Study title:

High-Accuracy Direct Aerial Platform Orientation with Tightly Coupled GPS/INS System

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16. Abstract

Direct sensor orientation by GPS/INS integrated system is a rapidly emerging technology supporting airborne and land-based mapping. Modern GPS and INS systems allow for the direct determination of platform position and orientation parameters with an unprecedented accuracy with a very short turn-around times. Thus, commercially available high-precision airborne integrated mapping system, Applanix POS/AV 510, was acquired to augment the existing OAE airplane sensor configuration with a GPS/INS system, supporting direct sensor orientation. The system represents a transition from the traditional photogrammetry-based paradigm of image georeferencing towards a highly automated and autonomous design following the trends of modern geoinformatics. The key component of the system is a high-precision integrated GPS/INS navigation system supporting the OAE existing imaging subsystem. The Applanix system was designed to deliver the object positions with decimeter-level accuracy, in a highly automated manner and limited human interaction, in near real-time. The final report presents the concept and design of a generic georeferencing GPS/INS system, followed by the POS/AV 510 manufacturer performance specifications, system operations and troubleshooting, and extensive field performance evaluation, based on test flights performed by the OAE staff.

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1. INTRODUCTION

Obtaining sensor orientation by direct measurements is a rapidly emerging mapping technology. Modern GPS and INS systems allow for the direct determination of platform position and orientation at an unprecedented accuracy. In airborne surveying, aircraft trajectory and platform orientation can be determined at the level of few cm and 20-30 arcsec, respectively at an almost continuous time scale. The use of such integrated GPS/INS systems offers immediate benefits for large-format camera-based airborne surveying by substantially reducing the need for ground control and by basically eliminating aerial-triangulation, except for system calibration. For emerging sensors such as LIDAR, RADAR, multi-/hyperspectral imagers, however, the use of the direct orientation systems is mandatory since indirect methods such as control point-based aerial-triangulation are not feasible. ODOT Aerial Engineering has been operating an airplane with a large-format Zeiss Jena LMK2000 camera. The introduction of a modern GPS/INS-based direct orientation system was not only highly desirable for economic reasons, but also mandatory if ODOT wanted to keep up with technological developments. Since ODOT predominantly performs corridor surveys over the highway infrastructure, the use of direct orientation makes it even more attractive in this case, since the savings due to the elimination of control points are quite substantial. By establishing a GPS/INS-based direct orientation technology for ODOT aerial operations, the foundations was given for future imaging sensor extensions such as the introduction of LIDAR systems or the like.

2. RESEARCH OBJECTIVES

The primary objectives of this research project were as follows:

- To augment the existing airplane sensor configurations with a commercially available GPS/INS system (Applanix POS/AV),
- To carry out test flights to benchmark the performance of the POS system against AIMS GPS/INS,
- To perform the extended quality assurance analysis based on the above mentioned airborne test with multiple sensors,
- To consult ODOT personnel in GPS/INS technology/data acquisition and processing,
- To consult ODOT personnel on future developments such as the introduction of high-resolution digital cameras (CCD), LIDAR systems, etc.

3. GENERAL DESCRIPTION OF RESEARCH

Sensor orientation, also called image georeferencing, is defined by a transformation between the image coordinates specified in the camera frame and the selected mapping reference frame. This process requires knowledge of the camera interior and exterior orientation parameters. The interior orientation (IO), i.e., principal point coordinates, focal length and lens geometric distortion characteristics are only concerned with the modeling of the camera projection system, and are provided by the camera calibration procedure (traditionally, analog cameras are laboratory-calibrated, while digital cameras are calibrated using well-defined indoor or outdoor calibration ranges). On the other hand, the exterior orientation parameters (EOP) directly define the position and orientation of the camera at the moment of exposure. In traditional airborne surveying, the exterior orientation parameters are obtained by aerial triangulation (AT) based on the object space information (ground control points) and their corresponding image coordinates. As a result of using a mathematical model (collinearity equations) representing the transformation between the object and image spaces, the EOP are determined, providing a relationship between the image coordinates and the global (or local) mapping reference frame. The combined bundle adjustment usually facilitates not only EOP determination, but may also involve rectification of the camera IO (pre-determined by laboratory calibration procedure). Unfortunately, the significant part of the AT cost is associated with the establishment of ground control points, which might be prohibitive in cases of mapping of remote areas. Consequently, the direct orientation provided by GPS/INS (i.e., direct EOP or DOP, without a process of AT), is highly advantageous, provided that the satisfactory accuracy level is achieved, as it virtually eliminates most of ground control, and problems of image matching and need of approximate tie points required for automatic AT to recover exterior orientation. However, a crucial point of application of direct georeferencing is the accuracy and reliability of DPO, depending primarily on sensor quality, stability and accuracy of the system calibration, quality of time synchronization, and the type of the data processing algorithm.

DPO, as explained earlier, can be accomplished by inertial navigation or a multi-antenna GPS, or, for the highest accuracy, by integration of both systems to utilize their complementary features. Thus, based on discrete measurements, georeferencing determines the time dependent vector $r_{M,INS}(t)$ and matrix $R^{M}_{BINS}(t)$ (see equation 2), hence the problem is equivalent to finding six parameters of rigid body motion, under the assumption that the sensor is a rigid body. Since we are dealing with discrete observations, some modeling and estimation are introduced to relate measurements to the unknown filter states, and interpolation is needed to relate the estimated trajectory to the epochs of image exposure. In principle, no external information such as ground control is needed, except for the GPS base station and the boresight calibration range, which is usually needed prior to the mapping mission. Since the DPO rotational components are naturally related to the INS body frame, in order to relate the GPS/INS-derived positions, INS-derived attitude components and image point coordinates, a multi-sensor system calibration is required. This procedure must be able to resolve (with a sufficient accuracy) the misalignments between the INS body frame and the imaging sensor frame (boresight transformation), and GPS/INS lever arm. The boresight components are usually determined on a specialized test range, while the linear offsets between the GPS antenna phase center and the center of the INS body frame are precisely measured using traditional surveying techniques. In addition, an imaging sensor must be calibrated to determine the camera interior orientation. The concept of georeferencing is illustrated in Figure 1 and described in a form of the coordinate transformation in equation 2, while the operational architecture of DPO determination with GPS/INS is presented in Figure 2.

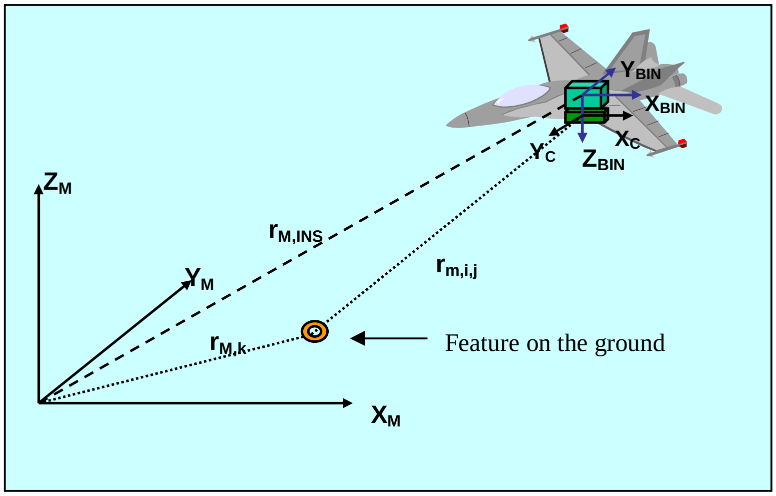

Figure 1. Direct georeferencing: the concept.

The mapping frame (m-frame) introduced in Figure 1 and equation 2 can be any 3D geodetic reference frame, such as WGS84, NAD83 or UTM (plus the height information) or any other selected Earth-fixed reference system. The body frame (b-frame) is defined as the INS sensor frame, attached to the IMU chassis. If the sensors are rigidly mounted in the vehicle (say aircraft), the changes of b-frame with respect to m-frame follow the motion of the aircraft. For the m-frame selected as a local level frame, East-North-Up (ENU), the three rotations by heading, pitch and roll angles, defined as $R_{\omega\phi\kappa}$, provide transformation from b to m-frame (equivalent to $R_{BINS}^{M}(t)$ in equation 2, where time argument indicates that this matrix varies with the motion of the platform). If the m-frame is selected as a 3D Earth-centered-fixed Cartesian frame (ECEF), the matrix $R_{BINS}^{M}(t)$ becomes a product of $R_{\omega\phi\kappa}$ (provided by INS) and R_{ENU}^{ECEF} (see equation 1); the subscript t indicates the time-dependence as a function of the platform coordinates, latitude φ and longitude λ.

$$R_{BINS}^{M}(t) = R_{ENU}^{ECEF}(t) \cdot R_{\omega\phi\kappa}(t) = \begin{bmatrix} -\sin\lambda & -\sin\varphi\cos\lambda & \cos\varphi\cos\lambda \\ \cos\lambda & -\sin\varphi\sin\lambda & \cos\varphi\sin\lambda \\ 0 & \cos\varphi & \sin\varphi \end{bmatrix}_t \cdot R_{\omega\phi\kappa}(t) \tag{1}$$

$$r_{M,i} = r_{M,INS}(t) + R_{BINS}^{M}(t)\left(s \cdot R_{C}^{BINS} \cdot r_{C,j} + b_{BINS}\right) \tag{2}$$

where:

$r_{M,i}$ – 3D *object coordinates in mapping frame*

$r_{M,INS}(t)$ – *time dependent* 3D *INS coordinates in mapping frame, provided by GPS/INS*

$r_{C,j}$ – *image coordinates of the object in camera frame C*

R_{C}^{BINS} – *boresight matrix between INS body and camera frame C*

$R_{BINS}^{M}(t)$ – *time dependent rotation matrix between body and mapping frames* (*measured by INS*)

s – *scaling factor*

b_{INS} – *boresight offset vector*

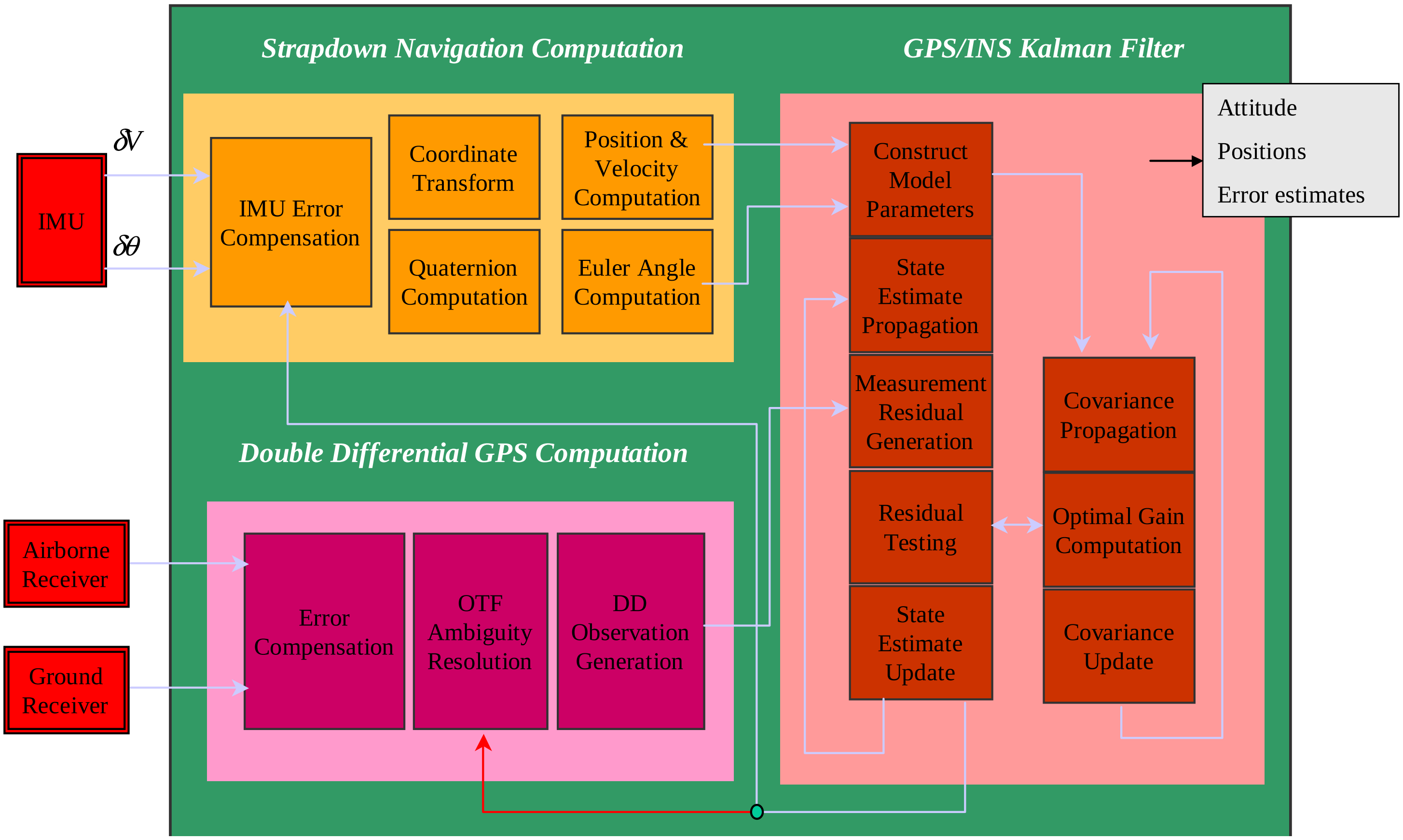

Figure 2. Operational architecture of DPO determination with GPS/INS.

In order to meet the project goals listed in Section 2, a commercially available integrated GPS/INS system, POS/AV 510, was acquired from Applanix Corp. The operational specs of the POS/AV 510 system are listed below, and the performance characteristic, achieved during the test flights is discussed in details in Appendix B.

APPLANIX
A TRIMBLE COMPANY

POS AV 510 V5 Specifications:
33BM61 IMU

1. Performance

POS AV 510 V5 Absolute Accuracy Specifications (RMS)

	C/A GPS	DGPS	RTK	Post-Processed
Position (m)	4.0 – 6.0	0.5 - 2	0.1 – 0.3	0.05 - 0.3
Velocity (m/s)	0.05	0.05	0.01	0.005
Roll & Pitch (deg)	0.008	0.008	0.008	0.005
True Heading [1] (deg)	0.070	0.05	0.04	0.008

[1] Typical mission profile, max RMS error

POS AV V5 510 Relative Accuracy Specifications

Noise (deg/sqrt(hr))	< 0.01
Drift (deg/hr) [1]	0.1

[1] Attitude will drift at this rate up to a maximum error defined by absolute accuracy in table above.

2. Physical

Temp. Range:	IMU	-20 deg C to +55 deg C
	PCS	-20 deg C to +60 deg C
Size:	IMU	150 mm L x 120 mm W x 100 mm H (5.9 in L x 4.7 in W x 3.9 in H)
	PCS	279 mm L x 165 mm W x 91 mm H (11.0 in L x 6.5 in W x 3.6 in H)
Weight:	IMU	2 kg
	PCS	2.90 kg
Power:	20 -32	Volts DC
	IMU	45 W, Max (supplied by PCS)
	PCS	30 W, Max

3. General - Sensors

IMU

- 250 Hz High performance DTG gyros, accelerometers

GPS

- 12 channel dual frequency (L1/L2), low noise, DGPS ready, 10 Hz raw data

4. Ethernet Input/Output (100 base -T)

Parameters	Time tag, status, position, attitude, velocity, track and speed, dynamics, performance metrics, sensor data
Display Port	Low rate (1 Hz) UDP protocol output
Control Port	TCP/IP input for system commands
Primary port	Real-time high rate (up to 250 Hz) TCP/IP protocol output

Specifications subject to change without notice
04 06 2003

5. Logging Output to Internal 1 Gbyte Flash Disk Drive and/or Ethernet (Buffered TCP/IP)

Parameters	Time tag, status, position, attitude, velocity, track and speed, dynamics, performance metrics, raw IMU data (200 Hz), raw GPS data (10Hz)

6. RS232 NMEA Output

Parameters	NMEA Standard ASCII messages Position ($INGGA), Heading ($INHDT), Track and Speed ($INVTG), Statistics ($INGST)
Rate	Up to 50 Hz (user selectable)
Baud	4800 to 115200 (user selectable)
Protocol	User selectable

7. RS232 High Rate Binary Output

Parameters	Time tag, roll, pitch, true heading, latitude, longitude, altitude Time of Validity pulse (250 Hz)
Rate	Up to 250 Hz (user selectable)
Baud	19200 to 115200 (user selectable)
Protocol	User selectable

8. RS232 Input Interface s

Parameter	Gimbal encoder input, AUX GPS Input (RTK, NavCom Starfire), RTCM104 DGPS Corrections Input
Rate	1 to 200 Hz
Baud	9600 to 115200 (user selectable)
Protocol	User selectable

9. Other I/O

1PPS	1 pulse-per-second Time Sync output, normally high, active low pulse
Event Input	Two input discretes used to mark external events. Discretes are TTL pulses > 1 msec width where rising or falling edge is time-tagged and logged (Max rate 100 Hz).

10. User Supplied Equipment

10.1 PC for POS Controller (Required for configuration)

- Pentium 90 processor (minimum)
- 16 MB RAM, 1 MB free disk space
- Ethernet adapter (RJ54 10 0 base T)
- Windows

10.2 PC for POSPac Post-processing Software

- Pentium 90 processor (minimum)
- 16 MB RAM, 1 MB free disk space
- Windows

4. RESULTS

The extensive system calibration and performance validation were carried out based on two test flights performed by Aerial Engineering Office. The data were processed and analyzed at OSU, and the detailed description of the results is provided in Appendix B. In particular, lever arm calibration, boresight calibration and navigation module quality check were performed, as detailed in Appendix A. Multiple CORS reference stations were used in the solution. Detailed analyses of the quality of the GPS and GPS/INS solutions were performed. The following data sets were used:

- Installation test flight
- Toledo dataset, Dec. 03 2002
- Franklin 670 dataset , Dec. 6 2002
- Defiance mapping dataset, Dec. 9 2002
- Defiance airport dataset, Dec. 10 2002

The boresight offsets and angles between the INS and the camera should be very stable, due to unique installation of the IMU in the camera cone. The offsets were surveyed very precisely by the OAE personnel, and the boresight angles were calibrated and are fixed in the Applanix data processing suite. The lever arm offsets between GPS and IMU should be dynamically calibrated during the GPS/IMU data processing.

5. CONCLUSIONS

Since the only way to test the performance is thorough independent georeferencing method, such as aerotriangulation (AT) based on control points, which for practical reasons is not performed, except for the system calibration, the following test procedures are suggested: (1) closely monitor the QA/QC (quality assurance/quality control) parameters during the navigation solution, as detailed below; and (2) run an automated AT (with no control) seeded by the GPS/INS solution that provides the image orientation refinement. Based on the extensive testing and system calibration, the following can be concluded in terms of operational practice in GPS/INS data processing to assure the best solution quality:

a. GPS Data processing

- Forward/backward data processing is recommended
- L2 should be used for ambiguity resolution, if possible
- L2 should be used for ionospheric modeling, if possible
- Criteria to control the quality of a GPS solution
    - “forward/backward separation”: normally for 20-30km baselines, the separation should be 20-30cm.
    - “Ambiguity Fixed Information”: Normally fixed solution is better than a float solution; however, if a substantial difference is found in the “forward/backward separation”, wrong integer ambiguity could exist in the forward or backward fixed solution.
    - “Combined RMS”: select the solution with smallest RMS when multiple solutions are performed.
    - “Position Standard Deviation”: select the solution with a minimum value.

- Ionospheric free model and relative ionospheric model should be peformed and compared; normally ionospheric free model will generate better solution.
- Different base stations with selected segments and different processing directions should be considered to select the best solution.
- "Standard Deviation" and "Rejection tolerance" for Code and Phase should be properly selected by checking residuals of the float solution.
- Different ionospheric noise models (mainly depending on the quality of L2 data) should be tested to get an optimal solution; normally, the "auto noise model" will work well.
- Test different KAR options, such as KAR time and search region size; if solution can not be found, default settings will work.

b. IIN Kalman Filter data processing

- Criteria to control the quality of the IIN Kalman Filter
  - Measurement Residuals should be noise-like.
  - Estimated Sensor Errors should reflect the quality of IMU hardware.
- "Adaptive RMS" for "Position measurement" should be used
- "Fixed RMS" for "Velocity measurement" should be used
- If IIN Kalman Filter fails, the "processing log" should be checked Normally the problem is caused by "too many consecutive measurement rejections".
  - Increase the "Number of consecutive measurement rejections" (50).
  - Increase the "Measurement Residual Ratio" from 3 to 5 or 6, but not too much, since it may decrease the reliability of the final solution.
  - Increase the "Scale factor" (1.0) in the "Adaptive RMS", but it may risk the reliability of the final solution
  - Do not use the "Velocity measurement", if too many rejections come from velocity.
  - Relax the quality of the GPS solution from ID to FD, CD, or even C/A. Also it will degrade the accuracy of the final solution, but at least some solution can be generated.
- Lever arm offsets should be properly calibrated either before the flights or re-calibrated in the data reduction procedure.

Based on the test flights analyzed in Appendix B it can be concluded that the Applanix system meets the performance specifications, as described by the manufacturer. Especially the recent update of the GPS/INS processing engine provides more robust georeferencing solution, and supports better user interface.

6. IMPLEMENTATION PLAN

The OSU staff worked in close collaboration with ODOT OAE personnel to assure that all functional aspects of the system's operation are followed during the field procedure. This included test flights, calibration and training seminars for the OAE staff.

The system is fully implemented and installed in the OAE airplane, and has been operational since fall 2002. To support daily operations and effective data processing and analysis, the "GPS/INS data processing strategies with POSPac Software" are included in Appendix A.

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APPENDIX A

GPS/INS data processing strategies with POSPac Software

1. Software overview

1.a. Objective of Appanix POS computing products

- Correlate sensory data derived from various sources such as GPS, gyros, accelerometers and other devices.
- Provide accurate navigation solution in real-time and post-processing.
- Extract and process raw data. (Post-processing)
- Identify and compensate for sensor and environmental errors. (Post-processing)
- Compute an optimally accurate, blended navigation solution. (Post-processing)

Workflow for data Post-processing

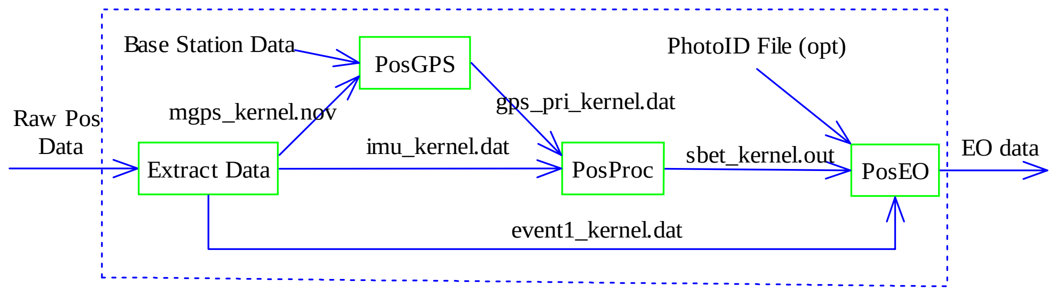

Figure 1A: Workflow for data post-processing

1.b. Data extraction

Objective:

- Extract stored raw GPS and IUM data, and detect potential data problems, such as gaps

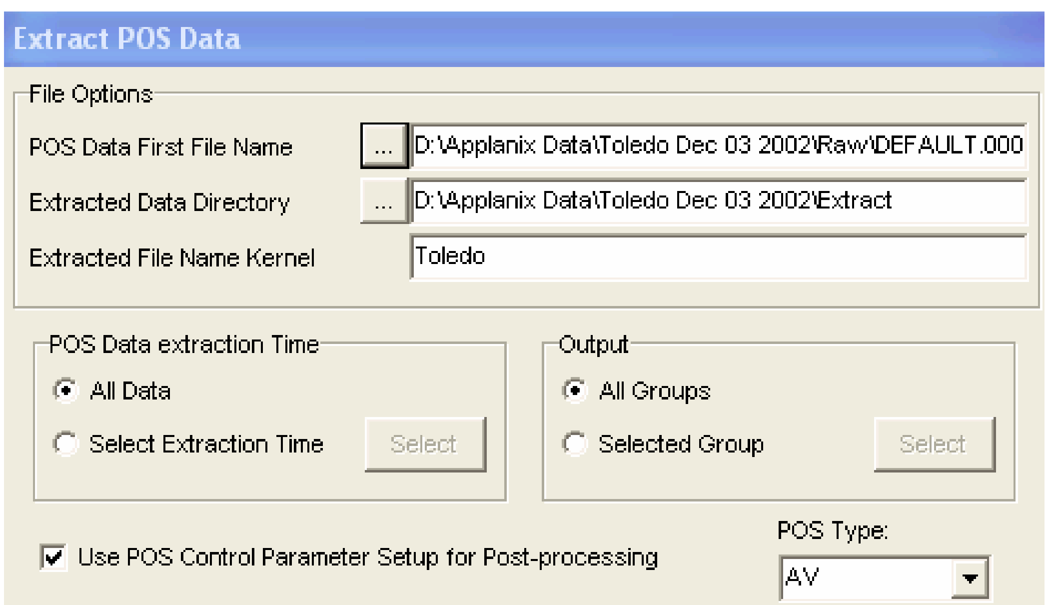

Figure 2A: Extract POS Data

Steps:

- Files options

- POS Data First File Name
- Extracted Data Directory
- Extracted File Name Kernel

Note: Directories for files and Kernel are important!!!

- POS Data extraction Time
  - All Data => Default option
  - Selected Extraction Time => Advanced option which will allow you select extracted Start Time and End Time (GPS Week and Seconds of Week)
- Output
  - All groups => Default option
  - Selected group => Advanced option to select specific types. (Figure 3A)
    - ✓ Required Group:
      - IMU Data
      - Primary GPS Data
    - ✓ Optional Group:
      - Events => if you want to get PosEO results
    - ✓ Recommended Group:
      - Navigation and Dynamic Data: GPS code kinematic solution
      - Navigation Performance Metrics: Accuracy for GPS code kinematic solution
      - Sensor Navigation Data: INS free navigation solution
      - Sensor Performance Metrics: Accuracy for INS free navigation solution

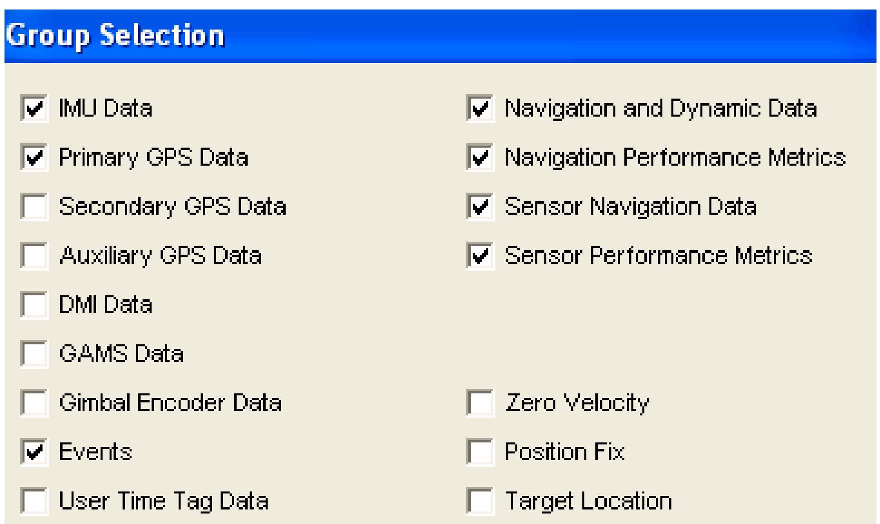

Figure 3A: Group Selection

- Use POS control parameter setup for post-processing: => Automatically extract all embedded real-time parameters, including lever arm and initial orientation coordinates, otherwise settings default to zero and must be entered later, manually.

After all steps of data extraction are finished, the following menus can be used to examine the quality check or data gaps of GPS and IMU data.

- “View” => “Extract Log File”
- “View” => “POS Data” => “Sensor Data” => “IMU Data”

- “View” => “POS Data” => “Sensor Data” => “GPS Navigation Data”
- “View” => “POS Data” => “Time Tagged Events”
- “View” => “POS Data” => “Real Time Navigation Solution” => “Vehicle Navigation Solution (wa)”
- “View” => “POS Data” => “Real Time Navigation Solution” => “Vehicle Navigation Performance Metrics”
- “Display” => “POS Data” => “Sensor Data” => “IMU Data”
- “Display” => “POS Data” => “Sensor Data” => “GPS Navigation Data”
- “Display” => “POS Data” => “Real Time Navigation Solution” => “3D Vehicle Trajectory”
- “Display” => “POS Data” => “Real Time Navigation Solution” => “Vehicle Navigation Solution (wa)”
- “Display” => “POS Data” => “Real Time Navigation Solution” => “Vehicle Navigation Performance Metrics”
- “Display” => “POS Data” => “Real Time Kalman Filter Data” => “POS Estimated Error and RMS”
- “Display” => “POS Data” => “Real Time Kalman Filter Data” => “POS Measurement Residuals and RMS”

Files created after data extraction (Table 1A)

File #	File Name	File Description
1	dephem_Kernel.dat	GPS Ephemeris Data
2	event1_Kernel.dat	Image Time Tagged Events
3	extract_Kernel.log	Extracted Log File
4	gps_pri_Kernel.dat	GPS Code Kinematic Solution
5	hwconf_Kernel.out	Hardware Configuration
6	iinr_Kernel.out	Binary file
7	iinz_Kernel. out	Binary file
8	imu_Kernel.dat	IMU raw data
9	mgps_Kernel.nov	Rover GPS raw data
10	navclk_pri_Kernel.dat	Clock Estimates for Rover GPS Receiver
11	obs_pri_Kernel.dat	GPS Rover Observation Data
12	rers_Kernel.out	Binary file
13	rinv_Kernel.out	POS Measurement Residuals and RMS
14	rmrs_Kernel.out	Binary file
15	rrms_Kernel.out	POS Estimated Errors and RMS
16	rtstat_Kernel.txt	Binary file
17	tm_Kernel.dat	Binary file
18	vnav_Kernel.out	Vehicle Navigation Solution
19	vrms_Kernel.out	Vehicle Navigation Performance Metrics

Table 1A: Files Created after Data extraction

Note: The file descriptions for File #6, 7, 12, 16, 17 are proprietary, please contact with Applanix for further description.

1.c. GPS solution using PosGPS

POSGPS is a full-featured kinematic and static GPS post-processing package running on Windows 95, 98, 2000, NT and XP using Waypoint's proprietary GPS processing engine.

- Support most single and dual frequency commercial and OEM receivers.
- Processes GPS/GLONASS combined data.
- Kinematic engine called Kinematic Ambiguity Resolution (KAR).
- Forward and Backward Kalman Filter

- Numerous options setting

1.c.1. Data loading

Preparing base and rover station data, and loading into database of PosGPS
Steps:

- Convert GPS raw data (Rover Station) and Rinex data (Base Stations) into database format of PosGPS (GPB)
  Note: While converting the rover GPS raw data (mgps_Kernel.nov), the options "***Make all epochs Kinematic***" must be checked. (Figure 4A) However, for Base Station, the option "***Make all epochs Kinematic***" must be unchecked.
- Creating a new project
- Loading base station GPB file
  Note: Please double check the Base coordinates and antenna height. Please select appropriate coordinate system and the height system (Ellipsoidal Height or Orthometric Height). (Figure 5A)
- Load rover station GPB file.
  Note: Leave remote antenna height as zero (offset applied in PosGPS)

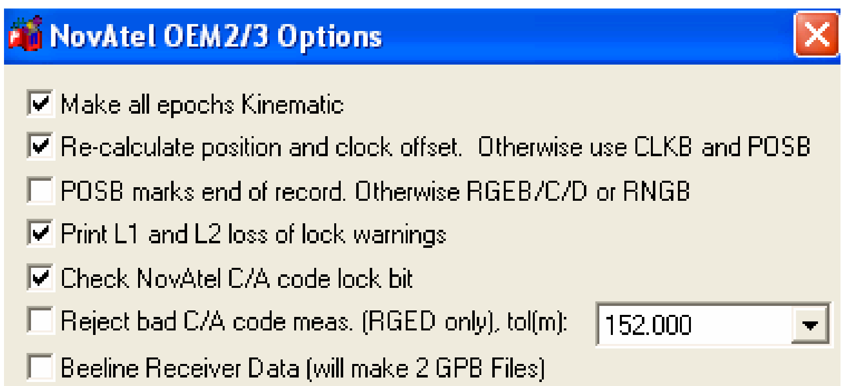

Figure 4A: Options for converting GPS Rover raw data to GPB format

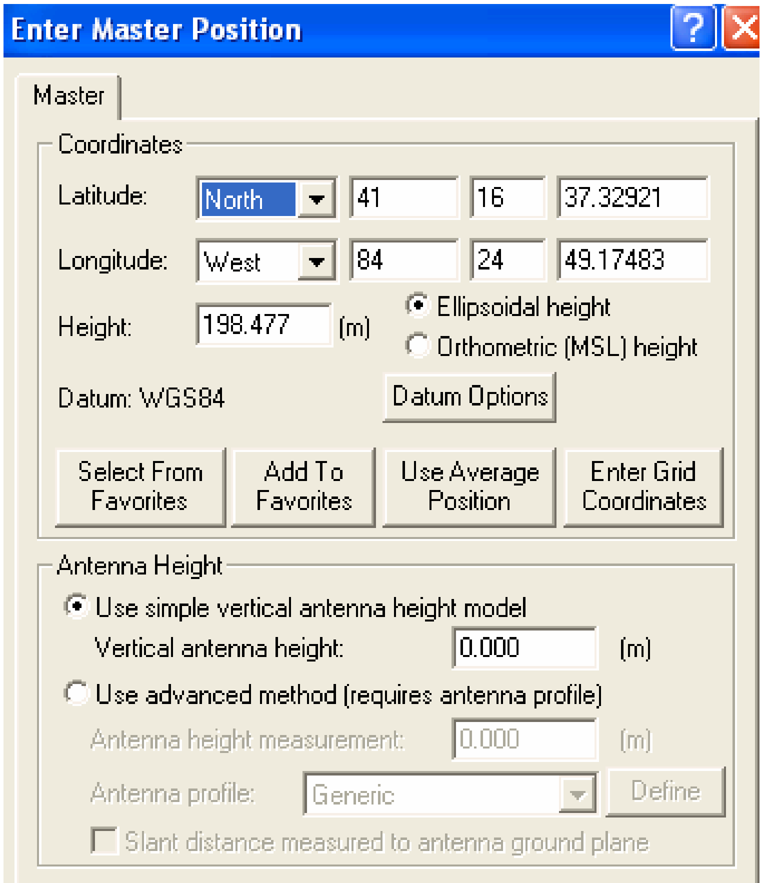

Figure 5A: Coordinates for Base Station

1.c.2. Data processing based on difference processing options

➢ GPS solutions (Table 2A)

For airborne dataset, Base-Rover separation is normally >10~20km, then a float ambiguity will be achieved. However, with the aid of ionosphere model or iono-free combination, a better solution (than float solution) may be able to resolve.

Frequency	baseline	Fixed	Float	Iono-Free
Single	Short	Highest accuracy	Less accuracy	×
	Long	Max to 10-20km, Higher accuracy	Less accuracy	×
Double	Short	Highest accuracy	Less accuracy	×
	Long	Max to 30-60km, Higher accuracy	Less accuracy	> Float

Table 2A: Solutions comparison in general cases for longer baselines

➢ GPS data processing options

The options for GPS data processing can be selected using the dialog box "Process GPS or GPS+GLONASS". Several different tab sheets are included in this dialog box.

- Process (Figure 6A)

- Process Direction: Both => Default, this option will allow the both forward and backward Kalman filter.

- Process Data Type

  - Automatic
    The feature automatically searches the data for dual frequency, single frequency or C/A code only. If the master and remote files are of a different type, then the less of the two will be used. The order is C/A only, single frequency then dual frequency.

  - Single frequency carrier phase
    This will process with C/A code, L1 carrier phase and L1 Doppler data in a combined Kalman filter. Each of these data variables must be available. Integer ambiguities can also be fixed using KAR, quick static or the fixed static solution. Single frequency is usually less reliable than dual frequency and has the disadvantage of not being able to correct for the ionosphere. Single frequency is normally always more accurate than C/A code only.

  - Dual frequency carrier phase
    For GPS receivers that track L2 carrier phase, processing dual frequency has two benefits. Integer ambiguity resolution (e.g. KAR, fixed solution and quick static) is much more reliable, and the resolution time is much faster. For instance, KAR using dual frequency data can resolve in a few minutes what could take 10-20 minutes in single frequency. Secondly, ionospheric correction can be enabled with dual frequency data. This greatly improves accuracies on baselines longer than 10 km. Please note that processing dual frequency on single frequency data will have no benefit, and may have adverse effects.

  - C/A code only (DGPS)
    This will process in an advanced differential correction mode. In kinematic mode, the accuracy will be the same as real-time differential (i.e. RTCM corrections). In static mode, the accuracy will be higher due to averaging effect. Normally, C/A only processing is only performed for data with no (or incomplete) carrier phase information.

  - Occupation mode
    This is a special mode of operation designed for use in high tree cover areas. In this mode, the user should stay stationary over each point for 2-5 minutes. Carrier phase lock need not be maintained during travel between points. Since the carrier phase is used in static mode (not kinematic) sub-metre accuracies can be achievable in

such terrain. GLONASS processing is also suggested to add additional satellites.

- Static Initialization

  - Float solution or kinematic initialization
    The float solution does not solve for integer ambiguities. This setting is also necessary for kinematic initialization. Since integers are not solved, the float solution tends to be less accurate than the fixed or quick static solutions. For longer baselines (>10 km in single frequency and >30-40 km in dual frequency) integers are often not solvable. In such cases, the float solution is often the best alternative. For dual frequency, be sure to enable the ionospheric free correction mode from the Dual Frequency Options.

  - Fixed static solution
    This method processes carrier phase in order to obtain a static fixed integer solution. If the integers are correctly determined, this mode is the most accurate. For longer baselines, an ionospheric correction is applied to the fixed solution. For single frequency, a minimum of 10 minutes is required and 15 minutes is suggested. For dual frequency, only a few minutes will work. However, users often choose to stay longer to lessen the likelihood that a point be re-observed. Note that time should be increased with baseline lengths for both single and dual frequencies.

  - Quick static solution
    Uses integer ambiguity techniques to quickly resolve baseline coordinates. This is an out-dated methodology. This feature is only retained in the software since there are a few instances when it will deliver a solution where the fixed solution will not. The quick static solution is normally not as reliable or as accurate as the fixed solution.

- Kinematic Ambiguity Resolution (KAR)

Kinematic Ambiguity Resolution (KAR) is the process of solving fixed integers on a moving antenna. KAR will also engage in static mode if the 'Engage KAR in STATIC mode' setting is enabled in the KAR Options. KAR is very useful to regain integer (high accuracy) positions at onset or after a loss of lock. KAR requires 5 or more satellites and 6 satellites are suggested.

  - Automatically
    KAR is enabled for dual frequency and disabled for single. KAR is not applicable for C/A only processing.
  - Off

This forces KAR to never be engaged.

- On
- Manual engage only
  It only engages KAR at times specified in the Advanced KAR options. KAR will not be engaged if there is a loss of lock.

▪ GPS+Glonass Processing

Normally, POSGPS will automatically detect if there is GLONASS data. However, if this detection fails or if the GLONASS data is causing problems, then satellite system type may need to be selected (i.e. GPS Only or GPS+GLONASS).

- Automatic
- GPS Only
- GPS+GLONASS

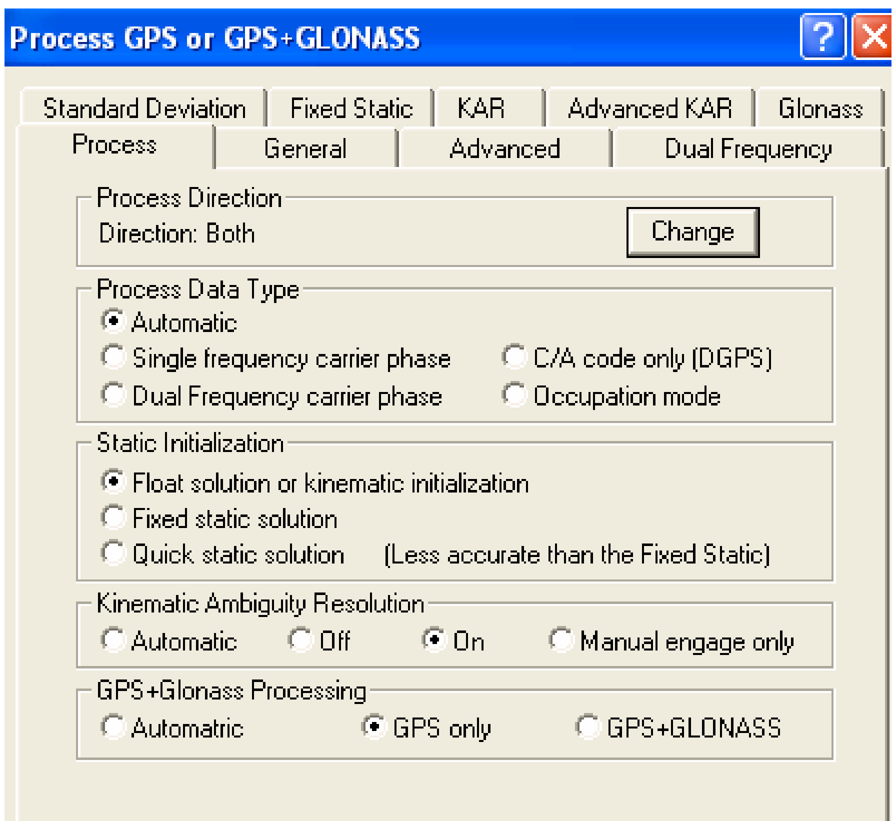

Figure 6A: Process for "Process GPS or GPS+GLONASS"

o General (Figure 7A)

▪ Elevation Mask
The default elevation cut-off for satellite processing is 10 degrees. You may wish to raise this to 15 degrees, but we do not suggest

that you lower it. If the default is set too high, you may miss satellites that are important to the geometry of the position. Lowering the mask can cause a solution degradation due to noisy data.

- Processing Interval
  The program automatically lines up both the master and remote data sets at the data collection rate. If this is not desired, you may specify the interval at which you wish to process the data. For instance, in static mode, processing with data intervals shorter than 15 s is not beneficial. In fact, it can result in overly optimistic accuracy estimates.

- Time Range
  Normally, POSGPS will process the entire data set. This means starting at the first epoch the master and remote has in common and ending at the last. Users may, however, wish to limit the scope of processing to avoid problematic time periods. Such time periods are usually isolated from the data plots. The beginning and end times are entered here. These times are for forward processing (i.e. begin time is before end time). For reverse processing, POSGPS starts at the end time and stops at the begin time The default time system is GPS seconds of the week (0-604800), but times can also be entered in hours, minutes and seconds. These are in the GMT time zone.

- Process Direction
  Use this option to process data sets in the forward, reverse or both directions. Both directions will process the forward first, followed by the reverse.

- Write Satellite Residuals
  These are needed for graphing individual satellite residuals. Forward only processing is highly suggested for analyzing satellite residuals, as the plotting functions can sometimes be confused by the reverse files.

- Processing Datum
  Normally, the processing datum is the same as that where your base station coordinates are referenced to. In this case, select the processing datum from the list. Alternately, processing can be in a global datum such as WGS84, and coordinates can be entered in the local datum.

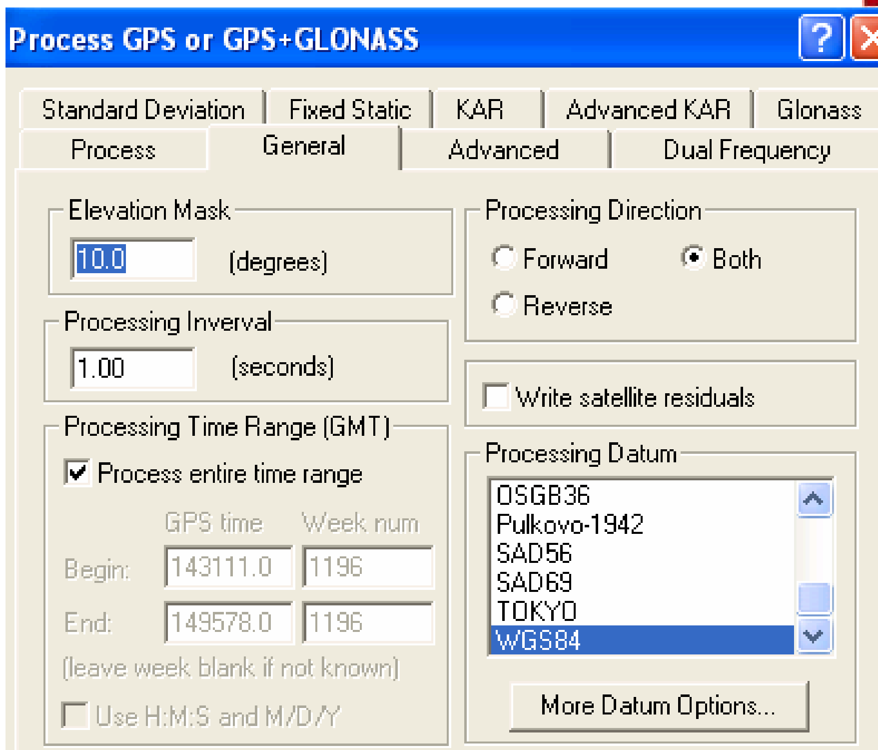

Figure 7a-A: General for "Process GPS or GPS+GLONASS"

- Advanced
  - Base Satellite
    This is the satellite initially used as the base for the differenced observations.
  - Satellites to Omit
    Normally, all satellites are used for processing. You may wish to omit satellites which have serious data problems. They will be noted in message log file. Satellites can either be omitted for the entire data set or for a selected time period. Minimizing the extent of an omission is always preferred.
  - Tropospheric Model
    Tropospheric corrections should always be used. POSGPS uses the Saastamoinen model as experience has shown that it works best. The 'Off' setting is to be used with simulator data where the tropospheric correction has been disabled.
  - Carrier Locktime Cut-off
    The number of seconds of carrier phase lock before data for that channel is deemed usable. This allows users to reject data for the first 'n' seconds since loss of lock. The default value is 4, but higher numbers (8-12 s) can be very beneficial to some GPS receivers—especially low-cost ones.
  - L1 Phase Cycle Slip Detection & Tolerance

These parameters govern how POSGPS detects cycle slips. In general, POSGPS relies on a procedure of using the locktime read or computed in the decoders combined with a Doppler check.

- Doppler
  The Doppler check tries to predict the L1 phase using the Doppler and compares to the actual value. Using zero as a tolerance lets POSGPS choose a value based on the interval.
- Locktime counter
  The locktime cycle slip check uses flags generated by the GPS receiver. This should normally always be enabled.
- Static fine check
  In static mode, the fine static check should be turned on. This allows POSGPS to detect very small cycle slips and is now by default ON. For the fixed solution, this is automatically used and cycle slips are also corrected.
- Skip serial drop-outs
  This should only be used for data sets that are susceptible to individual satellites skipping in and out due to serial data errors. Ashtech MBN, MPC an MCA records are the most susceptible. Some download (B-files) from Ashtech have also been observed exhibiting these phenomena. For receivers other than Ashtech, there should be no reason to use this option.

▪ Bad Data Control

- Reset filter
  The filter reset is a safety measure in the processing engine that prevents bad data from permanently harming the ambiguity values. This feature should protect carrier phase processing from ever being worse than DGPS. The filter reset is engaged when an unfixable carrier phase error has been detected, and induces a total loss of lock on all satellites. However, in some cases a small cycle slip is not as serious as the compensating measure (i.e. the filter reset). In such cases, disabling this feature may result in a better quality solution, especially for single frequency data sets.

- Write epochs containing bad data
  This command forces POSGPS to print out all positions that it computes, regardless of whether it has deemed the data to be good or bad. By default, POSGPS will not print positions for epochs for which the Kalman filter has detect large measurement errors. This option should only be used if you need a position for as many epochs as possible, and if you are not concerned about some low quality positions.

- Do not write epochs with poor statistics
  This option allows you to remove epochs from a solution that have quality numbers, or standard deviations greater than some threshold. This option can be used to attempt to filter out bad positions from the output.

- FWD/REV File Format
  This option allows you to select the format of the epoch output files. The Normal format is the format that POSGPS uses by default.

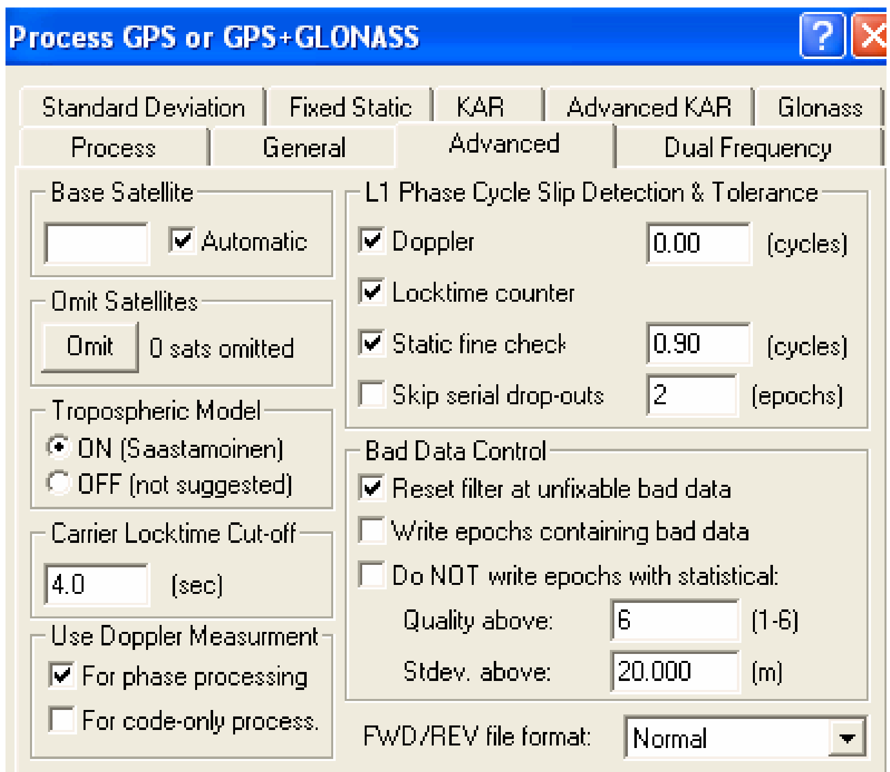

Figure 7b-A: Advanced for "Process GPS or GPS+GLONASS"

- Dual Frequency (Figure 8A)

POSGPS supports full dual frequency processing. For this feature to work, both the master and remote receiver must be dual frequency GPS receivers. By making measurements on both L1 and L2, the ionosphere error can be resolved. The effect of the ionosphere under normal conditions and in the absence of ionospheric storms is a small effect at 0.5 - 2 PPM (5-20 cm per 100 km). Because L1 and L2 carrier phase need to be combined to remove the ionosphere, the measurement noise will increase from sub 1 cm to 1-3 cm. A further problem occurs because L2 is more prone to cycle slips. For the ionospheric-free model, a cycle slip on L2 will induce a total cycle slip for that satellite. For the relative ionospheric model, this is not the case making it less sensitive to L2 slips. However, this adds additional noise to the solution, which can sometimes cause the relative model to be less accurate. Generally, ionospheric correction becomes beneficial on baselines greater than 10 km.

Another good reason for employing dual frequency is to improve the reliability of integer ambiguity search techniques. By combining the L1 and L2 carrier phase the so-called widelane is formed. These techniques are employed for Quick Static, Fixed Static and Kinematic Ambiguity Resolution (KAR). The result is that these techniques will work much more reliably, solve on longer distances and require less observation time.

- Use P2-Code in Kalman Filter
  Under normal circumstances P2-code measurements are not employed. This is because most dual frequency receivers use narrow correlators (or similar technology) for their C/A code measurements and these tend to be more robust and reliable than the P2-code. Enabling this feature will add this measurement to the Kalman Filter thereby causing a faster convergence.

- Use L2 for Ambiguity Resolution
  It is important for this feature to be enabled when using Quick Static or KAR as it allows widelaning to be used. There is no reason for disabling this option. In such a case, it is better to use single frequency processing.

- Use L2 for Ionospheric Processing

  - Relative Ionospheric Model
    This is normally used when static initialization occurs when the base and remote are close and the ionospheric error at that base-remote separation can be assumed to be zero. Using the relative transfer algorithm, the ionospheric error is accumulated as the base and remote get farther apart. The distance from the base station when the relative transfer starts can be set using the Engage Distance. If loss of lock occurs, then this ionospheric transfer cannot continue. After this point, this solution becomes very similar to the ionospheric free model. Because of this last feature, the relative model can be used even if the starting point is far from the base. Since the relative model is less sensitive to the noise of L2 data.

  - Engage Distance for Relative Ionosphere
    This parameter is combined with relative ionospheric processing and it sets the radius from the base station before the relative ionospheric correction starts. This is an advanced parameter and changing it will cause little difference in the final solution. Users may wish to lower this value during periods of high ionosphere activity. The default value is 4.0 km.

  - Ionospheric Free Model
    This can be used for static or kinematic data processing. The Iono-free solution will do a better job of resolving

the ionospheric error at the expense of being more susceptible to cycle slips. Static baseline should only use this method.

Note: For choosing between Iono-Free and Relative Iono Models there are several rules of thumb:

1) If the L2 data is very clean with minimal losses of lock, then the iono-free model often works better.
2) If the L2 data is continually losing lock, then the Relative model can be better.
3) The relative likes to start close, but it is not necessary. In many cases both models will give similar results.
4) It is also often a good idea to try both models. Sometimes one will work quite a bit better than the other.
5) Iono-free should be used in static. It will aid the fixed static solution if the iono noise model is used.

- L2 Small Cycle Slip Tolerance
  Both KAR and relative ionospheric processing check for small cycle slips on L2 by checking it against the L1 phase. Raising this value too high will increase the chance of a half cycle slip being detected. Lowering this value may cause false cycle slips to be induced by noise. Changing this value requires analysis of the results and should only be done by advanced users.

- Correct C/A code for Ionosphere
  By combining the C/A code and the P2-code, the ionospheric effect can be removed from the pseudorange measurement. However, this adds additional noise along the lines of a few metres. Thus, baselines need to be very long before the effect of the ionospheric is larger than the additional noise induced. Generally, baselines need to be 500 km or more in length.

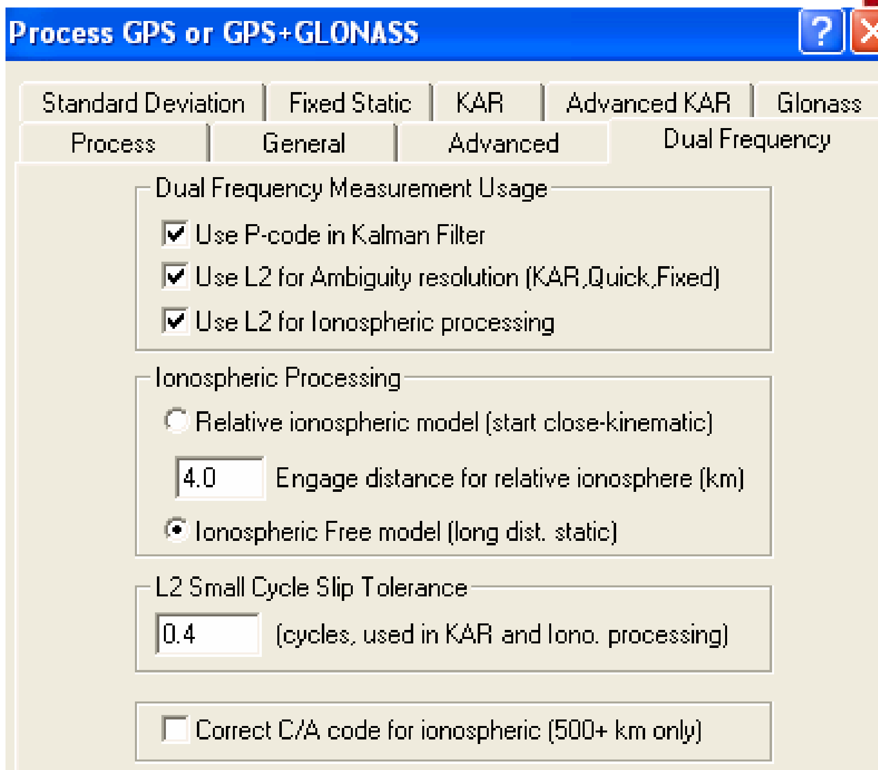

Figure 8A: Dual Frequency for “Process GPS or GPS+GLONASS”

- Standard Deviation (Figure 9A)

This dialog box allows the user to change some of the parameters used in the double difference Kalman filter. These settings control the weighting of the carrier phase and pseudorange (C/A code) measurements in the Kalman filter. The following statements normally apply:

1) Using accurate standard deviation values results in better float solution convergence. For float-mode processing, accuracies can sometimes be significantly improved. For fixed-integer processing, KAR resolution is generally faster, but the actual accuracy is not usually affected.

2) Lowering the C/A code standard deviation with respect to the carrier value causes the software to converge faster. If the C/A is over-weighted (i.e. standard deviation is too low), then it may converge to the wrong value.

3) The best way to evaluate optimal standard deviations is to use the Plot GPS Data function from the Output Menu. View the RMS-C/A code and RMS L1 Phase. Good standard deviation values are those where 90-95% of the RMS values fall below user-defined threshold. The values computed from the Processing Summary (under the Process Menu) can often be optimistic.

4) If the standard deviation is altered, the rejection tolerance should also be changed. Generally, the rejection tolerance for the C/A code should be 3-

4 times the standard deviation. For the carrier phase, the rejection tolerance should be 5-6 times.

5) Raising the carrier phase rejection tolerance is a useful way to making the Kalman filter less sensitive to noisy data. For airborne processing, 0.20 m can often result in better accuracies.

6) Note that the PPM value is added to the carrier rejection tolerance to account for the additional noise induced by the ionosphere.

7) Sometimes very bad Doppler data can induce position errors. POSGPS tries to protect against this, but this phenomena can still happen. In such a case, raising the Doppler standard deviation is a good remedy.

- Standard Deviation
  By default the C/A code is set to 7.0 metres. This is to account for possible multi-path on the C/A. However, if the C/A code measurements are quite clean then this number can be lowered to 1-3 metres. This will improve kinematic convergence times for the float solution. As for the carrier phase standard deviation, this should be left at 2 cm for most applications except for airborne data over longer baselines. 3-5 cm with a 20 cm rejection tolerance seams to be more proper for this type of data. If there are problems with the Doppler (phase rate) measurements, then the user may wish to raise the L1 Doppler standard deviation (to 1-5 m). The default value is 25-100 cm depending on the GPS receiver type.

- Rejection Tolerance
  This refers to the tolerance on the residuals over which the measurement will be assumed erroneous. The default values are 10 cm for L1 phase and 25 metres for C/A code. The L1 phase tolerance is also increased by the parts-per-million (PPM) value to account for ionospheric noise. The user may want to raise the L1 tolerance value to allow more leniencies for bad L1 phase measurements. This is closely associated with the reset filter flag in the advanced options. The default code rejection tolerance of 25 m is very forgiving. Users may wish to lower this value to reduce the number of poor pseudorange measurements that may bias the Kalman filter. Caution should be taken when lowering rejection tolerances too much. This is because if POSGPS cannot resolve which satellite is the problem, it will induce cycle slips on all satellites.

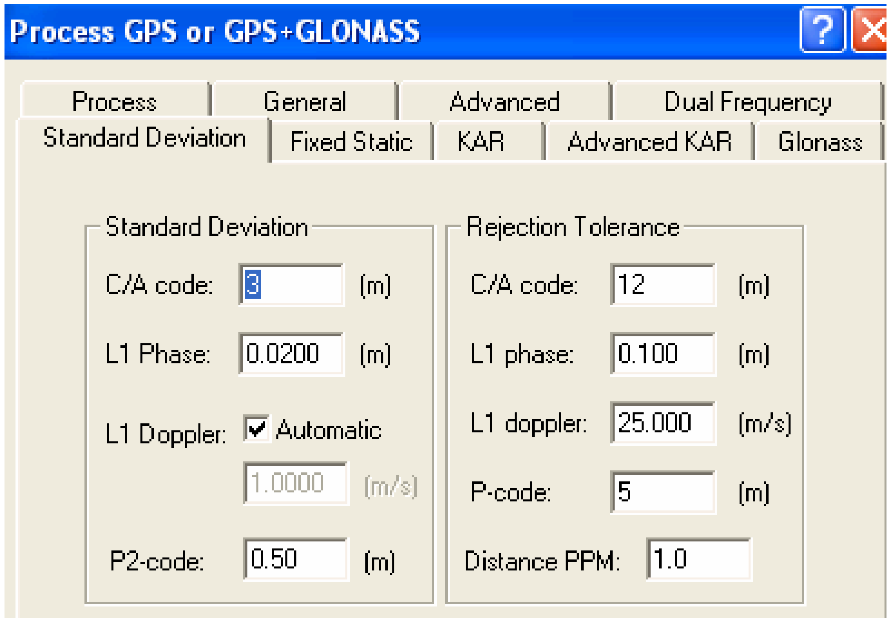

Figure 9A: Standard Deviation for “Process GPS or GPS+GLONASS”

- Fixed Static (Figure 10A)

This is for static data processing.

- Search Area Options:
  - Normal
    This is the default search area, which is a constant search region size.
  - Reduces as float solution accuracy improves
    An auto-reducing search area is helpful for situations where the fixed solution is failing the reliability tests. Normally, this would be the case on short baselines, possibly with single frequency measurements.
  - User defined search cube size
    A user defined search area is not often used. However, if the float solution is known to converge very close to the correction solution, then enter zero here.
- Ionospheric Noise Modeling
  This noise model corrects for the ionosphere in its computation. This can improve accuracies, but noise might be higher on short baselines.
  - Automatic
    This noise model chooses between Normal and Iono based upon the distance tolerance given.

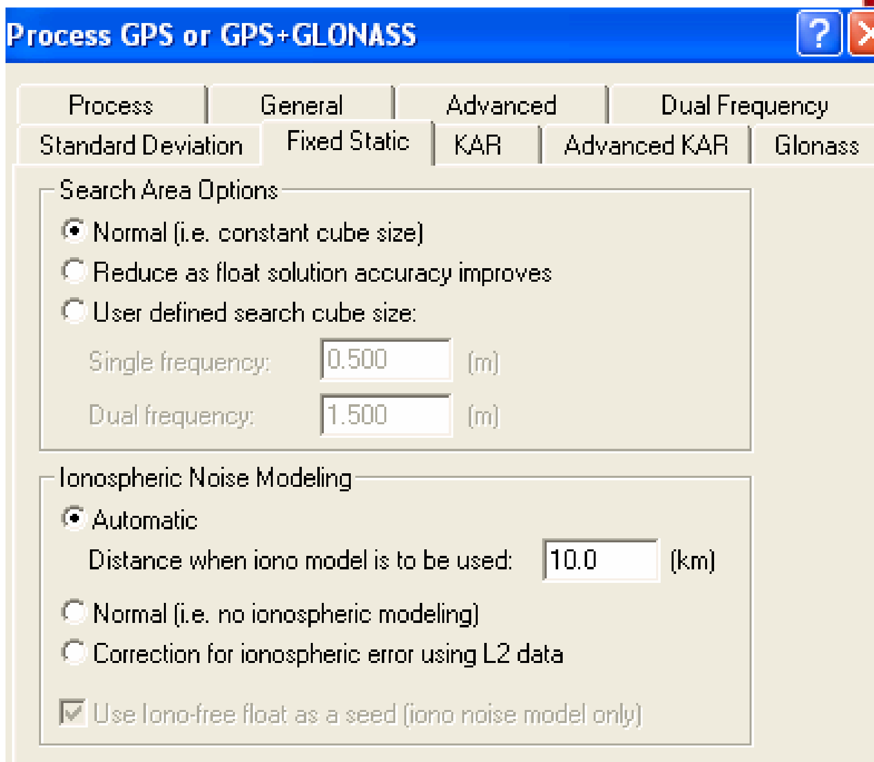

Figure 10A: Fixed Static for "Process GPS or GPS+GLONASS"

- Kinematic Ambiguity Resolution (KAR) (Figure 11A)

  Kinematic Ambiguity Resolution (KAR) is a technique that allows the user to compute an integer fixed solution (i.e. 2 cm accuracy) while the remote antenna is in motion. Typical applications would be kinematic initialization in marine environments and initialization after loss of lock. A KAR solution that uses dual frequency data is considerably more reliable than if only single frequency data is available. This is due to the additional measurements present with the L2 phase. However, KAR can deliver accurate results with single frequency, it just takes longer. Secondly, both single and dual frequency KAR requires at least 5 satellites. If KAR fails after a given length of time, then it starts searching over again.

  KAR may skip some data after loss of lock, but it will try to go backwards as far as possible. The .FSS or .RSS file (Static/KAR summary) will show when KAR was engaged and when it was restored. Additional KAR statistics will also be shown here.

  - Minimum Time
    - Single Frequency
      This is the minimum amount of time before KAR is invoked. The default value is 8 minutes.
    - Dual Frequency
      This is the minimum amount of time before KAR is invoked in dual frequency mode. The default value is

1.0 minute. Users may wish to lower this value for urban data sets where fast ambiguity determination is very helpful. Longer baseline airborne users may with to increase this number to minimize the effect of the ionosphere.

The value to the right is added to the time for every 10 km that the remote is from the base. For instance, if a dual frequency receiver is used, and the base-remote separation is 20 km, then the overall minimum time will be 1.0 min + 2.5 min*20/10 = 6 minutes.

- Maximum Time
  This is the time length before KAR will start searching over again. Lowering this value can cause fixed integer gaps to be lower. However, KAR will be prevented from using more data than indicated. This is more practical for dual than single frequency because single frequency KAR often needs 15 or more minutes to resolve. The default value is 30 minutes, and this value is normally left 'as is'.

- Search Region Size:
  - Single Frequency
    This is the size of the search area for single frequency KAR. Because the single frequency KAR is invoked after 8 minutes or so, this value can be quite small. The default value is 1.0 m. Valid values range from 80 cm to 1.2 m.
  - Dual Frequency
    For dual frequency KAR, there are two ways to determine the search area:
    - ✓ Use a fixed search range (e.g. 4.0 m by default). This value is often lowered to 2-3 m to speed up KAR resolution time
    - ✓ Auto-reduce, which means that the covariance information is used for search area estimation. To ensure that the entire search area is encompassed, the ambiguity standard deviation is multiplied by a factor (e.g. 3). If a user feels that the standard deviations are overly optimistic, then raising this factor can be helpful.

- Options for Engaging KAR
  KAR will not engage if the remote is too far from the base. This improves reliabilities. The distance tolerance for engaging KAR in both single and dual frequency is defined here. Normally, the maximum allowable distance for single frequency is 7.5 km, while for dual frequency it is 30 km. These values are designed for a period where the ionospheric activity is high (i.e. year 2000). In subsequent years, these tolerances can be lengthened. This option (i.e. 'Maximum engage distance') only controls when KAR is started.

Normally, KAR will not engage in static mode. This is to allow static processing methods to take precedence. However, for users that wish to engage KAR in static, the option 'Engage KAR while in STATIC mode' should be enabled. Please be sure not to combine this with either the fixed static solution or the quick static solution, as problems may develop.

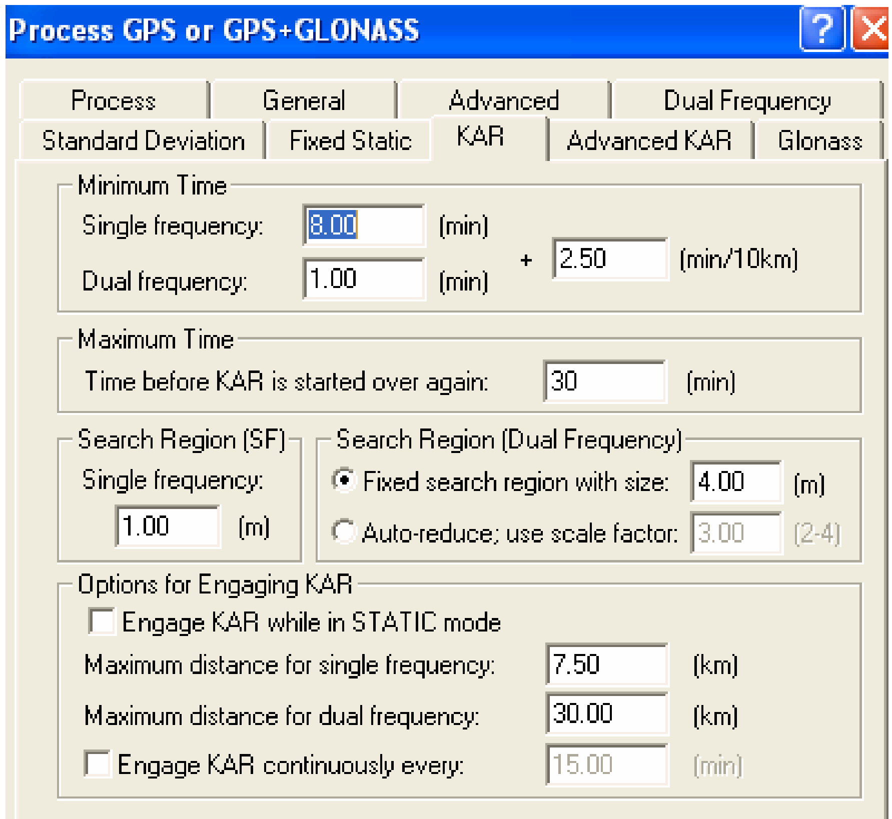

Figure 11A: KAR for “Process GPS or GPS+GLONASS”

- Advanced KAR (Figure 12A)

  - Advanced Setting

    - Stricter Reliability Tolerance
      The reliability is the ratio of the carrier RMS values between the second best and best intersections. Larger values indicate increased reliability. The tolerance for accepting a reliability number is dynamic within POSGPS. Enabling this checkbox will apply a more stringent tolerance. Basically, 0.5 is added to the existing dynamic tolerance. This setting would be used to reduce the occurrence of incorrect KAR intersections. The reason that users may not wish to use this all the time is that it can cause to KAR to take longer to resolve ambiguity or sometimes not resolve ambiguity at all.

- Stricter RMS Tolerance
  This option is similar to the above except that it applies a lower tolerance to the RMS value of the best intersection. The tolerance, normally 0.065 cycles, is lowered to 0.05 cycles. Like before, setting this will reduce incorrect KAR intersections. In fact, of the two, this feature is usually more effective. Some users may wish also to use both.

- Use Distance Weighting
  KAR has the ability to weight by the inverse of the base-remote distance (baselines shorter than 6 km will not be affected). This is helpful for airborne data as the effect of the ionosphere is distance dependent. By default, this setting is on.

- Use fast KAR
- Use fast KAR even for 5SVs
  If very fast KAR resolution is selected, then minimum time is greatly reduced, but it will reduce the reliability

- Refine L1/L2 KAR search

▪ Geometry (DD_DOP) Settings

These settings control how KAR reacts to poor satellite geometry. Note that KAR uses the DD_DOP for testing. The DD_DOP is approximately PDOP^2, but can be somewhat lower due to the differential implementation.

- Maximum Allowed DOP
  KAR will not search if the DD_DOP is greater than this tolerance. This is to preserve the reliability of the solution. KAR solutions with high DOPs can be unreliable. However, raising this value allows KAR to search where otherwise the software would skip past this data. The default value is 9.0.
- Engage on Poor DOP
  The number of cycle slip free satellites to maintain lock is four. In some cases this minimum is maintained, but the geometry of these satellites is very poor. This can be seen as a spike in the DD_DOP plot. Setting this checkbox will engage KAR after the DOP recovers from being very poor. The default tolerance is 25, but users may wish to increase or decrease this to control how KAR reacts at a poor DD_DOP.

▪ Data Usage Settings

- Use on interval
  This defines how many seconds between epochs that KAR will use for processing. Generally, if carrier phase errors are random (i.e. white noise), then using a lower interval will improve results at the expense of memory

usage and computational time. If errors are systematic (i.e. colored/ionospheric noise), lowering this value will help little.

- Exact interval (for interpolating data)
  GPS data can be interpolated with the 'Concatenate, Slice and Resample' utility or using the 'Download Service Data' feature. In either case, additional errors of 1-2 cm can be added to measurements, which is sufficient to cause KAR not to work. However, if the 'Exact Interval' check box is enabled and the data interval 'Use on interval' has been set to the original source data interval (e.g. 30 s), then KAR will not be affected. Users may also wish to lengthen the minimum KAR time (KAR Options) to use more data, as one point every 30 s is quite sparse.

▪ L2 Noise Model for KAR

KAR supports a number of L2 noise models, which model how POSGPS handles L2 data in dual frequency KAR. Due to anti-spoofing, L2 can be significantly noisier than L1 and this difference must be taken into account.

- High
  It is more robust and is less susceptible to ionospheric noise.
- Ionospheric correction
  This noise model corrects for the ionosphere, and seeds the ionospheric correction algorithms forming a more accurate KAR fix.
- Medium
  There should be few cases where it performs better than the new high noise model.
- Low
  The low noise model places more weight on L2. It normally does not perform as well as the previous noise models, but for short baselines it may be helpful.
- Automatic
  The automatic noise model is the default, and it chooses between the High and the Ionospheric correction noise model depending on the current distance. The distance tolerance is specified in the dialog box.

▪ Manual KAR Engage

Users can manually engage KAR at times that they feel it is necessary. For instance, there may be a perfect time when an airborne platform is very close to the base. In such a case, also consider lowering the minimum KAR time. The user must specify the time of engagement as well as the process direction. This feature works well combined with the process KAR (Manual Only) setting in the Process Settings. This will allow KAR to only be engaged when selected by the user.

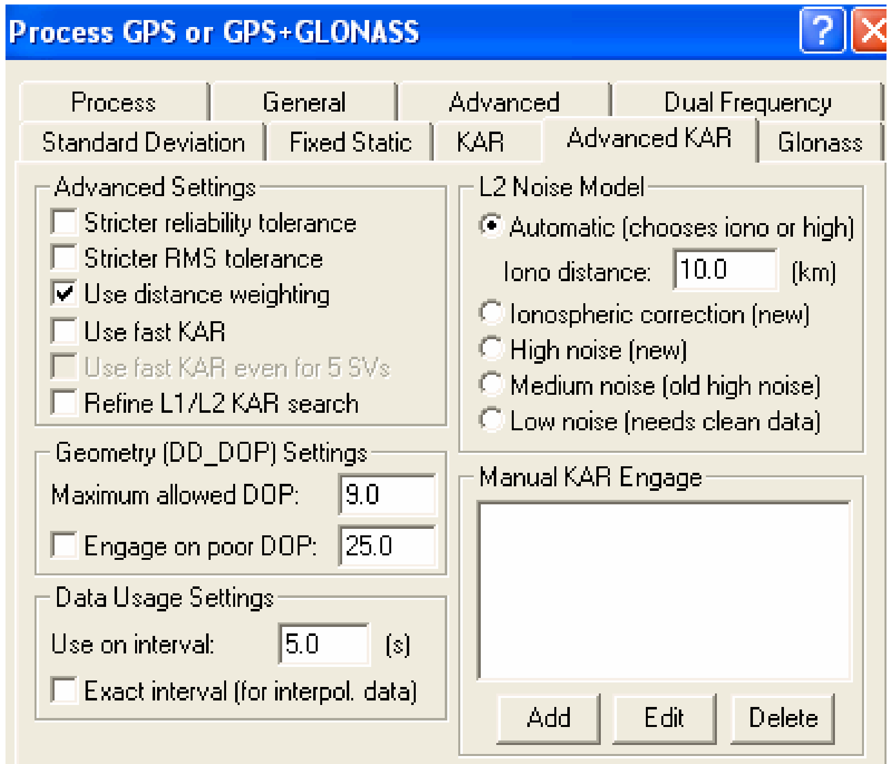

Figure 12A: Advanced KAR for “Process GPS or GPS+GLONASS”

o Glonass (Figure 13A)

The GLONASS options govern the way POSGPS will use GLONASS measurements when computing a solution

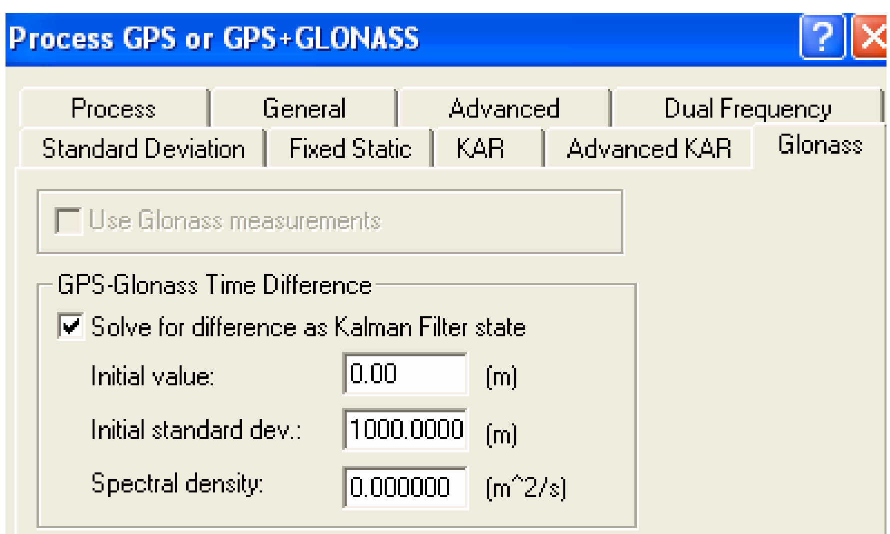

Figure 13A: GLONASS for “Process GPS or GPS+GLONASS”

1.c.3. Recommended options and potential problems for Airborne Datasets

As for airborne dataset, Base-Rover separation may be longer, normally >10~30km, the following options and tips should be considered.

1) Combine Forward and Reverse Solution
- The forward/reverse combination is a fast and easy check of the solution internal quality.
- The magnitude of the forward/reverse separation gives an indication of the reliability of the solution.

2) Use Static/Kinematic Flag
- Take advantage of the static part dataset to initialize GPS ambiguity if static part exists.
- Static part can be detected to check velocity estimation from float solution.

3) Processing Long Kinematic Baselines
- Use L2 for ionospheric processing
    - Ionospheric free Model: It works well when the remote initializes far from the base. However, a cycle slip on L2 will induce a total loss of lock for that satellite.
    - Relative ionospheric model: It works by only applying an ionospheric correction to the L1 signal and tends to have a higher L1 phase error than the iono-free, since it is only an approximation. However, cycle slips on L2 does not reset the ambiguity like the iono-free model. Hence, accuracies may be better if L2 cycle slips are present in large quantities.
- Use L2 for ambiguity resolution
- Use P-Code for Kalman Filter: C/A code can be corrected if P2 code is available. In many cases, this will simply add more noise, but the noise is very white, and overall improvements can be observed. It is often good to try with and without.

4) Eliminate problem satellites
- Detect problem satellites according to message logs or satellite residuals.
- Eliminate the problem satellites for the whole dataset or specific time periods.

Note: If the option "reset filter at unfixable bad data" is on (found in the Advanced Option tab of the processing options), large spikes may appear in every SV plot. Examining which satellite is the worst offender (that is, which has the largest satellite phase residuals) just prior to the filter reset, and omitting these satellites (up to just after the total loss of lock) will often not result in the total loss of lock induced by the filter reset option, and improve results considerably.

5) Set the proper standard deviation for kinematic convergence.
- Determine new standard deviation (C/A, P, L1, L2) according to the residual of a float solution.
- Modify the rejection tolerance according to the modification of new standard deviation.

6) Filter Reset in Kinematic Single Frequency
- The filter reset option can have a tremendous effect on accuracies.
- The filter reset will a cycle slip on all satellites if a small cycle slip has detected (since it cannot isolate which satellite the cycle slips happened on). Then, this small cycle slip may be left in the data.

- It is best to process once with this option on, combine the forward and reverse. Then process once without this option and combine. Use the one where the forward/reverse separation is lowest.

7) Processing Kinematic Data from Multiple Base Stations
- PosGPS does not support multiple base station data processing.
- Alternative approach.
  - Run forward/backward solution with one base station
  - Run forward/backward solution with another base station
  - Combine forward/forward or backward/backward solutions from two base stations.
  - Choose the best pair based on minimum combined forward/reverse separation, combined RMS, and combined position standard deviation.

8) Avoiding Missing Epochs
- Locktime cut-off option can ignore the first several seconds of data after a satellite rises.

9) Detecting and Fixing Incorrect Integer Intersections by KAR when it picks the wrong solution
- Check “combined forward/reverse separation”: => A near constant offset or poor performance in the combined forward/reverse separation.
- Check “Float/Fixed Ambiguity Status”.
- Compare fixed ambiguity solutions with float solution (difference and position standard deviation), to find which fixed solution is wrong.
- Processing direction of bad solution: => plot the L1 Phase RMS for each direction, the incorrect fix normally exhibits a linear growth to the carrier phase RMS
- Another way to determine the likelihood of a bad KAR fix is to view the Static/KAR summary file (.fss/rss). There will be records for each KAR fix. Look for fixes with poor RMS (>0.05 cycles), low reliabilities (<2-3) and/or large float-fixed separations (>1 m).
- Correcting the Problem caused by a bad KAR fix is normally a very easy problem to correct. It just requires one or more of the following settings to be changed. The first ones are more likely to help then the last.
  - Lengthen the minimum KAR time. As KAR uses more time, it usually rejects bad fixes better.
  - Enable the 'Stricter RMS tolerance' and/or the 'Stricter reliability tolerance' checkboxes in the Advanced KAR options.
  - If the auto-reduce KAR search area is used for dual frequency, try increasing the scale factor.
  - Use the KAR_SEP_TOL command to force KAR to only accept intersections that are close to the float solution. For instance, use a value of 1 m).
  - Lower the Maximum Engage Distance for KAR. Users may also wish to use the KAR_USE_DIST command and set the distance to a lower value as well.
  - If poor geometry is a concern, try lowering the 'Maximum allowed DOP' from the Advanced KAR Options.

10) KAR – Improving upon a 20-30 cm combined separation
- For long baseline airborne processing, this will be ok, however, it also may be improved

- Try both the Iono-free, relative models and combinations for forward and reverse.
- Enable the 'Engage KAR after poor DOP' option under the Advance KAR Options. This will be helpful if large DOPs are observed (plot the DD_DOP variable where DD_DOPS over 15-25 can cause instabilities). You may also need to check the message log file, as epochs with extremely poor DOPs are skipped and not visible on the data plots.
- Increasing either the KAR time or the KAR add time (i.e. #min/10km) can help as well, since KAR can sometimes pick the wrong L1 or L2 lane resulting in a 10-20 cm error.
- Try enabling the stricter RMS tolerance check box in the Advanced KAR Options. This will make KAR less likely to accept a bad solution.
- Try forcing the use of the Iono L2 noise model (or lower the Auto distance) in the Advanced KAR options. This causes ionospheric corrections to be more properly estimated.
- Try lowering the carrier PPM rejection (see Standard Deviation Options) to 0.5 or 0.25, as this makes the error rejection routines more sensitive. This is not always beneficial, but it is worth a try if nothing else helps.

11) Using KAR With Interpolated Data
- If the Download Service Data function was used to download CORS or IGS data, you have the option of interpolating to a higher interval. In such a case, the epochs not on the original interval (usually 30 s), has errors of ~1 cm. If KAR uses this data, it will often fail. Therefore, under the Advanced KAR options, set the 'Use on interval:' value to the original data interval of your data (e.g. 30 s). In addition, enable the 'Exact interval (for interpol. data) option. This will cause KAR to only use the data on the exact 'n' second interval. The minimum KAR time may need to be increased to compensate for less data being used by KAR.

12) L2 noise modeling
- High Noise model: => Less reliant on L2, reliable if L2 is noisy
- Iono Noise model: => Seeds the iono-free and relative ionospheric models, this can produce a more accurate final solution. Not only removes ionospheric error to improve reliabilities, but it also seeds the ionospheric correction (when engaged).
- Auto Noise model: => Chooses between the High and Iono noise models based upon the distance when the search is performed. The distance tolerance for choosing between the two noise models (i.e. High and Iono) can be specified in the Advanced KAR Options. In most cases the Auto setting works best.

13) KAR options – could not find a solution
- Resolving this problem is usually more difficult than resolving the problem of picking a wrong solution. This is because the inability to pick a solution is most often related to noisy carrier data on L1 and/or L2. Usually, playing with the KAR time and search region size is all that can be done.
- For dual frequency, switching to other noise models can help if there is a problem with L1 or L2.
- For dual frequency GPS data with good C/A code, set the C/A standard deviation to 2-3 meters.
- Change the size of the KAR Dual Frequency Search Region size to 1.5 meters. Use KAR Options.
- Raise the KAR Minimum Time for Dual Frequency to 3 or more minutes. Use the KAR Options as well
- From the Options Menu, select User Defined Options. Enter the command: KAR_SEP_TOL=0.75

- For single frequency KAR, the L1 phase needs to be very clean, and there has to be a period of at least 10 minutes without a loss of lock. These conditions are not always possible in many environments.

Note: Using this above procedures will help in finding a solution but may increase the chance of a false intersection as well. Therefore, it is important that FWD/REV solutions agree.

1.c.4. Export results of PosGPS to PosProc

“Output” => “Export to PosProc” (Figure 14A)

Results are exported to the PosProc module for further processing.

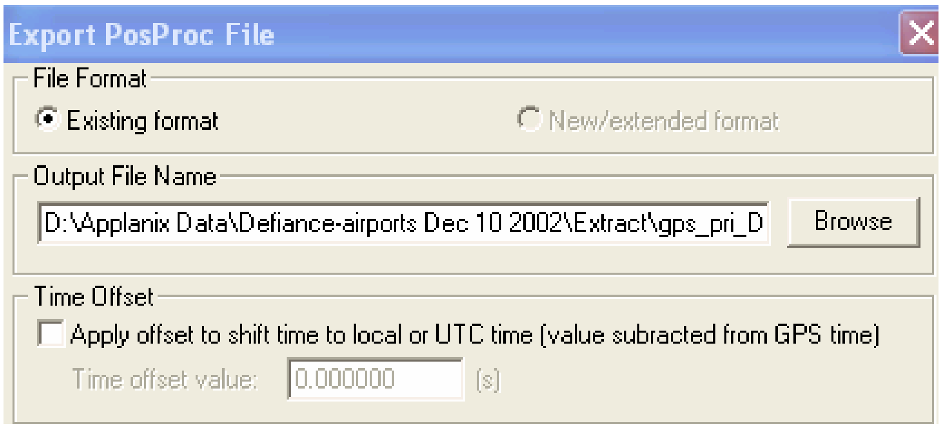

Figure 14A: Export to PosProc File

1.c.5. Other potential solutions if invalid or no solution for PosGPS is obtained

- Try other GPS kinematic software, for example, Trimble Office, Trimble Total Station with VRS, Javad Pinnacle, Laika SKI, or other GPS software package supporting multiple base stations.
- Generate output according to format of PosGPS. (Table 3A)

File Name: gps_pri_Kernel.dat

Column	Data Description	Unit
1	Time	GPS Week Second
2	Latitude	Deg
3	Longitude	Deg
4	Height	Meter
5	Velocity North	Meter/sec
6	Velocity East	Meter/sec
7	Velocity Height	Meter/sec
8	Standard deviation East	Meter
9	Standard deviation North	Meter
10	Standard deviation Height	Meter

Table 3A: File format for GPS Solution output file.

Note: Normally, the outputs of traditional GPS software package don’t include the velocity estimation, and then the velocity column can contain any value (double) put by the user. However, in the following step “IIN Kalman Filter”, the velocity measurement must be excluded.

1.d. IIN (Inertial Integrated Navigation) Kalman filter using POSProc SBET

1.d.1.IIN filter setup (Figure 15A)

- "Setup" => "IIN Filter"

The Kalman Filter setup window enables entry or editing of Kalman filter parameters which normally are not recommended to be modified from their default values.

- Editing Kalman Filter control parameters and values:
    - Prefilter Interval: specifies the iteration (repeat) interval of the averaging prefilter. The default value is 1 second.
    - Kalman Filter Interval: specifies the iteration interval of the Kalman filter. It must be an integer multiple of the prefilter interval. It can be equal to the prefilter interval, in which case the Kalman filter processes each constructed measurement, i.e. measurements are not averaged. The default value is 1 second.
    - Measurement Residual Ratio: specifies the ratio of the computed residual with the RMS residual used by the Kalman filter measurement residual test to accept or reject constructed measurements. The default value is 3.0 which implies that a measurement residual that is 3 times the Kalman filter predicted RMS residual is rejected, i.e. not processed, on the assumption that one or more of the data items used in the constructed measurement are bad. Selecting larger values risks the inclusion of bad data.
    - Exit after (default = 50) consecutive measurement rejections: The consecutive measurement rejections feature ensures that periods of data abnormality are identifiable and absolutely excluded.

- Measurements Sheet: Estimated measurement accuracy for selected aiding data.

    - Coarse and Fine Alignment: Some state and measurement parameters can have different values for the coarse and fine alignment error models. These include all system state process noise spectral densities, 1st order Markov state correlations times and all measurement noise standard deviations.
    - Adaptive/Fixed/Means RMS: Some measurements, notably those constructed from GPS position, velocity or attitude data, can be configured to use the RMS error included with the data. This is called adaptive measurement noise parameterization. Selecting Adaptive RMS enables the Kalman Filter to recognize and use embedded values. Also it will enable adaptive measurement noise parameterization. Select a measurement noise (Means RMS Scale) scale factor (default is 1.0). The Kalman filter multiplies the RMS error provided with the data by the specified scale factor and then selects the maximum of the scaled RMS error and the measurement noise RMS parameters specified in the edit boxes. The specified measurement noise RMS parameters become lower bounds on the measurement noise RMS that the Kalman Filter uses. Click on Fixed RMS to disable adaptive measurement noise parameterization. In this case the Kalman Filter ignores the RMS error in the data and uses the specified measurement noise RMS parameters as given.

- North, East, Down, X, Y, Z, SIN, COS Measurements:

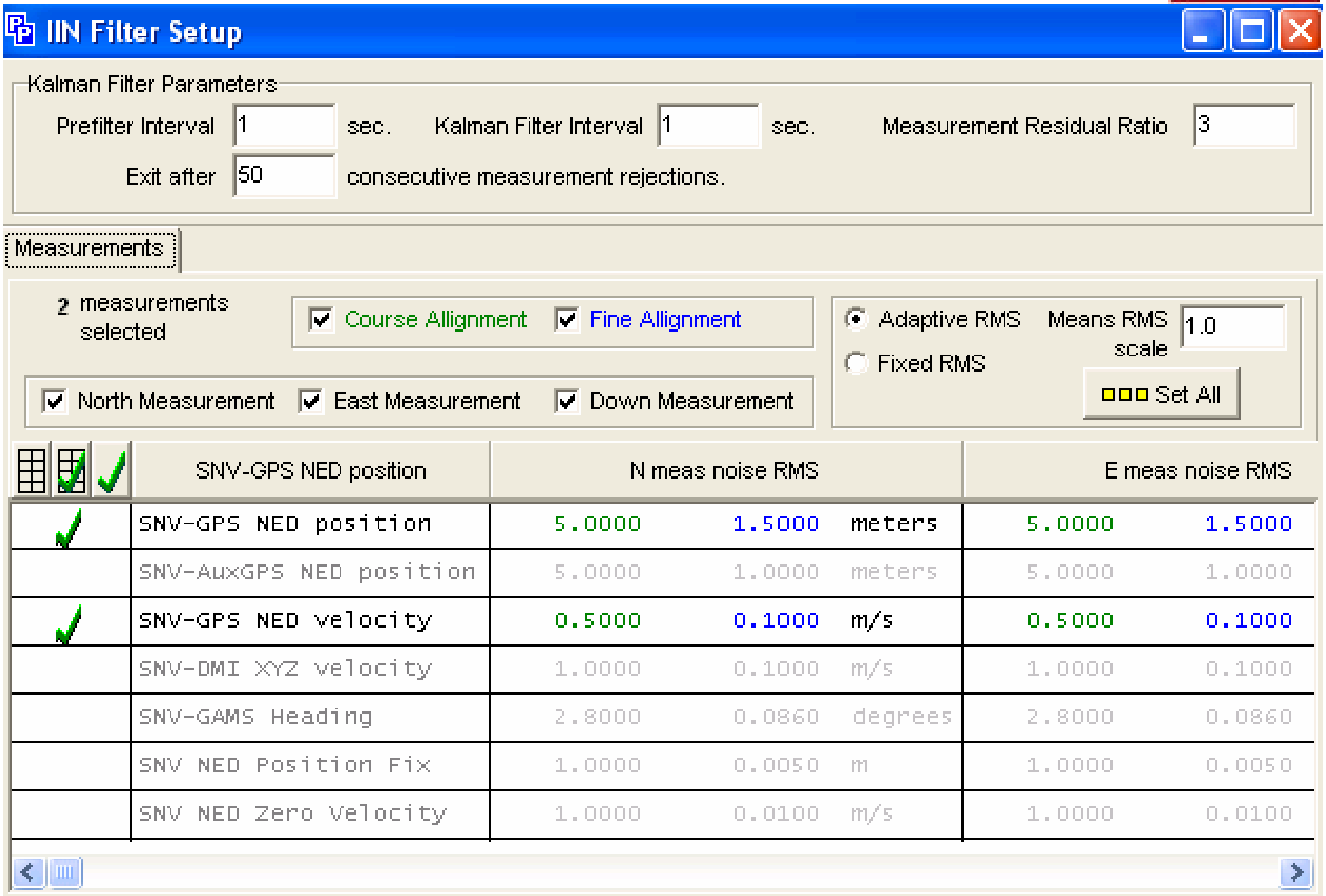

Figure 15A: IIN Filter Setup

1.d.2.Data processing

“Run” => “Proc” => “SBET” (Figure 16A)

System will automatically detect the quality of GPS solution (C/A, P, CD, FD, ID), and Time Tag (Start Time and End Time) for GPS and IMU data.

Note: There are several parameters that can be configured, and these parameters normally are not recommended to be modified from their default values.

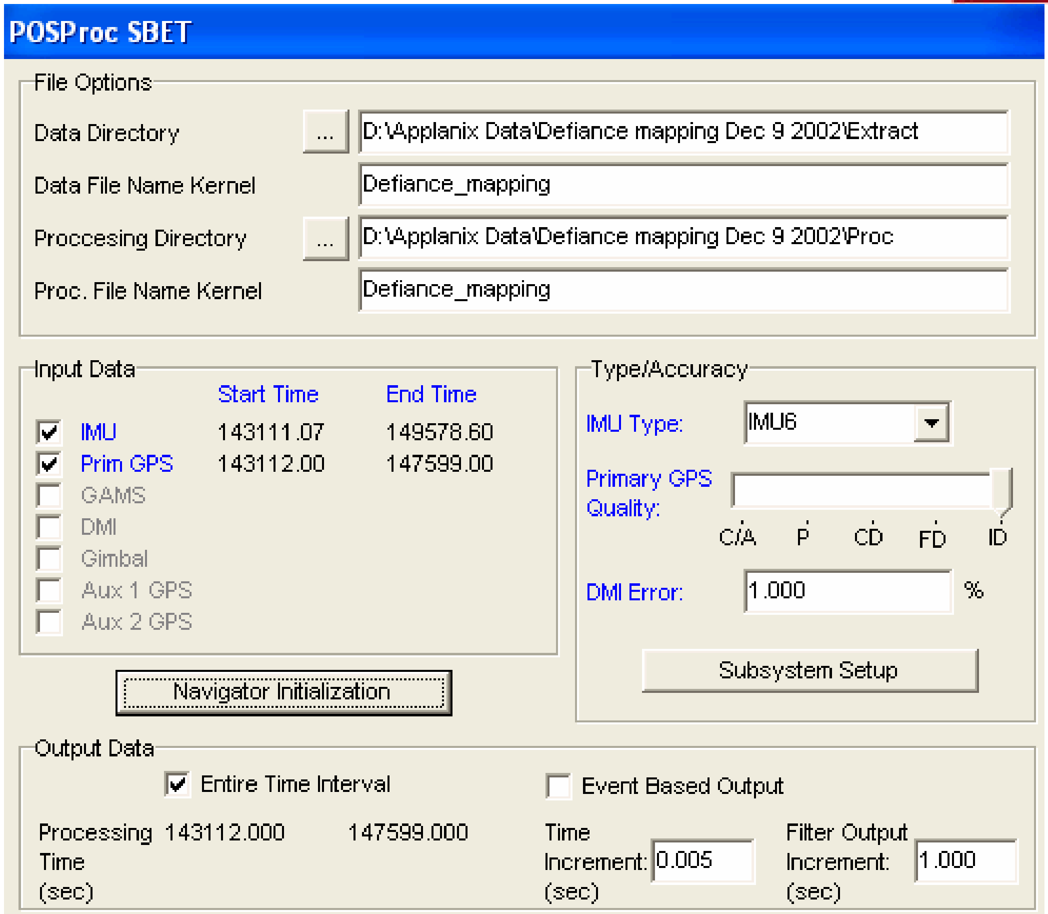

Figure 16A: POSProc SBET

- Quality of GPS Solution (Figure 17A)

Adjusts signal quality scale selection, from lowest (C/A) to highest (ID). The adjustable sliding scale represents the auto-detected quality of available GPS data (ID = highest, C/A = lowest). ID = Integer Carrier Phase Differential GPS, FD = Float Carrier Phase Differential GPS, CD = Code Differential GPS, P = P-Code GPS, C/A = Code GPS. Every time SBET/IIN is run, the selected grade of accuracy becomes the default setting.

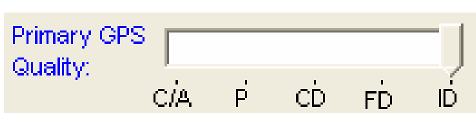

Figure 17A: Quality of GPS solution

Note: The higher the quality factor, the more weight was put in GPS solution in GPS/INS Kalman filter.

- Output
  - Processing Time (sec), Entire Interval (checkbox): Delineates the total quantity of available data output (Figures 18A, 19A).

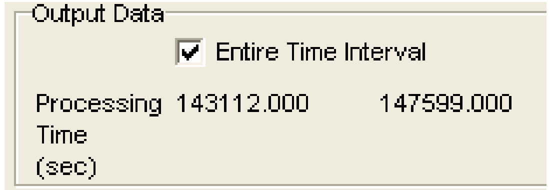

Figure 18A: Entire Time Interval

Figure 19A: Customized Time Interval

- Time Increment (sec): Regulates how frequent available data is output in the file.
- Kalman Filter Time Increment (sec): Regulates how frequent the Kalman Filter data will be output in the file.

➢ Navigator Initialization (Figure 20A)

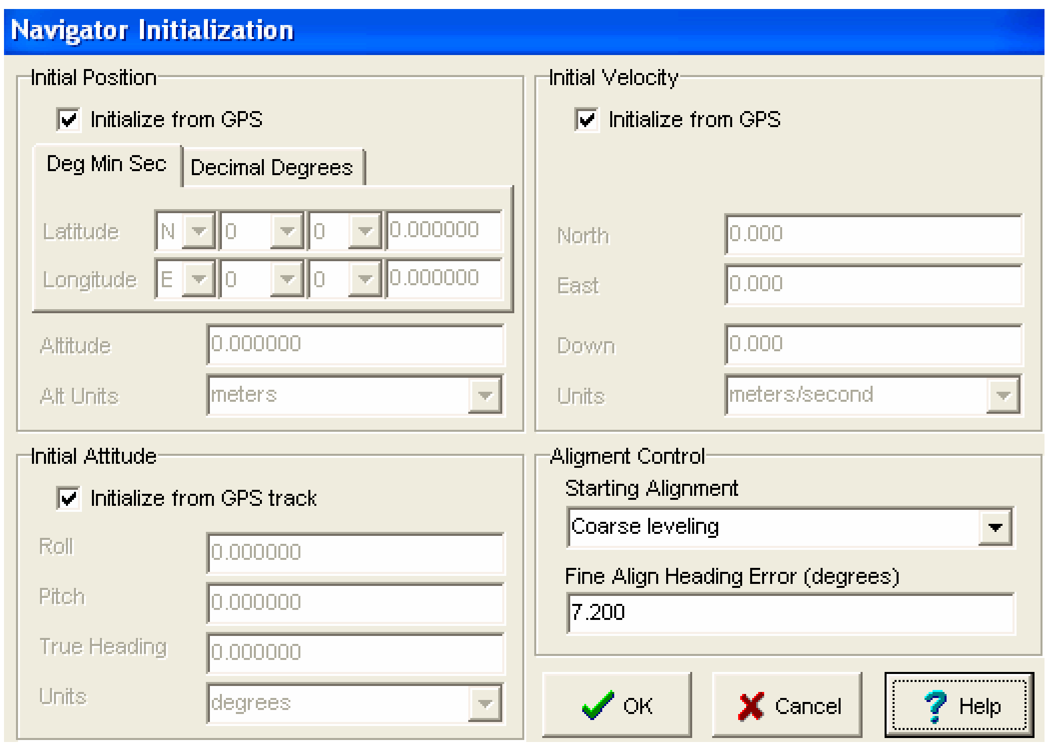

Figure 20A: Navigator Initialization

- Initial Position
- Initial Velocity
- Initial Attitude
- Alignment Control:

Starting alignment is the alignment mode in which IIN starts. Coarse Leveling to Fine Alignment are used to align the IIN inertial navigator when the inertial data comes from an IMU.

1) Select Coarse Leveling if initial roll, pitch and heading are completely unknown.
2) Select GC Coarse Heading Init 1 if roll and pitch are known to within 2 degrees accuracy but initial heading is unknown, and GPS is selected as a source of velocity aiding data.
3) Select PC Coarse Heading Init 1 if roll and pitch are known to within 2 degrees accuracy but initial heading is unknown, and DVS or DMI is selected as a source of velocity aiding data.
4) Select GC Coarse Heading Init 2 if initial heading is known to within 45 degrees accuracy, and GPS is selected as a source of velocity aiding data.
5) Select PC Coarse Heading Init 2 if initial heading is known to within 45 degrees accuracy, and DVS or DMI is selected as a source of velocity aiding data.
6) Select Fine Alignment if initial heading is known to within Fine Alignment Heading Error value (default is 10 degrees) accuracy. Fine alignment heading error is the heading error in degrees at which IIN transitions to Fine alignment mode. The default value of 10 degrees is sufficient. You can select a smaller value, which will postpone the transition to Fine Alignment mode. You should note that IIN outputs smoother data only in Fine Alignment.

➢ Subsystems Setup (Figures 21A, 22A, 23A)

Level arms for GPS, IMU and reference are inputted here.

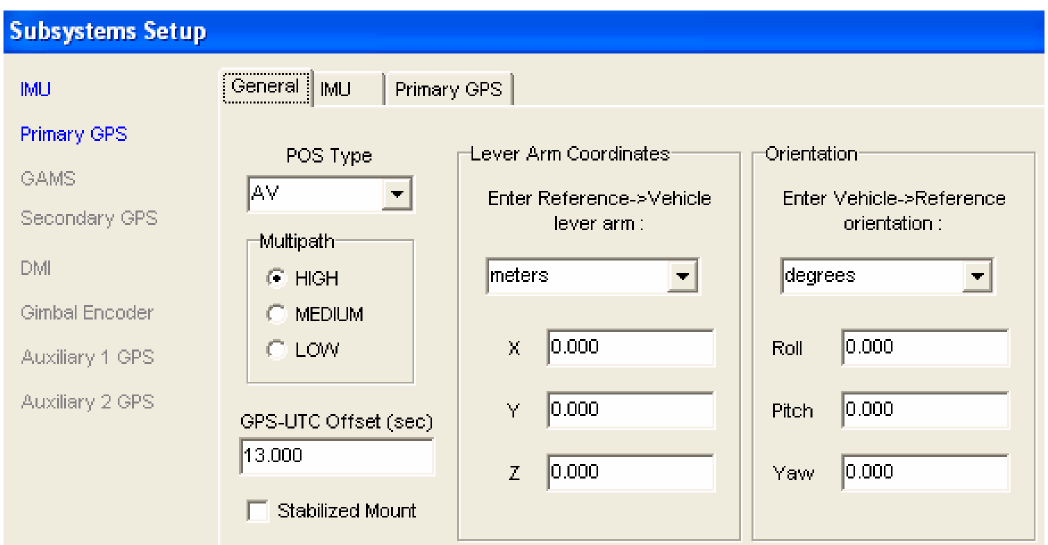

Figure 21A: General for Subsystems Setup

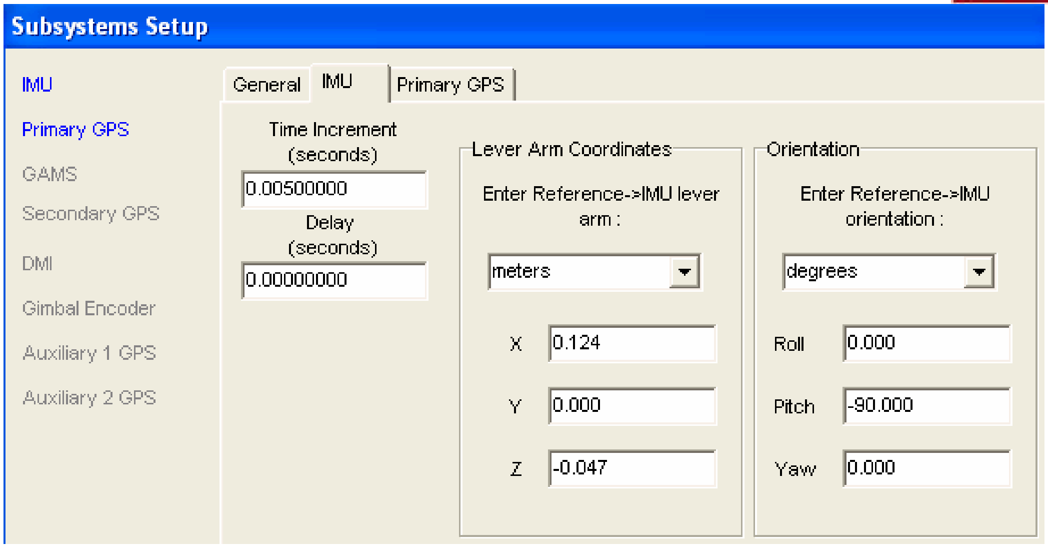

Figure 22A: IMU for Subsystems Setup

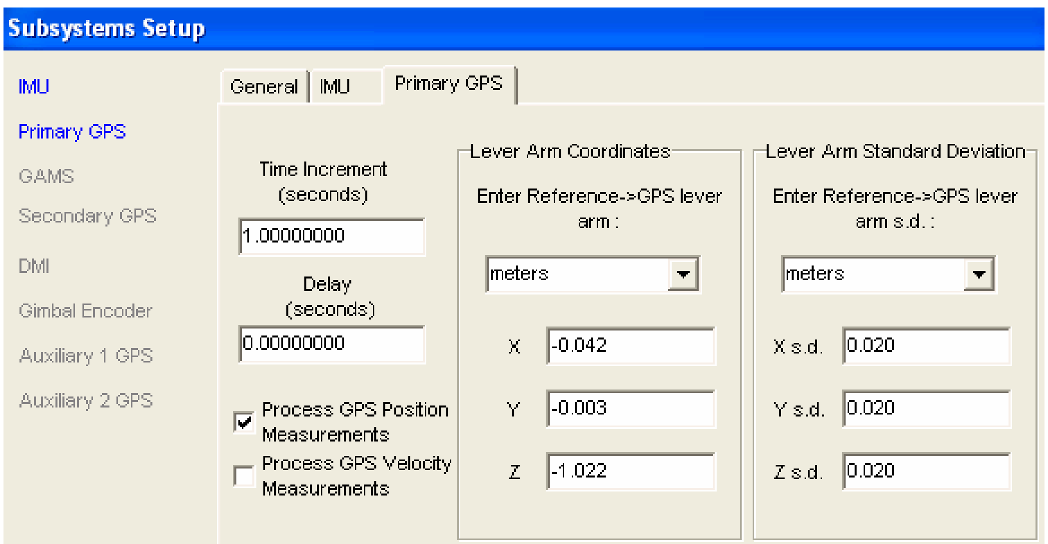

Figure 23A: Primary GPS for Subsystems Setup

1.d.3.Potential problems

- Kalman filter measurement rejections
  IIN will terminate, by default, after 50 continuous measurement rejections. This implies that
  1) the inertial and aiding sensor data are not consistent at the beginning of a processing run or throughout the run, or
  2) The Kalman filter error model is inconsistent with the inertial and aiding sensor data. Measurement rejections during the critical alignment phase can result in an abnormal alignment and a resulting inertial navigation solution whose errors grow rapidly to the point that the Kalman filter model of these errors is no longer valid.
- Wrong Configuration: An incorrect configuration may include an incorrect IMU, GPS or POS type.

- Wrong Geometry: An incorrect user-to-IMU frame geometry entered in the Subsystems window can result in measurement rejections. If the IMU is mounted with the IMU frame rotated with respect to the user frame, then continuous measurement rejections will likely occur.
- Time Alignment Error: A key requirement for a successful integration of inertial and aiding sensor data is good time alignment among the input data. Time alignment implies that the time stamps on the various input data are accurate and consistent with each other.
- Data Gaps in IMU Data: An inertial navigator computes a navigation solution essentially by integrating the IMU data (it in fact solves Newton's equations of 6 degree-of-freedom motion on the ellipsoidal rotating Earth). Continuity of IMU data is essential. An IMU data gap of more than one or two samples results in a sudden change in navigation accuracy that is inconsistent with the Kalman filter error model of inertial navigator errors. The inertial navigation solution becomes inconsistent with the aiding sensor data and measurement rejections can result. IMU data gaps are almost always caused by the IMU data acquisition system. If continuous measurement rejections appear to begin after a period of seemingly successful integration, then one or more IMU data gaps may be the cause. Viewing pre-processed (extracted) IMU data records and analyzing the results of the IMU continuity checking utility, at and around the time of measurement rejection may help identify and isolate error sources. Forcing data at specific error-ridden junctures may help resolve the problem.
- Incorrect Subsystem Error Statistics: If overly optimistic RMS errors arrive from the GPS receiver or other aiding sensor, and adaptive measurements are selected, the filter finds inconsistencies between the actual measurement errors and the predicted accuracy, resulting in measurement rejections. Moving the GPS Type slide bar, in a decreasing GPS accuracy direction as well as increasing the adaptive scale factor, and/or measurement RMS values, will help resolve the problem.
- Coarse Leveling Failure: Starting the Coarse Leveling alignment mode during acceleration maneuvers can cause coarse alignment failure where roll and pitch are computed incorrectly to the vehicle dynamics. For best results, start the post-processing integrated inertial navigation process when the vehicle is stationary or moving at a constant velocity.

APPENDIX B

Data processing and performance analysis

Level arm (Table 4B)

Reference	User0/IMU lever arm	0.124	0.000	-0.047	m
	User0/IMU Alignment Angles(R, P, Y)	0.000000	-90.000000	0.000000	deg
	Primary GPS Anntenna lever arm	-0.042	-0.003	-1.022	m
	Primary GPS Anntenna lever arm s.d.	0.02	0.02	0.02	m

Table 4B: Lever arm offsets

1.e. Toledo dataset on Dec. 03 2002

1) Data Description:

Toledo Dec. 03, 2002

The Applanix was "turned on" on the ground at OSU airport (approx. 10:05 AM). After about 10 minutes initialization on the ground we took off to our photo job in the Defiance area. About 10:50 AM we flew a "figure 8" pattern somewhere over Northwest Putnam County before starting taking any photo. The weather went bad so we decided to turn off the Applanix in flight on our way to the Toledo Metcalf airport. **In this block of data there is no photo events.**

At 1:50 PM the Applanix was again turned on (in flight start) on our way to the Toledo area in Lucas County for our next photo job.

At 15:30 the Applanix was turned off over Northern Lucas County in flight to OSU airport.

2) Base Stations (Table 5B)

Station Name	PCL1 XYZ	PCL1 BLH	Comment
Defi	467314.198	41 16 37.27488 N	CORS
	-4777688.986	84 24 48.84760 W	
	4185713.801	183.1981	
Tiff	574288.306	41 4 29.89682 N	CORS
	-4780915.736	83 9 1.41543 W	
	4168842.402	211.7497	
Tldo	542671.7084	41 36 46.22400 N	Trimble Office
	-4744847.3164	83 28 31.40175 W	
	4213652.4089	153.6196	
Sidn	494661.2160	40 18 37.26539 N	CORS
	-4845525.5550	84 10 15.90730 W	
	4104513.7730	293.5440	
Colb	592757.0630	39 57 35.11261 N	CORS
	-4859704.8780	83 2 44.74742 W	
	4074681.1330	186.5667	

Table 5B: Base Stations for Dec. 3, 2002 Toledo dataset
Note: PCL1: Phase Center for L1

3) Trajectory (Figure 24B)

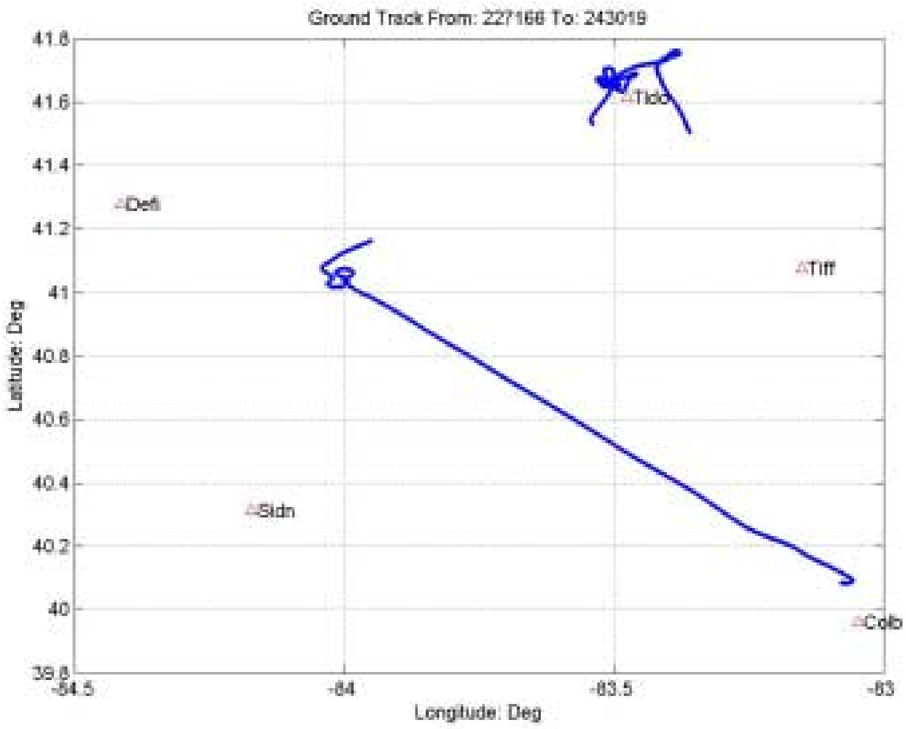

Figure 24B: Trajectory for Dec. 3, 2002 Toledo dataset

Five base stations are available for this dataset with varying Base-Rover separations. So, in order to utilize the nearest base stations, a strategy for GPS data processing can be carried out as followed:
Divide the original GPS dataset into two datasets and use different base stations for different segments. (Table 6B)

	Start Time	End Time	Forward Base	Backward Base
Segment I	227165	230313	Colb	Defi
Segment II	240586	243020	Tldo	Tldo

Table 6B: Two segments from the original dataset.

4) GPS Data processing for Segment I

Processing using Base Station Colb
Options used (Table 7B)

Category	Sub Category	Values
Process	Process Direction	Both
	Process Data Type	Dual frequency carrier phase
	Static Initialization	Float ambiguity or kinematic initialization
Dual frequency	Dual frequency measurement usage	Use L2 for Ambiguity resolution Use L2 for ionospheric processing
	Ionospheric processing	Ionosperic free model
Standard deviation	Standard deviation	C/A code: 3m L1 phase: 0.02m P2 code: 0.5m
	Rejection tolerance	C/A code: 12m L1 phase: 0.1m P2 code: 2.5m

Table 7B: Options used to process dataset segment I using base station Colb
Note: Others options will be same as default.

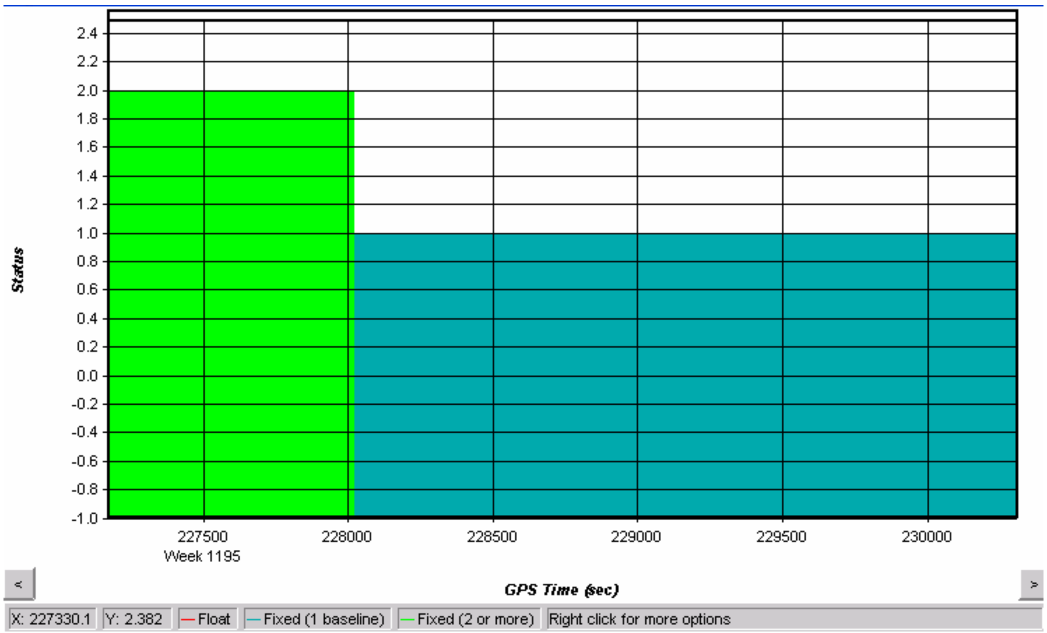

Figure 25B: Ambiguity fixed information for solution using Base Station Colb

Although the ambiguity fixed information for solution using base station Colb (Figure 25B) indicate good solution, however, the forward/backward separation (Figure 26B) show bad agreement in the begin and at the end between forward and backward solution. This should be the wrong solution is backward solution. The forward/backward separation of solution using base station Defi (Figure 27B) indicates a better agreement, even though this solution is based on float ambiguity.

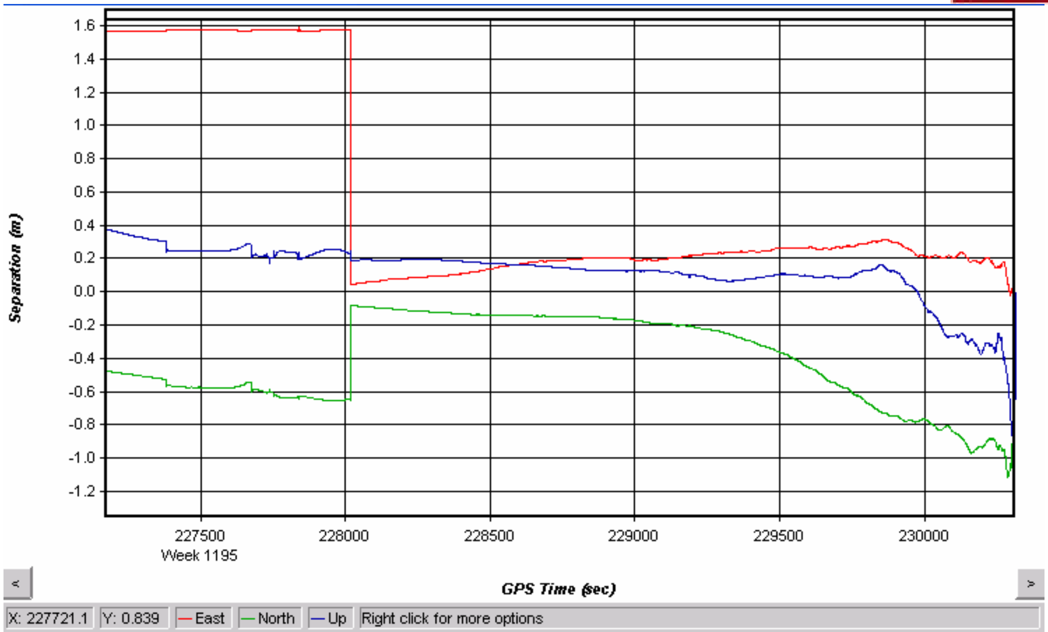

Figure 26B: Forward/Backward Separation of solution using base station Colb

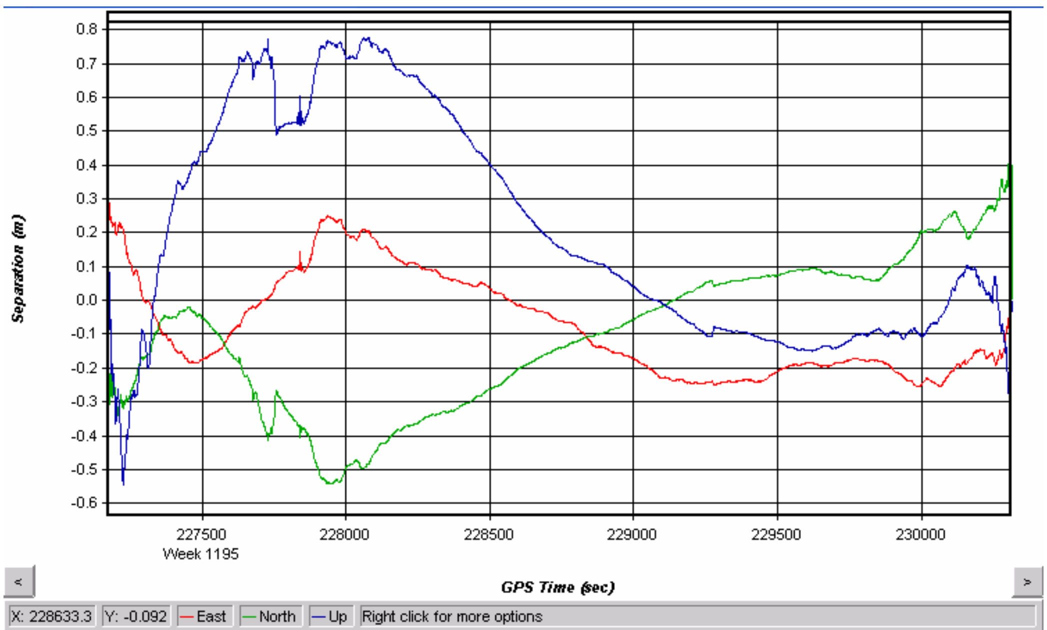

Figure 27B: Forward/Backward Separation of solution using base station Defi

The final solution can be achieved by combining the forward solution using base station Colb and the backward solution using Defi (Figure 28B).

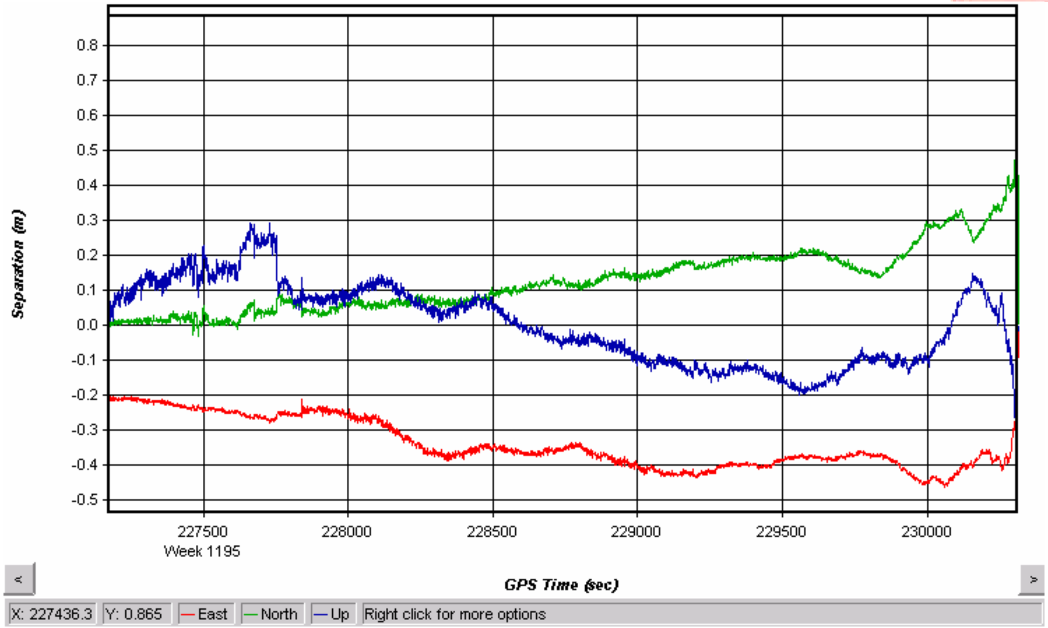

Figure 28B: Combined solution from forward solution using base station Colb and backward solution using base station Defi.

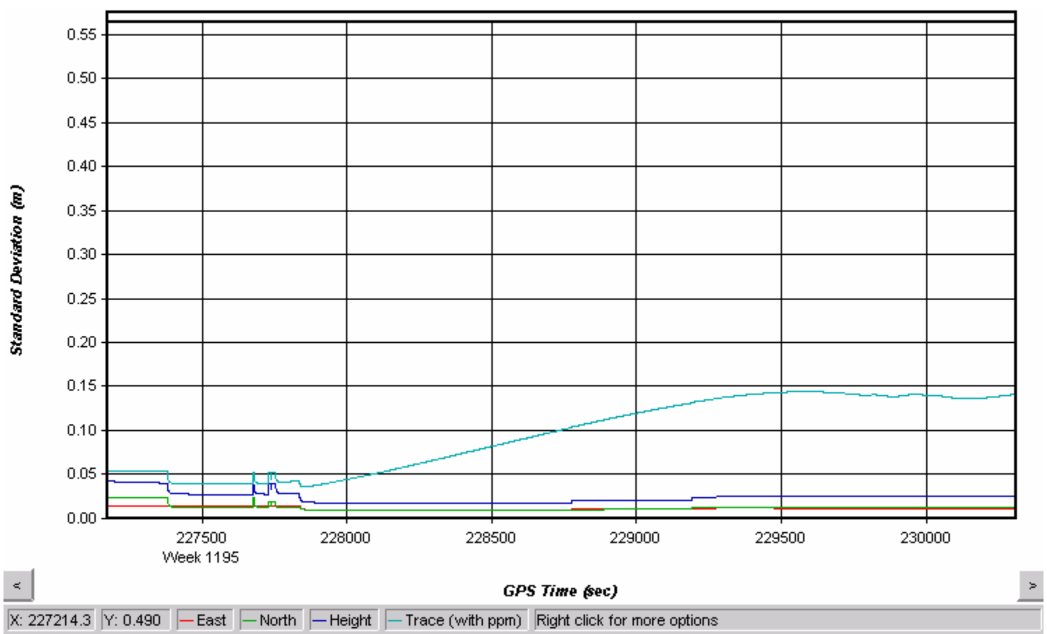

Figure 29B: Position Standard deviation of the combined solution.

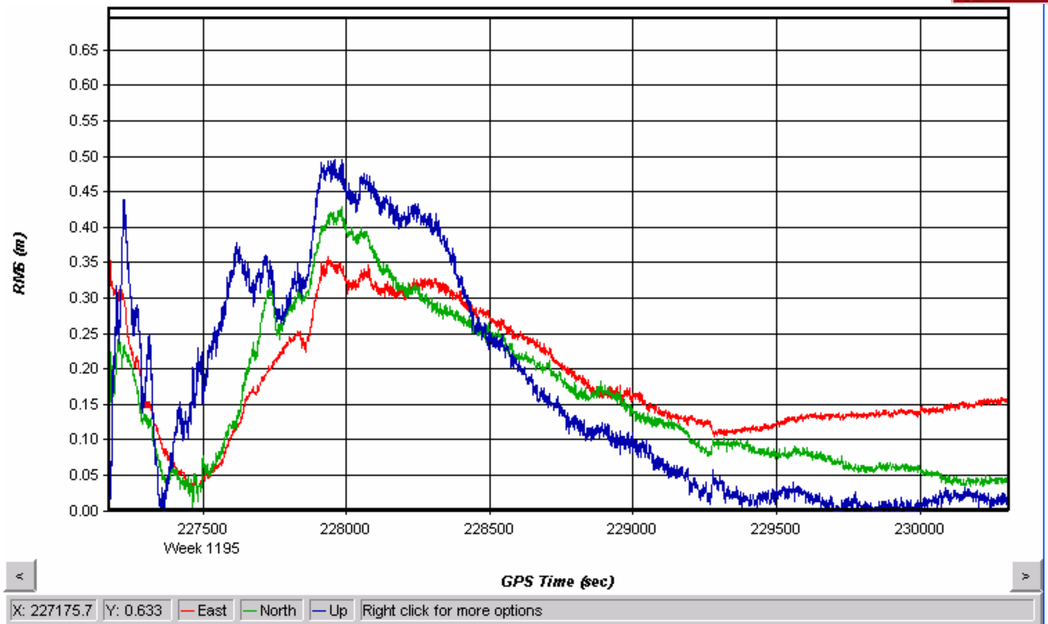

Figure 30B: Combined RMS of the combined solution.

5) IIN Kalman Filter Data processing for Segment I

Problems exist when running IIN Kalman Filter

```
227846.004896 - Too many consecutive IIN measurement rejections
```

Different parameter configurations were tested to process the data, but all failed.

6) GPS Data processing for Segment II

Processing using Base Station Tldo
Options were applied same as Table 7B.

The forward/Backward separation, the Combined RMS and position standard deviation indicate that the solution is a good solution.

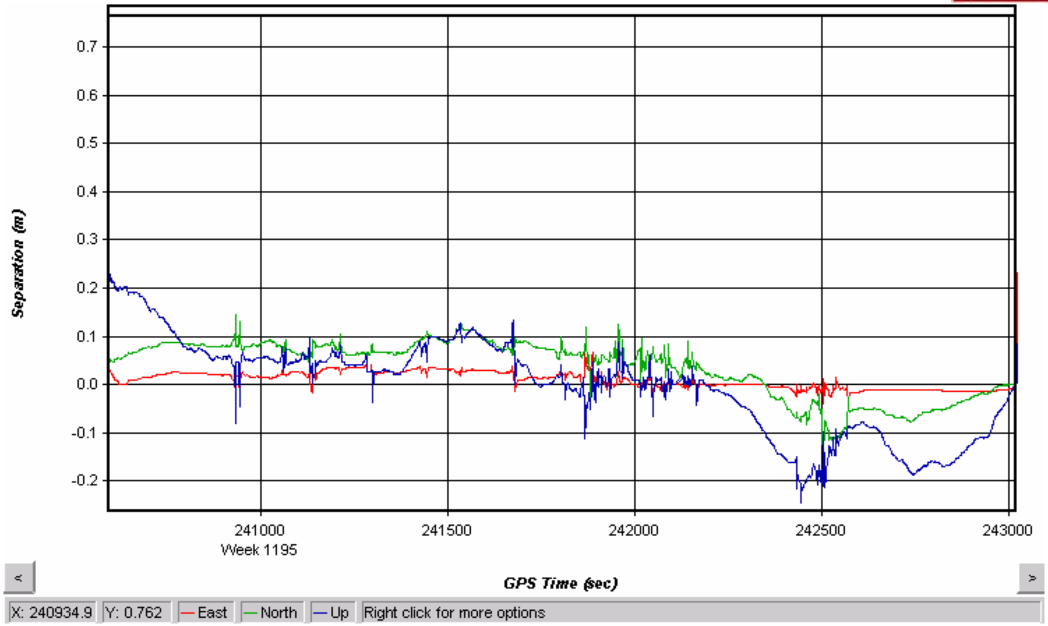

Figure 31B: Forward/Backward Separation

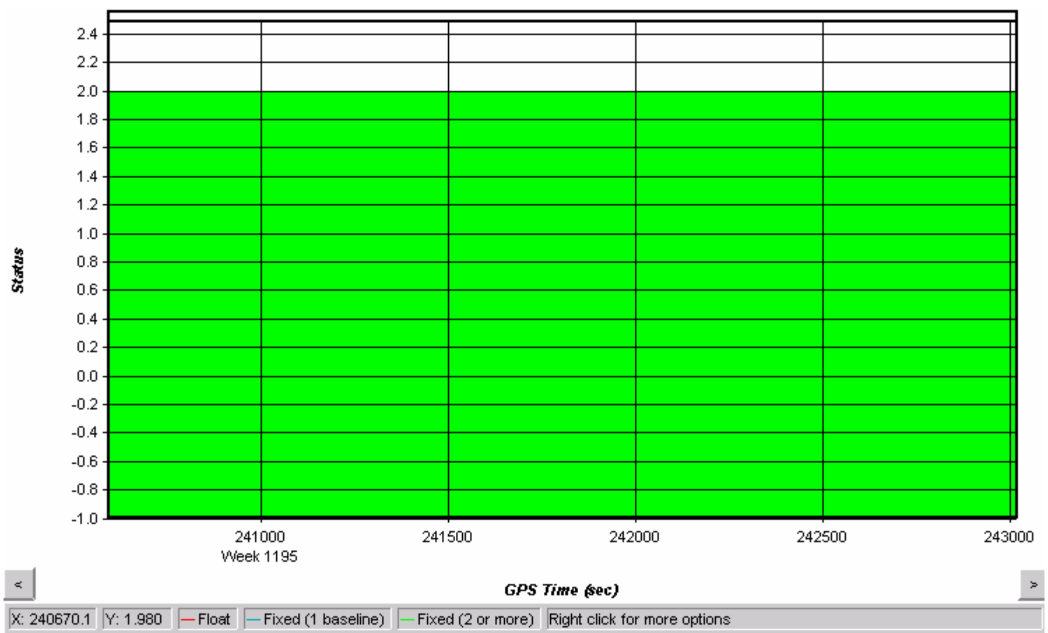

Figure 32B: Ambiguity Fixed information

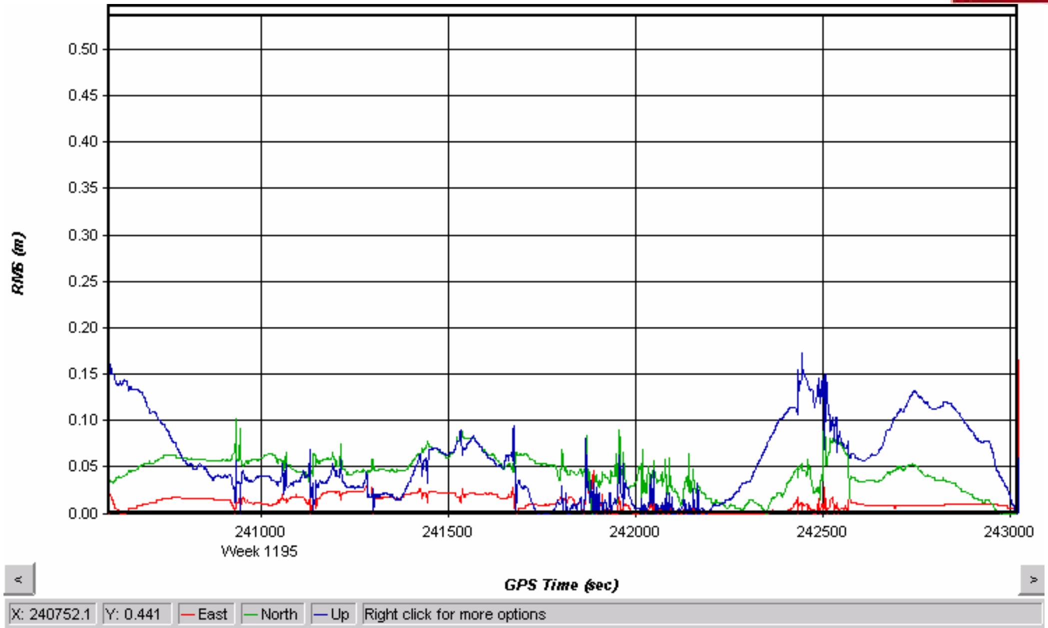

Figure 33B: Combined RMS

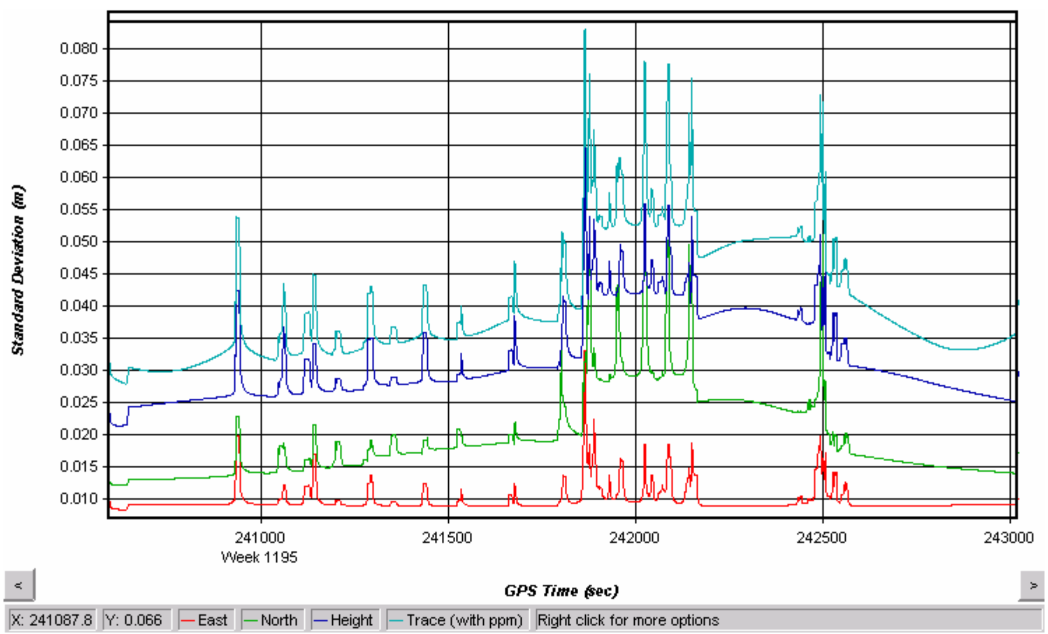

Figure 34B: Position Standard Deviation

7) IIN Kalman Filter Data processing for Segment II

Successfully obtained the solution using default parameters

The zero-mean bound measurement residuals of N, E, D indicate correctness of IIN Kalman Filter (Figure 35B).

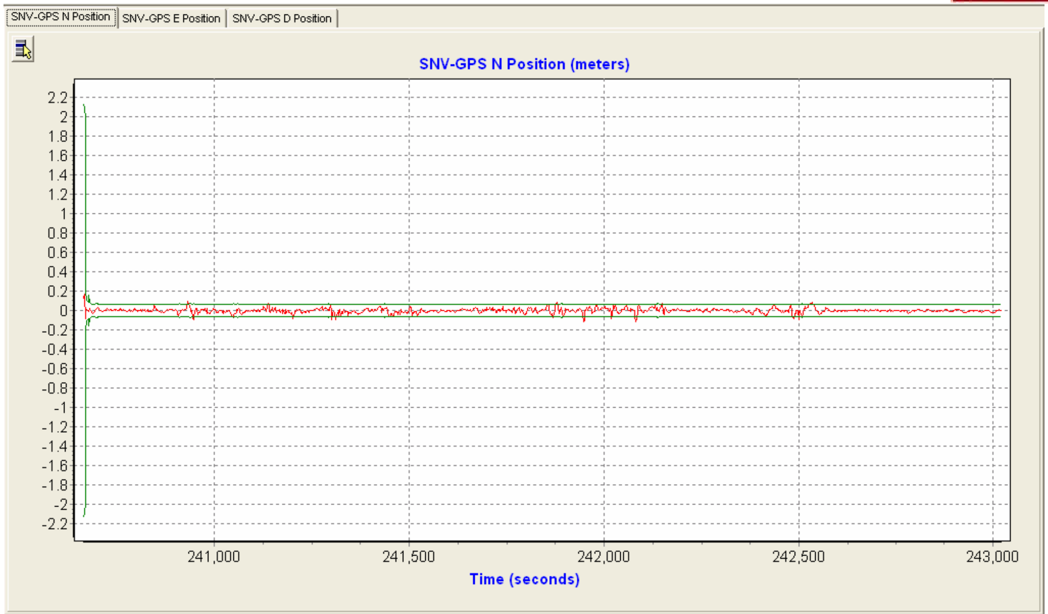

Figure 35B: Measurement Residual

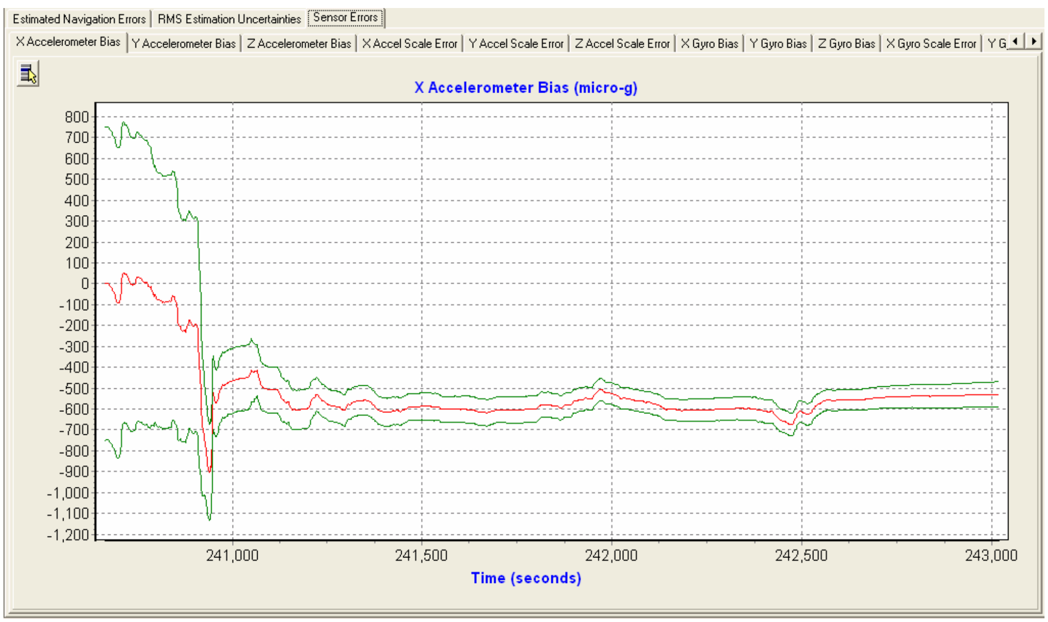

Figure 36B: Estimated Errors and RMS

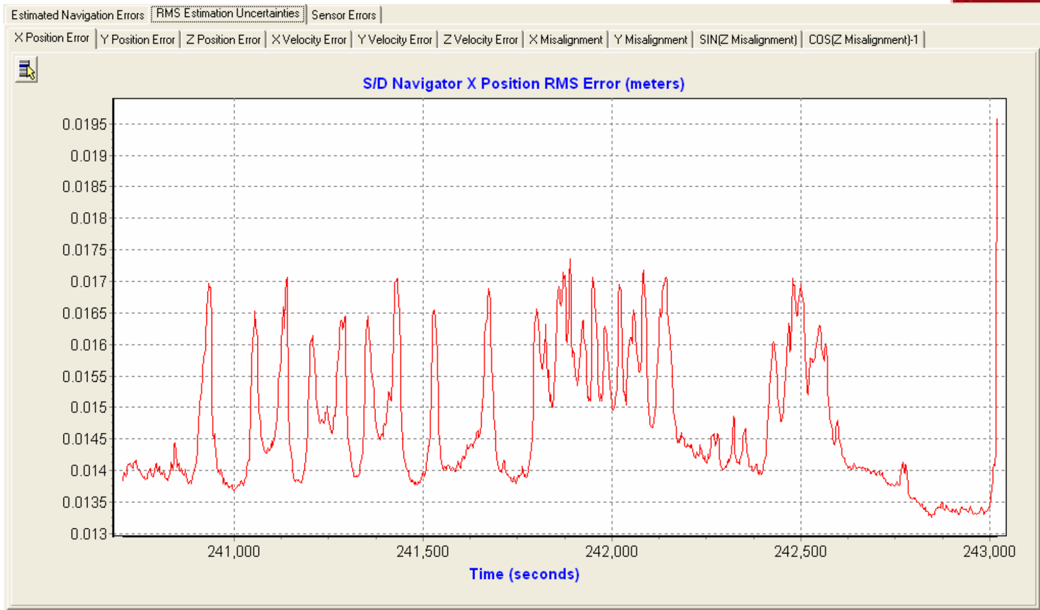

Figure 37B: Smoothed Estimated Errors and RMS

1.f. Franklin 670 dataset on Dec. 6 2002

1) Data Description

Franklin 670 dataset on Dec. 6, 2002
Applanix turned on in flight 10:00 over Western Franklin County. Then we flew for approx. 3 minutes straight and level. At 10:05 we flew a "figure 8" pattern. At 10:09 we started the climb up to the photo flight level.
On the site (over downtown Columbus), we flew until 10:28.
After flying straight for approx. 1 minute the Applanix was turned off in flight heading East from Franklin Co to Fairfield County.

2) Base Stations (Table 8B)

Station Name	PCL1 XYZ	PCL1 BLH	Comment
Mcon	698831.4080	39 39 39.03114 N	CORS
	-4867123.7930	81 49 45.12251 W	
	4049241.1370	272.7985	
Mtvr	634180.8892	40 22 56.57512 N	CORS
	-4824018.3128	82 30 38.38094 W	
	4110605.4927	286.6493	
Sidn	494661.2160	40 18 37.26539 N	CORS
	-4845525.5550	84 10 15.90730 W	
	4104513.7730	293.5440	
Colb	592757.0630	39 57 35.11261 N	CORS
	-4859704.8780	83 2 44.74742 W	
	4074681.1330	186.5667	

Note: PCL1: Phase Center for L1

3) Trajectory

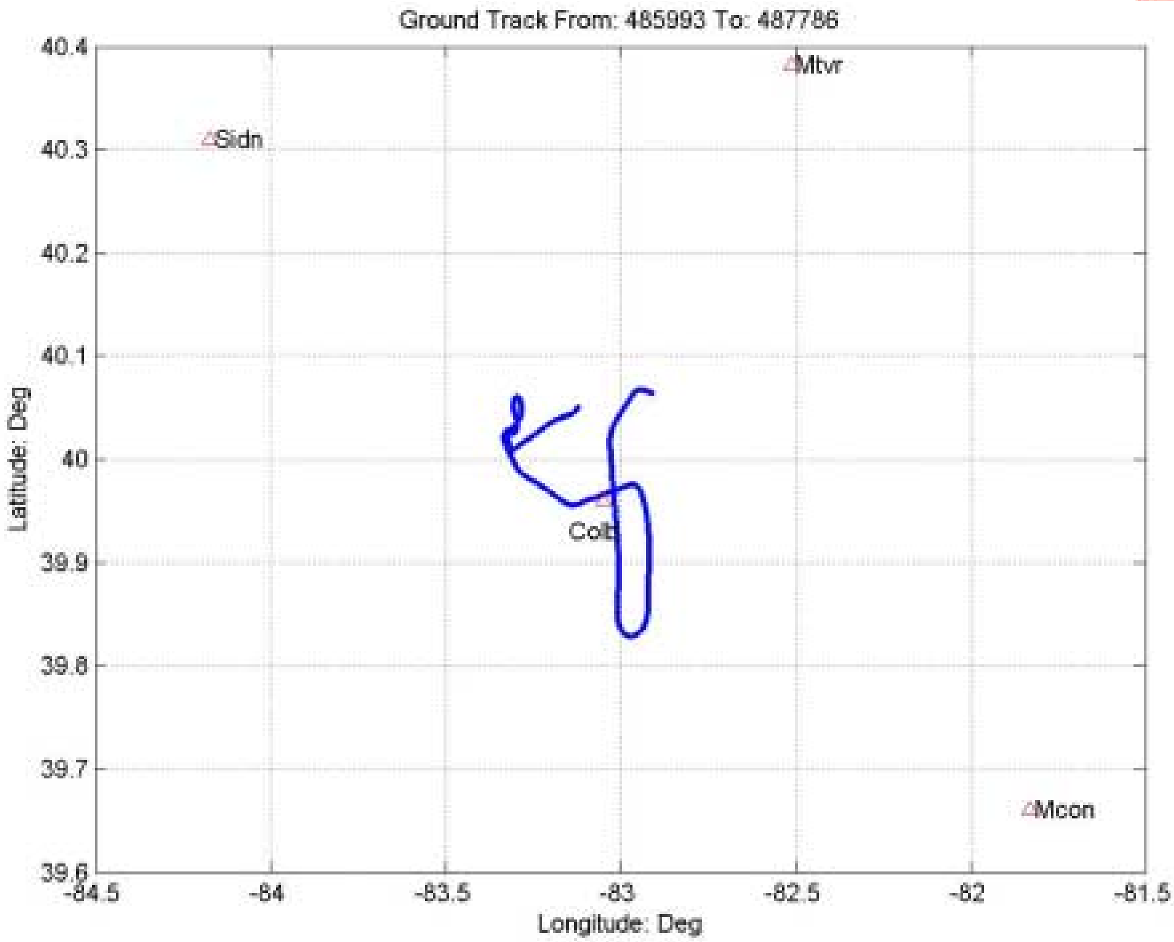

Figure 38B: Trajectory for Dec. 6, 2002 Franklin 670 dataset

4) GPS Solution

Time Problem
There was a jump in the RINEX file after the epoch
 2 12 6 15 29 46.0000000 0 7G 1G 2G 3G 6G25G13G20
The time jumped to
 2 12 9 15 33 20.5000000 0 6G 1G 2G25G13G 3G20
We got "9" to "6" since this epoch.

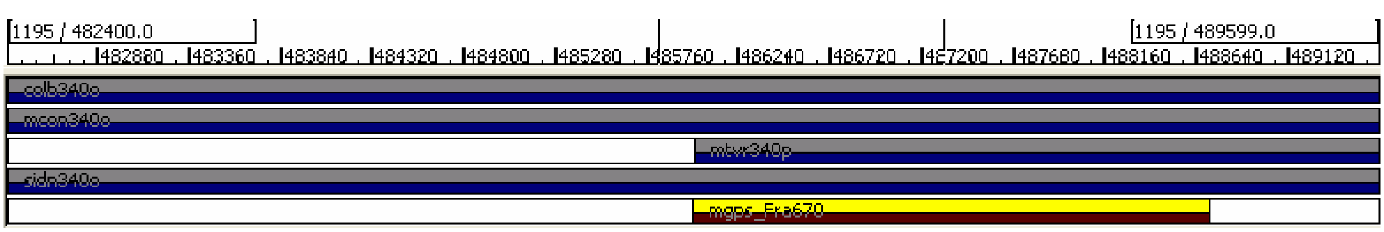

Figure 39B: Timeline for Base and Rover Stations after fixed the Time problem.

Note: The IMU data also have the same time problem.

Trajectory indicate that Colb should be the best base station

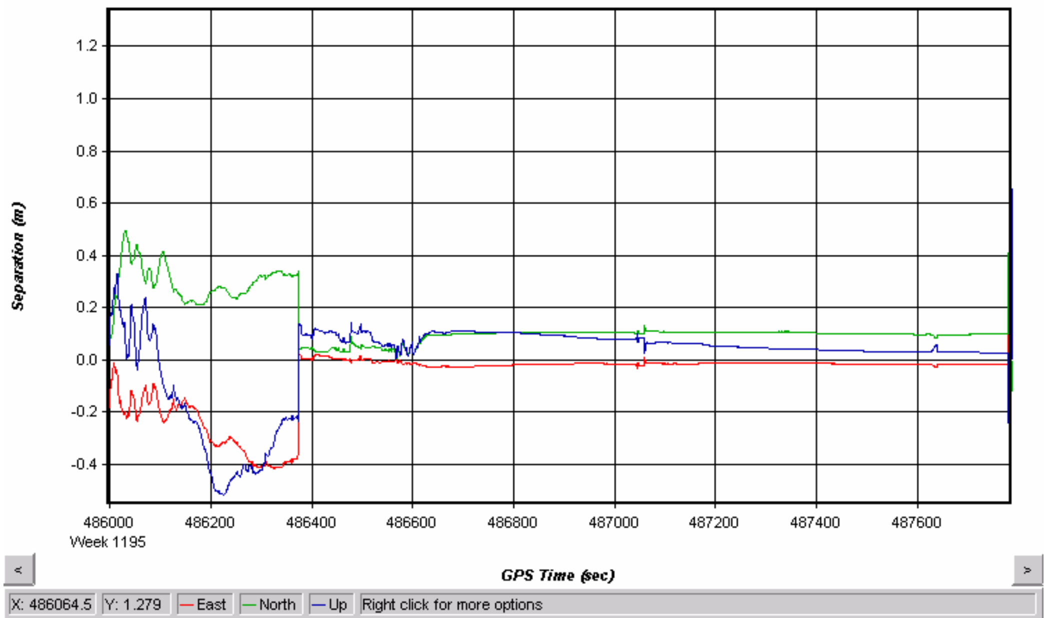

Figure 40B: Forward/Backward Separation

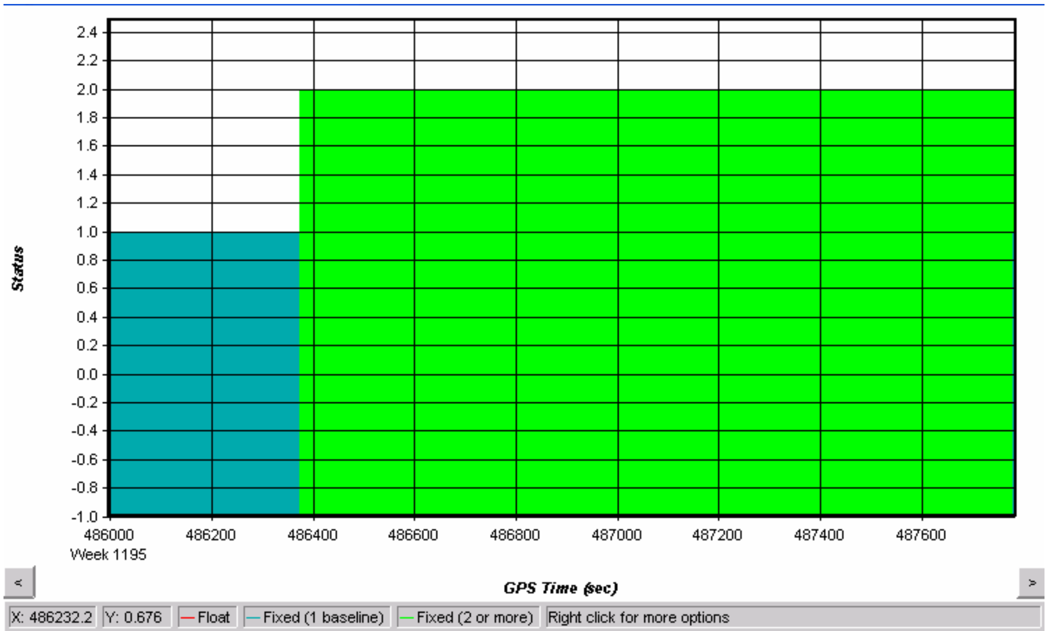

Figure 41B: Ambiguity Fixed Information

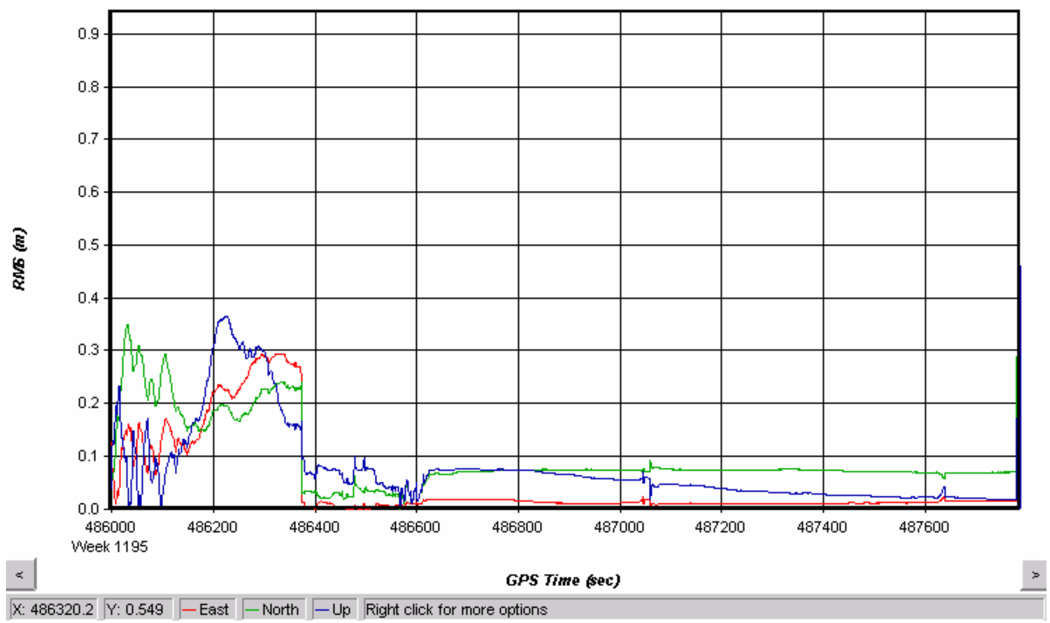

Figure 42B: Combined RMS

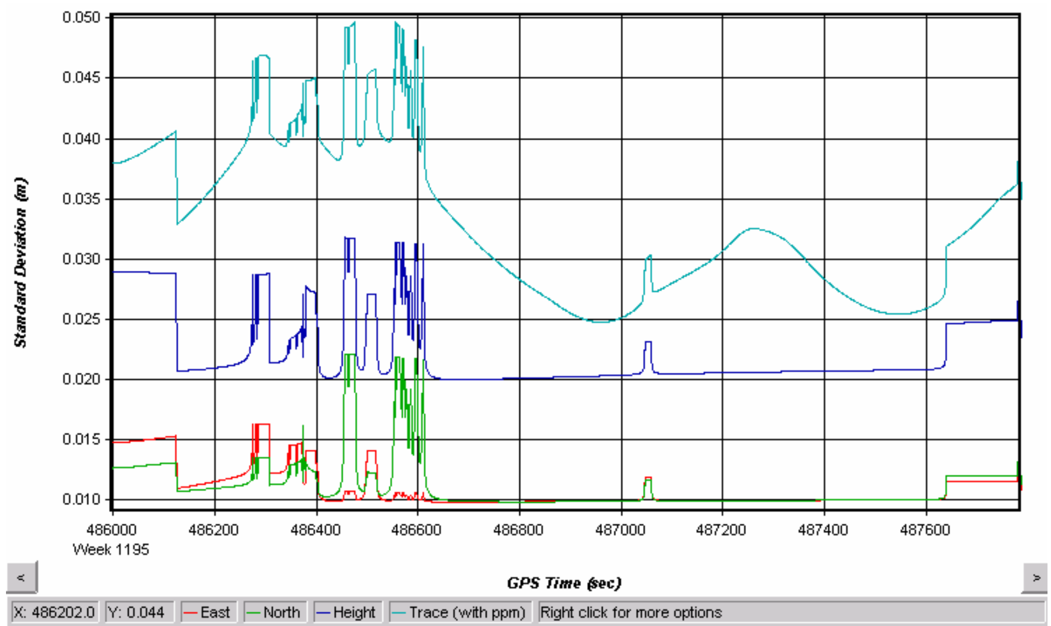

Figure 43B: Position Standard Deviation

5) IIN Kalman Filter solution

Successfully obtained the solution using default parameters

The zero-mean bound measurement residuals of N, E, D indicate correctness of IIN Kalman Filter (Figure 44B).

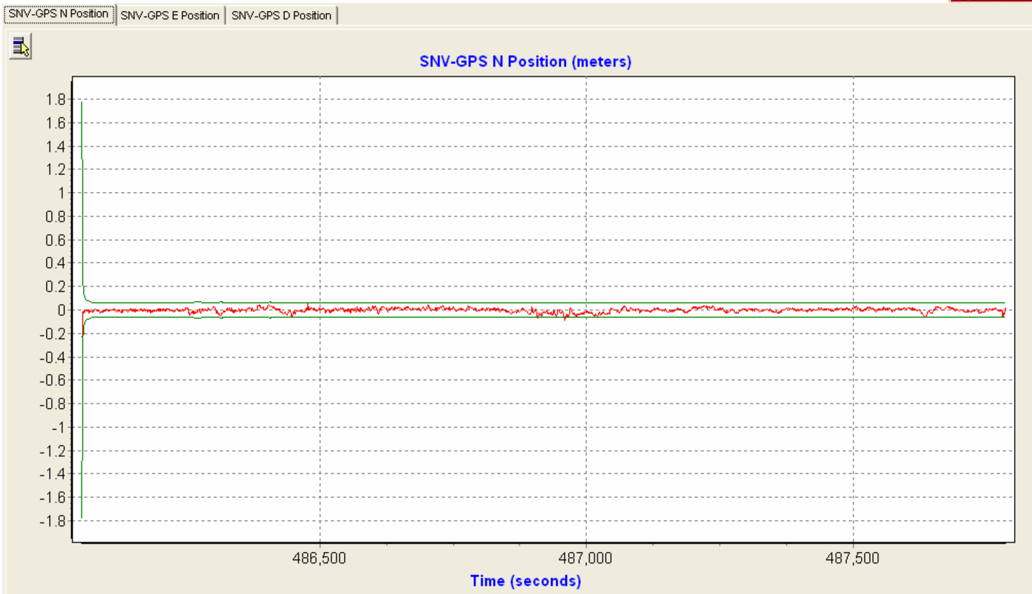

Figure 44B: Measurement Residual

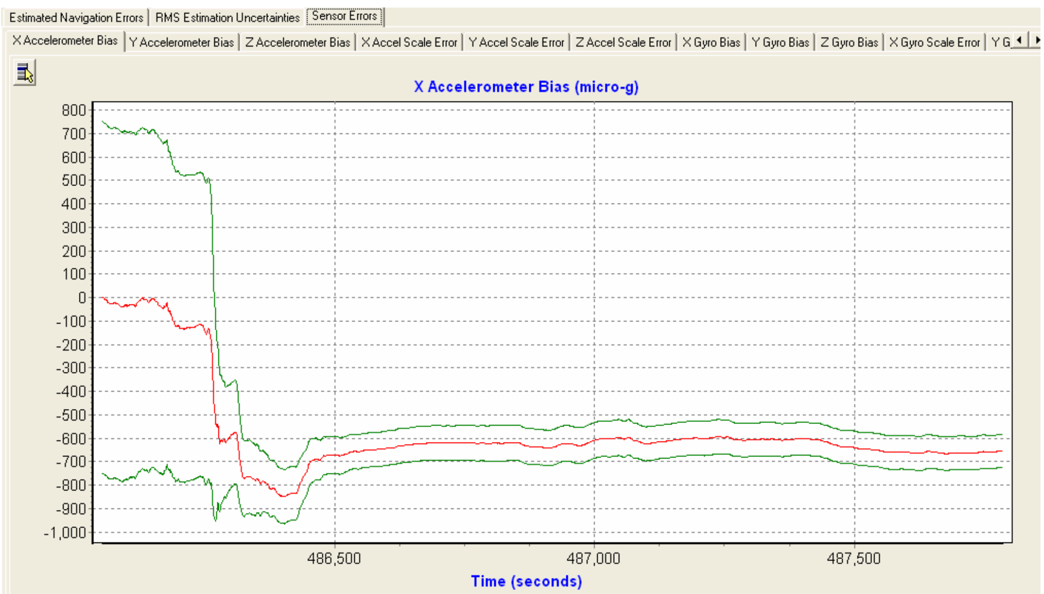

Figure 45B: Estimated Errors and RMS

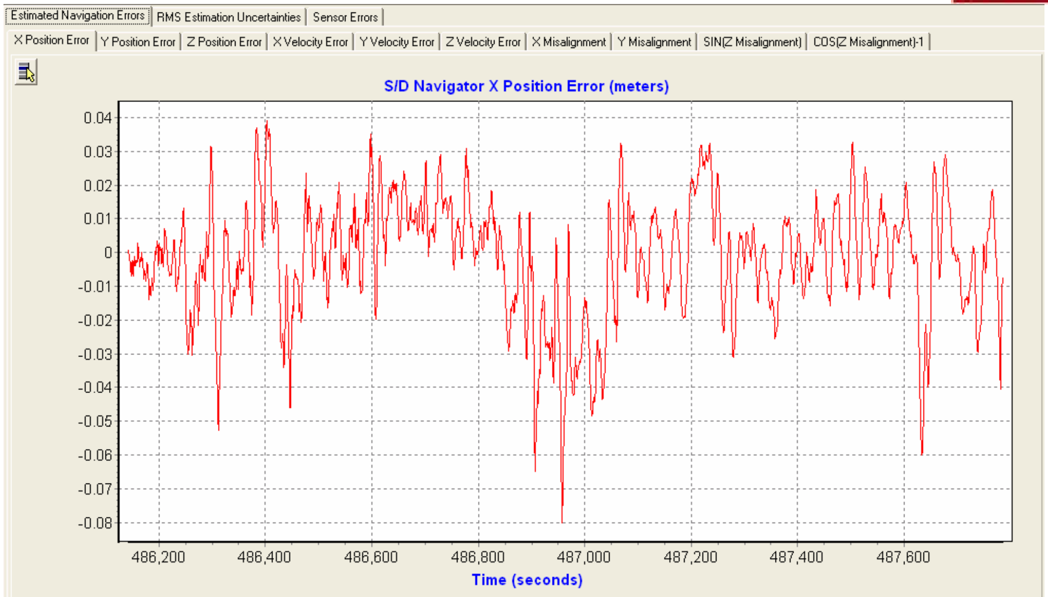

Figure 46B: Smoothed Estimated Errors and RMS

1.g. Defiance mapping dataset on Dec. 9 2002

1) Data Description

Defiance mapping dataset on Dec. 9, 2002
Applanix start on the ground at OSU airport at 10:34

The photo job was in Defiance County from 11:32 to 11:49

Applanix turned off on the ground at the ramp in OSU airport.

2) Base Stations (Table 9B)

Station Name	PCL1 XYZ	PCL1 BLH	Comment
Defi	467314.198	41 16 37.27488 N	CORS
	-4777688.986	84 24 48.84760 W	
	4185713.801	183.1981	
Tiff	574288.306	41 4 29.89682 N	CORS
	-4780915.736	83 9 1.41543 W	
	4168842.402	211.7497	
Kntn	539114.21240	40 37 49.64124 N	Trimble Office
	-4817544.83072	83 36 53.27947 W	
	4131538.01516	265.9687	
Sidn	494661.2160	40 18 37.26539 N	CORS
	-4845525.5550	84 10 15.90730 W	
	4104513.7730	293.5440	
Colb	592757.0630	39 57 35.11261 N	CORS
	-4859704.8780	83 2 44.74742 W	
	4074681.1330	186.5667	

Table 9B: Base Stations for Dec. 9, 2002 Defiance mapping dataset

3) Trajectory

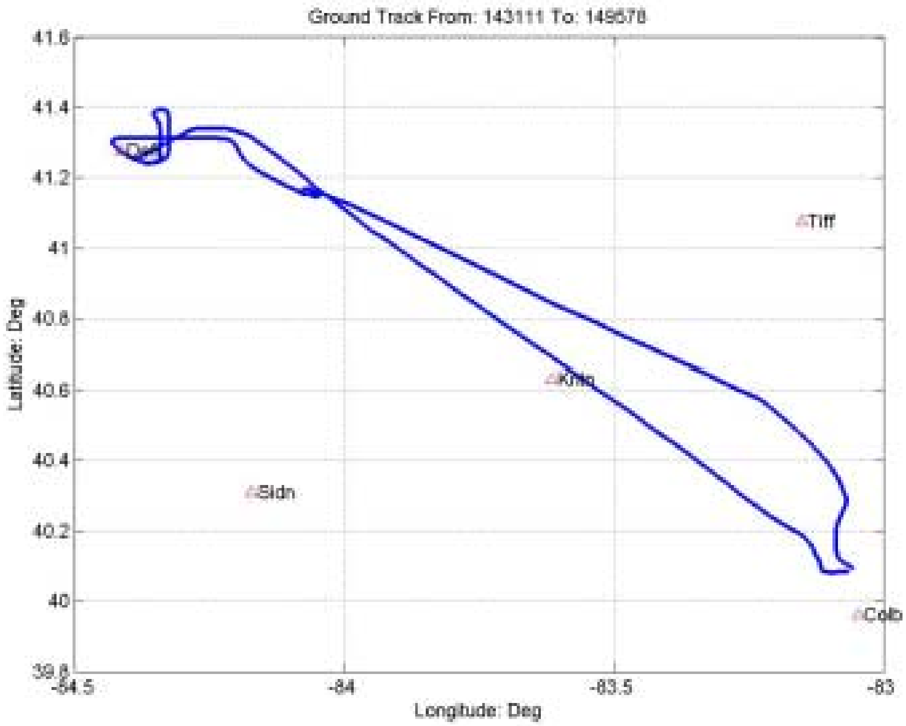

Figure 47B: Trajectory for Dec. 9, 2002 Defiance mapping dataset

4) GPS Solution

Trajectory indicates that Defi and Kntn should be the best base station, However, results indicate that Kntn have worse performance than Defi.

The following results are based on solution using base station Defi.

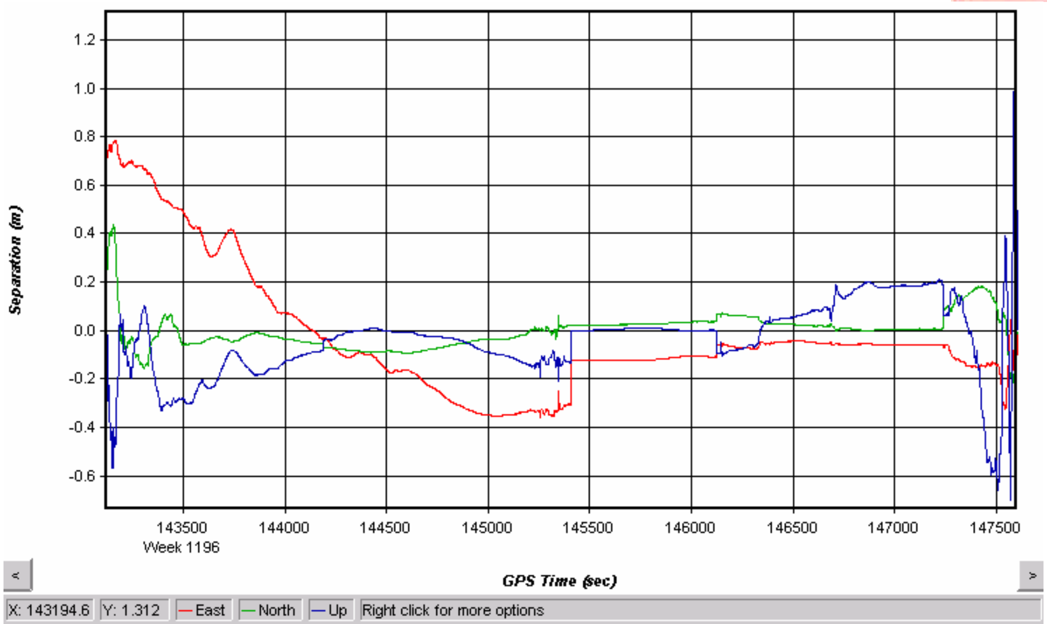

Figure 48B: Forward/Backward Separation

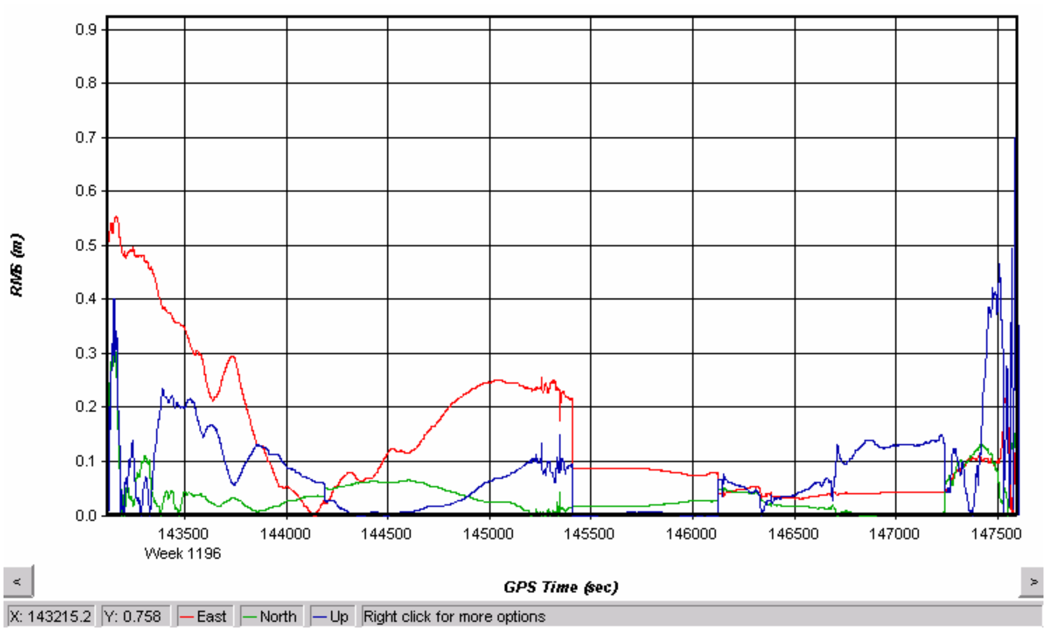

Figure 49B: Combined RMS

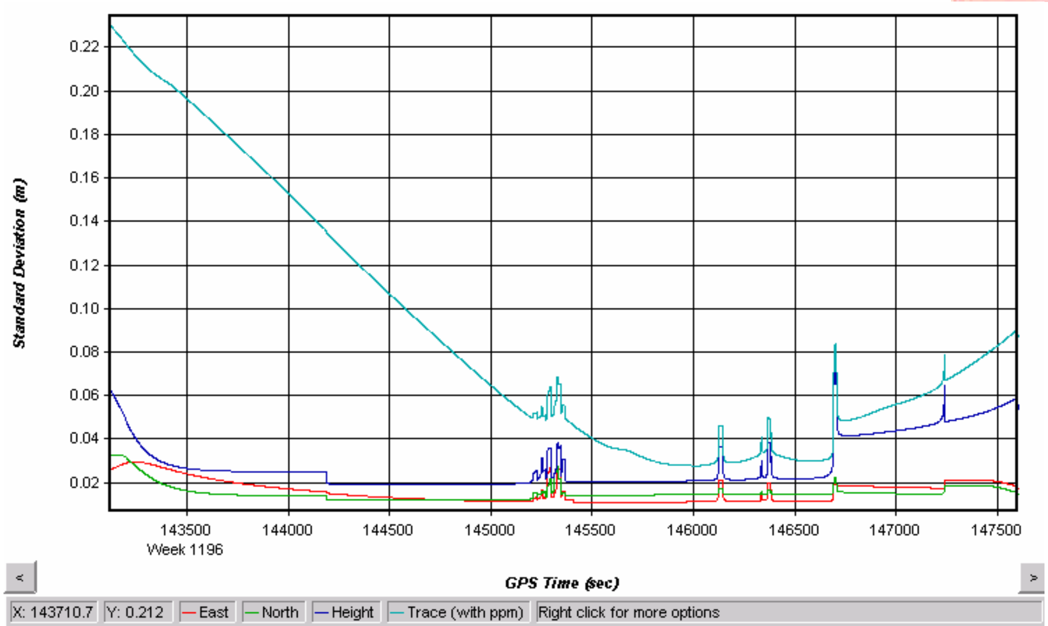

Figure 50B: Position Standard Deviation

5) IIN Kalman Filter solution

Successfully obtained the solution using default parameters

The zero-mean bound measurement residuals of N, E, D indicate correctness of IIN Kalman Filter (Figure 52B).

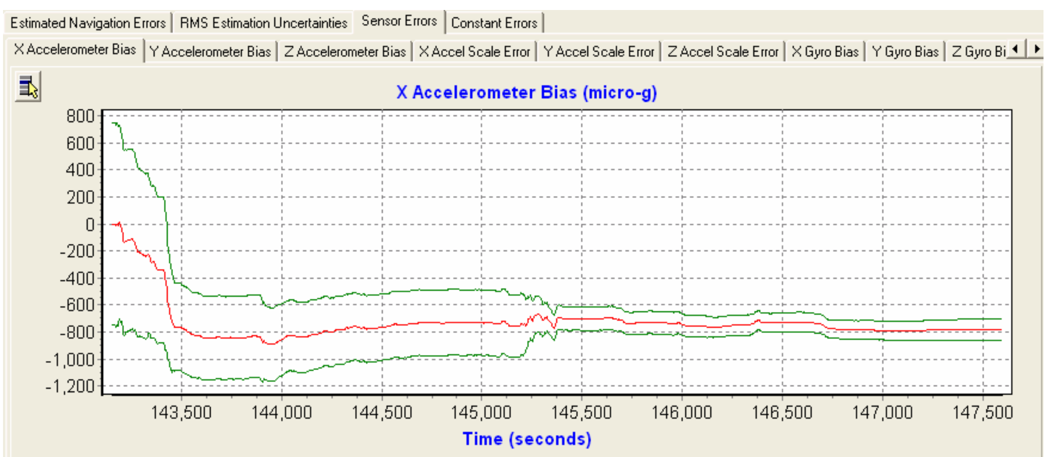

Figure 51B: PosProc Estimated Errors and RMS

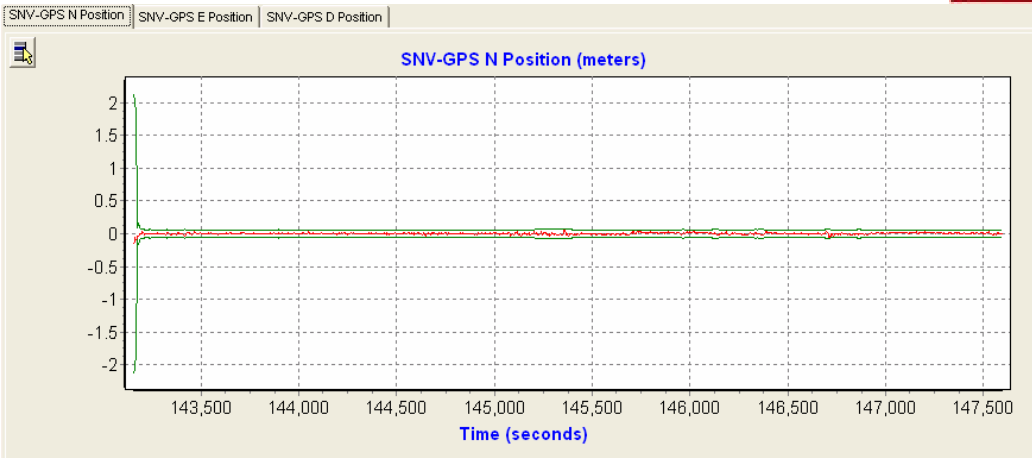

Figure 52B: PosProc Measurement Residuals and RMS

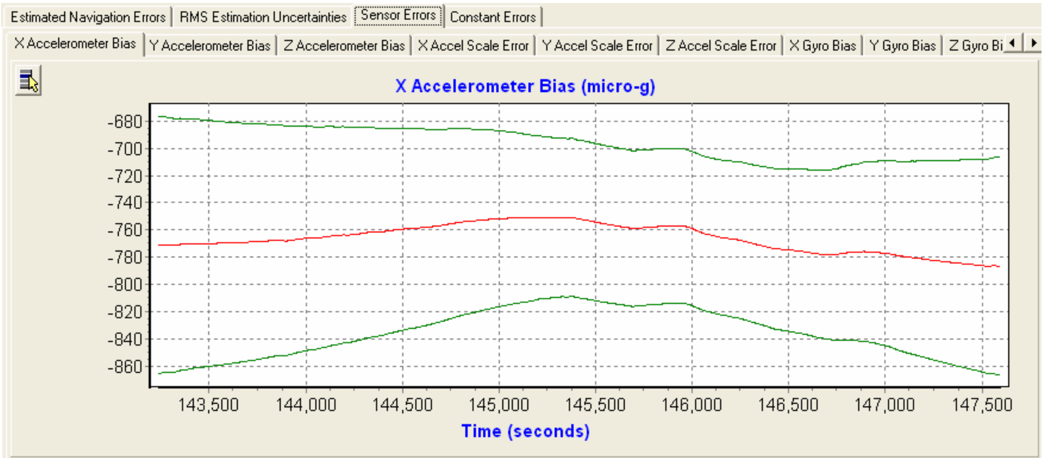

Figure 53B: PosProc Smoothed Estimated Errors and RMS

1.h. Defiance airport dataset on Dec. 10 2002

1) Data Description

Defiance airport dataset on Dec. 10, 2002
Applanix turned on in flight at 10:43 near the site in Defiance County.

Applanix turned off on the air at 12:56

2) Base Stations (Table 10B)

3) Trajectory (Figure 54B)

4) GPS Solution

The forward/backward separation of solution using Defi has a bad performance at the end of the data, so another base station Woos was applied to get another solution. The final solution is based on the forward solution using base station Defi and backward solution using base station Woos.

Station Name	PCL1 XYZ	PCL1 BLH	Comment
Defi	467314.198	41 16 37.27488 N	CORS
	-4777688.986	84 24 48.84760 W	
	4185713.801	183.1981	
Tiff	574288.306	41 4 29.89682 N	CORS
	-4780915.736	83 9 1.41543 W	
	4168842.402	211.7497	
Kntn	539114.21240	40 37 49.64124 N	Trimble Office
	-4817544.83072	83 36 53.27947 W	
	4131538.01516	265.9687	
Sidn	494661.2160	40 18 37.26539 N	CORS
	-4845525.5550	84 10 15.90730 W	
	4104513.7730	293.5440	
Colb	592757.0630	39 57 35.11261 N	CORS
	-4859704.8780	83 2 44.74742 W	
	4074681.1330	186.5667	
Woos			CORS

Table 10B: Base stations for Dec. 10, 2002 Defiance Airport Dataset

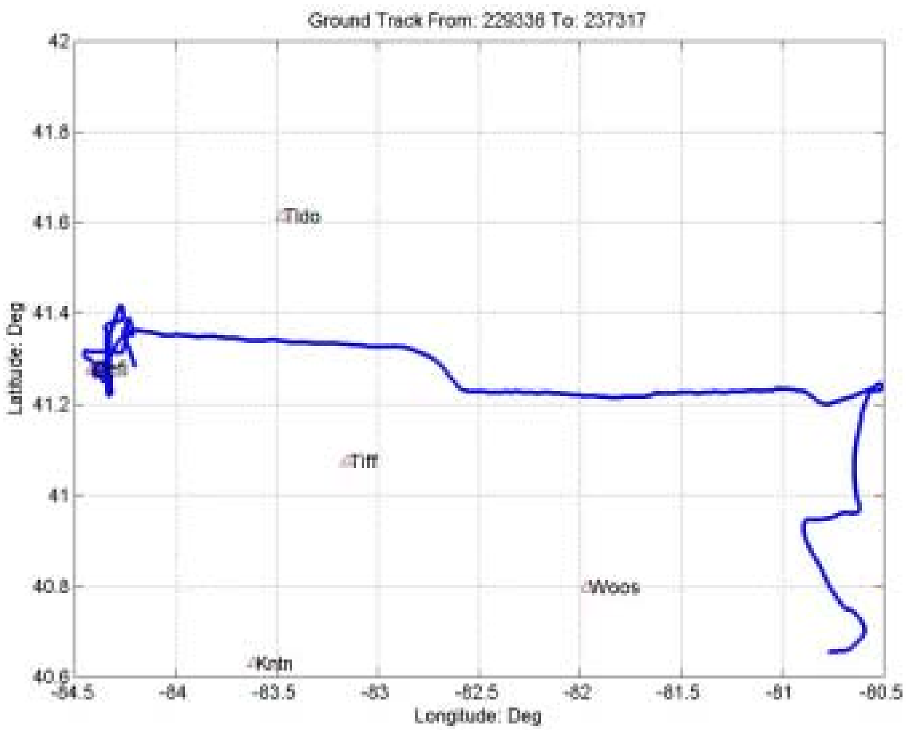

Figure 54B: Trajectory for Dec. 10, 2002 Defiance Airport Dataset

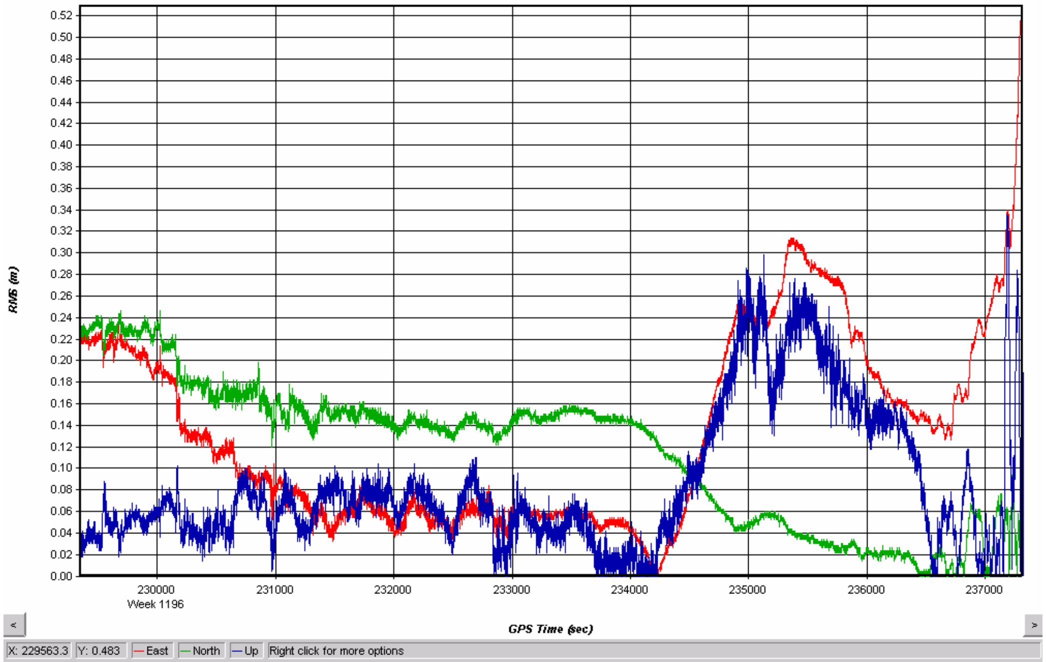

Figure 55B: Combined RMS

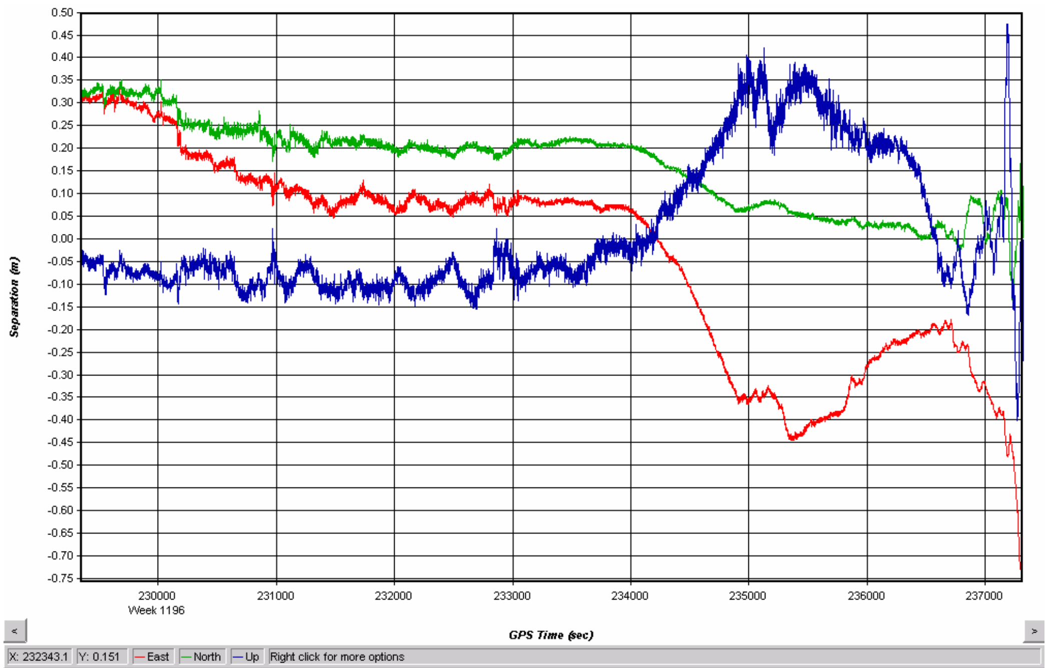

Figure 56B: Forward/Backward Separation

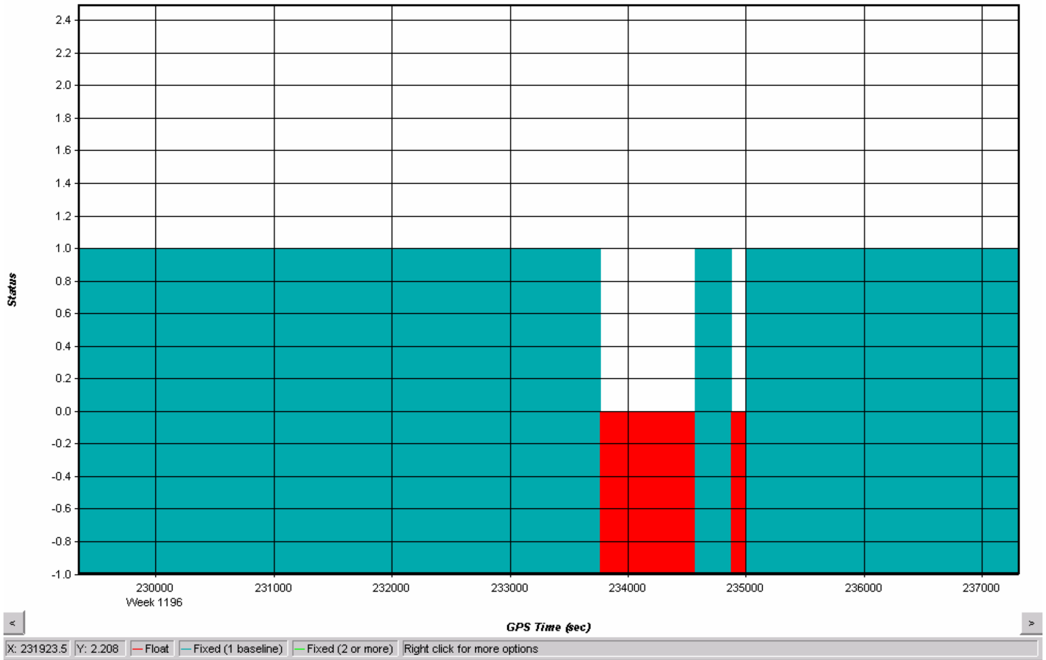

Figure 57B: Ambiguity Fixed Information

5) IIN Kalman Filter solution

Successfully obtained the solution using default parameters

The zero-mean bound measurement residuals of N, E, D indicate correctness of IIN Kalman Filter (Figure 59B).

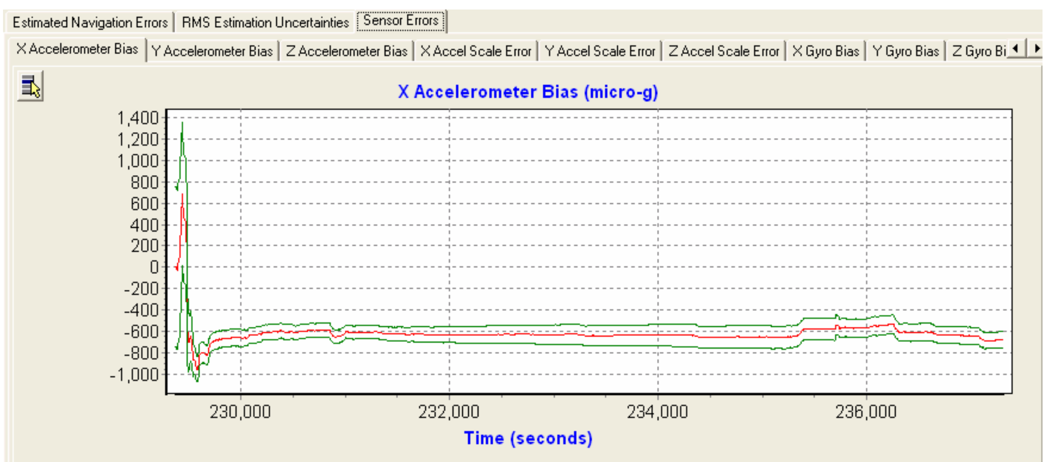

Figure 58B: PosProc Estimated Errors and RMS

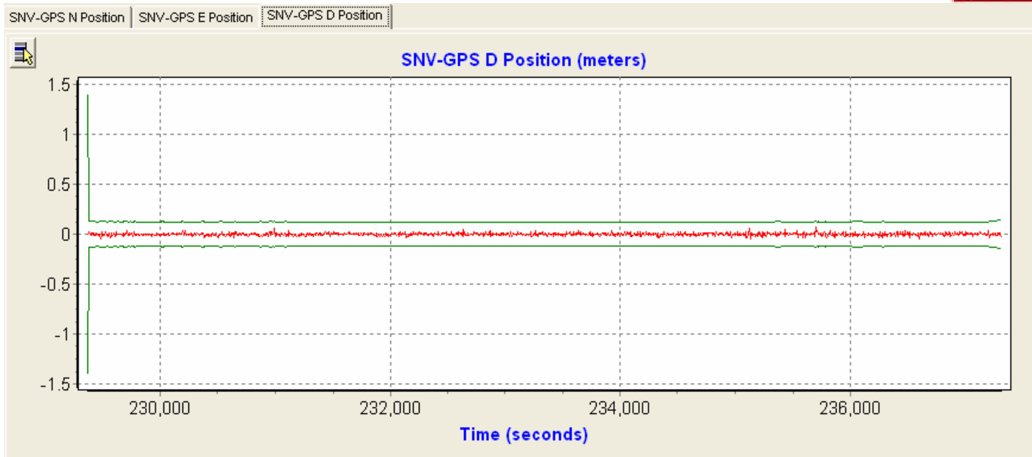

Figure 59B: PosProc Measurement Residuals and RMS

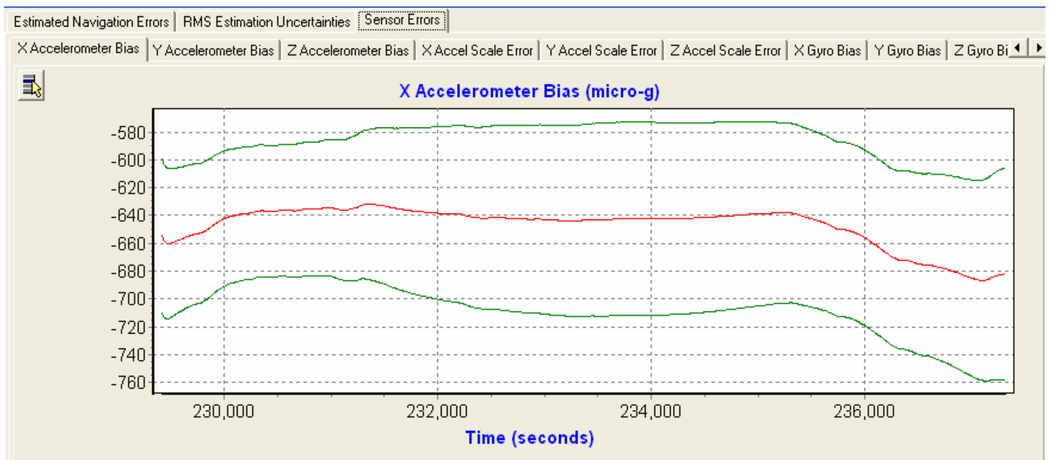

Figure 60B: PosProc Smoothed Estimated Errors and RMS

2. Addendum 1

2.b. Effects of GPS Data processing parameters

Numerous options provided in the GPS data processing PosGPS mainly focus on the

1) Usage of P code
2) Quality of Code and phase measurement
3) KAR engaged time and search region size
4) Ionospheric modeling

All these options, different from default setting are recommended to try and compare with the solution from default setting, only when problems exist in the solution from default setting.
Here, as an example, “Use P Code in Kalman Filter” was used to test the effect.

- Use P Code in Kalman Filter

Applying this option, normally will increase the convergence speed, and sometimes will lower the combined RMS, position standard deviation and forward/backward separation, depending on the quality of P-code. Normally don’t apply this option.

Before (Figures 61B, 62B, 63B, 64B): => do not apply this option

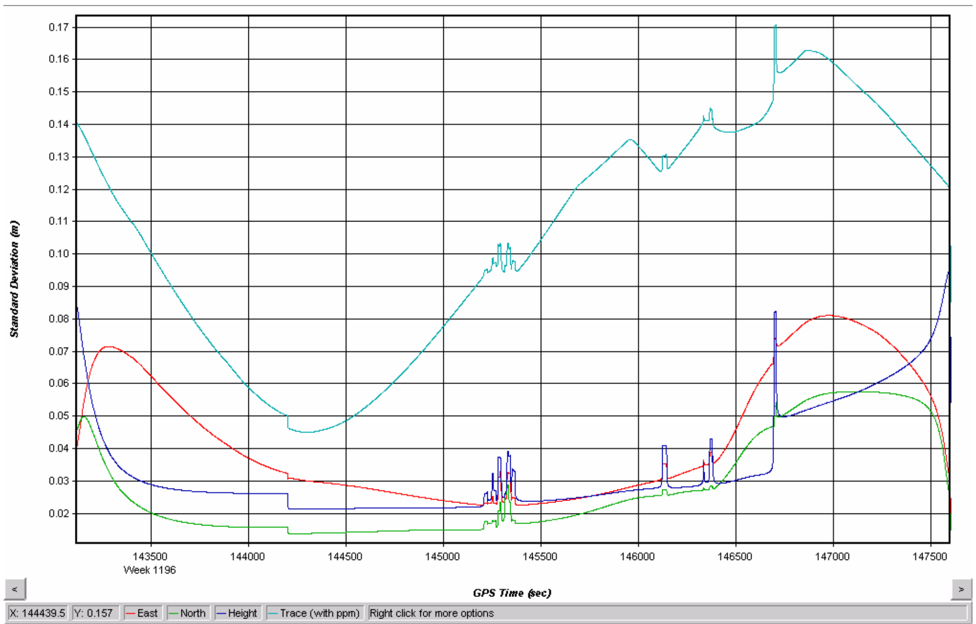

Figure 61B: Position Standard Deviation

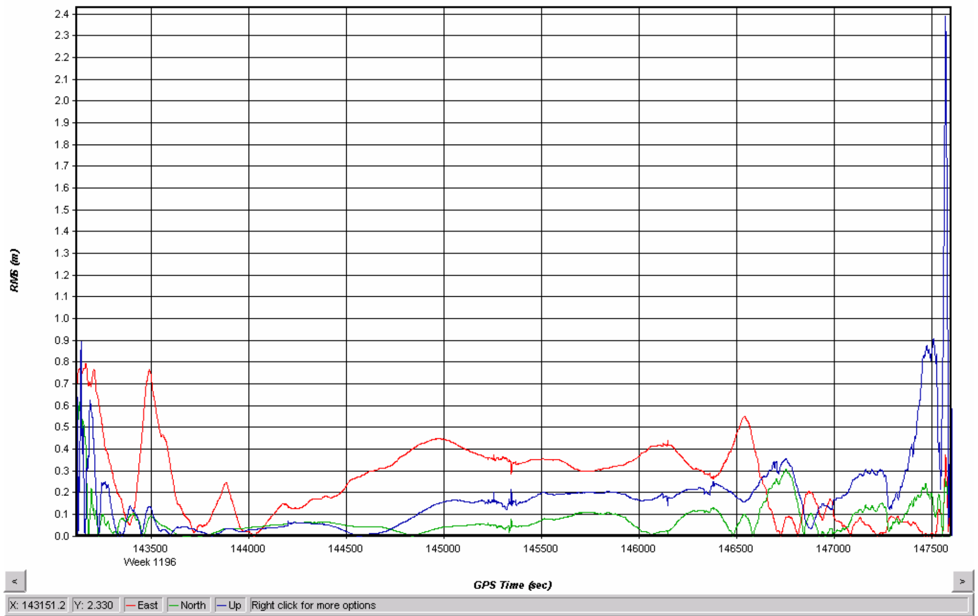

Figure 62B: Combined RMS

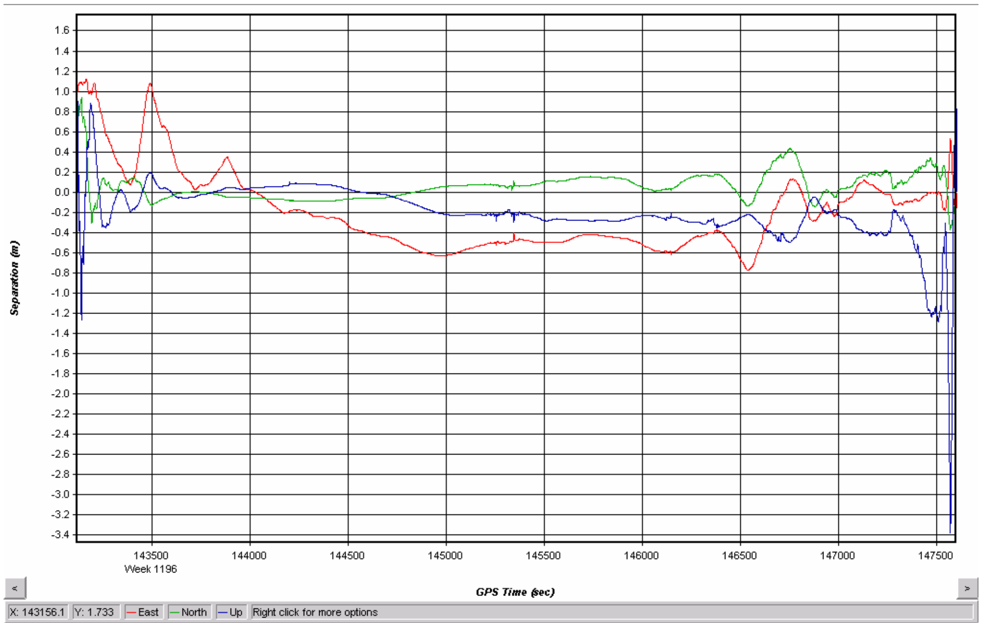

Figure 63B: Forward/Reverse Separation

After (Figures 64B, 65B, 66B): Apply this option

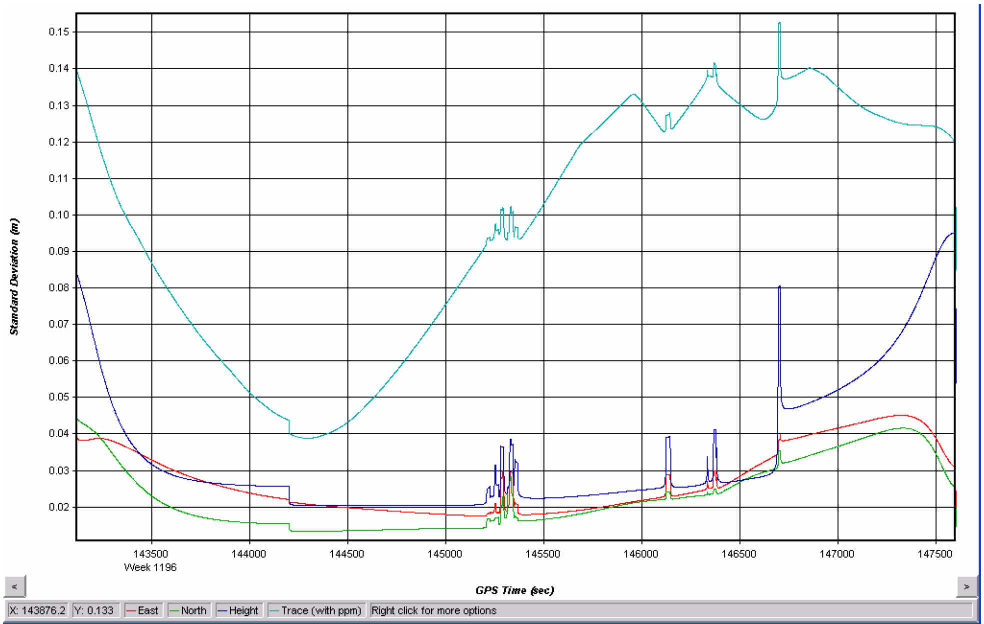

Figure 64B: Position Standard Deviation

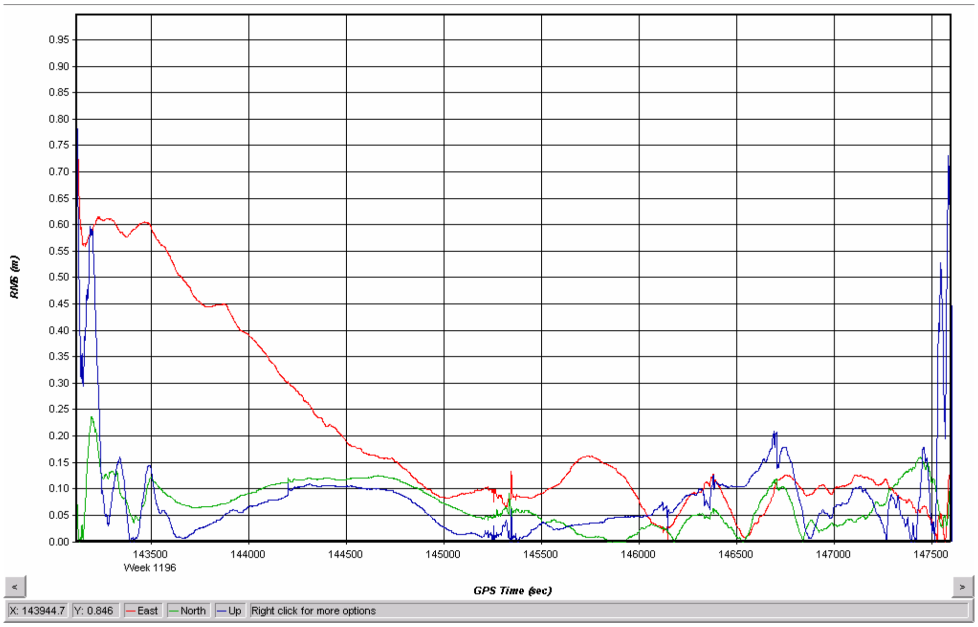

Figure 65B: Combined RMS

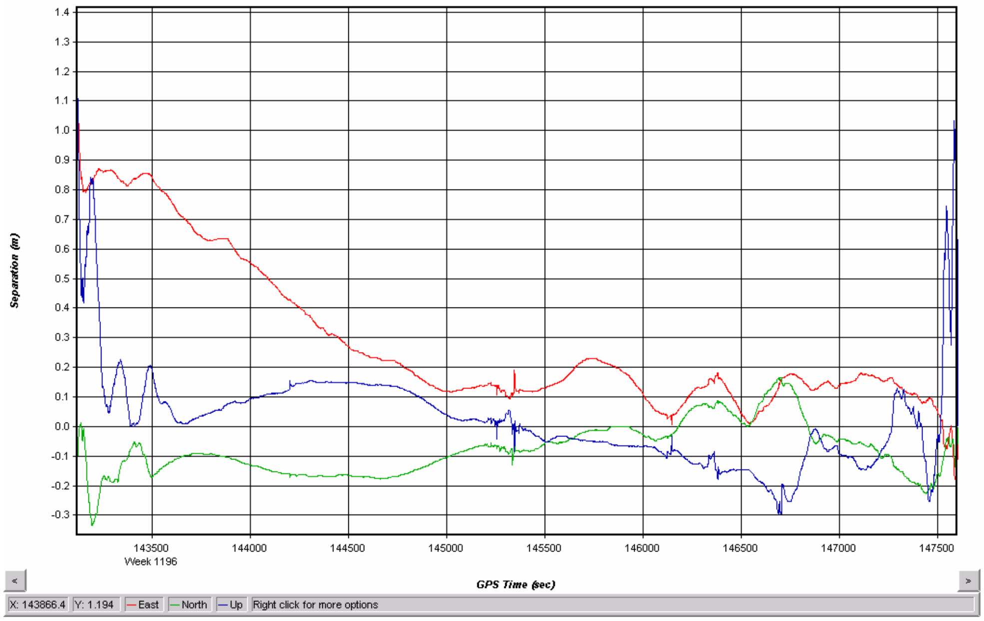

Figure 66B: Forward/Reverse Separation