GPS Correction Comparisons – RTK vs DGPS

Abstract

The position reported by a GPS receiver is not absolute. Many errors are introduced to the signal from the satellite. Satellite clock errors, propagation delay, and atmospheric interference are all factors in the accuracy of a position. Day-to-day measurements of a position can change depending on each of these factors. This document compares two methods to make corrections to these errors: Pseudo-differential (DGPS) and Real Time Kinematic (RTK) correction.

Introduction

Many unmanned vehicles rely on accurate GPS position in order to navigate a recorded path. The vehicle can accurately drive to within six inches of the recorded path. Day-to-day, week-to-week, and month-to-month repeatability of this path is important.

The difference in the accuracy of DGPS versus RTK is how each calculates position using the same GPS signal. The GPS signal from a satellite transmits Pseudo Random Code (PRC). Since the receiver receives the PRC from multiple satellites, it can align the received code to its own and calculate the propagation delay. Since the receiver also knows the position of the satellite, it can calculate the distance to the satellite. Once the receiver knows its distance (range) from four satellites, it knows its 3-dimensional position on earth. This is referred to as code-based positioning and is what DGPS uses for its underlying position calculations.

RTK uses carrier-based ranging for its underlying position information, which can provide range values that are orders of magnitude more precise than code-based positioning. The range is calculated by determining the number of carrier cycles between the receiver and satellite and then multiplied by the wavelength of the carrier signal. Not all GPS satellites transmit on the same frequency; if several frequencies are used to determine the position, the error of atmospheric delays and multi-path propagation of the signal are minimized.

Both DGPS and RTK use a base station with a known position that has a high degree of accuracy using a surveyed location or by averaging its position over time (12-18 hours usually). The base station of the DGPS setup compares this known position with the position calculated by the GPS signal. The differences between known and calculated positions are then transmitted to other receivers (i.e., rovers), which use the correction to calculate their position. The base station for the RTK setup transmits the phase of the signal that it observes and sends that information to the rovers who then compare that to the phase that they observe.

Two different GPS receivers were used to empirically compare DGPS and RTK performance: the NovAtel SMART6-L (PN: G2SR0GTT0) and the NovAtel SMART-V1 (PN: L1RV). Eight different configurations were used to compare the repeatability of the position, four for RTK and four for DGPS. The SMART6-L is a dual frequency (L1/L2) and the SMART-V1 is a single frequency (L1). The L1 frequency is 1575.42 MHz and the L2 frequency is 1227.60 MHz.

Table 1: GPS Configurations

Configuration	Base Receiver	Rover Receiver
RTK #1	SMART6-L	SMART6-L
RTK #2	SMART6-L	SMART-V1
RTK #3	SMART-V1	SMART-V1
RTK #4	SMART-V1	SMART6-L
DGPS #1	SMART6-L	SMART6-L

DGPS #2	SMART6-L	SMART-V1
DGPS #3	SMART-V1	SMART-V1
DGPS #4	SMART-V1	SMART6-L

Testing Methodology

In order to maintain the strictest accuracy of the results, a waypoint was independently surveyed, by McNeil Engineering. McNeil Engineering set a permanent "control point" (i.e., 2' long 5/8" rebar post embedded) into the ground at that point. The control point is at Latitude: 40.597411286°, Longitude: -111.907294997°, and Elevation: 4349.86 feet and has an accuracy of +/- 10 mm + 1ppm RMS. (For more information about the independently surveyed control point, contact Kairos Autonomi.) The configurations for both the DGPS and RTK base stations were set to use this as their reference point.

There is an oval line painted on the test course. Two locations on the oval were instrumented with a ruler to measure the deviation of each vehicle tire's outside edge as it crossed that point. A course was recorded using each configuration driving so that the left front tire traveled along the inner edge of the line. This course was then played back twice a day, once in the morning and then again in the afternoon using each configuration with the same vehicle and OCU that was used to record the course. As the vehicle passed each measurement location, the absolute measurement from the outside edge of the left front tire was recorded during each pass of a five-cycle loop. Additionally, the average error and maximum error were recorded for each loop, as reported by the Mobius operator control unit (OCU) software. These are the software error measurements of the vehicle as it drives the course.

Results

The average error that Mobius reported during all of the tests was 4.9" with a standard deviation of 1.1", meaning that Mobius reported that the vehicle was within 3.8"-6.0" of where it was supposed to be (refer to Table 2). This is the accuracy that the software and hardware of the system is able to achieve.

Table 2: Vehicle Pathing Error

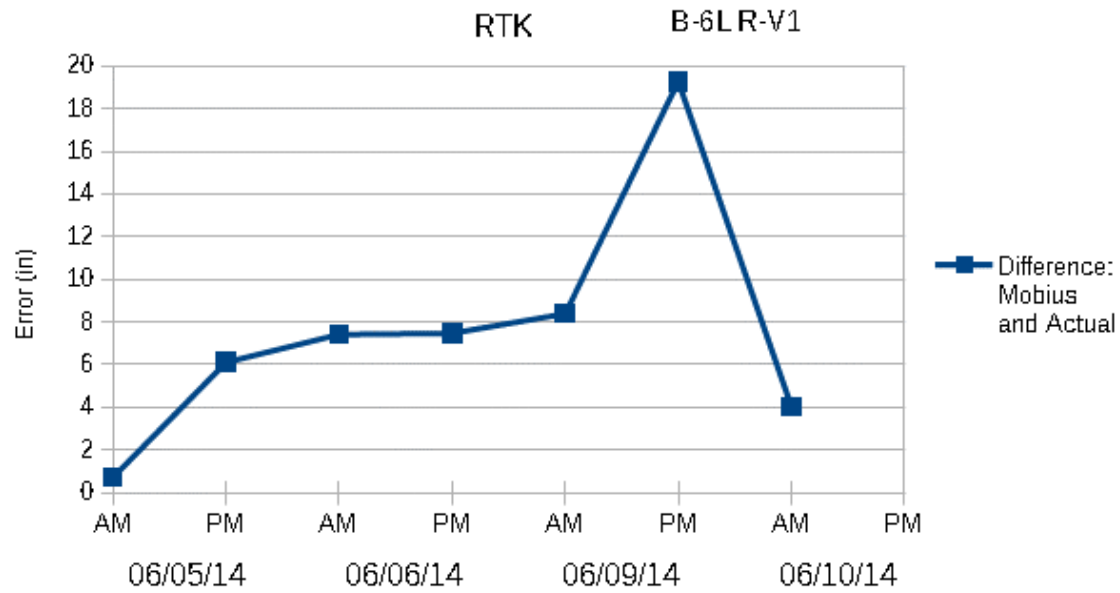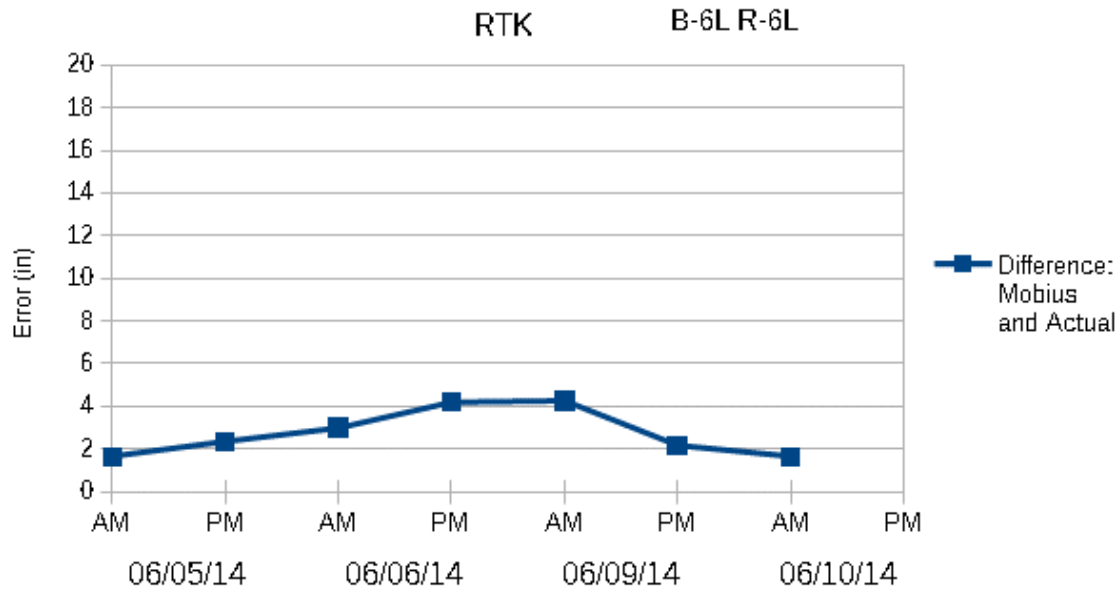|	Average	Standard Deviation	Range
Vehicle Pathing Error	4.9"	1.1"	3.8" – 6.0"

What is necessary then is to ensure that the reported GPS position is as accurate as possible. The average DGPS observed error was 20.2" with a standard deviation of 15.8" (refer to Table 3). The average RTK observed error was only 7.9" with a standard deviation of 5.6". In other words, when all other factors remain the same, the average off-path error of RTK had 60% less observed error than DGPS.
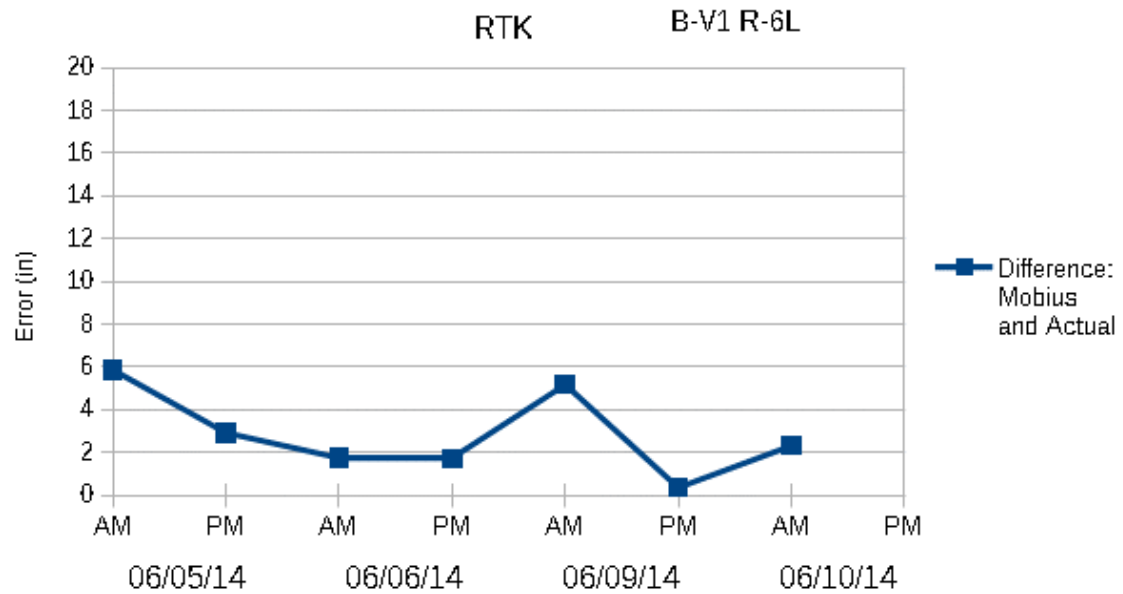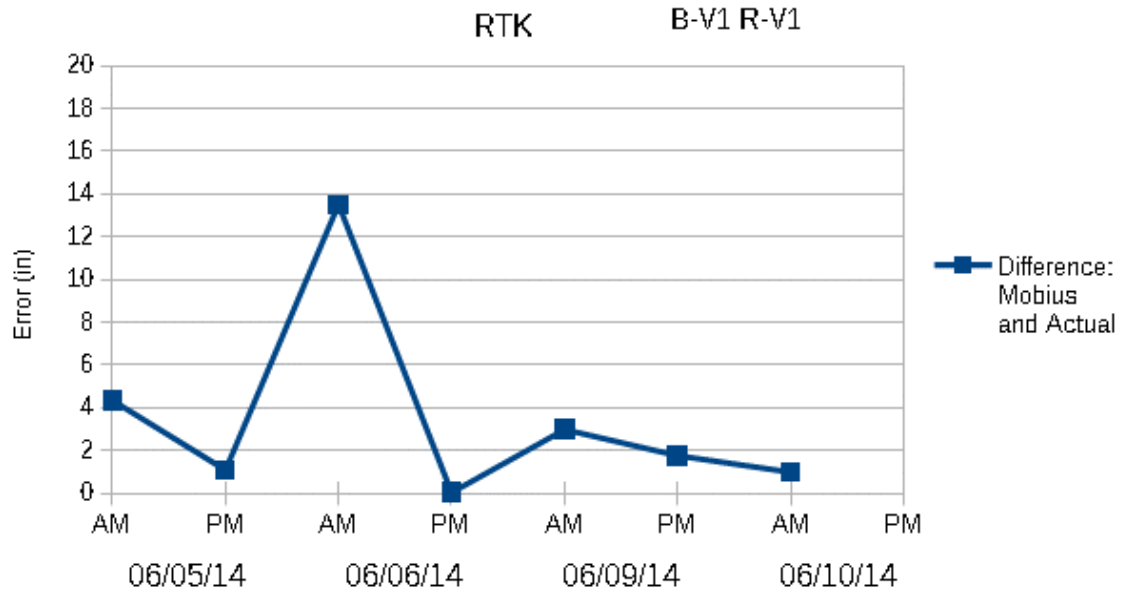
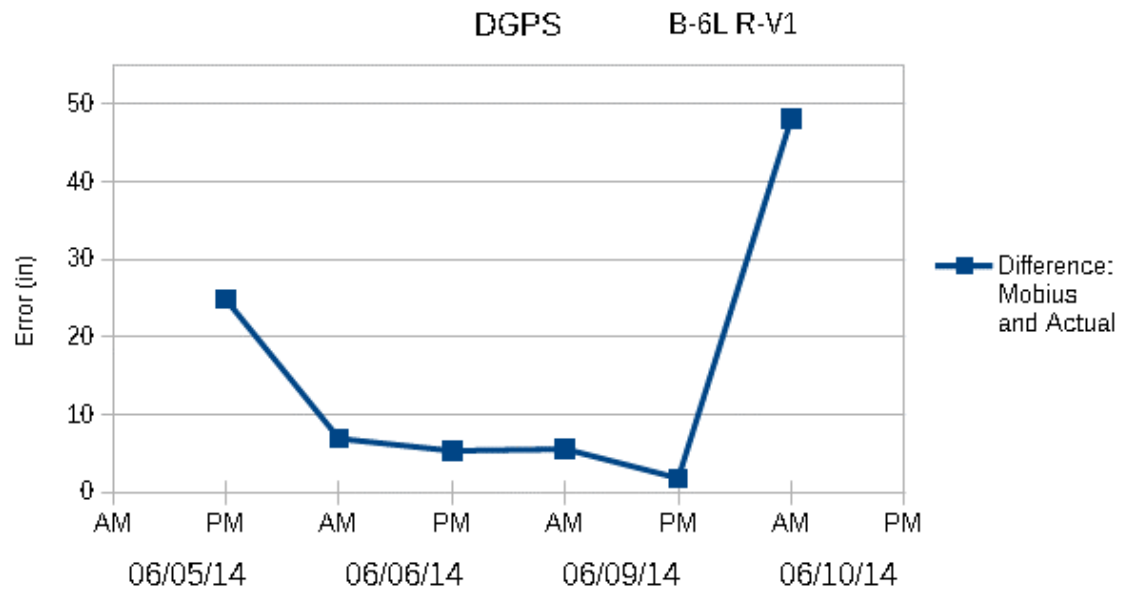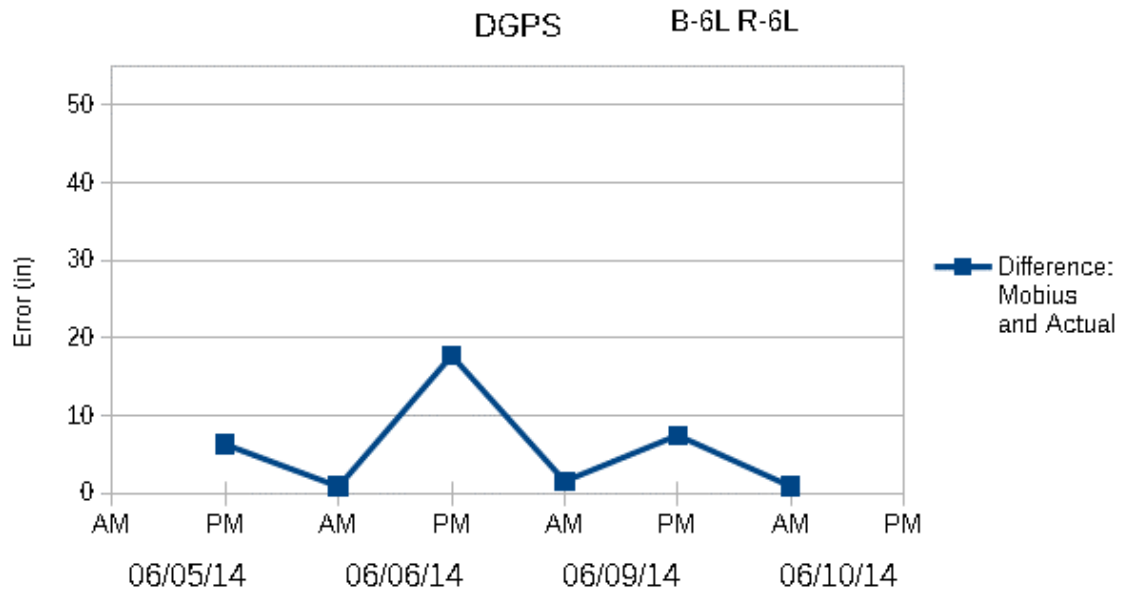**Table 3: Average and Standard Deviation of Observed Error**

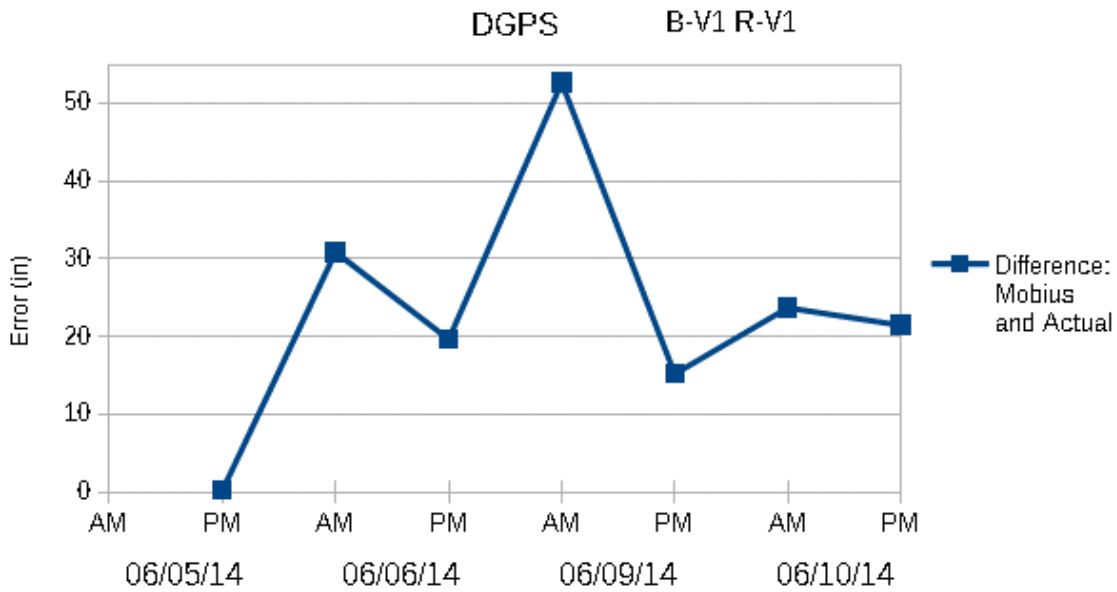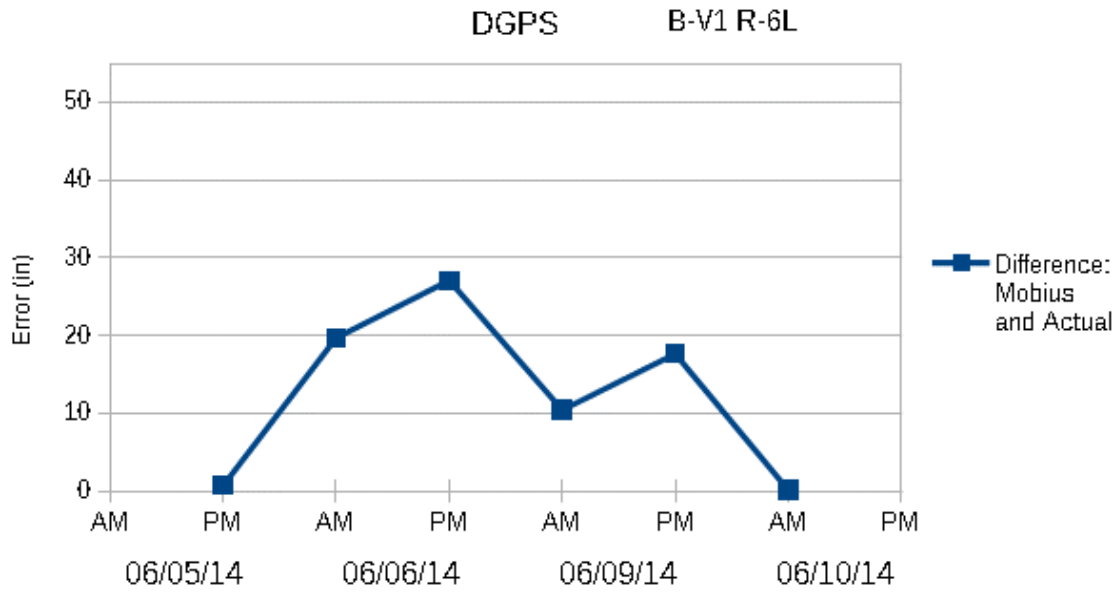|	Average	Standard Deviation	Range	Total Error: GPS + Vehicle
RTK	7.9"	5.6"	2.3" – 13.5"	6.1" – 19.5"
DGPS	20.2"	15.8"	4.4" – 36.0"	8.2" – 42.0"

Taking the upper ranges of each type of GPS, it can be seen that the worst-case error of RTK is 19.5" and of DGPS is 42.0" (adding the upper range of the system accuracy and the upper range of each type of GPS). In other words, when all other factors remain the same, the maximum observed error of RTK had 54% less observed off-path error than DGPS.

The following graphs show the difference between the physical error on the ground and the error that the vehicle reported as it traveled the course.

RTK   B-6L R-6L

RTK   B-6L R-V1

RTK · B-V1 R-V1

RTK · B-V1 R-6L

DGPS   B-6L R-6L

DGPS   B-6L R-V1

DGPS — B-V1 R-6L

DGPS — B-V1 R-V1

SMART-V1 versus SMART6-L

The observed off-path errors are not limited to the differences between the RTK and DGPS firmware, but are also impacted by the hardware units in use. The SMART-V1 is a single frequency GPS unit, while the SMART6-L is a dual frequency GPS unit. As a result, the SMART6-L provides more accuracy. This difference in hardware combined with the use of RTK or DGPS firmware results in combinatorial effects. The following two tables show the average of observed off-path errors with different hardware and firmware configurations. Table 4 highlights the average off-path errors, while Table 5 highlights the maximum off-path errors.

Table 4: Observed Average Off-Path Errors in SMART-V1 versus SMART6-L

	DGPS	RTK
SMART-V1 base and rover	29.135"	6.985"
SMART6-L base and rover	9.908"	6.357"

The average off-path distance when using exclusively SMART-V1s with DGPS is over 29", while SMART6-Ls running RTK have an average off-path error less than 6.5", which equates to 79% less off-path error distances.

Table 5: Maximum Off-Path Errors in SMART-V1 versus SMART6-L

	DGPS	RTK
SMART-V1 base and rover	60"	24"
SMART6-L base and rover	26"	10"

The relationships of the maximum off-path distances closely correlate to the average off-path distances, and result in 60% or more reduction in maximum off-path error distances. Of particular note, only the SMART6-L with RTK maintained a maximum off-path error under one foot.

Conclusions

The data demonstrate that using RTK correction instead of DGPS correction, there is better day-to-day consistency of path following along the actual path, specifically 60% less off-path error than a comparable DGPS configuration. In conjunction with the SMART6-L as both the base station and vehicle GPS units, the best performance can be achieved.

It was also observed that DGPS is suitable for same day path recording and playback but suffers with inconsistency over time.

Appendix A: GPS Configuration Scripts

```
[Standalone SmartV1 DGPS Base - GSL]
{restart off}
unlogall
pdpfilter disable
com com2 57600 n 8 1 n off on
interfacemode com2 none rtca off
log com1 gpggalong ontime 1.0
log com2 rtca1b ontime 1.0
log com1 bestposa ontime 1.0
fix position 40.597411286 -111.907294997 1327.84
saveconfig
'
[Standalone SmartV1 RTK Base - GSL]
{restart off}
unlogall
pdpfilter disable
com com2 57600 n 8 1 n off on
interfacemode com2 none rtcmv3 off
log com1 gpggalong ontime 1.0
log com2 RTCM1002 ontime 1.0
log com2 RTCM1006 ontime 1.0
log com1 bestposa ontime 1.0
fix position 40.597411286 -111.907294997 1327.84
saveconfig
'
[Standalone 6L RTK Base - GSL]
{restart off}
unlogall
pdpfilter disable
com com2 57600 n 8 1 n off on
interfacemode com2 none rtcmv3 off
log com1 gpggalong ontime 1.0
log com2  RTCM1004 ontime 1.0
log com2  RTCM1005 ontime 10
log com2  RTCM1002 ontime 1.0
log com2  RTCM1006 ontime 10
log com1 bestposa ontime 1.0
fix position 40.597411286 -111.907294997 1327.84
saveconfig
'
[MLT DGPS Configuration]
{restart off}
UNLOGALL
FIX NONE
RTKSOURCE NONE
SBASCONTROL ENABLE AUTO
PSRDIFFSOURCE RTCA ANY
COM COM2 57600 n 8 1 n off off
interfacemode com2 rtca none off
log com1 gpggalong ontime .1
log com1 gpgst ontime .1
log com1 gpvtg ontime .1
pdpfilter enable
pdpmode relative dynamic
COM COM1 57600 n 8 1 n off on
saveconfig
'
[MLT RTK Configuration]
```

```
{restart off}
UNLOGALL
FIX NONE
RTKSOURCE AUTO ANY
SBASCONTROL ENABLE AUTO
PSRDIFFSOURCE RTCA ANY
COM COM2 57600 n 8 1 n off off
interfacemode com2 rtcmv3 none off
log com1 gpggalong ontime .1
log com1 gpgst ontime .1
log com1 gpvtg ontime .1
pdpfilter enable
pdpmode relative dynamic
COM COM1 57600 n 8 1 n off on
saveconfig
'
```
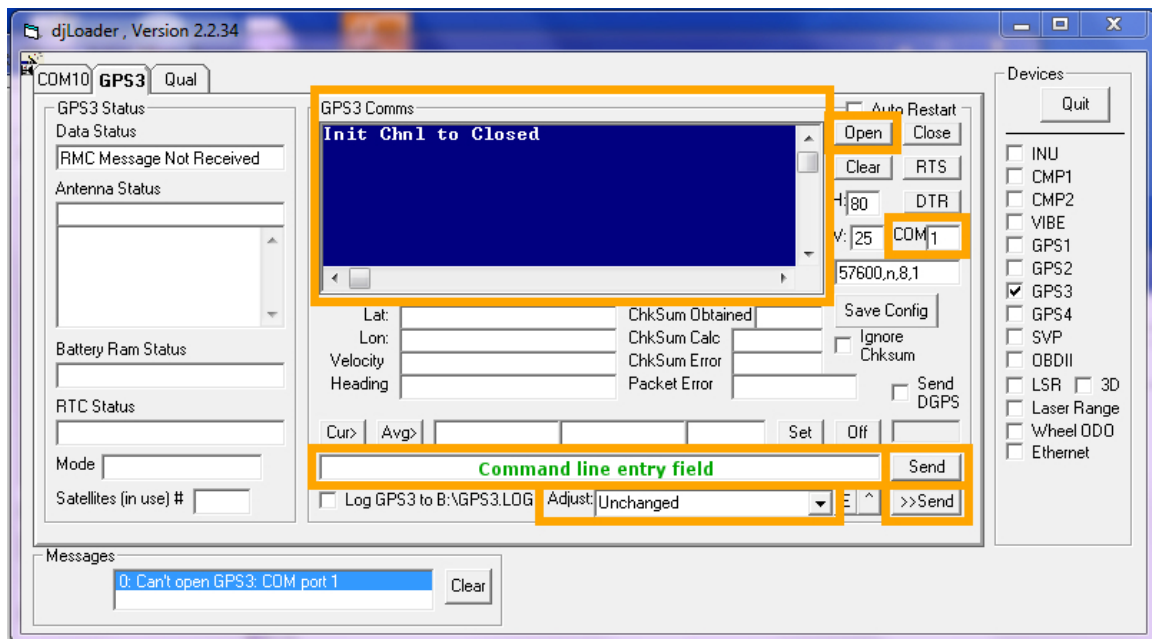
Appendix B: GPS Configuration Steps

For the Tower GPS:
1. Launch djLoader.
2. Ensure "COM" is set to "1" and data is streaming. If not, set "COM" to "1" and click the "Open" button; verify data is streaming.
3. Enter "freset" into the command line entry field, then click the "Send" button.
4. Enter the RTK code from NovAtel into the command line entry field to unlock RTK functionality. This is a unique number for each GPS receiver. It is assigned by NovAtel upon upgrade. Customers may contact NovAtel directly to purchase an upgrade or Kairos can assist (may result in a lower upgrade fee).
5. In the bottom center of djLoader's GPS3 tab, click the "Adjust:" dropdown. Choose "Standalone SmartV1 RTK Base – GSL" or "Standalone 6L RTK Base – GSL", then click the ">>Send" button. This will send the corresponding commands from the included "GPSCommands.txt" file.

For Vehicle GPS':
1. Boot the vehicle's Pronto4 system.
2. VNC into the system (see system documentation for specific steps)
3. Launch djLoader.
4. Ensure "COM" is set to "2" and data is streaming. If not, set "COM" to "2" and click the "Open" button; verify data is streaming.
5. Enter "freset" into the command line entry field, then click the "Send" button.
6. Enter the RTK code from NovAtel into the command line entry field to unlock RTK functionality. This is a unique number for each GPS receiver. It is assigned by NovAtel upon upgrade. Customers may contact NovAtel directly to purchase an upgrade or Kairos can assist (may result in a lower upgrade fee).
7. In the bottom center of djLoader's GPS3 tab, click the "Adjust:" dropdown. Choose "MLT RTK Configuration", then click the ">>Send" button. This will send the corresponding commands from the included "GPSCommands.txt" file.

GPSCommands.txt - Notepad

File Edit Format View Help

```
[Standalone SmartV1 RTK Base - GSL]
{restart off}
unlogall
pdpfilter disable
com com2 57600 n 8 1 n off on
interfacemode com2 none rtcmv3 off
log com1 gpggalong ontime 1.0
log com2 RTCM1002 ontime 1.0
log com2 RTCM1006 ontime 1.0
log com1 bestposa ontime 1.0
fix position 40.597411286 -111.907294997 1327.84
saveconfig

[Standalone 6L RTK Base - GSL]
{restart off}
unlogall
pdpfilter disable
com com2 57600 n 8 1 n off on
interfacemode com2 none rtcmv3 off
log com1 gpggalong ontime 1.0
log com2  RTCM1004 ontime 1.0
log com2  RTCM1005 ontime 10
log com2  RTCM1002 ontime 1.0
log com2  RTCM1006 ontime 10
log com1 bestposa ontime 1.0
fix position 40.597411286 -111.907294997 1327.84
saveconfig
```

GPSCommands.txt - Notepad

File Edit Format View Help

```
[MLT RTK Configuration]
{restart off}
UNLOGALL
FIX NONE
RTKSOURCE AUTO ANY
SBASCONTROL ENABLE AUTO
PSRDIFFSOURCE RTCA ANY
COM COM2 57600 n 8 1 n off off
interfacemode com2 rtcmv3 none off
log com1 gpggalong ontime .1
log com1 gpgst ontime .1
log com1 gpvtg ontime .1
pdpfilter enable
pdpmode relative dynamic
COM COM1 57600 n 8 1 n off on
saveconfig
```

Contact Information

Kairos Autonomi
498 West 8360 South
Sandy, Utah 84070 USA
801-255-2950 (office)
801-907-7870 (fax)
www.kairosautonomi.com