PositioNZ-PP - A GPS Post-Processing Service for New Zealand

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SUMMARY

Australia currently provides an Online GPS Processing Service (AUSPOS) which allows users to submit dual frequency, geodetic quality GPS data via the internet, to calculate precise coordinates. This service uses IGS (International Global Navigation Satellite System Service) products and GPS network data to achieve precise solutions globally. The AUSPOS system currently uses the Microcosm software suite for completing the GPS processing, however this software's GPS processing functionality has limitations and no longer uses some of the latest processing techniques.

New Zealand has a network continuously tracking GPS sites (PositioNZ) which are primarily used for defining and monitoring New Zealand's official geodetic datum (NZGD2000). The general public has access to the network's GPS data, however the public does not have access to an automated system for computing a consistent set of NZGD2000 coordinates such as AUSPOS.

Land Information New Zealand (LINZ) in conjunction with Geoscience Australia decided to design a new GPS post-processing system. The implementation for New Zealand is called PositioNZ-PP with the Australian implementation being rolled into the next version of AUSPOS. The system has the same logical design as AUSPOS, but uses Bernese for the GPS processing. The system also uses non-IGS regional network GPS stations and provides users with more processing control.

The processing logic and system implementation of the PositioNZ-PP service will be reviewed.

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1. INTRODUCTION

Since 2000 Geosciences Australia (GA) has provided the Australian Positioning on-line Global Positioning System (GPS) post-processing service AUSPOS. This system uses GPS orbit and station data from the International Global Navigation Satellite System (GNSS) Service (IGS) to compute coordinates for user stations in terms of the International Terrestrial Reference Frame (ITRF) and the Geodetic Datum of Australia (GDA94). It requires users to submit GPS RINEX data observed in static mode for precise coordinate results. The system is available for public international use, but produces sub-optimal results in the New Zealand context due to the limited number of Continuously Operating Reference Station (CORS) that are part of the IGS network in the region.

New Zealand currently has a regional CORS GNSS network called PositioNZ. This network consists of 33 stations on mainland New Zealand (Fig 1), with an additional two on the Chatham Islands, and three in Antarctica. The New Zealand mainland network has a nominal station spacing of 100-150km. Land Information New Zealand (LINZ), in collaboration with GNS Science (New Zealand's government-owned Earth sciences research institute), has been installing and operating the PositioNZ network since 2001. The primary purpose of the network is for defining and monitoring the New Zealand Geodetic Datum 2000 (NZGD2000).

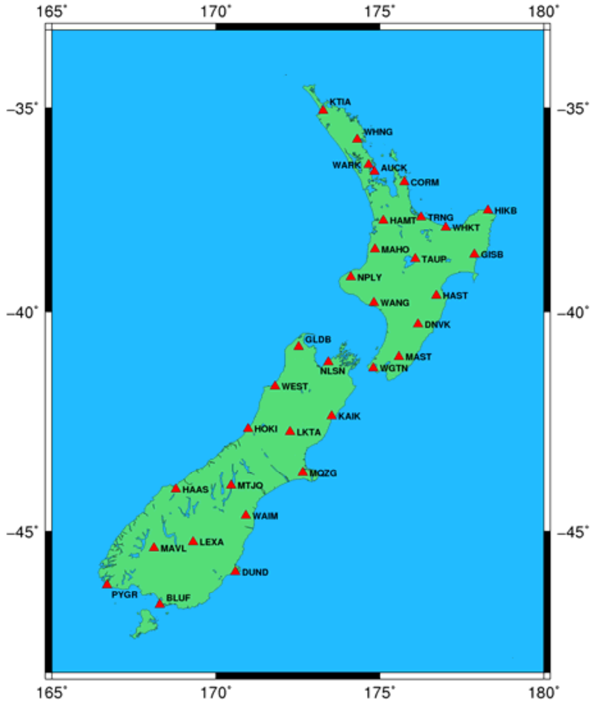

Fig 1: LINZ's CORS PositioNZ network

At present the PositioNZ network only tracks and records GPS information. However from July 2010 LINZ plans to upgrade the network to track the Russian Global Navigation Satellite System (GLONASS) to support Real Time (RT) positioning applications (Collett 2010). For each CORS, LINZ stores 30 second pseudo range and carrier phase GPS data. Hourly and 24-hour files are made freely available on the LINZ website in the Receiver INdependent EXchange (RINEX) format. These files can be downloaded and used for a variety of GPS post-processing applications such as Differential GPS and Static or Rapid Static GPS processing.

After PositioNZ became operational, LINZ investigated options to enhance the network so the public could more easily benefit from the infrastructure and the raw data that it produced. One of LINZ's recommendations was to look at options for providing an automated post-processing system for the PositioNZ network. Like AUSPOS, this would provide users with a simple and consistent way to generate position solutions in ITRF and NZGD2000. As part of this recommendation two options were proposed. One of the options was to leverage the existing AUSPOS service. The other was for LINZ to develop its own custom system using specialised high-precision GPS processing software. The AUSPOS option would require LINZ to submit further PositioNZ stations to IGS and to collaborate with GA to modify the AUSPOS system so NZGD2000 user positions could be generated (Office of the Surveyor-General 2003).

In 2006 GA and LINZ had discussions about the possibility of collaborating to develop a new post-processing GPS service. GA wanted to re-develop the AUSPOS system to use the latest high-precision GPS technology and to modernise the IT infrastructure that it used. LINZ saw this as a great opportunity to leverage the knowledge that GA had with the AUSPOS service, while also designing the service to use the PositioNZ network, and provide solutions in terms of NZGD2000. GA also saw the benefits in sharing development costs and transferring knowledge of the AUSPOS system to LINZ.

In mid 2006, GA and LINZ began development of a unified GPS post-processing system that would share the same core system, but would have organisational extensions for coordinate generation and web delivery. LINZ branded it's version of the service as PositioNZ-PP, while GA continued to use the AUSPOS name.

2. SYSTEM DESIGN GOALS

The design goals of the New Zealand and Australian GPS post-processing system in essence were the same as the AUSPOS service, with a few enhancements. It would:

- be accessible through the internet via a simple webpage interface
- provide centimetre-level positioning with dual frequency geodetic GPS data
- allow users to obtain a position by supplying a single RINEX data file
- use the highest quality global GPS processing standards
- use IGS data, augmented with regional CORS networks (such as PositioNZ)
- be a 24 hour, 7 days a week service

- provide results that are returned by email with a facility to download at a later date
- provide NZGD2000 coordinates for New Zealand users, GDA for Australian users, and ITRF anywhere on earth
- provide national grid and orthometric height coordinates
- output a printable report that lists the results and processing standards
- provide a solution output that can be used for adjustment with other data
- provide the ability to continuously process data over Universal Time Coordinated (UTC) data boundaries.

A key driver is to make the service's user web page interface simple and easy to use. This interface would include the option for:

- data to be processed by supplied user data file, instead of by UTC day
- the processing report to be provided in Portable Document Format (PDF) or text format
- overriding defined antenna type and height for the RINEX data file, and
- delaying processing the job until the highest quality IGS orbit and earth rotation parameters become available.

3. SYSTEM ARCHITECTURE

The architecture for the system is broken into the front-end public component and the back-end component.

The front-end component is designed to be deployed into a sub-network (demilitarized zone) which sits outside the organisation's internal network for external exposure of the service to the public. This component is different for each organisation but must communicate with the same remote interface that the back-end system exposes. In the LINZ context, the PositioNZ-PP front-end component is a series of web pages that allow users to submit and view the status of jobs currently processing, as well as view the results of previously submitted jobs. There is also documentation and help about the service, service status information, and system statistics about all jobs submitted to the service. The service is developed using the Microsoft .NET software framework and the Microsoft Internet Information Services (IIS) web server technologies. The PositioNZ-PP service requires users to login with a username and password to submit jobs and view the results of previously submitted jobs. This provides a basic level of security against internet attacks, as well as persistence session management so users can see the status of jobs and retrieve the results of previously processed jobs. As an added level of security, files that are submitted are rigorously validated to ensure both RINEX validity and to ensure a minimum level of GPS data quality.

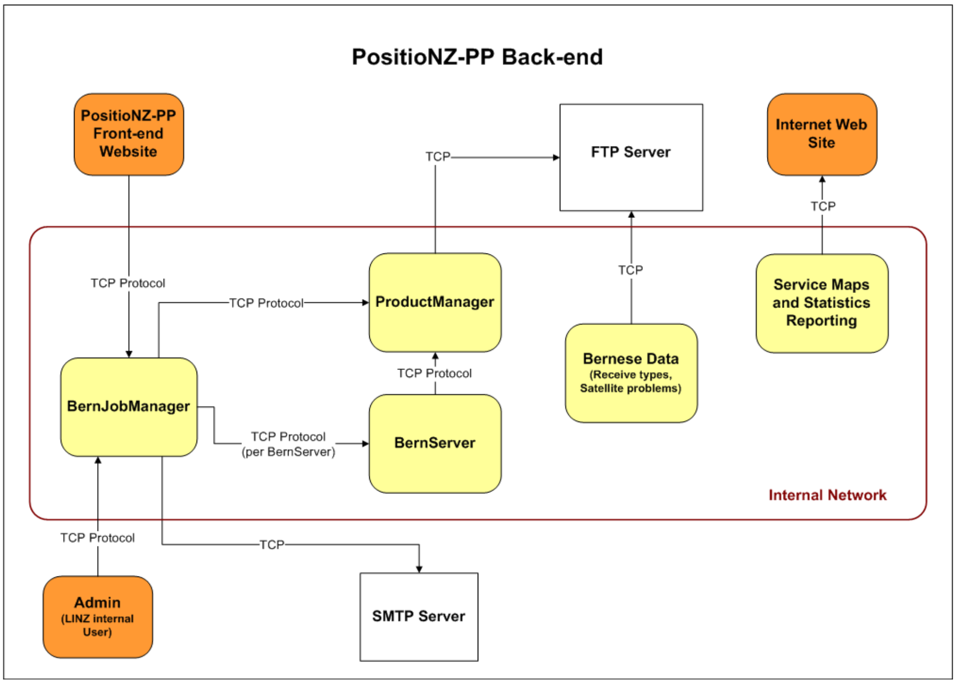

Fig 2: PositioNZ-PP back-end

The back-end component is where the development effort has been shared between GA and LINZ. It allows for the management and processing of GNSS data in GPS 'static' mode only. It has been developed to be portable between the UNIX and Microsoft Windows platform because of the difference in Information Technology (IT) infrastructure used at each organisation. In the LINZ architecture it will be deployed within the organisations internal network. The component has three main services (see Fig 2); The ProductManager, BernServer, and the BernJobManager.

The ProductManager downloads data from File Transfer Protocol (FTP) sites, quality checks the GNSS data and provides an interface to query and request files. The service can be configured to download data from multiple FTP sites at specific intervals, and can also be requested to download specific data. The majority of GNSS data is obtained from IGS data centres.

The BernServer is the main GNSS processing service and relies on the Bernese version 5.0 processing package (Dach et al., 2007) for parameter determination. In particular the Bernese Processing Engine (BPE) is used for custom development and automation. The role of the BernServer is to process supplied RINEX data by selecting the appropriate processing strategy. The BernServer communicates with the ProductManager for GNSS data and data quality information. The design philosophy behind having the BernServer component, rather than having a single service (BernJobManager) that also does all the processing, allows the back-end system to scale to support more simultaneous job processing. In PositioNZ-PP, only one BernServer service will be deployed, but if user demand increases then further BernServer instances will be setup on additional computers.

The BernJobManager controls the distribution and management of jobs. Once a BernServer becomes available the manager dispatches the next job in its queue to that BernServer for processing. When the BernServer has finished processing the job, the manager takes the results, generates a report, emails the results to the user and archives the job. The BernJobManager also maintains a database of processed jobs for reporting purposes. Users with access to the BernJobManager service also have the ability, via a webpage, to view the state of jobs currently being processed, as well as the option to cancel jobs that are in progress.

All communications between the BernServer, BernJobManager, and ProductManager use Transmission Control Protocol/Internet Protocol (TCP/IP) and custom platform independent messaging protocol. The front-end component communicates with the BernJobManager back-end component using this custom messaging protocol.

4. SERVICE REQUIREMENTS

The PositioNZ-PP user requirements are similar to the original AUSPOS service. The user must submit RINEX dual frequency (L1 and L2) GPS files that contain both code and carrier phase data. The RINEX files can be compressed and submitted to the service using the ZIP, BZIP2, GZIP or UNIX compression formats. Optionally, the user can also decide to submit Hatanaka compressed RINEX files for greatest possible compression ratio. Like the original AUSPOS service, users can submit up to seven RINEX files per job. However a new feature has been added to the PositioNZ-PP service where the user does not need to specify the antenna type and height. Rather the antenna type and height is extracted from the RINEX header and is reported to the user in a pre-submission page. The user can change and confirm the information before final submission.

Before any precise processing is carried out, the user-supplied RINEX data is pre-processed and checked against a set of basic requirements: at least 30 minutes of observed dual frequency data is required; multi path factor for L1 and L2 observables must be less than 2.0; the ratio of cycle slips over the total number of observation must be less than 0.3; the data observation interval must be no larger than 30 seconds. If the RINEX data file has a smaller observation interval then it is reduced to 30 seconds.

5. PROCESSING METHOD

PositioNZ-PP only supports the ‘Static’ processing mode. This means observation data spans of at least 2 hours are required. However the best results are achieved with 12 to 24 hours of data.

The basic logic behind the GPS processing is that the user station data is pre-processed and an approximate user position is found. This user position is then used to select the best three CORS sites for baseline static processing. Using the baselines and reference station coordinates an average position is computed for the user station. The GPS processing is done using Bernese, which provides state-of-the-art modelling, detailed control over all relevant processing options and international standards adherence.

There are seven main stages to the GPS processing (see Fig 3); orbit generation; single point positioning; reference station determination; data-screening; float solution; ambiguity resolution; and final solution combination. Throughout the processing, the IGS ITRF2000 reference frame (IG0b) is used, a 10° elevation cut-off is used for observations, ocean loading displacement is calculated at reference stations using the GOT00.2 tide model available from Onsala Space Observatory (http://www.oso.chalmers.se/~loading), and absolute (azimuth and elevation) antenna models from IGS are used.

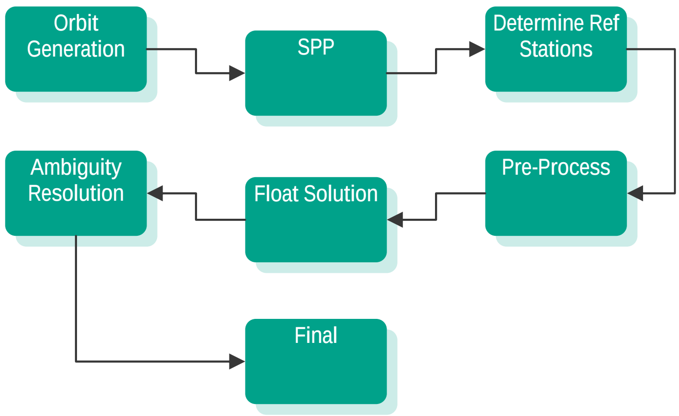

Fig 3: High level processing logic for PositioNZ-PP

The orbit generation stage requires IGS precise orbit and Earth Rotation Parameter (ERP) data. IGS provides three levels of precise ephemeris data: ‘final’ which takes 13 days to compute; ‘rapid’ which takes 17 hours to compute; and ‘ultra rapid’ which takes 3 hours to compute. The final product has a nominal accuracy of 20mm while the rapid and ultra rapid products have a nominal accuracy of 30mm and 50mm respectively. An error of 50mm in orbit gives an actual error of 0.2mm on baseline which has a length 100km or 2mm on a baseline which has a baseline which has a length of 1000km (Dach et al., 2007). The BernServer communicates with ProductManager to try and obtain the best quality product for span of the submitted user RINEX files.

After the orbit generation, each submitted RINEX file has a priori coordinates generated for reference station selection and for later parameter estimation. This is done using single point positioning which requires the RINEX code observation data. Once all user stations have a priori coordinates, the reference stations are selected for baseline creation. Reference stations are selected based on three key criteria: availability and quality of station data; the distance to the user station; and geometric spread of reference stations in terms of the user stations. A minimum of three reference stations with quality data are required for processing to continue. All IGS reference station coordinates are obtained from published IG0b coordinates and velocities. In the case of PositioNZ CORS, the coordinates are calculated using the GNS reference station prediction model.

Once all of the reference stations have been selected, baselines are formed from each reference station to the user stations. These baselines are then pre-processed. First, cycle slips in the carrier phase data are detected using triple-differencing processing. Once any slips have been removed, initial double-differencing processing is carried out. Residual analysis is carried out on this processing to identify and remove further bad observations or satellites. The cleaned double-differenced observations are then used to determined more precise user station coordinates. At the same time, site-specific tropospheric parameters are determined. These parameters are required because a tropospheric model may not provide sufficient accuracy during the ambiguity resolution stage with long baselines.

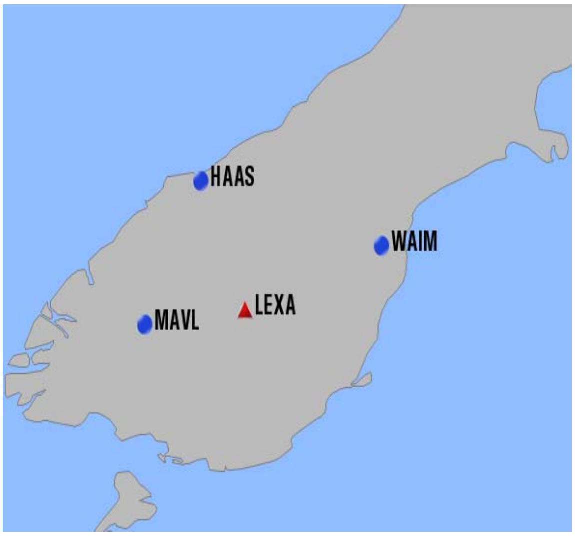

Fig 4: Example selection of three CORS within PositioNZ-PP

The last stages of the processing involve the determination of carrier phase ambiguities using the Quasi Ionosphere-Free (QIF) resolution method. The QIF method is used because the observation processing sessions are of a sufficient length, both L1 and L2 observations are available, and it provides good results for baselines of an arbitrary length (Dach et al., 2007). If a statistically significant number of ambiguities are resolved using this method they are retained for introduction into the final solution. This final solution first computes a minimally constrained solution using final double differenced baselines. At this point a Solution Independent Exchange Format (SINEX) file is created which the user can later use for integration into other adjustments. Then a comparison of the minimally constrained solution against the known reference station coordinates is done to check the quality of the baselines. Lastly, the final user station coordinates are computed by fully constraining the reference station coordinates.

Error analysis of this processing methodology indicates that a Root Mean Square (RMS) of 20mm for 2 hours of data, 8mm for 4 hours of data and 5mm for 24 hours of data can be achieved. These errors are only indicative and will vary depending on network geometry and the specific reference station prediction models used.

6. NZGD2000 COORDINATES

The main purpose of PositioNZ-PP is to provide NZGD2000 coordinates for the New Zealand public. Generating a user NZGD2000 coordinate requires two steps. The first involves computing the coordinate in the IG0b reference frame. This is done as part of the main GPS processing within Bernese. The second step is to shift the IG0b coordinate to the NZGD2000 datum using a similarity transformation, and then to propagate that coordinate to the NZGD2000 reference epoch of 2000.0 using the New Zealand Deformation Model (NZDM). Both of these steps introduce multiple error sources that contribute to the overall absolute positional uncertainty.

The first component required for generating a NZGD2000 coordinate is a similarity transformation from IG0b to NZGD2000. To establish this transformation a conventional 14-parameter Helmert transformation is calculated. This is achieved by first computing IGb00 coordinates and velocities using the available GPS data for stations used in the NZGD2000 realisation. Then comparing those coordinates against the published NZGD2000 coordinates and associated NZDM velocities. The RMS of this computed transformation is 6.1 mm in position at epoch 2000.0 and 1.4 mm/year in velocity. This means that the RMS of transformation degrades to 18.7mm at epoch 2010.0 (Beavan 2008).

The second component required for the NZGD2000 coordinate transformation is the NZDM. The NZDM is part of NZGD2000 and is used to correct coordinates and survey observations to the datum’s reference epoch. NZDM is a horizontal grid surface velocity model which covers the extents of NZGD2000. It is based on the GNS deformation model which is a continuous horizontal surface velocity model calculated throughout New Zealand using all GPS data (Beavan 2008). LINZ currently has not published the NZDM for public use. However the PositioNZ-PP service uses an internal version of the NZDM which contains data derived from the 3.0 version of the GNS deformation model. This version of the model has a nominal RMS of 1.7mm/year (Beavan 2008).

The overall accuracy for a coordinate from the service must account for all error sources in both GPS processing and coordinate transformations. Based on the errors stated above, and at a processing epoch of 2010.0, the expected horizontal RMS is 32mm using 2 hours of data, 27mm using 2 hours of data, and 18mm for 24 hours worth of data. It must be noted that these are nominal absolute accuracies in terms of NZGD2000. The relative accuracy of generated coordinates using the PositioNZ-PP methodology will be much better, due to the correlations in the similarity transformation and NZDM.

7. REFERENCE STATION MODELLING

A fundamental requirement for the PositioNZ-PP processing is accurate coordinates for the CORS at the epoch of the user data being processed. IGS provides coordinate and velocity data in terms of its own ITRF realisation which provides for global stations. However in the New Zealand context the PositioNZ CORS, most of which are not part of the IGS network, also required a method for calculating coordinates at a given epoch.

New Zealand lies across the obliquely convergent Australian and Pacific plate boundary. To the northeast of New Zealand the Pacific plate is subducted beneath the Australian plate and to the southwest of New Zealand the Australian plate is subducted beneath the Pacific plate. Through central New Zealand the oblique collision of the continental plates has resulted in a combination of strike slip and uplift motion with horizontal motions of 40-55mm/yr along the plate boundary (Walcott 1984). In addition to the plate motions, New Zealand experiences the effects of other deformation events such as large earthquakes, volcanic activity, and more localised effects such as landslides.

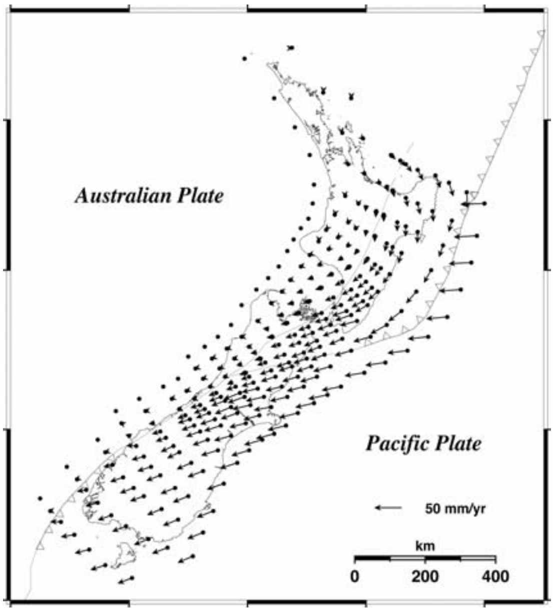

Fig 5: GNS deformation model showing horizontal velocities (Beavan 1998).

Because of the inconsistent motion across New Zealand (see Fig 5), a set of coordinates and velocities are not adequate for high precision GPS processing. One approach to deal with this problem is to compute weekly solutions constrained to a regional set of IGS stations, and then interpolate between weekly solutions to determine the coordinate for the processing epoch. However this method cannot predict future positions and it does not accurately account for events that occur at specific, well-defined epochs. A better solution to the problem is a more complex model which contains linear terms, annual and semiannual terms, offsets, plus more complex terms to take account of slow earthquakes and post-seismic slips (See Fig 6 for example). This model is similar to the one proposed and used by Scripps for the SECTOR Epoch Coordinate Tool (Nikolaidis 2002).

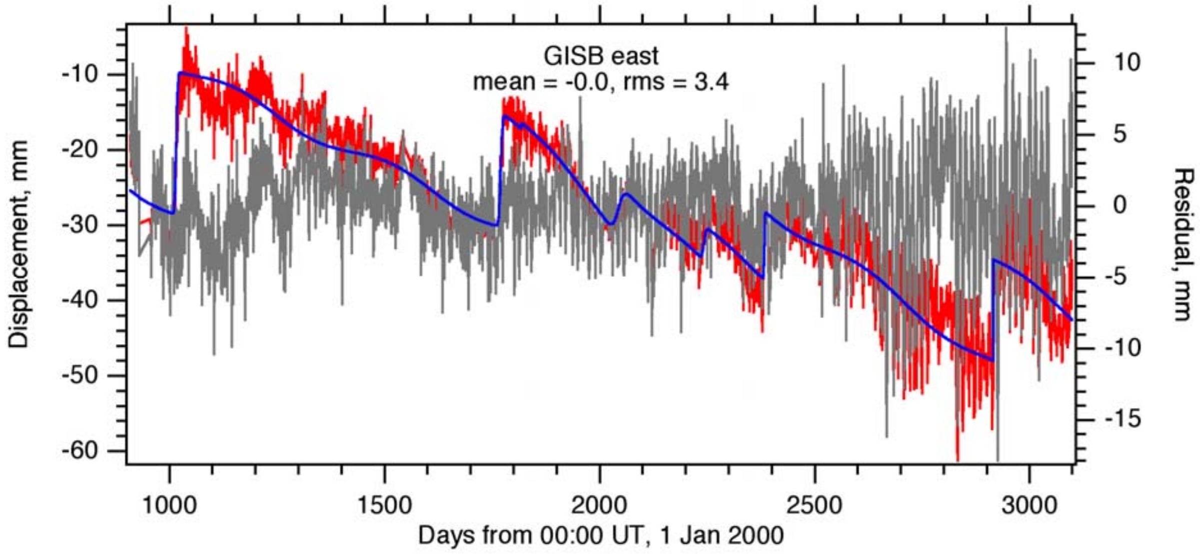

Fig 6: Plot showing the coordinate time series output (red), the models parameters (blue) and the residuals (grey) for the easting component of the PositioNZ GISB station. (Beavan 2008).

In 2006 LINZ contracted GNS to implement such a model for all of the PositioNZ CORS. GNS already computes daily coordinate solutions in the IGb00 for all of the PositioNZ CORS as part of their GeoNet project (GNS Science 2010). Each of these time series was analysed by specifying the times of coseismic offsets and equipment offsets, and then computing the other unknown model parameters using non-linear least squares (Beavan 2008).

As part of a quality control check, output from the model was tested against the average of daily solutions at the time of the prediction. The tests revealed < 3 mm bias between the predicted and actual solutions, and standard errors at the 1-3 mm level. While this indicates a sufficient level of accuracy, biases were detected in the model because it was not designed to fit the regional common-mode signal that is present in all the time series solutions. This regional signal is believed to derive from the satellite orbits, and/or regional-scale to global-scale atmospheric and hydrological mass movements, and/or use of non-optimal models in the processing (Beavan 2005). GNS noted that the predication accuracy could be improved by a factor of two if the regional common-mode signal was more correctly modelled (Beavan 2008).

8. FUTURE PLANS

There are plans to further develop the PositioNZ-PP system once it has been thoroughly tested and is in production. One area that has already been identified for improvement is the inclusion of extra GPS processing strategies which could allow for optimised processing depending on the observation spans, available observables and/or baseline length. National Geodetic Survey (NGS) has already implemented an improvement to their OPUS positioning service to do rapid static GPS processing, which allows the generation of accurate solutions with as little as 15 minutes of data (NGS 2010). This OPUS-RS service could be used as a guide for improving PositioNZ-PP processing strategies.

The developed version of PositioNZ-PP does not allow the users to specify the reference station to be used during processing. This option could be valuable if the system's automatic selection process chooses sub-optimal stations.

Currently PositioNZ-PP does all of the GPS processing in the IG0b reference frame. This frame is no longer the latest available and the service should be updated to use ITRF2005 or ITRF2008 once it become available. However for this change to be fully implemented a new station prediction model will have to be generated using GeoNet CORS daily solutions that have been computed in terms of that reference frame.

LINZ runs and maintains a national geodetic control database (GDB). This service provides NZGD2000 station coordinate metadata, monument photos, and monument diagrams for the New Zealand public. The primary users of this database are cadastral surveyors, civil engineers and mapping utility companies. Currently the only way for the general public to get stations added to or updated in the database is to make a formal request to LINZ. If the priority of the request is low the station may not get processed. If an extension was created to PositioNZ-PP to create accurate NZGD2000 stations within the GDB, then users could get fast updates for their specific areas of interest. For such a system to be successful data quality standards and LINZ approval processes would need to be created. NGS has created a service called OPUS-DB which is identical to this proposal.

9. CONCLUSIONS

The current usage of AUSPOS clearly shows that there is a large need for online GPS post-processing service both from a national and international perspective. Once the PositioNZ-PP service is up and running users will also see the benefits within the New Zealand context. The ease of use and ability to determine NZGD2000 coordinates will hopefully prove very useful to the New Zealand spatial community.

10. ACKNOWLEDGEMENTS

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BIOGRAPHICAL NOTES

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