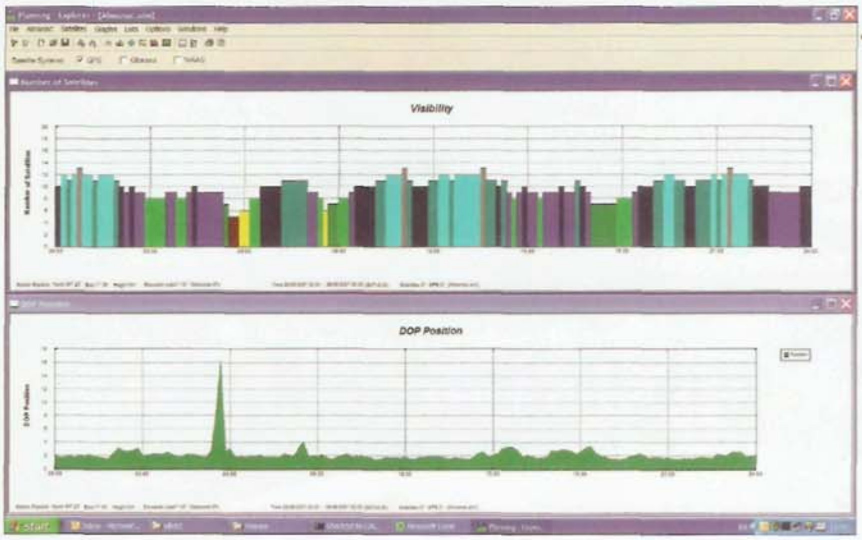

Figure 17: GPS satellite visibility and geometry in the North Sea, June 2007.

Refinements to the filtering and smoothing procedures are to be investigated in conjunction with the use of motion sensor data for compensation of antenna motion. Investigation into the relationship between GPS solution, vessel motion, and GPS geometry may help determine any weather dependency of the systems.

The concept of tidal accuracy, as it relates to vertical datums, has been discussed. In the future it is likely that all heights will be referred to a GPS ellipsoidal datum, and a bespoke model will manage the transformation between this and traditional tidal datums. Until such times, GPS ellipsoidal heights may be transformed to a tidal datum using existing Mean Sea Level and co-tidal models.

References

- International Hydrographic Organization (1998) IHO Standards for Hydrographic Surveys, International Hydrographic Organization, Special Publication No. 44, 4th edition, April, pp23.
- Adams R. (2004). Seamless Data and Vertical Datums - Reconciling Chart Datum with a Global Reference Frame. Hydrographic Journal, 113, 9-14.
- Adams, R. Iliffe, J. Ziebart, M. Turner, J. Oliveira, J. (2006). Joining up Land and Sea - UKHO/UCL Vertical Offshore Reference Frame. Hydro International, December, 7-9.

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Biography of the Author

Dave Mann is a graduate of the University of Nottingham with a Masters degree in Geodesy, and has been involved in various aspects of land and hydrographic surveying for 25 years. For most of his career he has been employed by Gardline, initially as a field surveyor, later as Assistant Chief Surveyor, now as Survey Support Manager, responsible for the development, integration and support of survey systems.

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