Revision Log

Revision	Date	Description	Author	Technical	Manager	User	Quality	Review Date
1	11-4-2003	Verbiage change/Classification Change	Jim Chance					
0	9-11-2003	Issued for Internal Review	Jim Chance	JR Hudson	Tim Patro	Sales	Jim Chance	9-11-04

Static Accuracy of C-Nav RTG V13.1

1. Introduction:

This paper describes the horizontal and vertical accuracy of C-Nav GcGPS receivers operating with software version 13.1 and antenna locations clear of significant blockage. The results are also generally applicable to version 13.2, which is not different than 13.2 in anyway that would be expected to effect the results.

The X, Y, and Z error of each receiver position with respect to the survey position was determined at each epoch. The mean error, the standard deviation, and the error at various confidence levels was determined.

A study was made of the relationship between the information contained in the GGA, GSA, and GST and the magnitude of the errors. Using insights gained during this study a filtered was developed to minimize errors. After filtering the statistics of the filtered data set were reexamined.

2. Data Sets Studied:

Data for this study were collected from five C-Nav™ SF2000RM receivers statically located on surveyed points. The receiver locations were well spread out about the globe. The receivers were using software version 13.1. The collection time at each station spanned approximately 25 days. This long time span was used to ensure that the data set was truly representative of the system performance in a variety of conditions. Further information regarding the monitoring stations is presented in Table 1.

Receiver & Software	S #	Location	Start Time	End Time	Total # of Epochs:	Epochs complete and valid
C-Nav™ SF2000RM V13.1	250179	Houston, TX N 29.80410 W 95.55881 HAE = 8.45	July 5, 2003	July 30, 2003	2,038,058	2,037,974
C-Nav™ SF2000RM V13.1	264894	Lafayette, La N 30.19919 W 92.00158 HAE = -13.60	July 5, 2003	July 30, 2003	2,122,263	2,122,099
C-Nav™ SF2000RM V13.1	264121	San Paulo, Brazil S 23.61841 W 46.67677 HAE = 801.30	July 5, 2003	July 30, 2003	2,207,106	2,207,101
C-Nav™ SF2000RM V13.1	250307	Singapore S 1.30255 E 103.86227 HAE =110.66	July 5, 2003	July 30, 2003	1,962,262	1,962,257
C-Nav™ SF2000RM V13.1	250374	Surrey, England N 51.416400 W 0.530788 HAE = 69.67	July 5, 2003	July 30, 2003	2,154,975	2,154,813

Table 1: Data Sets Studied

The antenna locations were surveyed in using Auto-GIPSY. The C-Nav GPS receiver raw L1/L2 C/A code and phase measurements for a 24-hour period were recorded and converted to RINEX observation data files. These files were then submitted to the Auto-GIPSY process at JPL. The Auto-GIPSY process uses the RINEX files and IGS precise ephemeris to calculate antenna position with millimeter level accuracy.

3. Accuracy of the Position Data:

At each epoch the X, Y, Z error with respect to the surveyed position was tabulated for each receiver. Various filters were applied to the recorded NMEA data. The filters were used to remove those positions that were likely to have reduced accuracy due to the factors discussed above. The improvement in accuracy due to filtering is not very significant.

- Filter 0 is unfiltered. Only invalid or incomplete data was removed.
- Filter 1 is the suggested standard filter. It removes epochs that where not dual frequency RTG, epochs during pull-in following a mode transition, periods where constellation was too weak to allow good positioning, and points which had poor accuracy and reliability statistics. All filtering was based upon data in the NEMA strings that are available in real-time to the user.
- Filter 2 is a tighter than standard filter. It is intended to include only those points that a very conservative user willing to accept poor availability would retain.

The filters are further described in Table 2.

Filter	Mode	Time since 2d/3d Transition Secs	Time Since s/d Phase Transition Secs	Min # of SV	Max RMS of PRR	SD of AE	Max RMS of Error Ellipse	Missing or Invalid NEMA
0	Any	Off	Off	Off	Off	Off	Off	yes
1	3D	2400	2400	5	01.3	1.25	0.75	yes
	RTG DF							
2	3D	2400	2400	5	0.2	0.35	0.2	yes
	RTG DF							

Comment: Page: 3
Internally this was called filter 2.2

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Internally this was called filte 2.3.

Table 2: Filter Descriptions

Statistics for the horizontal accuracy of each receiver are presented in Table 3 for both filtered and unfiltered data. Statistics for the vertical accuracy are given in Table 4 for both filtered and unfiltered data.

Filter	Location	% of data rejected	Confidence Level			Mean	Std Dev
			67% m	95% m	99% m		
0	Houston	0.002%	0.09	0.19	0.28	0.03	0.10
	Lafayette	0.006%	0.11	0.22	0.32	0.04	0.11
	San Paulo	0.0000%	0.10	0.18	0.28	0.07	0.07
	Singapore	0.0002%	0.07	0.16	0.23	0.00	0.08
	Surrey	0.0075%	0.08	0.17	0.29	0.05	0.11
	Mean of Locations		**0.09**	**0.18**	**0.28**	**0.04**	**0.09**
	Std Dev of Locations		0.02	0.02	0.03	0.03	0.02
1	Houston	1.2%	0.09	0.19	0.28	0.03	0.09
	Lafayette	2.4%	0.11	0.22	0.32	0.04	0.10
	San Paulo	0.3%	0.10	0.18	0.28	0.07	0.07
	Singapore	0.8%	0.07	0.15	0.22	0.00	0.08
	Surrey	1.8%	0.08	0.17	0.23	0.05	0.06
	Mean of Locations		**0.09**	**0.18**	**0.27**	**0.04**	**0.08**
	Std Dev of Locations		0.02	0.03	0.04	0.03	0.02
2	Houston	18.9%	0.08	0.19	0.26	0.04	0.09
	Lafayette	31.2%	0.09	0.21	0.30	0.05	0.09
	San Paulo	34.6%	0.10	0.18	0.30	0.07	0.07
	Singapore	13.6%	0.07	0.15	0.21	0.04	0.08
	Surrey	14.1%	0.08	0.16	0.23	0.05	0.07
	Mean of Locations		**0.08**	**0.18**	**0.26**	**0.05**	**0.08**
	Std Dev of Locations		0.01	0.02	0.04	0.01	0.01

Table 3: Horizontal Accuracy Statistics for data sets about the survey location.

Filter	Location	% of data rejected	Confidence Level			Mean	Std Dev
			67% m	95% m	99% m		
0	Houston	0.002%	0.18	0.39	0.46	0.08	0.18
	Lafayette	0.006%	0.19	0.40	0.52	0.09	0.21
	San Paulo	0.000%	0.16	0.36	0.46	0.08	0.16
	Singapore	0.0002%	0.16	0.30	0.39	0.07	0.14
	Surrey	0.0075%	0.12	0.32	0.44	0.03	0.21
	Mean of Locations		**0.16**	**0.35**	**0.45**	**0.07**	**0.18**
	Std Dev of Locations		0.03	0.04	0.05	0.02	0.03
1	Houston	1.2%	0.18	0.38	0.46	0.08	0.17
	Lafayette	2.4%	0.18	0.39	0.51	0.09	0.17
	San Paulo	0.3%	0.16	0.36	0.46	0.08	0.16
	Singapore	%	0.16	0.30	0.39	0.07	0.14
	Surrey	1.8%	0.11	0.31	0.42	0.03	0.14
	Mean of Locations		**0.16**	**0.35**	**0.45**	**0.07**	**0.16**
	Std Dev of Locations		0.03	0.04	0.05	0.02	0.02
2	Houston	18.9%	0.18	0.38	0.45	0.08	0.17
	Lafayette	31.2%	0.18	0.38	0.49	0.09	0.17
	San Paulo	34.6%	0.16	0.36	0.46	0.08	0.16
	Singapore	13.6%	0.16	0.29	0.37	0.07	0.14
	Surrey	14.1%	0.11	0.31	0.42	0.10	0.10
	Mean of Locations		**0.16**	**0.34**	**0.44**	**0.08**	**0.15**
	Std Dev of Locations		0.03	0.04	0.05	0.01	0.03

Table 4: Vertical Accuracy Statistics for data sets about their mean elevation.

The data confirms that the precision of positions created by the C-Nav receiver using the RTG methodology is similar worldwide.

4. Effect of Correcting the Vertical Position for Earth Tides:

C-Nav operates in ITRF 2000 (= WGS84 (G730) +/- ~ 0.02 m) , which is a reference frame fixed to Earth's center of mass (COM). An internal algorithm converts the altitude output to the EGM96 geoid which is fixed relative to ITRF 2000. The reference stations used in this

experiment are not fixed to Earth's COM but instead on Earth's terrestrial surface. The gravitational force of the moon and sun distort Earth and cause the relationship between the COM and the terrestrial surface to vary diurnally and semi-diurnally. Thus points fixed to Earth's surface "move" in ITRF 2000. Because the observer is typically rising and falling with the terrestrial surface the movement is not apparent without special instrumentation. The vertical coordinate for terrestrial points are usually given in a "zero-tide" or "tide-free" system. Removing the estimated Earth tide from C-Nav's output makes it valid in the "zero tide" system. In order to evaluate the size of this effect we computed the Earth tides at each location using "Quicktides" and reduced the altitudes measured directly by C-Nav. A considerable improvement in vertical accuracy was made as indicated in Table 5.

Filter	**Location**	**% of data rejected**	**95% Confidence Level**	
			As output by Receiver	**Post-processed for Earth Tide Correction**
0	Houston	0.002%	0.39	0.26
	Lafayette	0.006%	0.40	0.25
	San Paulo	0.000%	0.36	0.22
	Singapore	0.0002%	0.30	0.28
	Surrey	0.0075%	0.32	0.20
	Mean of Locations		**0.35**	**0.24**
	Std Dev of Locations		0.04	0.3

Table : Effect of Earth Tide Correction

5. Bias of Filtered Data:

The mean position of the data processed using the standard filter was compared to the surveyed position. The biases of the mean positions with respect to the surveyed positions are given in Table 7. Antenna phase center offsets would be common to both the survey and mean data and are therefore not represented in the biases.

	North	East	Horizontal	Z
Houston	-0.03	-0.01	0.03	0.08
Lafayette	-0.03	-0.02	0.04	0.09
San Paulo	0.02	-0.07	0.07	0.08
Singapore	0.00	0.00	0.00	0.07
Surrey	-0.04	0.00	0.04	0.03
Mean			0.036	0.07
Standard Deviation			0.025	0.023

Table 7: Bias of standard filtered data wrt surveyed position

6. Conclusions:

1. C-Nav receivers using V 13.1 RTG dual frequency mode have a horizontal accuracy of 0.19 +/- 0.03 meters at the 95% confidence level.

2. C-Nav receivers using V 13.1 RTG dual frequency mode and no Earth tide correctors have a vertical accuracy of 0.35 +/- 0.05 meters at the 95% confidence level.

3. C-Nav receivers using V 13.1 RTG dual frequency mode and Earth tide correctors have a vertical accuracy of 0.24 +/- 0.04 meters at the 95% confidence level.

4. C-Nav receivers using V 13.1 RTG dual frequency mode have a horizontal bias of 0.04 +/- 0.04 meters at the 95% confidence level.

5. C-Nav receivers using V 13.1 RTG dual frequency mode have a vertical bias of 0.06 +/- 0.03 meters at the 95% confidence level.

6. This level of accuracy is valid worldwide.