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Late Cenozoic geology, Ancient Pacific Margin NATMAP Project, report 1: long-baseline, dual-frequency, GPS static positioning trial, Stewart River map area, Yukon Territory[1]

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Abstract: A dual-frequency GPS receiver was used to establish benchmarks along the Yukon River between Dawson City and its confluence with the White River as a field trial of this technology. Conventional static GPS occupations with long baselines (>300 km) obtained decimetre-scale accuracy in horizontal and vertical positions after post-processing. These benchmarks will be applied to a ground-penetrating-radar survey of fill thickness below the Yukon River that will look for indications of recent subsidence or uplift along the river's channel.

Résumé : À titre de mise à l'épreuve sur le terrain de la technologie, on a utilisé un récepteur GPS à deux fréquences pour implanter des repères le long du fleuve Yukon entre Dawson et le confluent du fleuve et de la rivière White. L'utilisation d'occupations GPS statiques classiques avec de longues lignes de base (> 300 km) a permis d'établir, après post-traitement, des positions horizontales et verticales d'une exactitude décimétrique. On utilisera ces repères dans le cadre d'un levé au géoradar visant à déterminer l'épaisseur des dépôts de remplissage sous le fleuve Yukon et de déceler des indices de subsidence ou de soulèvement récents le long du lit du fleuve.

[1] Contribution to the Ancient Pacific NATMAP Project

INTRODUCTION

Field investigations of the late Cenozoic geology of the Stewart River map area (115-O, 115 N) and adjacent areas (Fig. 1) began during the summer field season of 1999 as a part of the new Ancient Pacific Margin NATMAP Project. Much of this region has been regarded as unglaciated or as having been glaciated during the early Pleistocene (Bostock, 1966; Hughes et al., 1969; Duk-Rodkin, 1999). Because the region has not undergone glacial modification, Tertiary plateau surfaces, straths, pediments, and terrace gravels survive. Late Cenozoic neotectonism in this region and its effect on the evolution of the Yukon River and the many placer-gold-bearing tributary basins that are graded to it are topics to be addressed as part of this study. In the past, the demonstration of warping or tilting of initially level or uniformly inclined surfaces with respect to mean sea level could only be accomplished by establishing networks using ground-based levelling techniques tied to geodetic vertical control points. Horizontal co-ordinates (latitude and longitude) were traditionally established using either triangulation or trilateration surveys. Because levelling surveys tended to follow roads, railways, and rivers and triangulation and trilateration surveys usually required mountain tops for intervisibility, all three dimensional co-ordinates usually cannot be attributed to all control points. In addition, such networks and measurements require a dedicated team of surveyors with extensive logistical support. It is neither practically nor economically feasible to integrate such surveys into routine field geological surveys.

Figure 1. *Map showing the location of the Stewart River NATMAP area and the permanent GPS data-receiving stations.*

In recent years, static global-positioning-system (GPS) technology (*see* Natural Resources Canada, 1995) has made it possible to obtain decimetre-level accuracy of elevation above mean sea level as well as horizontal positions to the centimetre level. However, static GPS positioning requires the setup and operation of a GPS reference station at a control point with known horizontal and vertical co-ordinates in the area of operation. In remote and relatively mountainous areas such as the Stewart River map area, it is impractical to operate a local base station since it requires one dedicated crew member to operate the base station distant from the area of fieldwork, as there are few first-order, three-dimensional control points in the region. Furthermore, if single-frequency GPS receivers are used for surveys at high latitudes, the distance between the base station and the rover is limited because of errors introduced by the ionosphere, which is more perturbed at higher latitudes. Dual-frequency GPS receivers have the potential to eliminate these problems in two ways: 1) by using dual-frequency, carrier-phase (wavelengths) measurements (i.e. by utilizing both the L1 and L2 frequencies that are broadcast by GPS satellites), ionospheric errors can be eliminated; 2) by eliminating ionospheric errors, baseline lengths can be increased up to several hundreds of kilometres, thus potentially permitting the use of existing permanent GPS reference stations. This would eliminate the need for a local base station while still delivering decimetre-level accuracy. Thus, accurate horizontal and vertical positioning could in theory be integrated into field geology operations without the added burden of setting up and operating a local temporary base station.

This paper reports on the results of a trial static GPS survey along the Yukon River using a dual-frequency GPS receiver and post-processing incorporating dual-frequency data from permanent reference stations.

APPLICATION OF GPS

The trial GPS survey was carried out by the one of the authors (Froese) in support of a ground-penetrating-radar (GPR) survey of the Yukon River floodplain between the confluence of the White and Klondike rivers. This project focused on quantifying the suballuvial (bedrock) topography of the main channel using GPR. The purpose of this work is twofold. First, to test the ability of GPR to determine variations in the alluvial fill. Second, to find out whether or not variations in fill thickness could be used to determine the location of zones of uplift (relatively thinner depth to bedrock) or subsidence (greater depth to bedrock) along the channel. This work, which is ongoing, has shown some slight variations in the alluvial fill along this reach of the Yukon River. In particular, one location below the mouth of the Stewart River shows significant variation in thickness relative to sites upstream and downstream.

The purpose of the GPS survey was to establish a series of control points along the Yukon River that would support future investigations in the area. In particular, these control points will be used with conventional altimeter surveys to determine elevations of Plio-Pleistocene ancestral Yukon River terraces.

Elevations above mean sea level better than 5 dm were required for these locations. A dual-frequency GPS receiver was used for to determine the level of accuracy achievable over long (hundreds of kilimetres) baselines using the static GPS positioning method under field conditions typically encountered in remote areas.

DUAL FREQUENCY GPS AND STATIC POSITIONING METHOD

It is important to recognize that GPS can be used in a number of different modes. To date, the most popular usage of GPS in the field for geological surveys has been with single-frequency GPS receivers. The least expensive of these receivers typically use the L1 C/A code for determining the ranges to the satellites and thereby the position of the receiver's antenna. Inherent in the positional error of these receivers are the effects of selective availability or SA. Because these receivers are unable to correct their positions, it is necessary to use the 'worst case scenario', namely that the horizontal accuracy is 100 m and the vertical position, 156 m — at the 95% confidence level (United States Department of the Interior and United States Department of Transportation, 1986). This is what is commonly referred to as an 'uncorrected single-point position'. Although some receivers are capable of averaging a position, it must be noted that this position is averaged about the mean of the collected position and not necessarily about the 'correct co-ordinates'. Single-frequency, 'survey-grade' receivers are available that typically are able to use both code and phase measurements to determine the ranges to the satellites. In addition, it is possible to record the raw GPS observable data and through post-processing, to correct the data. This achieves submetric accuracies over short baselines. Over longer baselines, it is necessary to use dual-frequency, geodetic-quality receivers, primarily because of errors introduced by propagation delays experienced by the GPS signal as it travels through this part of the ionosphere. By using two frequencies, the propagation delays can be determined. Relative positions using dual-frequency receivers at both a reference station and at the remote site can yield decimetre-scale and better accuracies over long baselines. The accuracy achieved is a function of a number of factors including receiver/antenna type, temporal length of data sets, and postprocessing techniques.

For this survey, a mobile, dual-frequency receiver collected field data at the position to be located. This is referred to as the 'unknown'. The base station receivers were continuously operating GPS stations located in the Yukon Territory and Alaska with precisely known locations and elevations above mean sea level. Occupation time often exceeded one hour in order to acquire data from satellite constellations arranged in favourable geometric positions relative to the mobile and permanent receivers. This resulted in better positional accuracy for the measured locations.

FIELD METHOD

Field equipment included a Trimble 4800 dual-frequency receiver that was mounted onto a tripod using a tribrach to level the antenna horizontally and to centre it precisely over a temporary control point established on the Yukon River floodplain. A Trimble TC-01 data logger was connected to the 4800 receiver to record the GPS data as well as ancillary station information including station number and height of antenna above the temporary control point. It was monitored for position dilution of precision (PDOP) value, which is an indication of the geometrical robustness of the GPS satellite constellation geometry with respect to the receiver's antenna (a PDOP value below 7 indicates good spatial distribution of satellites). A rechargeable battery powered the GPS receiver. The battery was recharged with a gasoline-powered generator. All equipment was transported from site to site in an eight-person inflatable boat powered by an outboard motor.

The mobile GPS receiver was levelled and set directly above the temporary control point. The height of the GPS receiver was measured from the benchmark to the antenna before and after each GPS observation period (minimum 1 hour of data collected at each site). The height of antenna is used in postprocessing to correctly determine the elevation of the control point.

While the GPS data were being recorded, permanent control points were established by driving 20 cm stakes with identification tags into terrace walls above the level of ice-jam floods. These permanent vertical control points were located with respect to the temporary benchmarks occupied by the GPS using a theodolite and a levelling rod. The theodolite was levelled to the GPS antenna and a levelling rod was used to measure the angle to the permanent vertical control point.

GPS data were archived daily in a notebook computer. Field log sheets were used to record information such as a polar plots of the positions of mountains, trees, and other barriers that could mask out the GPS signals (cycle slips) or cause signal reflection (multipaths).

The 10 stations of the GPS survey were located at roughly 10 km intervals between Dawson City and the confluence of the Yukon and White rivers (Fig. 2). Three to four GPS positions were measured per day.

POSTPROCESSSING OF GPS DATA

Global positioning system data from permanent receiving stations at Whitehorse (WHIT), Glenallen (GNAA), and Central Alaska (CENA) were acquired following field measurements. Data from Alaska were downloaded from the United States National Geodetic Survey's National Continuously Operating Reference Stations (CORS) via the Internet.

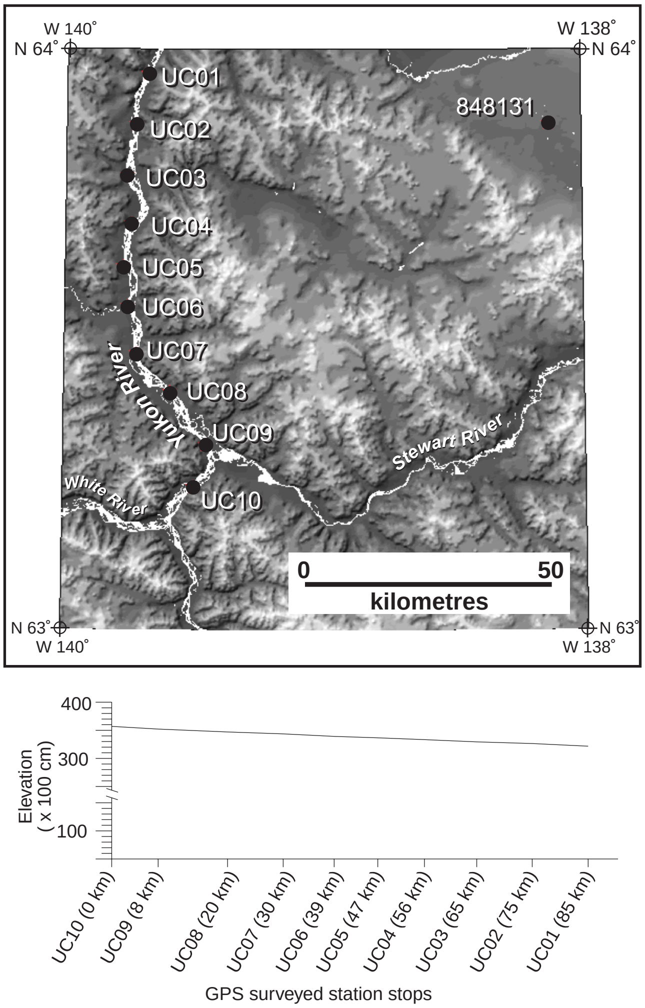

***Figure 2.** Map showing the GPS traverse route.*

Whitehorse GPS data were obtained from the Geological Survey of Canada, Pacific Geoscience Centre, Sidney, British Columbia. The permanent GPS receiver in Whitehorse (WHIT) is one of many in a network of permanent GPS receivers of the Western Canada Deformation Array (WCDA) that was established in western Canada to investigate crustal deformation in southwestern British Columbia. Postprocessing was carried out using Trimble Navigation Ltd.'s GPSurvey software.

A baseline solution was determined between the mobile and permanent GPS stations. Baseline solutions solve for integer ambiguity, compute relative distances between the two receivers, and generate statistics indicating the quality of the baseline data set. Baseline processing involves two steps:

1. Baseline processing estimates of the receiver locations. Co-ordinate seeding was used for this survey. Known co-ordinates were entered for the permanent GPS receiver in order to locate the position of the mobile GPS receiver.
2. Resolution of integer ambiguity. When a GPS receiver first locks onto a GPS satellite, it measures the first partial wavelength or phase and then it counts how many whole wavelengths pass through the antennae. The integer ambiguity is the unknown number of full wavelengths. If the GPS software computes the number of wavelengths to the closest integer, then it computes a *fixed solution*. However, for long baselines, *float solutions* are common because errors are present in the data due to relative differences in the properties of the ionosphere over long distances. This does not mean that the results should be rejected, especially for long baselines. However, other statistics should be examined as a check for serious errors in the data set.

Several statistics can be used to determine the quality of the data including the reference variance, the root mean square (RMS), and the residual plots. *Reference variance* refers to how well the errors of the measured data compare with the expected error generated by the software. The reference variance should be close to 1 or less. The *root mean square* is a measure of the dispersion of the observations about the mean value of the observations. It should be less than 15 mm. The *residual plots* graphically illustrate the quality of the data. An ideal plot of residuals (Fig. 3) shows residuals with values of less than 15 mm about the mean.

A *minimally constrained adjustment* is used to check network integrity exclusive of a reference co-ordinate system. During this process, outliers are removed from the data set and accurate error estimates are calculated. When the minimally constrained adjustment is performed successfully, the baseline networks are internally consistent with each other. The fully constrained adjustment is used to check for network integrity and to establish the unknown within a reference co-ordinate system (e.g. NAD83). Instead of fixing one control point, all the known control points are fixed. The results from the fully constrained adjustments are reported below.

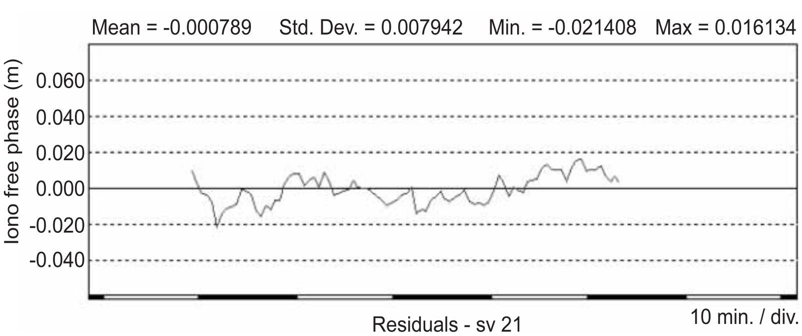

Figure 3.

Example of a residual plot showing the GPS satellite signal measurements.

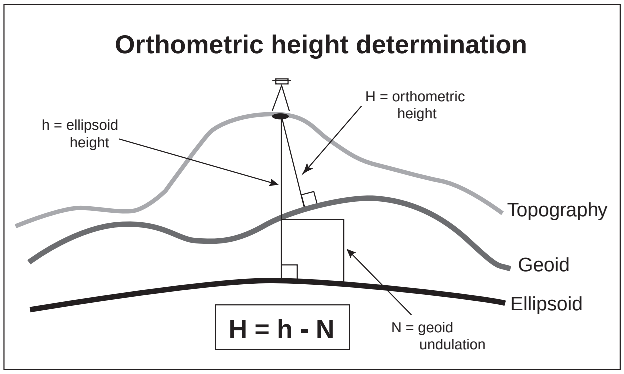

Figure 4. *Illustration showing the three surfaces.*

The calculation of the *orthometric height* (elevation above mean sea level) requires additional computation. Orthometric heights are measured in relation to the *geoid*. The geoid is a theoretical, continuous surface that is perpendicular to the direction of gravity and that approximates mean sea level. The geoid surface undulates with respect to the centre of the Earth. However, GPS elevation measurements are calculated with respect to the *WGS-84 ellipsoid* rather than the geoid. Calculating the orthometric height (H) is straightforward as long as the elevation difference between the ellipsoid and the geoid, the geoid separation (N), is known (Fig. 4). This can be expressed as the following:

$$H = h - N$$

where ‘H’ is equal to the orthometric height (mean sea level), ‘h’ is the height above ellipsoid, and ‘N’ is the geoid separation or geoid undulation.

The geoid separations for the field station positions were derived from the HT-01 geoid model based on 1328 survey stations (CGVD28 vertical controls) established across Canada by the Geodetic Survey Division of Geomatics Canada. Vertical controls are widely spaced in northern Canada. Their accuracies are in the decimetre range. This is in contrast to vertical controls in southern Canada where accuracies are in the ±5 cm range at a 95% confidence level (Mainville et al., 1997).

RESULTS

Table 1 presents data for the baseline solution for each baseline generated. Listed are reference variance and root mean squares as measures of the initial quality of the data set before performance of a network adjustment (minimally and fully constrained adjustment). The height of instrument (H.I.) is the vertical distance between the temporary control point and the antenna.

Results of the positions after performing the fully constrained adjustment are listed in Table 2. Positions in Tables 1 and 2 refer to the positions of the temporary benchmarks established on the Yukon River floodplain. The northing and easting values are referenced to Universal Transverse Mercator (UTM) grid of zone 7, NAD83 datum. The vertical elevation (H) is the corrected elevation above mean sea level.

Table 1. Table showing the baseline results.

From Station	To Station	Reference variance	Distance (m)	1.96σ* (m)	RMS (m)	H.I. (m)
WHIT	UC01	1.780	425401.479	0.0151	0.019	1.583
CENA	UC01	4.795	293321.277	0.0497	0.024	1.583
GNAA	UC01	1.320	378580.984	0.0840	0.012	1.583
WHIT	UC02	2.097	418688.039	0.0127	0.017	1.607
CENA	UC02	2.619	297799.861	0.0208	0.018	1.607
GNAA	UC02	3.532	371975.498	0.0624	0.021	1.607
WHIT	UC03	5.744	411809.856	0.0166	0.029	1.739
CENA	UC03	1.756	302904.742	0.0084	0.015	1.739
GNAA	UC03	4.552	365943.904	0.0370	0.024	1.739
WHIT	UC04	4.931	403932.567	0.0517	0.024	1.677
CENA	UC04	8.421	309712.973	0.1251	0.030	1.677
GNAA	UC04	6.347	362463.025	0.0788	0.025	1.677
WHIT	UC05	5.086	398329.798	0.0193	0.022	1.630
CENA	UC05	2.101	314313.077	0.0215	0.015	1.630
GNAA	UC05	3.130	357670.157	0.0918	0.019	1.630
WHIT	UC06	0.989	391795.413	0.0088	0.010	1.532
CENA	UC06	2.653	320290.241	0.0158	0.017	1.532
GNAA	UC06	3.343	355202.037	0.0376	0.019	1.532
WHIT	UC07	1.623	383882.004	0.0128	0.016	1.496
CENA	UC07	4.386	327747.137	0.0141	0.021	1.496
GNAA	UC07	2.283	353133.973	0.0247	0.017	1.496
WHIT	UC08	1.174	374006.872	0.0086	0.011	1.507
CENA	UC08	1.714	337625.529	0.0318	0.014	1.507
GNAA	UC08	2.552	356563.738	0.0221	0.017	1.507
WHIT	UC09	3.457	361742.922	0.0142	0.020	1.584
CENA	UC09	2.166	349747.115	0.0124	0.015	1.584
GNAA	UC09	2.204	359349.304	0.0717	0.017	1.584
WHIT	UC10	2.722	357099.516	0.0121	0.022	1.640
CENA	UC10	3.505	354029.504	0.0231	0.021	1.640
GNAA	UC10	2.840	354723.068	0.0290	0.018	1.640
WHIT	848131	1.162	379043.514	0.0091	0.011	1.299
CENA	848131	2.794	361187.700	0.0216	0.017	1.299
GNAA	848131	1.929	442949.375	0.2207	0.014	1.299

* 1.96σ = 95% confidence level

The fully constrained adjustment positions and related error values indicate horizontal and vertical positions to be accurate within the range of <1 to <3 decimetres at the 95% confidence level. This exceeded our original accuracy requirements. Figure 2 presents a profile of the Yukon River floodplain constructed from this data. It shows a smooth, consistent slope of approximately 42 cm/km.

As a further test, a static GPS position was determined for a geodetic monument (station 848131, *see* Fig. 2) situated along the Klondike Highway east of Dawson City. The known location is a monument set by the Geodetic Survey Division. Horizontal values between the GPS and the position established by Geodetic Survey Division only differ by 40 cm for the easting and by 9.7 cm for the northing. The difference in elevation is 1.89 m. The elevation of the Geodetic Survey Division monument was Doppler derived and is accurate to ±3 m.

Sources of error

Errors were present, although they were at an acceptable level for this field trial. Errors in some of the GPS occupation stops were due in part to noisy GPS satellite signals such as

Table 2. Results from the GPS survey with horizontal and vertical positions.

Station	Northing (m)	1.96σ* (m)	Easting (m)	1.96σ* (m)	h (m)	1.96σ* (m)	H (m)
UC01	7092976.248	0.078	564465.056	0.166	332.150	0.115	321.720
UC02	7083215.891	0.026	562573.234	0.029	336.968	0.032	326.450
UC03	7073458.592	0.161	561163.261	0.143	340.055	0.226	329.410
UC04	7064211.707	0.085	562174.220	0.098	344.143	0.074	333.380
UC05	7056009.544	0.082	560973.972	0.195	347.460	0.141	336.610
UC06	7048317.827	0.053	561960.553	0.059	350.035	0.061	339.160
UC07	7039435.025	0.135	563746.795	0.157	354.552	0.202	343.630
UC08	7032252.998	0.273	570538.575	0.375	357.919	0.373	347.030
UC09	7022074.050	0.054	577517.027	0.139	363.034	0.091	352.180
UC10	7014075.652	0.115	575489.432	0.126	368.044	0.139	356.980
848131	7085991.292	0.023	641212.923	0.042	632.589	0.048	623.680

* 1.96σ = 95% confidence level

multipath and cycle slip. For example, station UC04 in Table 1 has a high reference variance and a high root mean square value that indicates a less precise data set compared with the other occupations. The antenna was set 3 m from the terrace wall, which masked some of the GPS satellites on the horizon and could have reflected the GPS signal (multipath). At this occupation, poor satellite geometry was obtained with PDOP values greater than the acceptable level. Therefore, choosing a good site with no major obstruction and planning GPS occupation times for the best satellite geometry can eliminate errors. In addition, errors could be eliminated during the post-processing routine by importing precise satellite orbit data (ephemerides) instead of the broadcasted satellite orbit data that were used for this project. Precise ephemerides are computed by the International GPS Service after the fact and minimize the errors associated with the predicted broadcast orbits.

It is significant to note that from the perspective of a lack of dense forest cover and distance to topographic barriers, the Yukon River floodplain is about as ideal an environment as can be found for GPS satellite observations in this part of the Yukon Territory. Another way of attaining more accurate solutions is through longer observation times (a few hours instead of one hour). However, this would not be practical as a part of field geology operations because of the general decrease in efficiency that it would cause.

CONCLUSIONS

Static dual-frequency relative GPS positioning using a single receiver and long baselines to permanent GPS reference receiving stations exceeded our minimum accuracy objectives. The operation of a single, dual-frequency GPS receiver as a part of geological fieldwork is feasible with careful logistical planning. The accuracy of GPS positions is highly dependent on choosing a good site with good visibility of the horizon and planning the best time for optimum satellite constellation. Also, choosing the right receiver for the task must be considered and for this field trial, the dual-frequency GPS receiver proved to be acceptable.

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