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NRL Report 7511

Range Navigation Using the TIMATION II Satellite

[Unclassified Title]

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Space Metrology Branch
Space Systems Division

February 12, 1973

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ABSTRACT
(Confidential)

The TIMATION (Time Navigation) technique of passive ranging can be employed to provide a worldwide navigation and time-transfer service. Passive ranging is accomplished by measuring the time difference between electronic clocks located within the satellite and the navigator's receiver. Navigation results were obtained with a prototype system consisting of the TIMATION II satellite and four ground stations. The results indicate a CEP position-fixing capability of 33 meters (100 feet) using dual-frequency range measurements. The analysis of the data includes ionospheric refraction, instrumentation error, and the effect of satellite trajectory position error in both the observed and predicted regions.

PROBLEM STATUS

This is an interim report on one phase of the problem; work on this and other phases is continuing.

AUTHORIZATION

NRL Problem R04-16
Project A3705382 652B1F48232751

Manuscript submitted Oct. 18, 1972.

RANGE NAVIGATION USING THE TIMATION II SATELLITE
(Unclassified Title)

INTRODUCTION

(U) The TIMATION (Time Navigation) experiment for satellite navigation is now being developed under the sponsorship of the Naval Material Command, PM-16. When the TIMATION II satellite was launched Sept. 30, 1969, the project was sponsored by the Naval Air Systems Command. TIMATION II transmits range and doppler signals near 150 and 400 MHz. These signals can be used to correct range or doppler for first-order ionospheric refraction. Four U.S.-based ground stations are used to track the satellite and to collect telemetry information from the sensors on board the satellite. Other ground stations are used to control the satellite subsystems, including its ability to tune (in phase and frequency) the on-board quartz crystal oscillator.

(U) The overall physical configuration for TIMATION II is given in Fig. 1. TIMATION II is equipped with a high-precision quartz crystal oscillator capable of frequency stabilities on the order of a few parts in 10^{11} per day. TIMATION II is equipped with active thermal control of the oscillator environment, which effectively eliminates oscillator frequency fluctuation due to temperature changes.

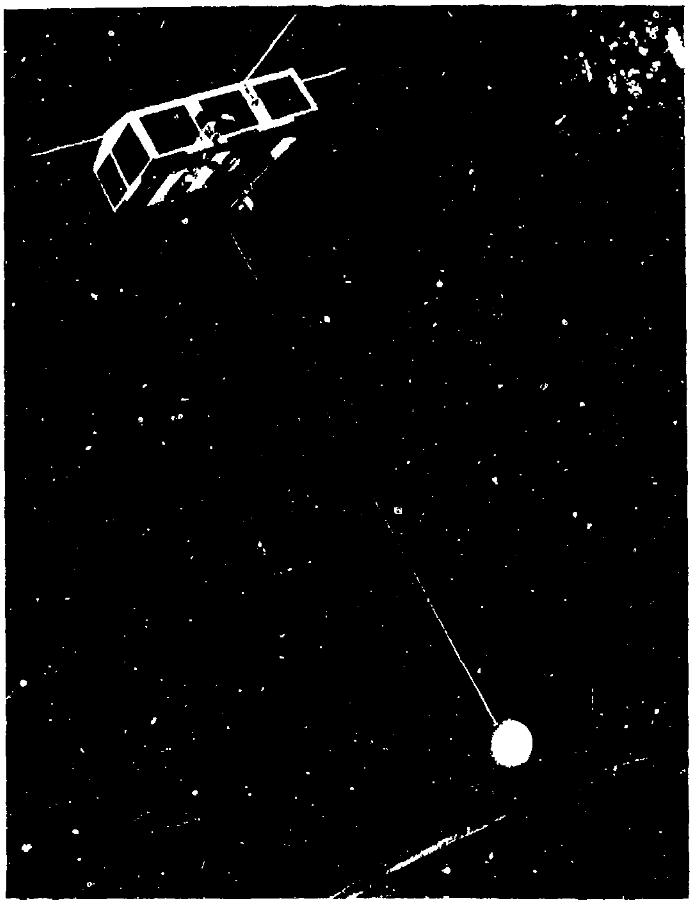
(U) Ranging information is provided by means of coherent modulation of the carrier, with modulation frequencies within the range from 100 Hz to 1 MHz. The range receiver synthesizes a similar set of frequencies which are phase compared with the received signal.

THE TIMATION II SATELLITE

(U) The TIMATION II satellite has an overall configuration similar to the TIMATION I satellite (1); hence only a summary of its features will be given in this report. The satellite weighs approximately 125 pounds and consumes an average of 18 watts of power, furnished by solar cells and batteries. Two-axis gravity-gradient stabilization is provided by using an extendable boom. Temperature control is achieved by (a) careful design of the satellite (2) to provide a temperature range from 0°C to +20°C inside the satellite, and (b) active temperature control of the quartz-crystal frequency standard to maintain its external temperature to within a fraction of a degree. Linearly polarized dipoles are used for the 150- and 400-MHz antennas. A separate telemetry antenna is used. This antenna is mounted on the side and has more than 40 dB of isolation from the main antennas. In addition, a magnetometer is used to sense attitude changes of the satellite.

(U) The frequency of the oscillator may be electromechanically tuned in discrete steps of approximately 3.6×10^{-12} parts per pulse. The phase of its transmissions may be advanced or retarded in discrete steps of 33.3 nanoseconds per pulse. These two features provide control over the satellite clock synchronization and clock rate.

(U) TIMATION II is in a 500-naut-mi, near-circular orbit which has an inclination of 70 degrees to the equatorial plane. With this orbit, several passes of 12 to 16 minutes duration each will be available during the day at each of the four TIMATION tracking stations.



(U) Fig. 1 - The TIMATION I satellite

TIMATION RANGING CONCEPT

(U) The TIMATION II satellite carries a highly stable crystal oscillator, from which nine modulation frequencies of the two carriers of 150 and 400 MHz are obtained. The modulation frequencies are 100 Hz, 312.5 Hz, 1 kHz, 3.125 kHz, 10 kHz, 31.250 kHz, 100 kHz, 312.5 kHz, and 1 MHz. The transmitted modulation frequencies can be received and phase compared with a similar set of coherent tones synthesized from an oscillator, or "clock," at the receiver site. This system is thus a frequency interferometer which will measure the time difference between the received signal and the local time with ambiguities of 80 milliseconds, based on the highest common divisor of 12.5 Hz, and which has an accuracy based on the precision of the phase comparison of the highest tone (1 MHz). In the system, the resolution of the phase comparison is 1 percent of a period, giving a time resolution of 10 nanoseconds when using the 1-MHz tone. The error of the time comparison of the received and local signals is slightly more than 10 nanoseconds, due to phasemeter zero adjustment, nonlinearity, differential phase shift in the receiver, noise, and other lesser factors. This measurement may be converted to ranging information by multiplying by c, the speed of light in a vacuum. This conversion shows that 10 nanoseconds is within 15 percent of 10 feet. This ranging information, which depends on the navigator's position, also includes information on the time difference between the satellite clock and the navigator's clock.

(U) The actual time difference between the received signal and the local reference is the time difference between the satellite oscillator, or "clock," and the ground clock, plus the propagation time required for the signal to propagate from the satellite to the receiver. The time indicated by the components of the received signal is subject to some error due to the dispersive effect of the ionosphere.

(U) The user's time base is obtained from the user's frequency standard, using suitable countdown and comparison circuitry. The timing requirements for the ground-station clock are higher than for the user's clock. The ground stations are equipped with cesium-beam frequency standards which are kept in time synchronization with the UTC time base.

(U) The system user, or navigator, is not required to have a frequency standard of the same precision as required for use in the satellite. For example, quartz-crystal frequency standards with stabilities on the order of a few parts in 10^{10} per day would be suitable for use by a TIMATION II user.

SATELLITE TRAJECTORY CALCULATIONS

(U) The satellite trajectory computation is made by the Naval Weapons Laboratory (NWL), using doppler tracking data obtained from the TRANET tracking network. The orbit determination is performed on the NWL computer using their ASTRO (3) program, which performs a statistical estimate of the dynamic and observational parameters of the state variables at epoch. The force model accounts for accelerations from the following sources: (a) earth gravitational accelerations, (b) sun and moon gravitational accelerations, (c) solar and lunar tidal bulge effects, (d) atmospheric drag, and (e) radiation pressure. The earth's gravitational acceleration includes coefficients for the earth's gravitational potential as a function of longitude as well as latitude. Other parameters, such as drag and the positions of the tracking stations, are included in the model. A weighted least-squares estimate is then performed based on observational data, obtained over time arcs ranging from two to four days.

(U) The first-order ionospheric refraction can be measured by means of the dual frequencies in the TIMATION II satellite. With the inclusion of the ionospheric refraction, NWL determines the position of TIMATION II to ±10 meters during the observation span. The positional accuracy outside of the observed data span remains near ±10 meters for extrapolations on the order of 12 to 24 hours. Beyond one-day extrapolations, the error may grow rapidly.

(U) For operational purposes the satellite ephemeris would require updating on a frequent basis. However, for the purpose of analyzing the Timation system performance, the analysis is done using the satellite trajectory during the observed data span. This choice minimizes the contribution of satellite positional error to the total navigational fix error.

RANGE NAVIGATION TESTS

(U) Range observations on the TIMATION II satellite are taken at four receiver sites— Ft. Collins, Colorado; Perrine, Florida; Chesapeake Bay, Maryland (CBD); and Naval Research Laboratory, Washington, D.C. These data are read at one-minute intervals and sent via phone lines to a time-sharing computer service, where it is stored for processing. Some initial preprocessing and internal system checks utilize the time-shared computer, but the range-navigation computations are made on the large NRL computer. The computations include a least-squares solution (4) which uses the range measurements for each pass to solve for latitude, longitude, and clock correction. The latitudes and longitudes are compared to the surveyed values for the receiving sites to determine navigational accuracies. The clock corrections are used to study the satellite and station oscillator behavior and to make time transfers and station synchronizations between pairs of ground stations.

(U) The following criteria are followed for data selection. For the range-navigation solutions, only those passes meeting the following restrictions are used: (a) maximum elevations between 15 and 70 degrees, (b) symmetrical data, and (c) at least two minutes of data on both sides of the point of closest approach.

(U) Navigation solutions are performed using three different combinations of range data: (a) 400-MHz data only, (b) 400- and 150-MHz data, and (c) 400-MHz data using a theoretical model of the ionosphere and troposphere to determine refraction effects. Use of 400-MHz data with no refraction correction results in a navigation fix which may be in error up to several hundred meters, due to ionospheric refraction. When the 400-MHz data are corrected using a theoretical model of the atmosphere (5), more accurate results are obtained. The Chapman model, which is used for this purpose, uses the method of ray tracing called the "linear layer" method. This method involves two principal ideas - first, tracing the ray through the troposphere, and second, tracing the ray through the ionosphere. For the theoretical correction, a table of range-error values for the 150-MHz and 400-MHz frequencies at different elevation angles was calculated and included in the navigation program. For the required elevation angle, an interpolation is done to find the corresponding range error. A more accurate way to remove the first-order ionospheric refraction effects is to combine the 150-MHz and 400-MHz range measurements (4). This procedure will be referred to as the dual-frequency-correction method.

(U) In addition to inclusion of corrections for the refractive effects of the atmosphere, the frequency differences between the oscillator in the satellite and the oscillators at the ground stations are computed and included in the navigation solutions. For the time span covered in this report, the difference in frequency is ±9 parts in 10^{10}.

(U) Two stations use the dual-frequency method of refraction correction. CBD had the first 150-MHz receiver; then in April 1971 a 150-MHz receiver was installed at Colorado. The Colorado receiver was subsequently moved, in September 1971, to Florida.

RANGE NAVIGATION RESULTS

(U) The statistical measures used for computing the navigational accuracies of a set of passes are the circular error probable (CEP) and the root mean square (RMS). The CEP is defined as the value of the radius of a circle that contains 50 percent of all data samples. In this report, TNAV, or total navigation error, is defined as the square root of the sum of the squares of the errors in latitude and longitude for a given pass—that is, the differences in latitude and longitude between the computed and the surveyed position of the station antenna.

(U) A summary of navigation results is given in Tables 1 through 4. Included are results from the four field stations previously mentioned. One location, included in Table 1, but not mentioned earlier, is Fort Valley, Virginia. The CBD station was moved to this site for approximately one month near the end of 1970. This move is of significance as a reference point in discussing the CBD navigation results. In Figs. 2 through 4, three time spans are covered. They are (a) before moving to Fort Valley, (b) the time at Fort Valley, and (c) the time after leaving Fort Valley. These three groups of graphs include all the observed data covered in Table 1. An analysis of these navigation solutions shows that the best results were obtained while at Fort Valley. This outcome is possibly due to the lack of electronic interference at the Virginia site. On examining just the CBD data, the time prior to the move to Fort Valley produces better navigations than the period after returning to CBD. One possible reason for this is a change of the 150-MHz receiver; a new one was installed at CBD after the station was reopened. Another possibility is the increased interference observed from newly activated transmitters located near the CBD site.

(U) Each of these three time spans is represented by three graphs (Figs. 2 through 4). Consistently, navigation fixes using the dual-frequency method are an improvement over the navigation solutions using only the theoretical models, and both of these results are better than the results using no ionospheric correction. To further illustrate the importance of the need for a correction for ionospheric refraction, consider the first graph of each set (400-MHz range, no correction). On these graphs, approximately 75 percent of the passes within a circle scribed with a radius (TNAV) equal to 150 meters are night passes. This fact illustrates that the effects of the ionosphere are less at night than during the day, resulting in more accurate nighttime navigations. Use of the Chapman model brings the day passes toward the origin to a greater degree than the night passes. The results show that in the second graph (400-MHz range, navigation with refraction correction) of each set, no distinction exists between the TNAV's of the day and the TNAV's of the night passes. When the dual-frequency method is used, all the passes are brought closer to the origin. The results again show no discernible difference between night and day passes.

(U) In Tables 1 through 4, the navigation runs are in groups of 75 passes or less. There are two reasons for this. First, the navigation program was written so that it cannot solve more than 75 passes at a time. Second, the magnetic tapes that store the trajectory information contain approximately 200 passes, and only one tape can be used per computer run. Not all of these 200 passes are taken at each station, and of the ones taken not all can be used in the navigation runs. From the 200, perhaps less than 75 can be used; of if more than 75, the data must be divided into two runs. Examples of typical navigation runs over the time covered by this report are given in Figs. 5 through 8.

(U) The criteria used in selecting acceptable passes were mentioned previously in this report. First mentioned were requirements for maximum and minimum elevation angles. CBD will be used as an example here (Table 5). Any of the other stations would show similar results. The data again are separated relative to the move to Fort Valley, Virginia. The data are separated according to maximum elevation angle within each time span for the three corrections used. The first separation is by thirds; under 30 degrees, and over 30 degrees and under 60 degrees, and over 60 degrees. These divisions do not alter the navigation results. The answers are independent, within the limits originally set, of maximum elevation angle.

(U) From November 1970 through July 1971, navigation solutions were made using a predicted orbit, in addition to the observed orbit from which the previous results were obtained. The orbit is determined by data from the 15 TRANET tracking stations. For the observed region, orbit fits of ten meters or less are realized. The uncertainty in the position of the satellite increases as a function of the length of time into the predicted orbit region. This uncertainty shows up in poorer navigation solutions.

(U) The satellite trajectory data sent from NWL consists of two days of observed data, followed by seven days of predicted data. During this nine-month period the trajectory was sent every fourth day; in the navigation runs a cycle of two days of observed data, then two days of predicted data were used. When computing an orbit, the fit of ten meters no longer holds in the predicted region. A graph depicting the increasingly poorer answers is presented in Figs. 9a and 9b. These examples show how TNAV increases as a function of time into the predicted region. The stations used in this example are NRL and Florida. The days in these graphs were chosen because for each two-day period, at least four passes were taken at both of the stations. The same days are used to illustrate the similarity in overall slope for each two-day run. For each station the four passes used are not necessarily the same, which indicated that the trajectory for this predicted period is the reason for the resulting increased navigation errors.

(U) Figure 10 is used to compare the navigation error resulting from the use of orbital data in the observed and predicted regions. In making the comparison of observed versus predicted data, it is useful to know the orientation of the satellite velocity vector at the time the satellite is at maximum elevation with respect to the ground station. The TIMATION II satellite has an inclination of 70 degrees, and the ground stations are located at mid-latitudes (30 to 40 degrees). These parameters result in a north-to-south orientation, with a small east component, of the velocity vector of the satellite at the maximum elevation point. The positional error due to the use of predicted satellite trajectory has its largest error component along the track of the satellite orbit, which results in a navigation error that displaces the station along the direction of the velocity vector and appears primarily as a latitude error of the station. A cross-track error appears primarily as a longitude error. The observed data span shows cross-track, longitude errors. In the predicted region, the predominant error is along-track, or latitude, errors. These errors are summarized in Table 6. For all the stations and all the corrections, the CEP's of the longitudes and latitudes are given for both the observed and predicted regions. These CEP's were calculated by taking the magnitude of the error in latitude or longitude for all the passes and computing an average. When these results, for the observed and the predicted time spans, are compared, the latitude CEP consistently shows the greater change. Figure 11 combines the CEP's of latitude and longitude to give graphic representations of these changes. When comparing the predicted to the observed runs, the similarities are evident at all the stations for the corrections used.

CONCLUSIONS

(C) Of the three navigation solutions calculated, the solution using the dual-frequency ionospheric correction provide the best navigations, with an average CEP position-fixing capability of 48 meters. The single-frequency method, using a theoretical ionospheric model, is next best, with an average CEP position-fixing capability of 68 meters. The least acceptable results use the simple single-frequency solution, with an average CEP position-fixing capability of 156 meters. The best navigation results were from the dual-frequency solution at Fort Valley, Virginia, with a CEP position-fixing capability of 33 meters. The navigation errors caused by use of a predicted orbit are a result of the uncertainty in the position of the satellite, especially along the track of the orbit. This bias results in more latitude than longitude error. The accuracy of the navigation solutions is independent of their maximum elevation angles.

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Special thanks are extended to Mr. R. J. Anderle, Mr. Robert Hill, and Mr. Lawrence Beuglass of the Naval Weapons Laboratory for their assistance in the calculations of the TIMATION orbit trajectories.

REFERENCES

1. NRL Space Metrology Branch, "The TIMATION I Satellite" (Confidential Report, Unclassified Title), NRL Report 6781, Nov. 18, 1968
2. Easton, R. L. and Bartholomew, C. A., "The Thermal Design of the TIMATION I Satellite," NRL Report 6782, Jan. 1969
3. "Documentation of ASTRO Mathematical Processes," NWL Tech. Report TR-2159
4. McCaskill, T. B., Buisson, J. A., and Lynch, D. W., "Principles and Techniques of Satellite Navigation Using the TIMATION II Satellite," NRL Report 7252, June 17, 1971
5. Lamont V. Blake, "Ray Height Computation for a Continuous Nonlinear Atmospheric Refractive-Index Profile," Radio Science, Vol. 3, No. 1, 85-92, Jan. 1968

Table 1 (C)
Range Navigation Summary

Time of Year (Days)	Number of Passes	Single Frequency (400 MHz) No Correction		Single Frequency (400 MHz) Theoretical Correction		Dual Frequency (150/400 MHz)	
		CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)
OBSERVED REGION (CBD)							
173-183(1970)	23	173	226	87	108	44	53
185-205	31	172	206	70	110	40	51
209-232	39	156	192	75	104	43	49
233-267	52	134	182	62	113	47	61
268-302	57	209	264	71	113	40	53
54- 63(1971)	23	181	210	71	110	43	58
65- 70	10	189	243	92	112	36	47
70- 82	25	210	263	68	112	39	63
84-118	25	152	181	49	88	61	66
119-140	56	133	161	85	100	51	68
143-174	36	146	177	89	97	61	71
175-200	38	174	185	74	97	70	75
237-253	31	106	118	54	74	53	55
255-265	14	122	188	45	86	47	80
268-290	28	131	175	56	104	46	50
291-324	48	143	166	43	57	43	54
343-355	12	101	117	62	71	58	71
PREDICTED REGION (CBD)							
141-202(1971)	67	167	196	93	138	85	124
OBSERVED REGION (Fort Valley, Va.)							
309-334(1970)	36	155	252	50	107	33	47

Table 2 (C)
Florida Range Navigation Summary

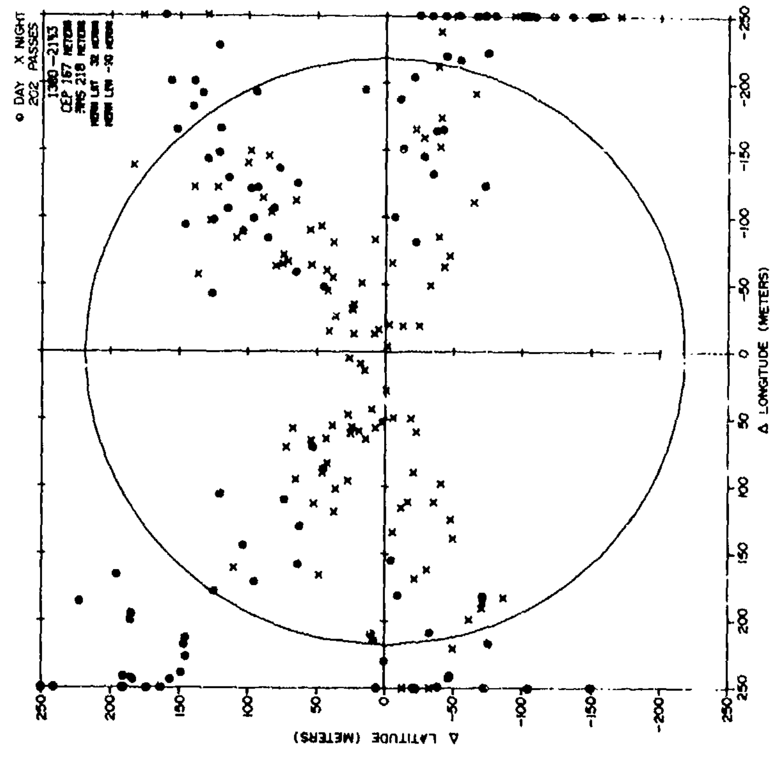
Time of Year (Days)	Number of Passes	Single Frequency (400 MHz) No Correction		Single Frequency (400 MHz) Theoretical Correction	
		CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)
OBSERVED REGION					
185-207(1970)	36	186	218	88	153
209-238	64	153	204	64	88
239-265	45	108	189	69	136
267-302	60	291	357	110	209
303-334	69	206	254	97	124
338- 49(1971)	53	93	197	71	95
52- 83	51	176	242	75	117
84-140	62	119	197	62	113
143-196	48	120	171	69	111
237-290	75	134	184	66	92
291-320	39	93	141	66	104
PREDICTED REGION					
335- 51(1971)	56	248	326	164	270
86-114	21	182	319	163	203
142-202	42	150	209	100	146

Table 3 (C)
NRL Range Navigation Summary

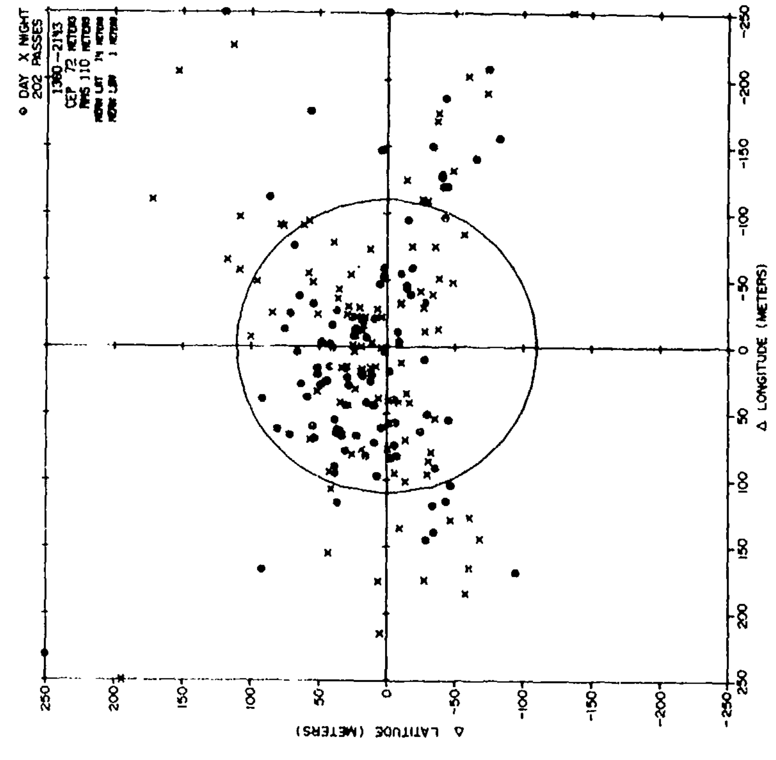
Time of Year (Days)	Number of Passes	Single Frequency (400 MHz) No Correction		Single Frequency (400 MHz) Theoretical Correction	
		CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)
OBSERVED REGION					
185-204(1970)	51	219	274	156	196
209-225	45	185	232	101	108
226-238	31	158	249	97	112
239-250	32	135	176	80	108
250-266	42	116	149	87	113
267-298	70	184	272	128	152
299-302	10	192	243	116	132
303-320	52	267	307	165	184
320-334	31	239	279	141	164
337-358	34	171	213	106	124
8- 49(1971)	64	166	301	113	230
52- 69	42	203	218	117	162
70- 83	39	187	265	111	147
84-126	62	130	160	81	99
127-140	36	152	176	103	117
143-174	46	134	169	110	133
175-200	42	168	189	95	116
237-270	59	138	163	76	97
270-290	48	151	312	113	245
291-324	57	161	186	83	113
PREDICTED REGION					
335-356(1970)	32	291	404	243	367
360- 51(1971)	62	206	307	134	251
86-114	25	183	267	170	227
141-201	70	145	166	103	130

Table 4 (C)
Colorado Range Navigation Summary

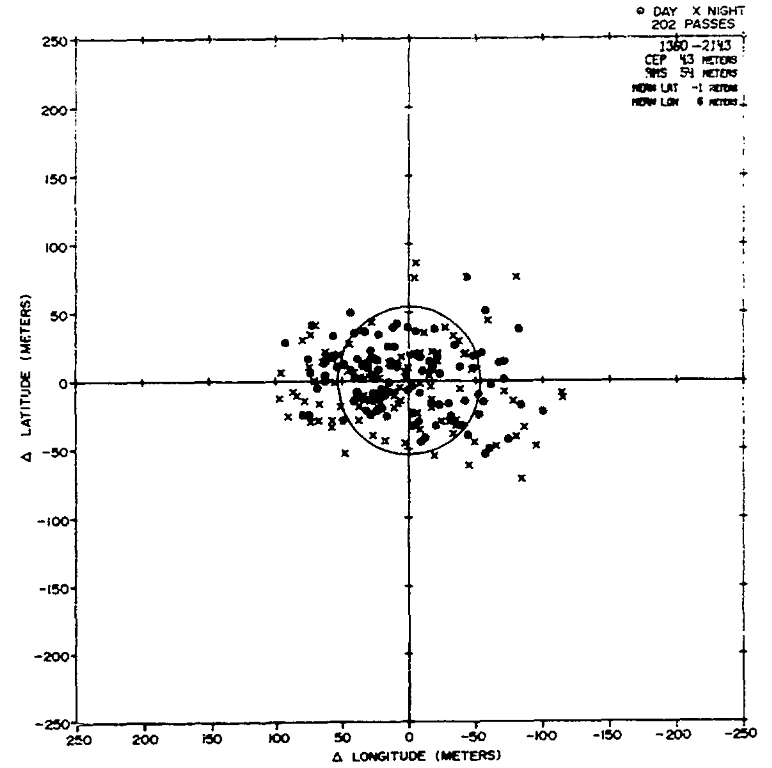
Time of Year (Days)	Number of Passes	Single Frequency (400 MHz) No Correction		Single Frequency (400 MHz) Theoretical Correction		Dual Frequency (150/400 MHz)	
		CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)	CEP (meters)	RMS (meters)
OBSERVED REGION							
185-208(1970)	28	181	292	106	283		
209-238	58	126	160	78	112		
239-267	71	76	123	51	88		
267-302	64	215	338	72	133		
303-320	53	208	268	83	118		
321-334	36	142	244	82	118		
338-353	19	71	112	59	139		
4- 49(1971)	44	107	324	72	245		
52- 69	41	159	183	81	108		
69- 83	39	140	210	81	109		
84-117	24	159	222	94	172		
118-140	45	125	220	85	168	78	179
143-200	13	105	245	85	148	86	153
155-196	41	136	213	97	209	89	206
237-276	75	119	188	99	155	109	172
281-290	21	108	146	107	136		
292-324	74	106	132	94	133		
PREDICTED REGION							
334-356(1970)	19	234	326	204	306		
360- 51(1971)	41	278	326	175	298		
86-114	13	283	272	178	235		
141-202	16	142	343	185	303	150	314
157-197	31	143	330	128	248	110	257



(a). 400 MHz, no correction

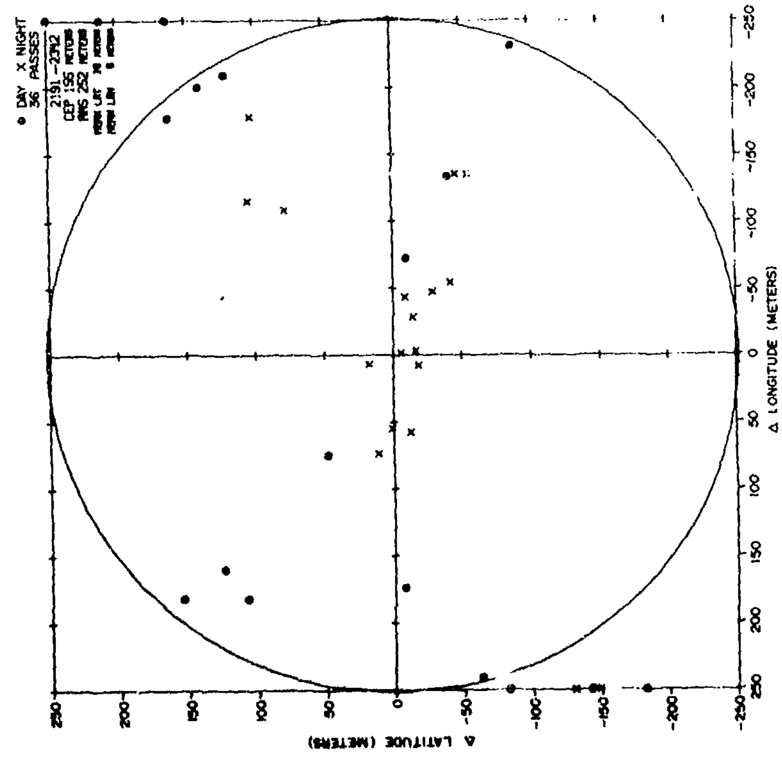


(b). 400 MHz, with refractive correction

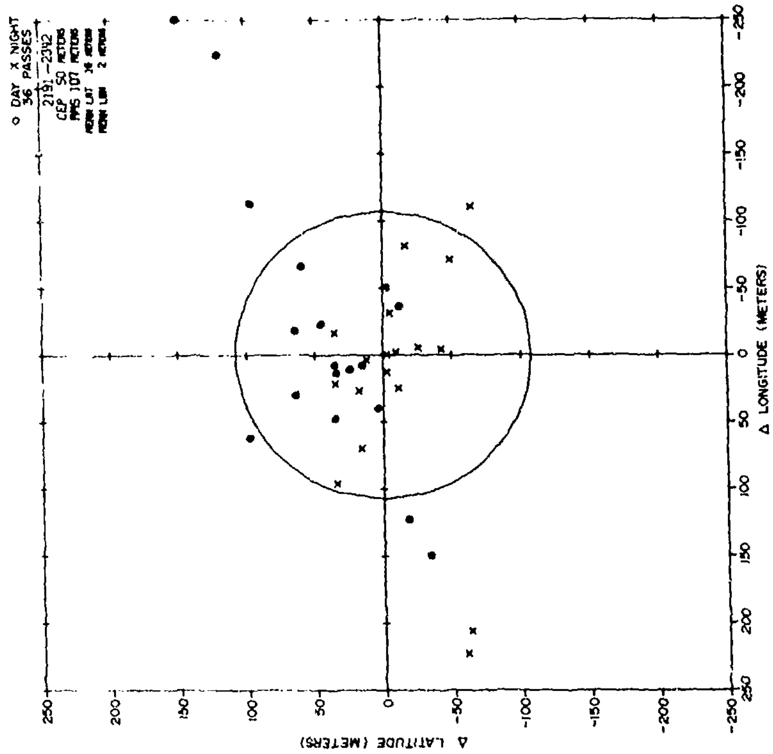


(c). 150 and 400 MHz

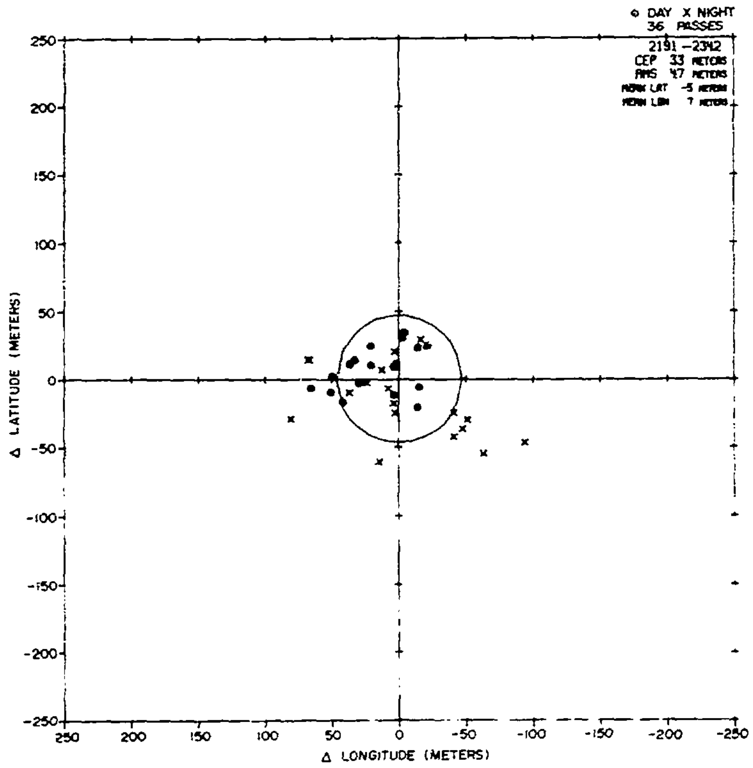
(C) Fig. 2 - Navigation results from CBD prior to the move to Fort Valley, Virginia



(a). 400 MHz, no correction

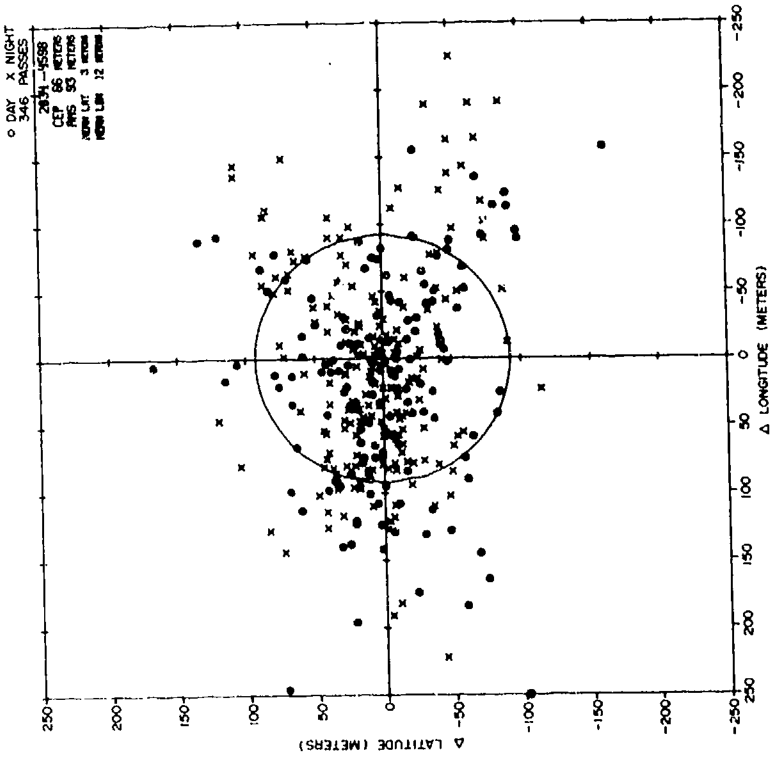


(b). 400 MHz, with refractive correction

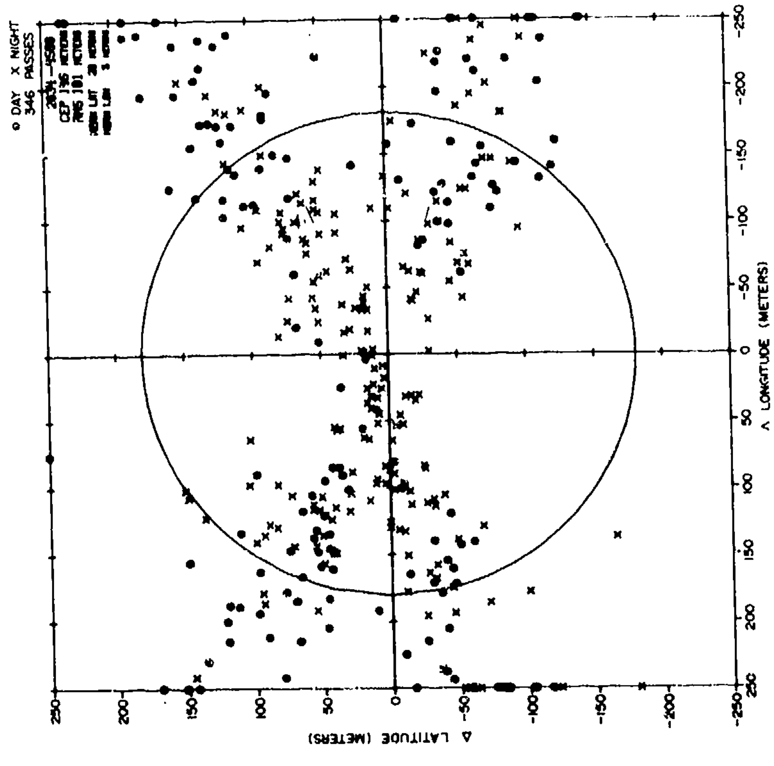


(c). 150 and 400 MHz

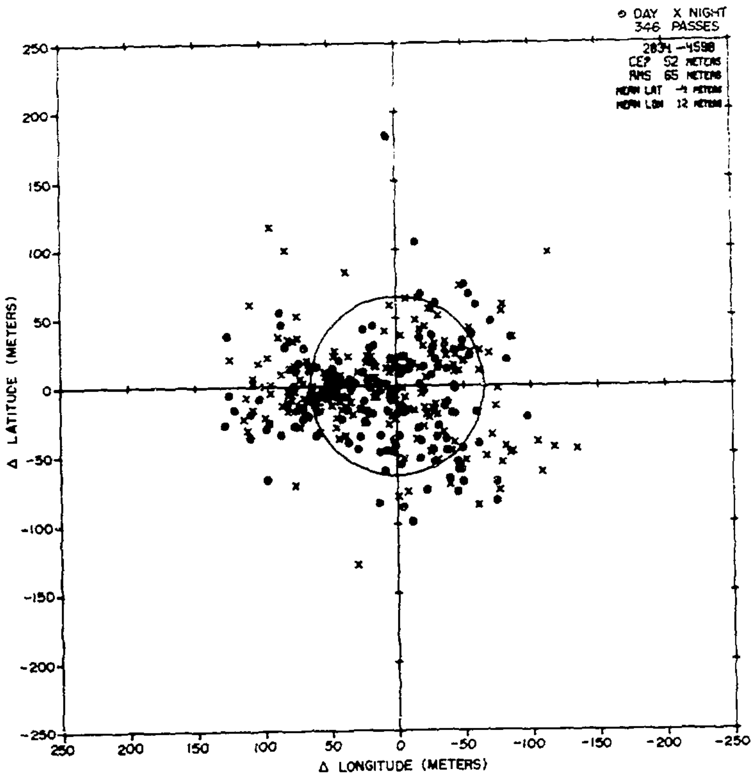
(C) Fig. 3 - Navigation results taken at Fort Valley, Virginia



(b). 400 MHz, with refractive correction

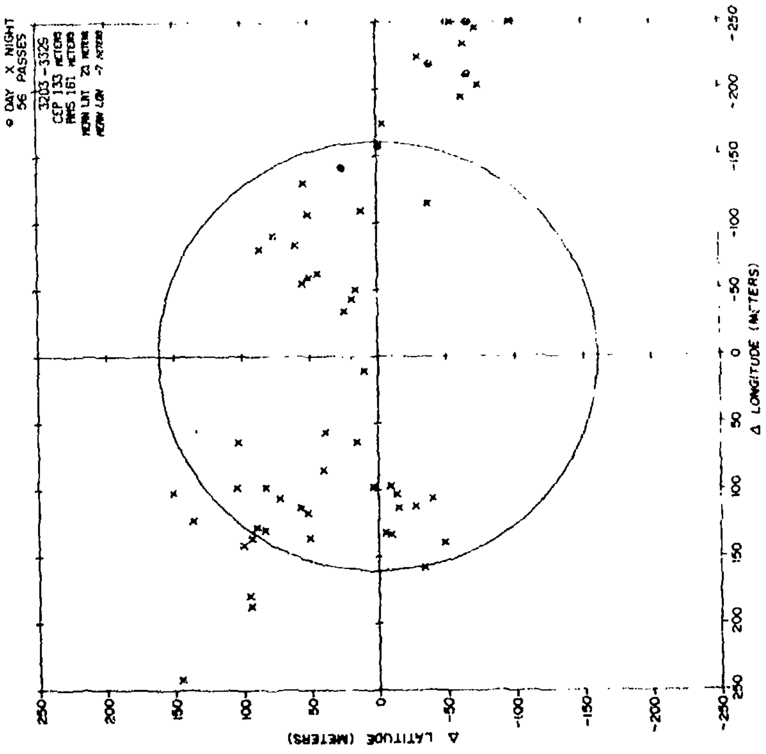


(a). 400 MHz, no correction

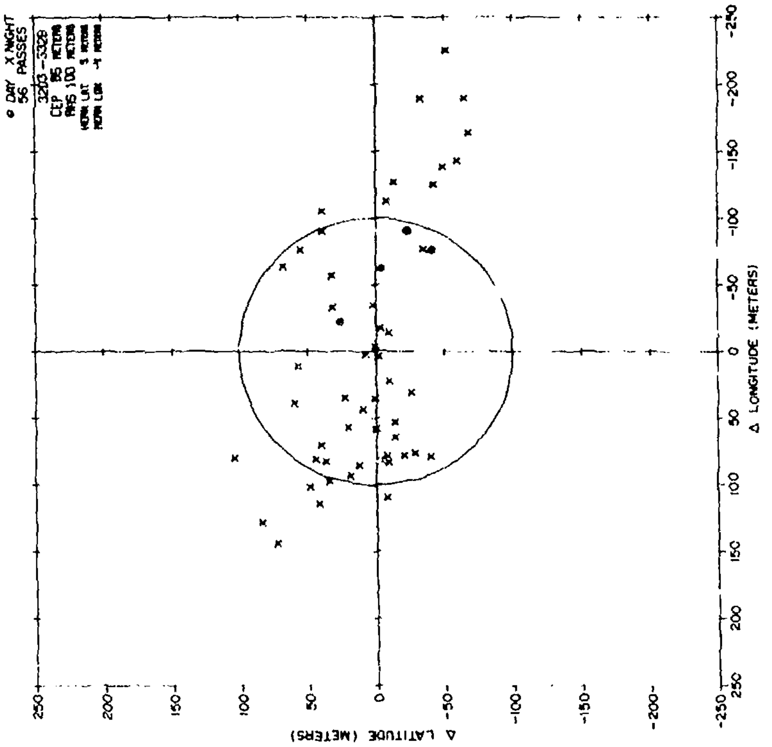


(c). 150 and 400 MHz

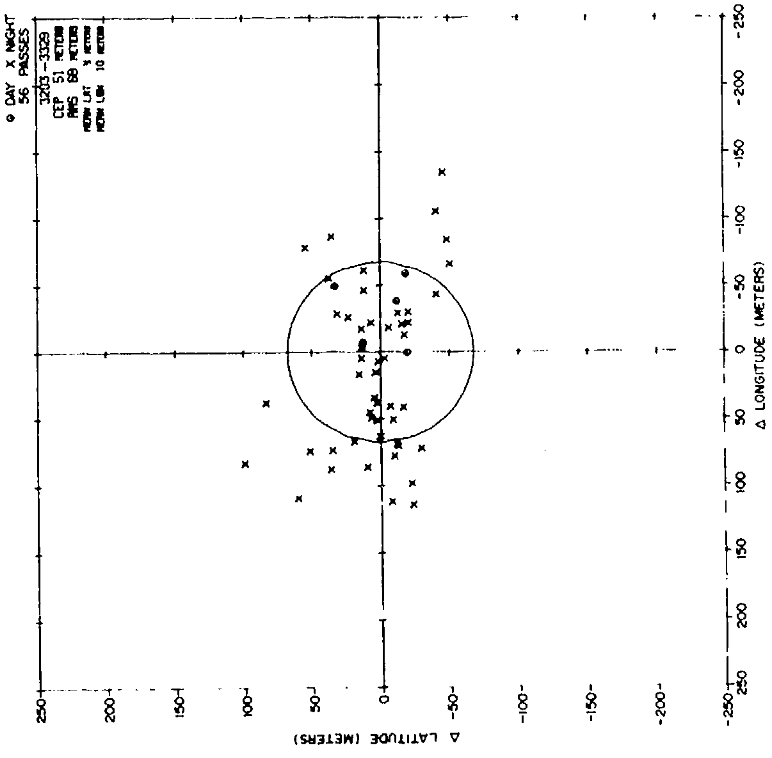
(C) Fig. 4 - Navigation results from CBD following the move from Fort Valley, Virginia



(a). 400 MHz, no correction

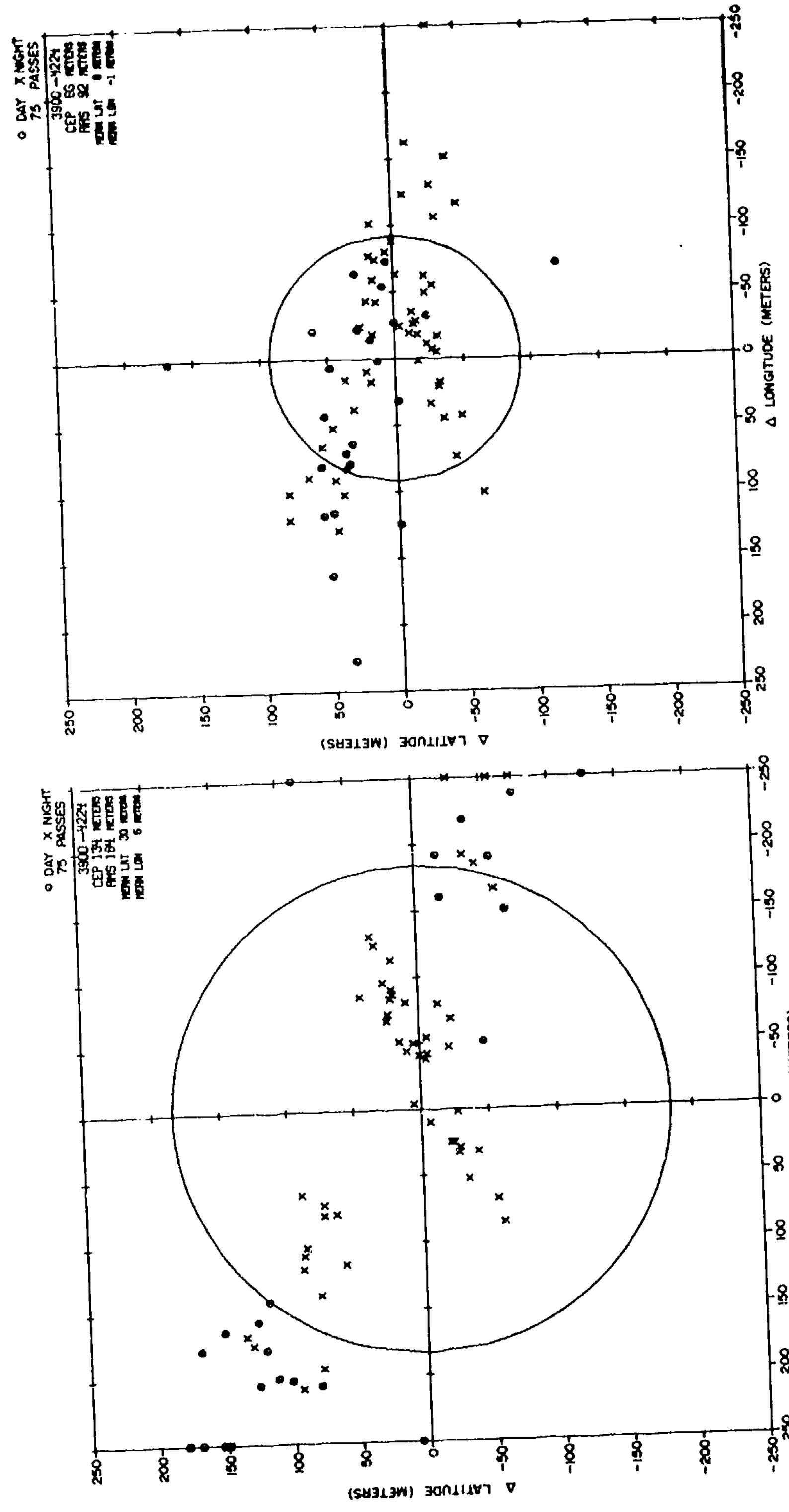


(*b*). 400 MHz, with refractive correction



(c). 150 and 400 MHz

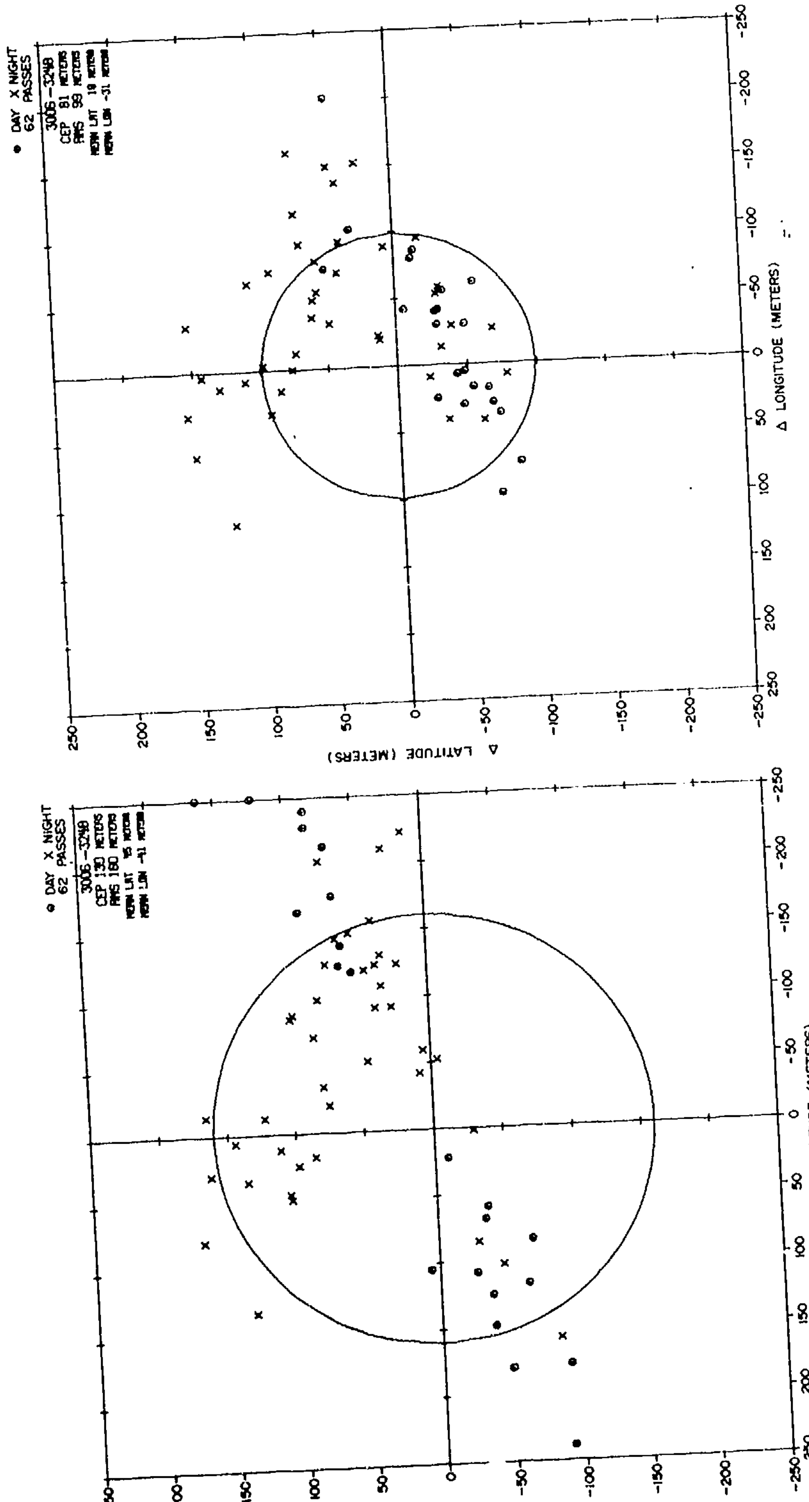
(C) Fig. 5 - CBD range navigation run



(a). 400 MHz, no correction

(b). 400 MHz, with refractive correction

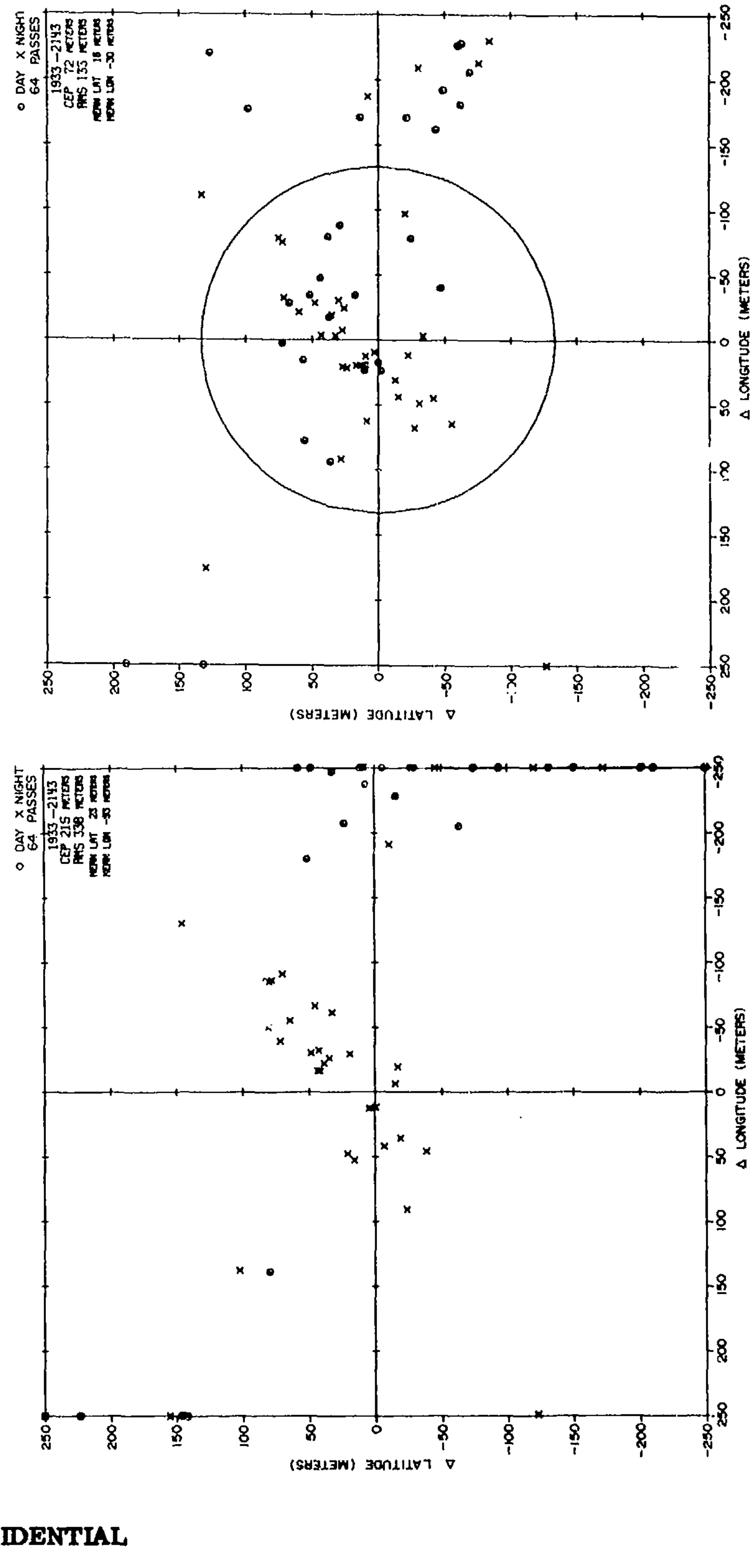
(C) Fig. 6 - Florida range navigation run



(b). 400 MHz, with refractive correction

(a). 400 MHz, no correction

(C) Fig. 7 - NRL range navigation run



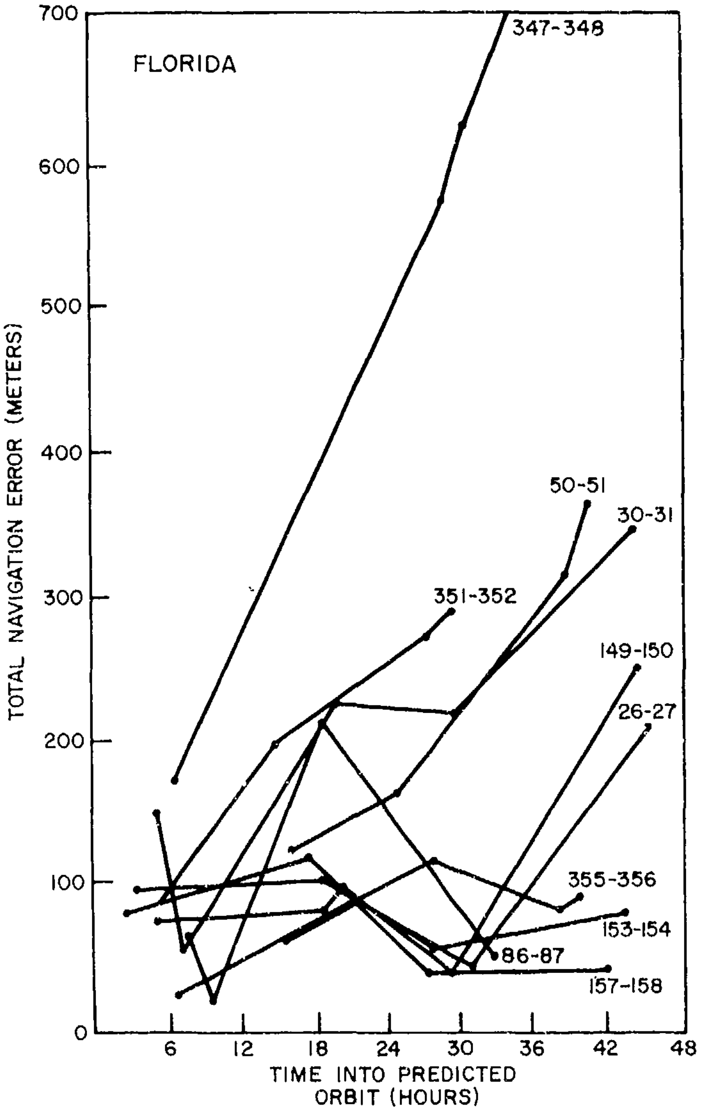
(a). 400 MHz, no correction

(b). 400 MHz, with refractive correction

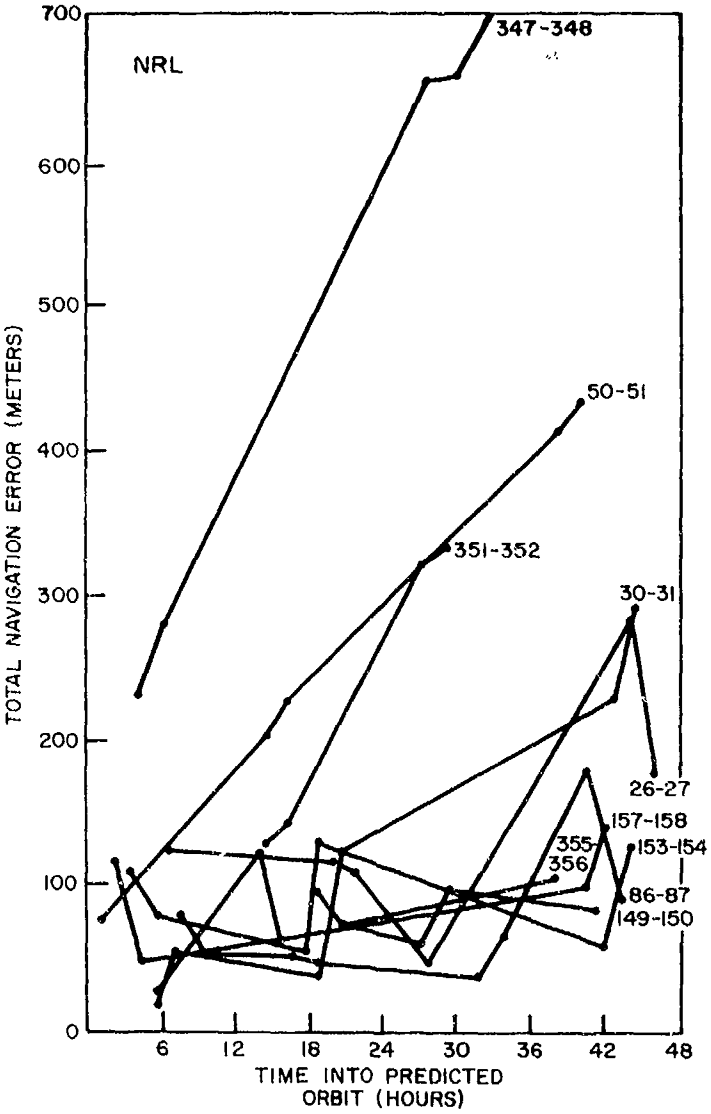
(C) Fig. 8 - Colorado range navigation run

Table 5 (C)
Relationship Between Navigation Accuracies and Maximum Elevation Angles for Passes Taken at CBD Station

Elevation Angles	Passes 1360-2143			Passes 2834-4598		
	No. of Passes	CEP (meters)	RMS (meters)	No. of Passes	CEP (meters)	RMS (meters)
Single Frequency, No Correction						
Under 30°	54	156	185	116	120	140
Over 30° and Under 60°	110	165	213	182	154	178
Over 60°	38	203	271	49	200	259
Under 45°	113	155	188	226	134	156
Over 45°	89	200	251	120	170	220
Single Frequency, With Correction						
Under 30°	54	73	114	116	56	78
Over 30° and Under 60°	110	62	95	182	73	88
Over 60°	38	91	141	49	83	133
Under 45°	113	72	103	226	63	83
Over 45°	89	71	118	120	76	109
Dual Frequency, 150/400 Correction						
Under 30°	54	48	61	116	48	67
Over 30° and Under 60°	110	39	50	182	51	63
Over 60°	38	46	54	49	67	70
Under 45°	113	44	57	226	52	66
Over 45°	89	41	50	120	50	64

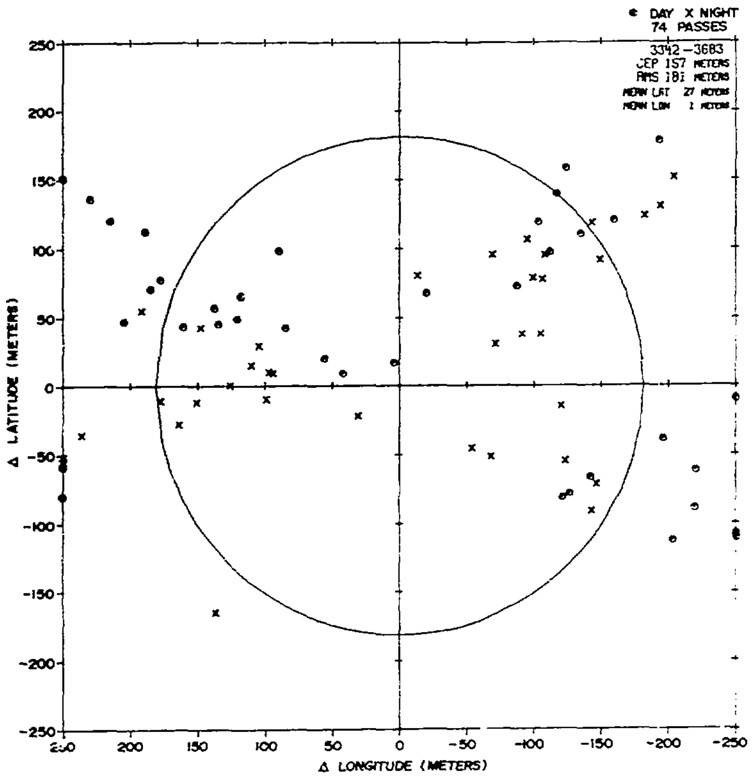


(a). Florida predicted

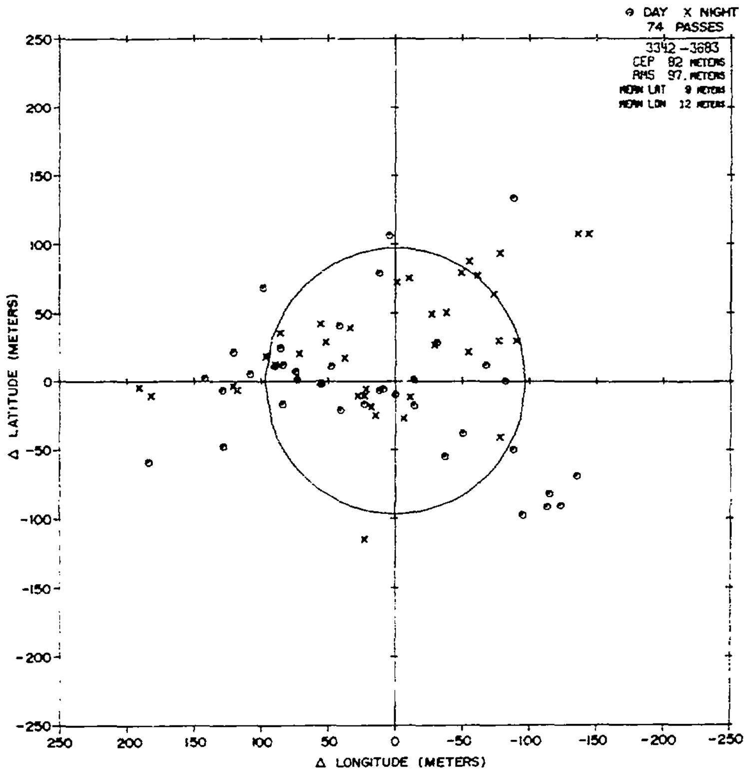


(b). NRL predicted

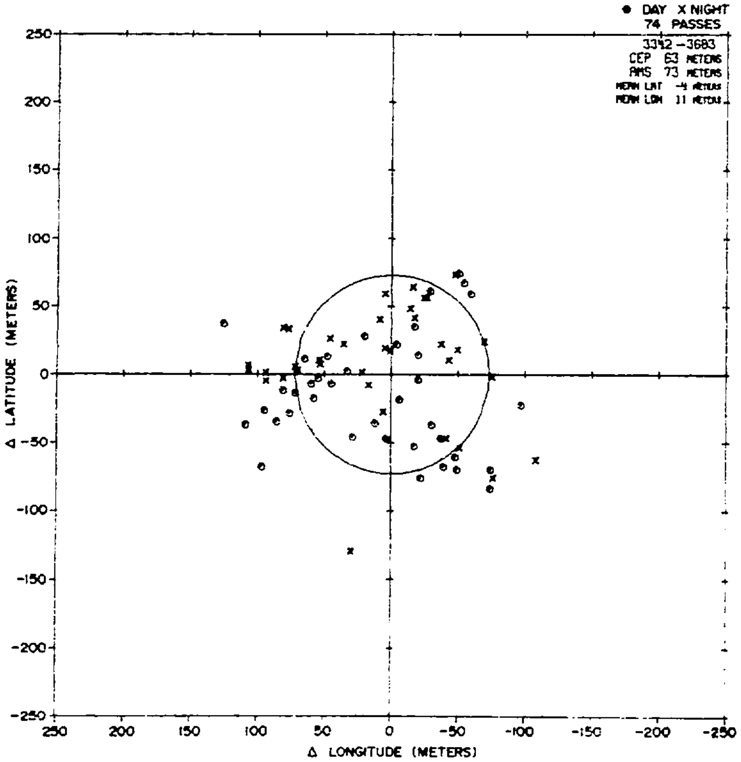
(C) Fig. 9 - Relationship between total navigation error and time into predicted region



(a). CBD range navigation observed orbit, 400 MHz, no correction

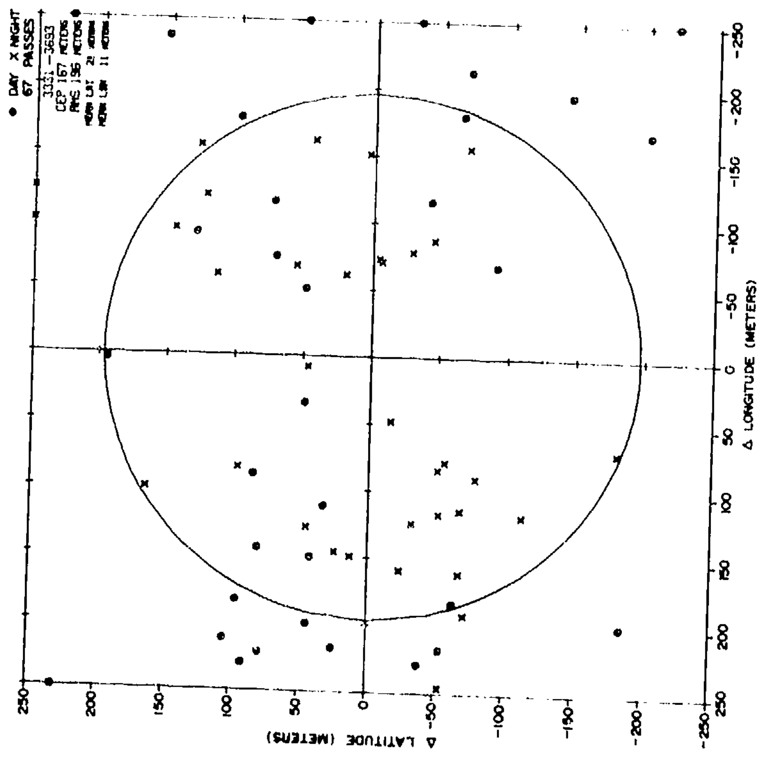


(b). CBD range navigation observed orbit, 400 MHz, with refractive correction

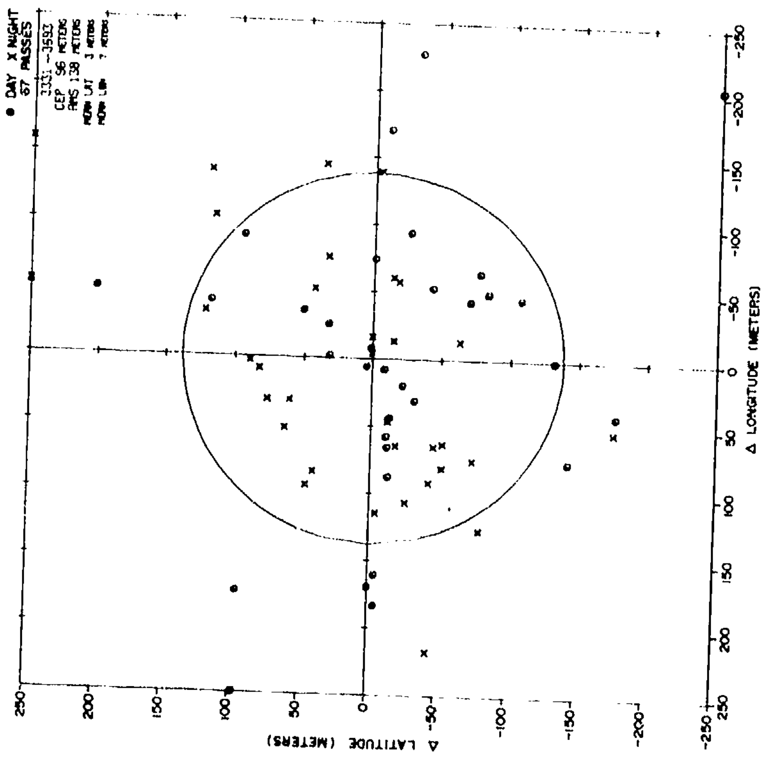


(c). CBD range navigation observed orbit, 150 and 400 MHz

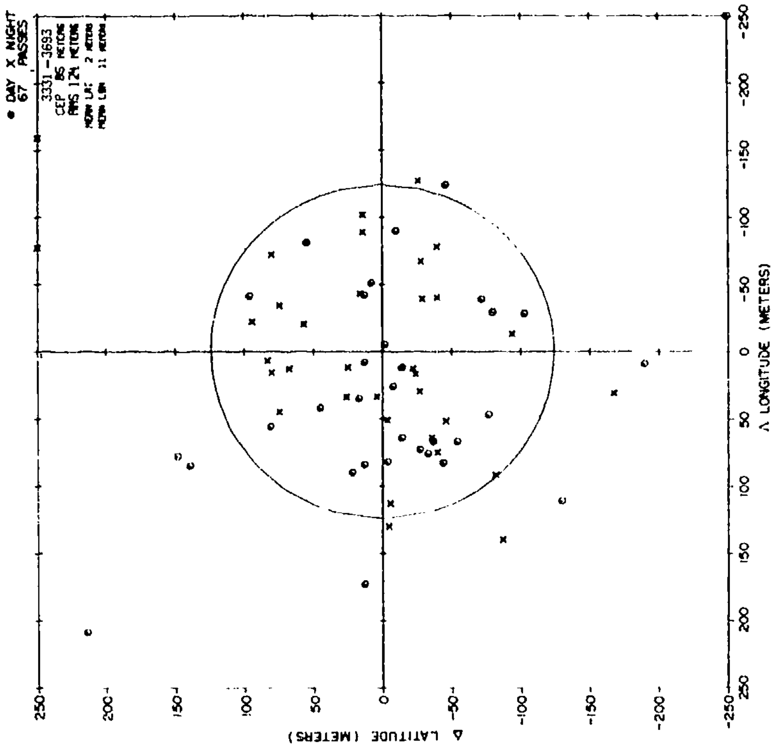
(C) Fig. 10 - Comparisons between navigation using a predicted orbit and an observed orbit



(d). CBD range navigation predicted orbit, 400 MHz, no correction

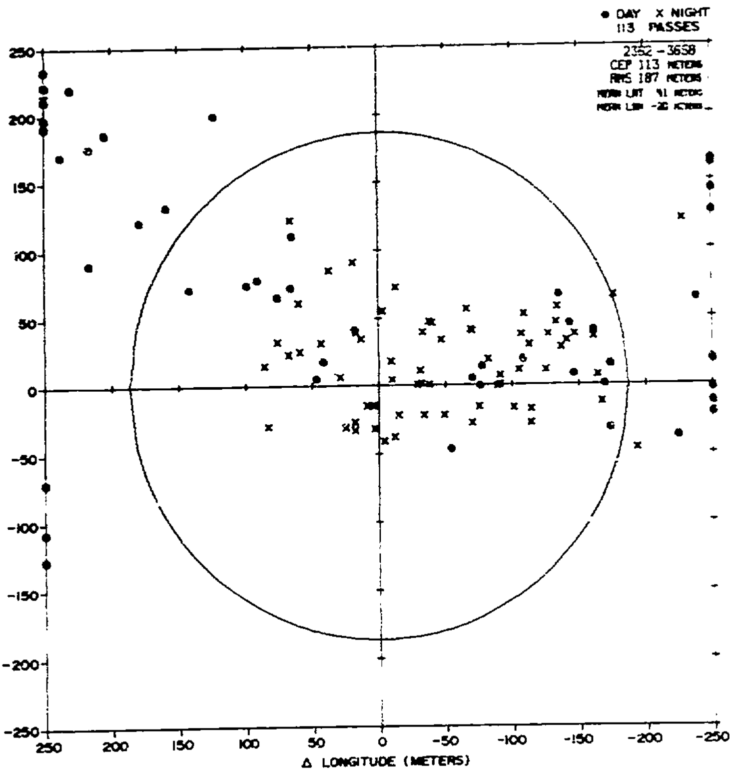


(e). CBD range navigation predicted orbit, 400 MHz, with refractive correction

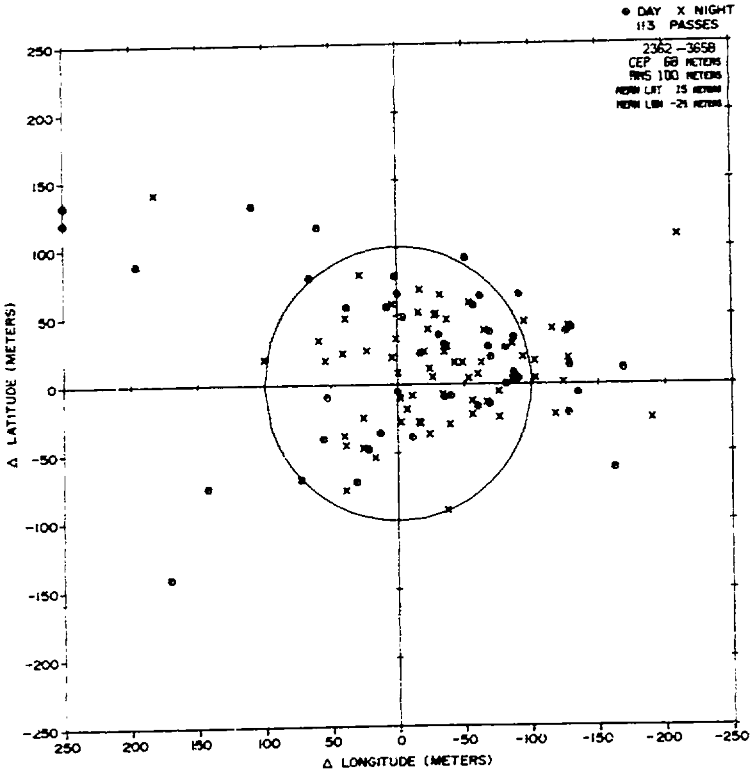


(f). CBD range navigation predicted orbit, 150 and 400 MHz

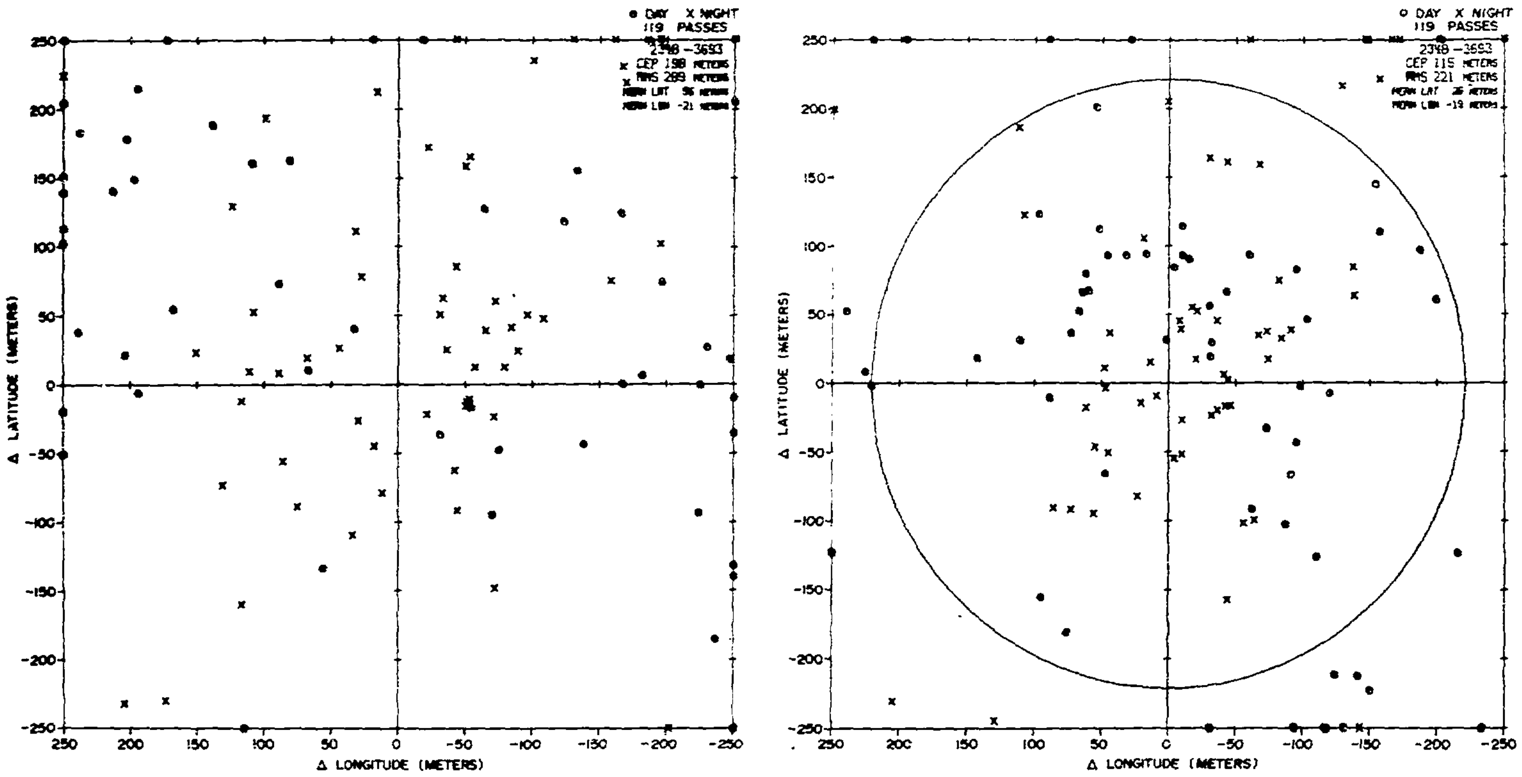
(C) Fig. 10 (Continued) - Comparisons between navigation using a predicted orbit and an observed orbit



(g). Florida range navigation observed orbit, 400 MHz, no correction



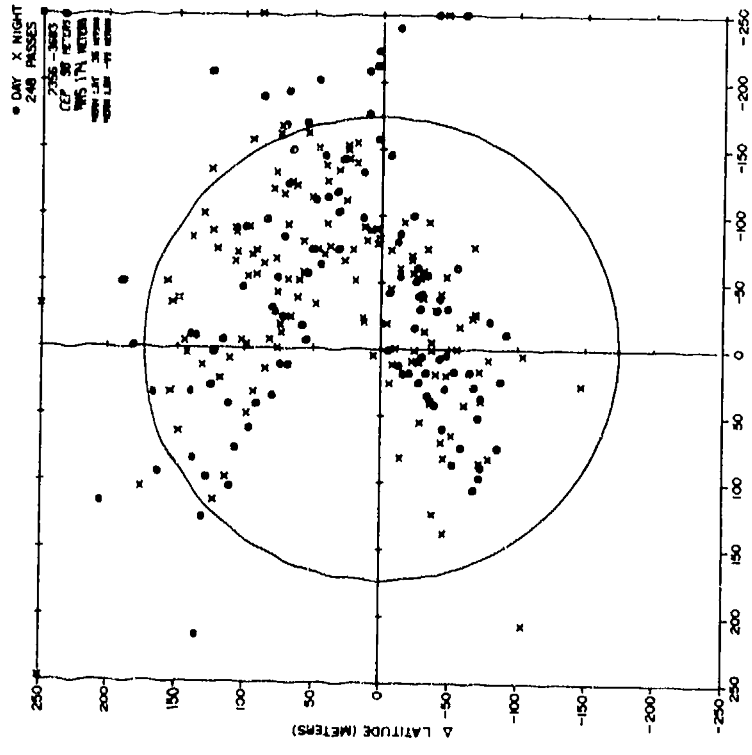
(h). Florida range navigation observed orbit, 400 MHz, with refractive correction



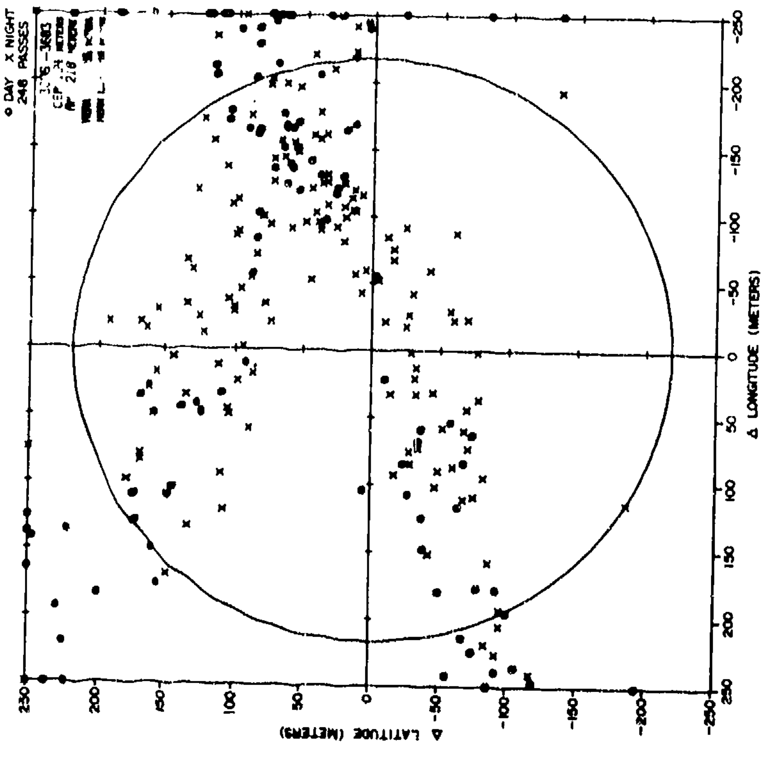
(i). Florida range navigation predicted orbit, 400 MHz, no correction

(j). Florida range navigation predicted orbit, 400 MHz, with refractive correction

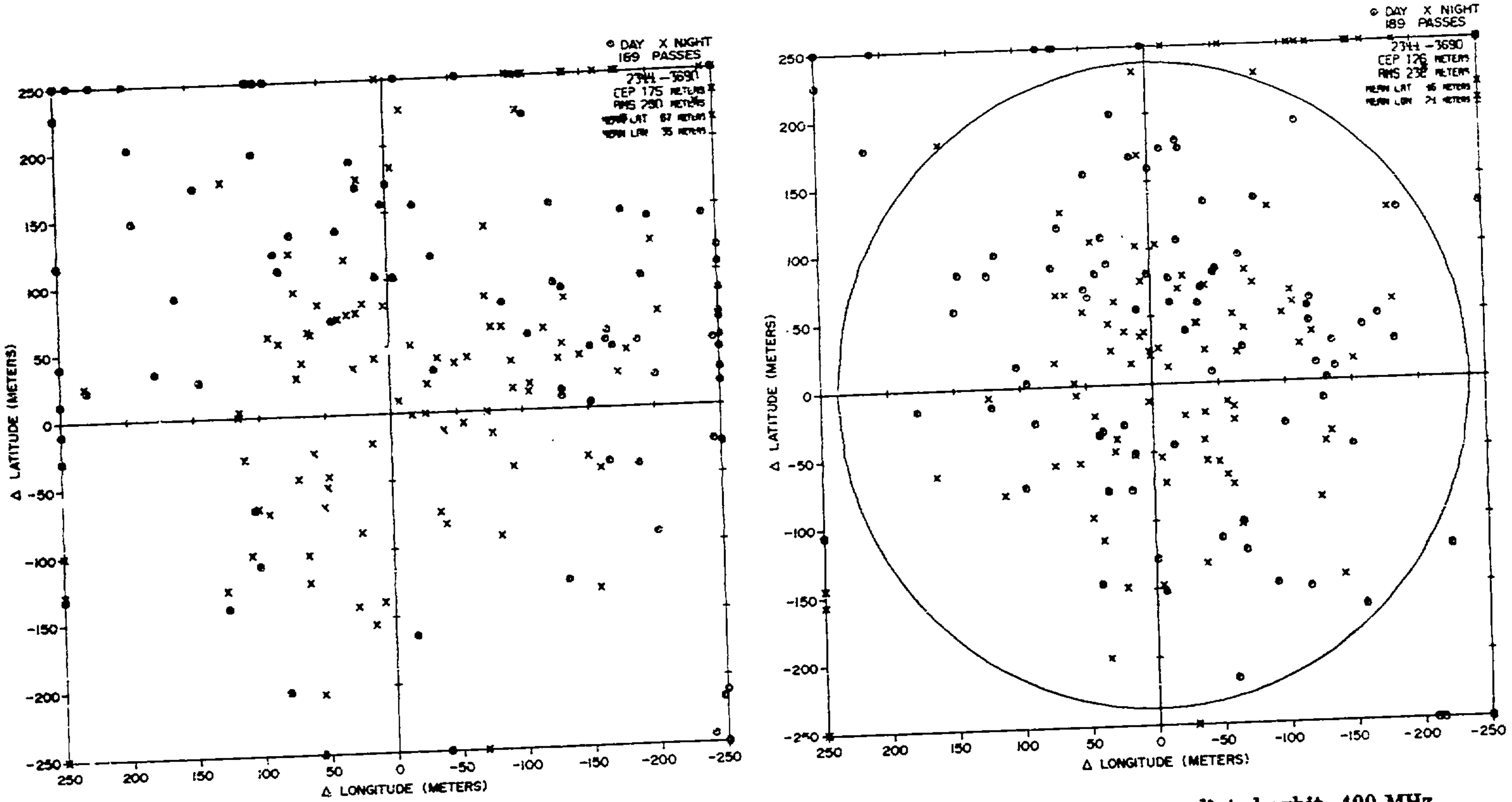
(C) Fig. 10 (Continued) - Comparisons between navigation using a predicted orbit and an observed orbit



(l). NRL range navigation observed orbit, 400 MHz, with refractive correction



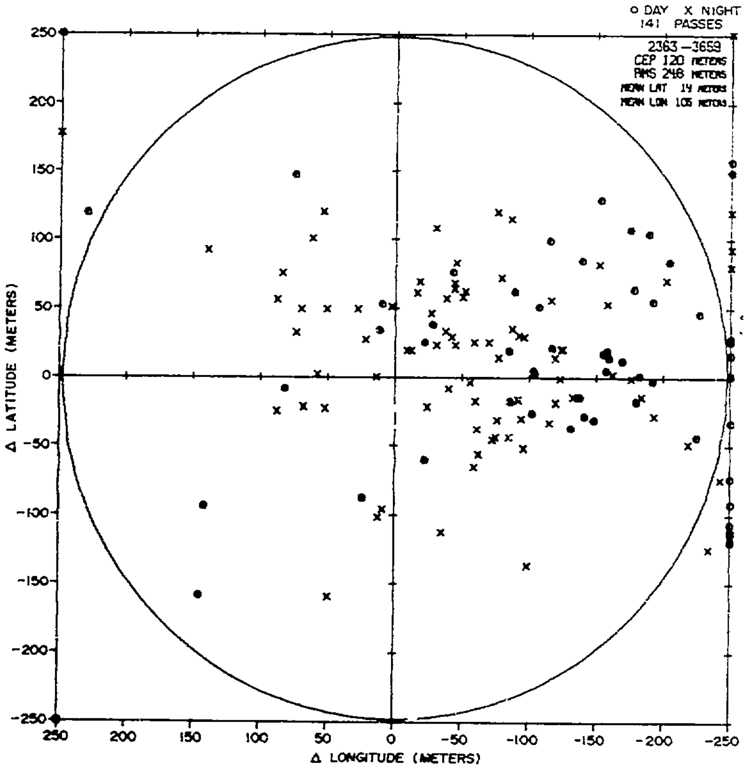
(k). NRL range navigation observed orbit, 400 MHz, no correction



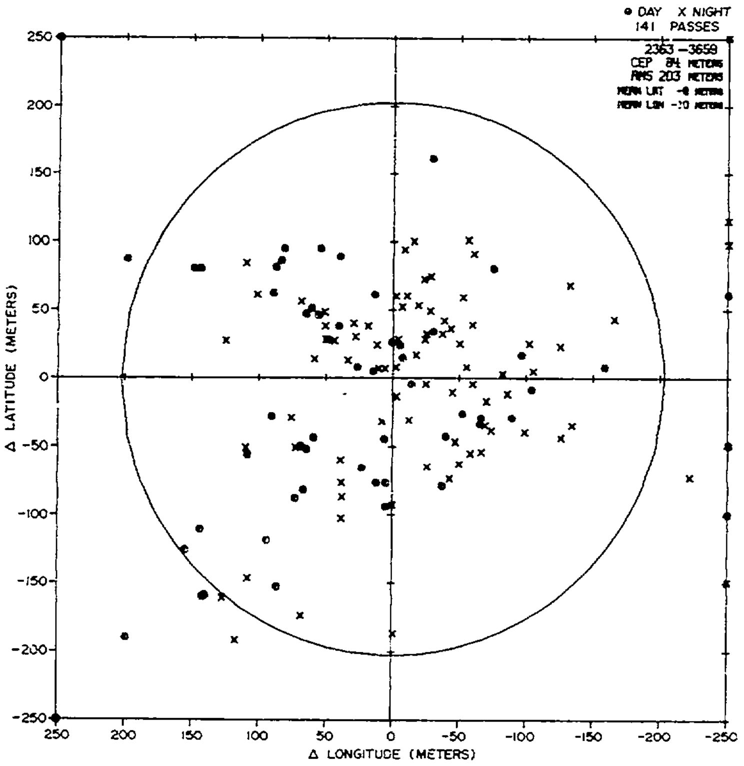
(m). NRL range navigation predicted orbit, 400 MHz, no correction

(n). NRL range navigation predicted orbit, 400 MHz, with refractive correction

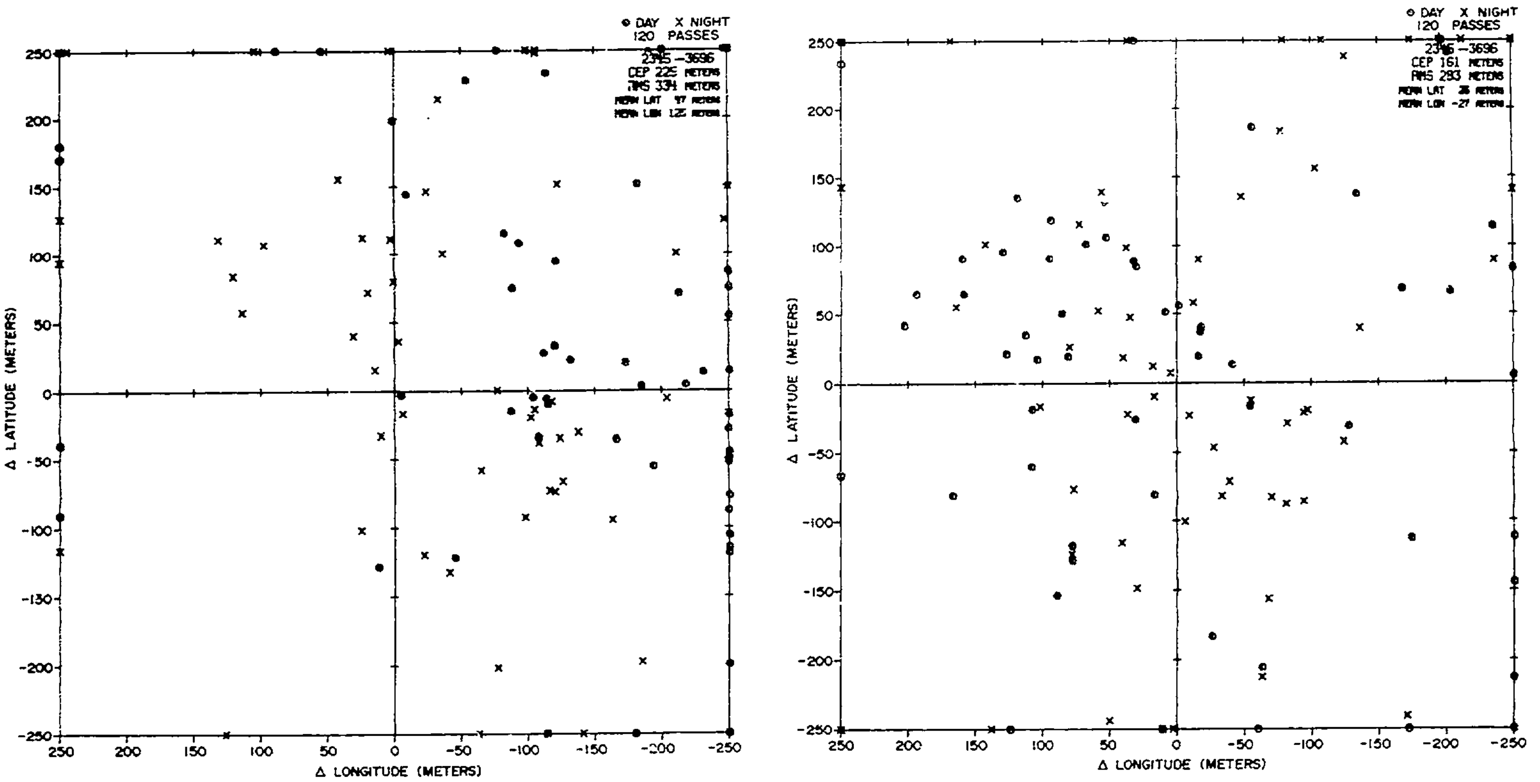
(C) Fig. 10 (Continued) - Comparisons between navigation using a predicted orbit and an observed orbit



(o). Colorado range navigation observed orbit, 400 MHz, no correction



(p). Colorado range navigation observed orbit, 400 MHz, with refractive correction



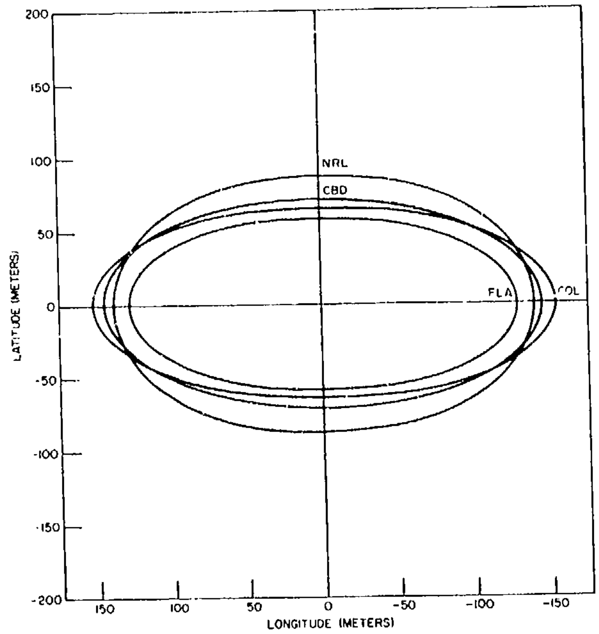
(q). Colorado range navigation predicted orbit, 400 MHz, no correction

(r). Colorado range navigation predicted orbit, 400 MHz, with refractive correction

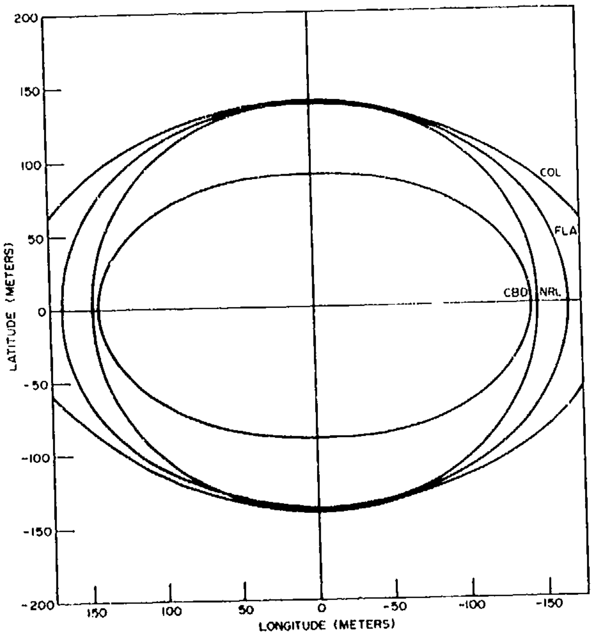
(C) Fig. 10 (Continued) - Comparisons between navigation using a predicted orbit and an observed orbit

Table 6 (C)
Comparisons Between Predicted and Observed CEP's

Stations	Number of Passes	Predicted Region CEP		Number of Passes	Observed Region CEP	
		Latitude (meters)	Longitude (meters)		Latitude (meters)	Longitude (meters)
Colorado						
Single Frequency (Theoretical)	120	141	140	141	69	97
Single Frequency (No Correction)	120	140	195	141	64	153
Florida						
Single Frequency (Theoretical)	119	129	91	113	39	65
Single Frequency (No Correction)	119	138	168	113	58	128
NRL						
Single Frequency (Theoretical)	189	132	97	248	69	79
Single Frequency (No Correction)	189	141	147	248	87	139
CBD						
Single Frequency (Theoretical)	67	65	77	74	38	68
Single Frequency (No Correction)	67	88	144	74	71	146
Dual Frequency	67	63	65	74	34	50

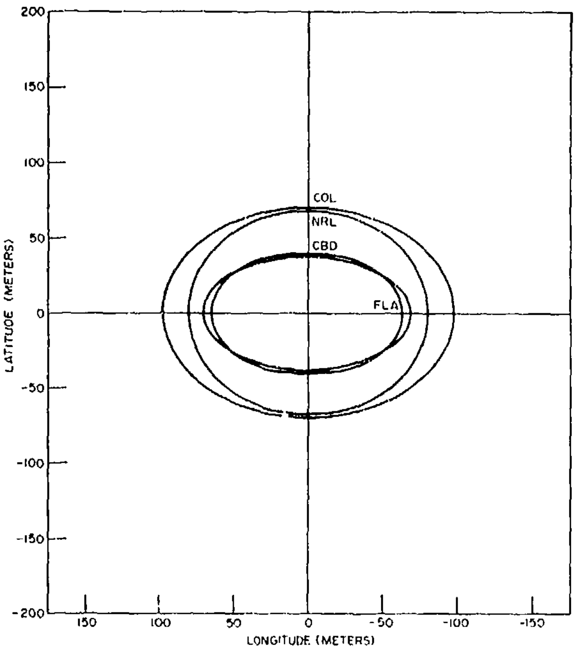


(a). Observed data, all stations, single frequency with no ionosphere correction

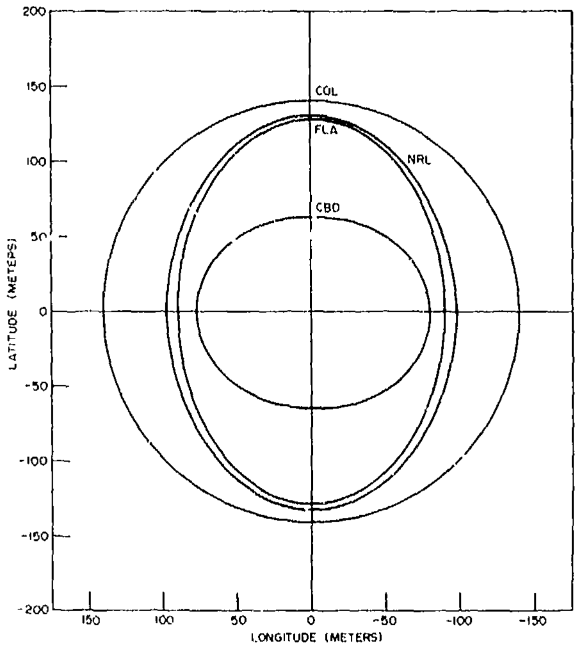


(b). Predicted data, all stations, single frequency with no ionosphere correction

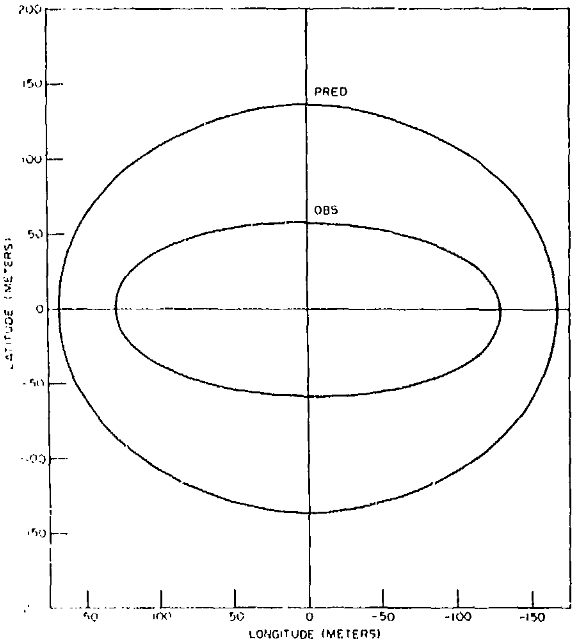
(C) Fig. 11 - Combined latitude and longitude CEP's for observed and predicted data, all stations, and all corrections



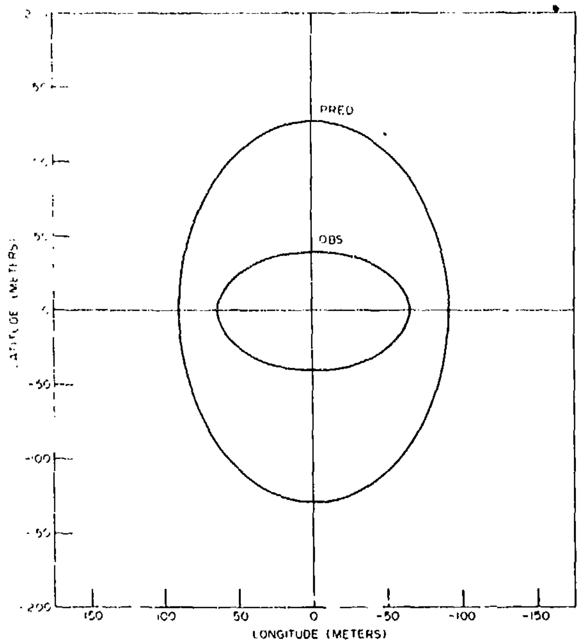
(c). Observed data, all stations, single frequency with theoretical model correction



(d). Predicted data, all stations, single frequency with theoretical model correction

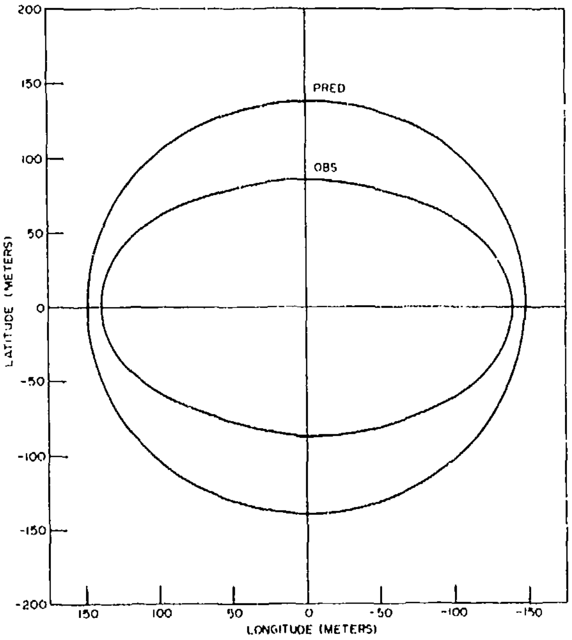


(e). Florida predicted and observed single frequency with no ionosphere correction

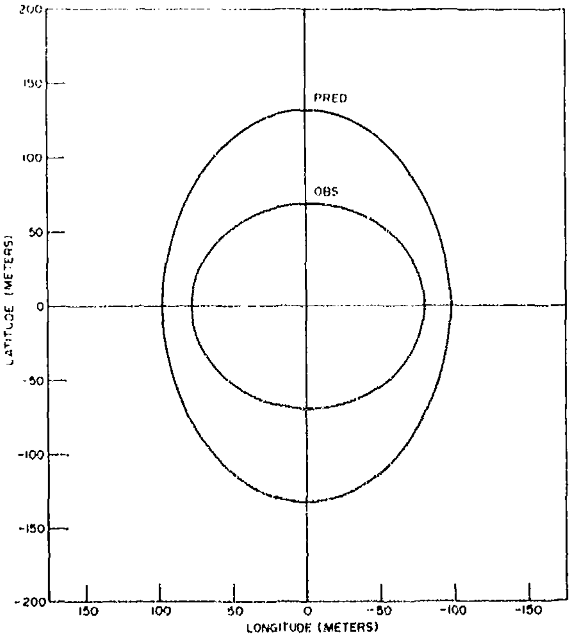


(f). Florida predicted and observed single frequency with theoretical model correction

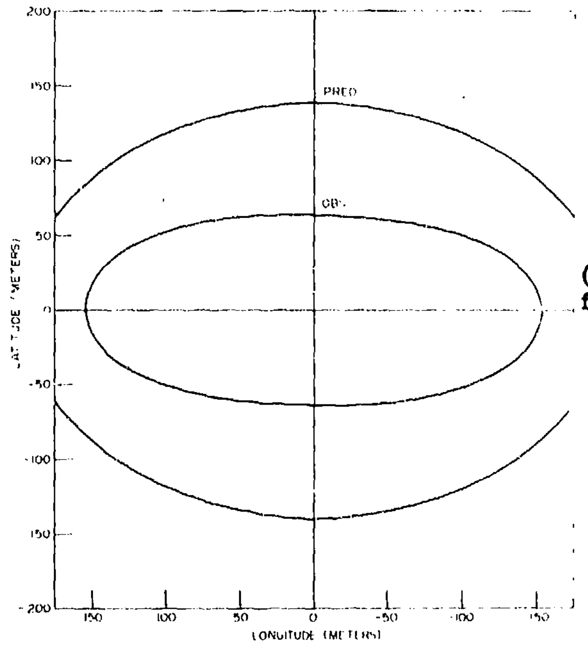
(C) Fig. 11 (Continued) - Combined latitude and longitude CEP's for observed and predicted data, all stations, and all corrections



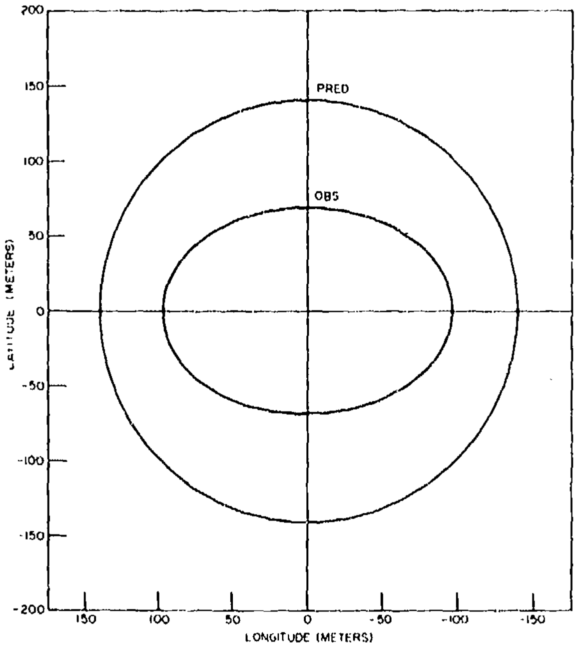
(g). NRL predicted and observed single frequency with no ionosphere correction



(h). NRL predicted and observed single frequency with theoretical model correction

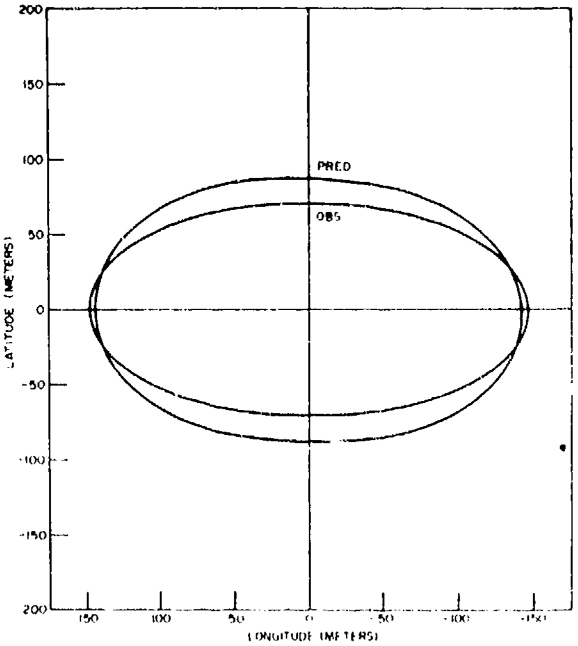


(i). Colorado predicted and observed single frequency with no ionosphere correction

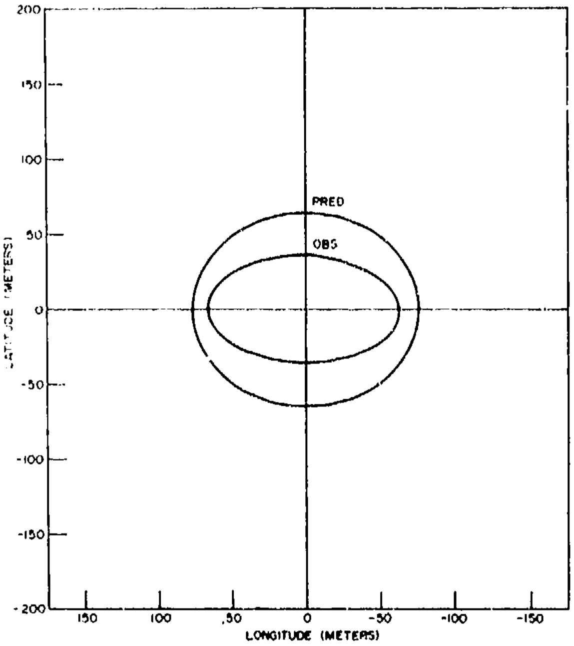


(j). Colorado predicted and observed single frequency with theoretical correction

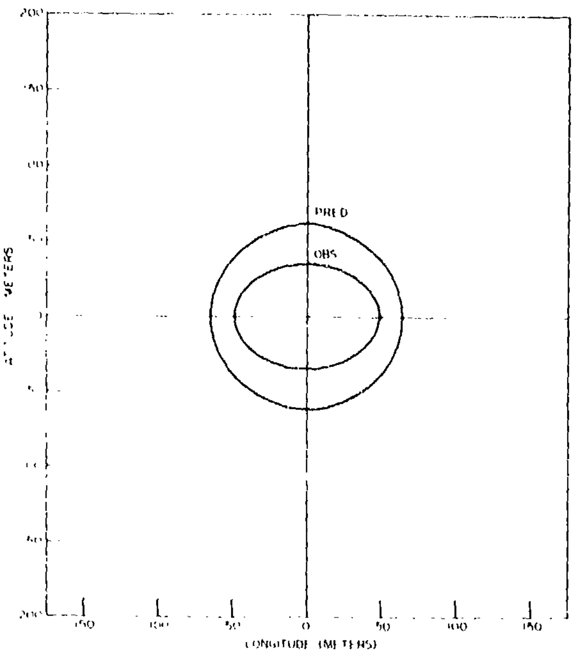
(C) Fig. 11 (Continued) - Combined latitude and longitude CEP's for observed and predicted data, all stations, and all corrections



(k). CBD predicted and observed single frequency with no ionosphere correction



(l). CBD predicted and observed single frequency with theoretical correction



(m). CBD predicted and observed dual frequency correction

(C) Fig. 11 - Combined latitude and longitude CEP's for observed and predicted data, all stations, and all corrections

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13. ABSTRACT (Confidential)

The TIMATION(Time Navigation) technique of passive ranging can be employed to provide a worldwide navigation and time-transfer service. Passive ranging is accomplished by measuring the time difference between electronic clocks located within the satellite and the navigator's receiver. Navigation results were obtained with a prototype system consisting of the TIMATION II satellite and four ground stations. The results indicate a CEP position-fixing capability of 33 meters (100 feet) using dual-frequency range measurements. The analysis of the data includes ionospheric refraction, instrumentation error, and the effect of satellite trajectory position error in both the observed and predicted regions.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
TIMATION Satellite navigation Passive ranging Clock correction Ionospheric refraction Dual frequency Observed orbit Predicted orbit Quartz crystal oscillator Elevation angle						

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NRL Report 7511

Range Navigation Using the TIMATION II Satellite

[Unclassified Title]

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Space Metrology Branch
Space Systems Division

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