Comparison of GPS Results from Different Processing of Ambiguity Parameters - A Case Study in the Amery Ice Shelf Region, East Antarctica

Lau N. Nguyen[1], R. Coleman[2,3,4], M. King[5], and P. Morgan[6]

[1] Department of Geomatics Engineering, HCMC University of Technology, 268 Ly Thuong Kiet Street, District 10, Hochiminh City, Vietnam
Tel: 84-08-8655142 Fax: 84-08-8627351 E-mail: nnlau@hcmut.edu.vn

[2] School of Geography & Environmental Studies, University of Tasmania, Private Bag 78, Hobart, Tasmania 7001, Australia

[3] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, Tasmania 7001, Australia

[4] Antarctic Climate and Ecosystems CRC, University of Tasmania, Private Bag 80, Hobart, Tasmania 7001, Australia
Tel: 61-3-6226-2108 Fax: 61-3-6226-2989 E-mail: Richard.Coleman@utas.edu.au

[5] School of Civil Engineering and Geosciences, Cassie Building, University of Newcastle upon Type, Newcastle upon Tyne NE1 7RU, UK
Tel: 44-191-222-7833 Fax: 44-191-222-8691 E-mail: m.a.king@ncl.ac.uk

[6] School of Information Sciences and Engineering, University of Canberra, Canberra, 2601, Australia
Tel: 61-2-62012557 Fax: 61-2-62015231 E-mail: Peter.Morgan@canberra.edu.au

Abstract

This paper is an extension of the paper by King et al. (2000), where two techniques were described to process GPS data collected on a floating Antarctic ice shelf. King et al. (2000) showed good agreement for the vertical component using both processing techniques but the comparison of horizontal components was not included.

In this paper, we give a more complete comparison between the two processing approaches and the resulting comparison of horizontal coordinates. Due to particular disadvantages of GPS processing in the Amery Ice Shelf (AIS) region, solutions with floating ambiguity terms are usually used in the analysis instead of fixed ambiguity solutions. However, we demonstrate that when different treatments of ambiguity parameters are used in the processing, significant effects on the horizontal coordinate accuracy are seen. More importantly, ambiguity float solutions yield misleading periodical signals in the horizontal components. This could lead to a misinterpretation of geophysical processes, such as ice shelf.

1. Introduction

GPS has been used as an effective tool for improving our knowledge of Antarctic ice sheet dynamics, for example, Hulbe and Whillans, 1994; Hamilton et al., 1998; Phillips et al., 1998; Manson et al., 2000. In the paper by King et al. (2000), we summarised a number of "static" GPS measure-

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ment campaigns observed on the Amery Ice Shelf (AIS) between January 1998 and January 1999. We also discussed in that paper some specific processing problems associated with these GPS data sets, such as:

- A weak satellite geometry due to the GPS satellites not passing above 75 degrees elevation at the majority of Antarctic coastal sites.
- Baseline lengths between ice and stable rock sites being mostly greater than 50 km, and usually about 100-300 km.
- Much of our data appear to be affected by a high level of ionospheric disturbance in this region, at latitudes of 70-74°S in the high energy aurora zone
- The GPS observations are conducted on fast-moving ice with horizontal velocities of up to 4-9 cm/hour, i.e. about 300-800 m/year. In addition, the floating ice shelf is affected by ocean tides with maximum changes of 30 cm/hour in the vertical.

Under the above difficult conditions, normal ambiguity resolution strategies usually fail in most GPS processing algorithms. Instead, float ambiguity solutions are more acceptable in our analysis. These solutions, though providing high stability in the vertical components (King et al., 2000; 2003), show strange periodical signals in the horizontal components. In particular, the coordinate solutions appear to be sensitive to different strategies for fixing ambiguity parameters. These ambiguity options are examined in section 2. In order to prove that the periodical signals on horizontal components are an artifact of the float ambiguity solution, we introduce our own strategy for fixing ambiguities in section 3. Section 4 draws some useful conclusions.

2. Processing Strategies with floating Ambiguity Parameters

We have chosen the 1997/1998 AIS campaign with two moving ice sites (V3 and V5) and one stationary rock site (Barkell Platform - BARK). The distances between the ice sites and BARK are approximately 22 km and 40 km for V3 and V5 respectively (King et al., 2000).

The Leica 9500 dual-frequency GPS receivers on the ice sites recorded in static mode at 5 sec epoch rates, but the processing must be done in kinematic mode (or non-static mode) where station coordinates need to be changed or updated after specific time periods. In our analysis, sites V3 and V5 are computed relative to the fixed rock site at BARK. The IGS SP3 ephemerides were used and held fixed along with the coordinates of BARK.

Two different processing approaches have already been introduced in King et al. (2000). One is making use of GAMIT software (King and Bock, 1999) by cutting the long session into 1-hour sub-sessions. Each 1-hour sub-session is then processed independently with floating ambiguity

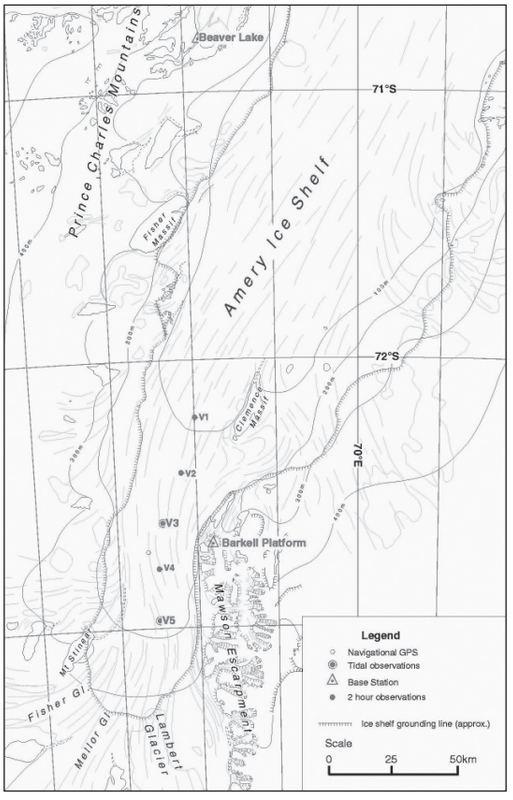

Figure 1: GPS stations V3, V5 and BARK on the Amery Ice Shelf

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terms. The local north, east and up coordinates, resulting from this processing method, are plotted as circles in Figure 2.

The second processing approach is based on a newly developed, sequential GPS processing technique (Nguyen, 2000). This approach gives us more flexible options than using GAMIT for a number of different data combinations. Particularly, we can apply two different processing strategies as follows

- **Strategy 1:** Ambiguity parameters are renewed at the same time as the station coordinates - say, every 15 minutes. This strategy is similar to that used in the GAMIT solution, although a 15 minute period is used rather than a 1 hour period as used in GAMIT. The local north, east and up coordinates resulting from this strategy are given in Figure 2 (dots).
- **Strategy 2:** Only station coordinates are renewed. Ambiguity parameters are maintained continuously in the processing. As a result, the number of unknowns in the processing is significantly reduced. The results of this case are plotted as red dots in Figure 3, along with the results from strategy 1 (green dots).

It can be seen from Figure 2 that strategy 1 gives results identical to the GAMIT results. However, there are significant differences between the two strategies in the horizontal components, especially the east component. Both strategies show suspicious periodical variations in the east component. The east component resulting from strategy 2 has nearly double the period and smaller amplitudes (~0.1 m) than those resulting from strategy 1 (~0.2 m), as shown in Figure 3.

The signals evident in the east components are clearly correlated with the vertical component but it is very difficult to find a physical explanation for this. Are the motions due to the dynamics of the ice shelf or is the signal from our float ambiguity solution? The question becomes "which of the two processing strategies is better?" In an attempt to answer some of these questions, we try to solve for the fixed ambiguity solutions in the data sets.

3. Ambiguity Resolution for Non-Static GPS Data

For a fixed ambiguity solution, we first attempted to use several available commercial software packages, capable of processing kinematic GPS data with on-the-fly ambiguity resolution capability, such as SKI-Pro, Trimble Geomatics Office and Pinnacle. Unfortunately, these software packages could not provide an acceptable result since the success rates of ambiguity resolution were too low - between 20% - 30%.

The continuous processing approach of Nguyen (2000) was therefore applied. This processing technique was originally designed for high precision static GPS processing, not for kinematic

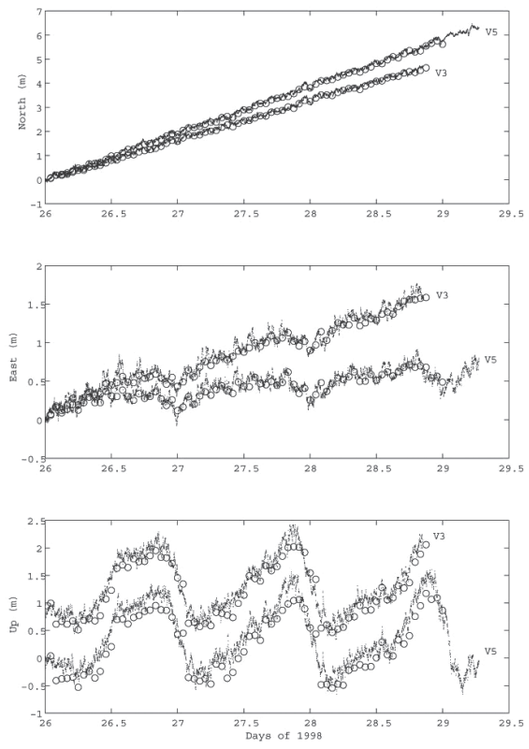

Figure 2: Comparison of GAMIT results (circle) and strategy 1 (dot)

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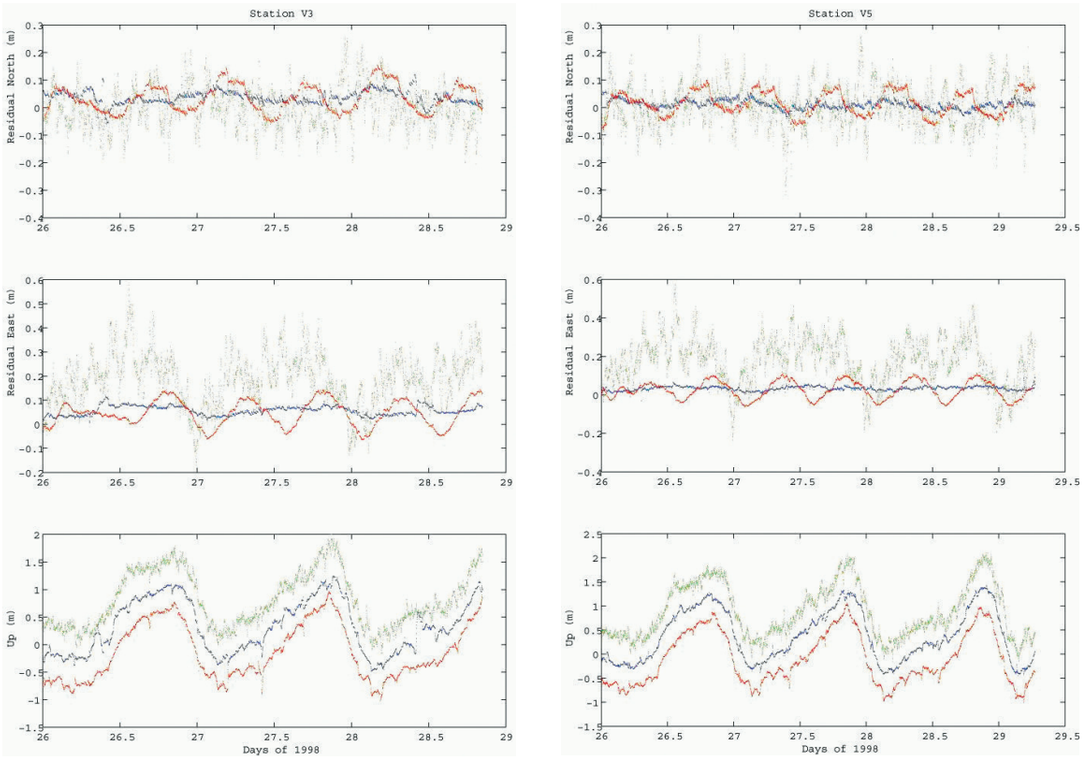

Figure 3: Comparison of strategy 1 (green), strategy 2 (red) and fixed ambiguity (blue) solutions. The velocity trends have been removed from the horizontal components. Up components of strategies 1 and 2 have offsets of +0.5 m and -0.5 m respectively applied.

processing. However, since its engine is an extended Kalman filter, it is possible to account for the change of parameters at each epoch. We decided to maintain ambiguity parameters continuously in the processing. Hence, each ambiguity parameter has longer data segments to be computed for its correct integer ambiguity set and consequently has higher reliability in the resolution. However, the price to be paid for adopting this strategy is that:

- The data must be free of cycle slips.
- An incorrect fix on an ambiguity set at a time will adversely affect the apparent station coordinates and then propagate to the other ambiguities.

Our ambiguity resolution procedure is carried out in two steps

- Step 1: Wide-lane ambiguities are estimated using the Melbourne-Wubbena combinations (e.g. Blewitt, 1989). These combinations are independent from station coordinates and hence independent from the mode of GPS data (static or kinematic). However, the quality of the code measurements is crucial, especially multipath effects. To make this procedure successful, it is necessary to average wide-lane ambiguities over long observation spans (Dong and Bock, 1989). In this aspect, keeping ambiguity parameters continuously will offer more advantages.
- Step 2: Narrow-lane ambiguities are solved using ionospheric-free combinations. This step is extremely difficult because the ambiguity search space is still large, primarily due to the impact of re-initialising station coordinates frequently and residual ionospheric delay. In order to improve these issues, we account for

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ice station movements in this step by correcting the initial coordinates with the values of the local north, east and up components at each epoch, which were obtained from a float ambiguity solution (such as those resulting from strategy 1). This improves significantly the success rate of the narrow-lane resolution - up to 97% of ambiguities were fixed successfully.

The resulting local north, east and up components of the fixed ambiguity solution are plotted in Figure 3 (blue dots). The horizontal components of station V5 are plotted separately in Figure 4 at a larger scale.

Table 1 gives computed velocities of stations V3 and V5, which were extracted from the different solutions using data spanning 3-4 days. Compared with the fixed ambiguity solution, the float ambiguity solutions give similar errors in the north component, typically from 0.4-3.0 m/year. Strategy 2 offers better velocities (within 0.7-0.9 m/year) in the east component than strategy 1 (within 1.8-7.0 m/year).

We can clearly see from Figures 3 and 4 that the fixed ambiguity solution has achieved a greater stability for the horizontal components. Periodic motion is still observed but with much smaller amplitudes (about 3-4 cm), that are close to the processing noise levels. These results complement the findings of King et al. (2003) and highlight the care needed when processing high-precision GPS time series.

4. Conclusions

From the results, it can be noted that:

- The periodical signals in horizontal components (especially the east component) with amplitudes of greater than 5 cm are not caused by any ice shelf dynamics, but are a consequence of the GPS float ambiguity solutions. The reasons for the aliasing of the vertical component into the horizontal components, particularly the east

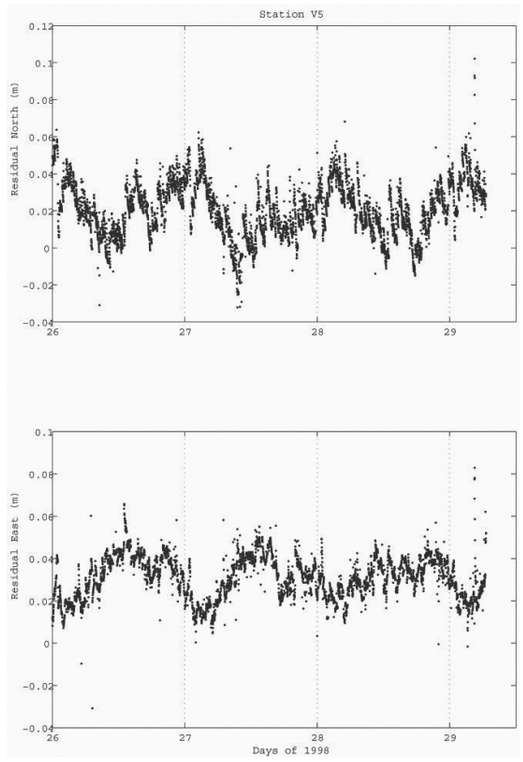

Figure 4: Residual North and East components of station V5 in the fixed ambiguity solution. The velocity trend was removed from the horizontal components

Table 1: Velocities of V3 and V5

Station	Direction	Velocity (m/year)		
		Strategy 1	Strategy 2	Fixed ambi.
V3	North	599.4031	602.0079	598.9937
	East	176.0374	174.9334	174.2455
V5	North	708.4810	708.1841	705.9212
	East	50.9643	57.4532	58.0448

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component, are due to the weak satellite geometry in the Antarctic region, where the along track orbit is predominantly in the east west direction. Further discussion is given in King et al. (2003).

- If we assume that the fixed ambiguity solution is the standard for comparison, the two float ambiguity solutions give good agreement in the vertical component. The solution using strategy 2 appears to be closer than strategy 1 to the fixed ambiguity solution for the horizontal components with a maximum deviation of 0.1 m. The solution of strategy 1 gives the worst result in the east component with a maximum deviation of 0.5 m.

In general, we conclude that if a fixed ambiguity solution is not achievable under the conditions present in the Antarctic region, float ambiguity solutions are still very useful, especially when ambiguity parameters are maintained continuously in processing. Such float solutions can provide typical precisions of 0.1 m in position and 3.0 m/year in horizontal ice velocity compared with the fixed ambiguity solution for the numerical example shown in this paper. However, it should be re-emphasized that most of the periodic signals observed in horizontal components are largely removed with the solution of fixed ambiguity parameters in the processing. However, such horizontal signals should be interpreted carefully, so that they are not viewed as "real" ice shelf dynamics, or station movement, without a physical basis.

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Lau N. Nguyen is currently head of geodetic laboratory at Department of Geomatics Engineering, Hochiminh City University of Technology, Vietnam, where he received his B.S. degree in Surveying and Mapping in 1990. He obtained his Ph.D. degree in Global Positioning System from University of Tasmania, Australia in 2000. His research interests are major in high precision GPS processing; deformation monitoring using GPS; software development.

Richard Coleman was Professor at the Centre for Spatial Information Science, University of Tasmania, Australia. Currently he is Professor in Marine Science and Director of the PhD Program in Quantitative Marine Science. His research interests are oceanographic and climate change research using satellite and insitu data; GPS applications for global change, especially Antarctic ice sheets and sea level studies.

Matthew King is a NERC Postdoctoral Research Fellow working at School of Civil Engineering and Geosciences, University of Newcastle upon Type. He received his B.Surv and Ph.D. (in Geodesy) from University of Tasmania, Australia. His research interests are deformation monitoring using GPS; subsidence monitoring of offshore platforms; dynamics of ice streams and ice shelves; Antarctic geodesy.

Peter Morgan was an Associate Professor at School of Information Sciences and Engineering, University of Canberra, Canberra, Australia. Currently he is an Honorary Professor at the University of New South Wales at the School of Surveying and Spatial Information Systems. His research interests are Global Positional System (GPS) including the mapping of large temple complexes; and, the level of phosphorus and other algae supporting nutrients in fresh water, especially raw and treated sewage.

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