NASA Technical Memorandum 100736

Analysis of NOVA-1 Doppler Data

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OBJECTIVE

The intent of this work is to prepare a set of doppler tracking data for the NOVA-1 satellite to be included in a data base of satellite tracking data. This data base is to be used in a solution for the gravity field of the Earth. This new gravity field model is needed so that the orbit of the proposed TOPEX satellite can be determined accurately enough for the satellite's missions to be accomplished.

INTRODUCTION

TOPEX (Ocean TOPography EXperiment) is to be a dedicated satellite whose primary instrument will be an altimeter with an anticipated precision of 2 cm. This altimeter will be used to measure sea surface elevation to an expected accuracy of a few centimeters. This accuracy is necessary for worthwhile information about ocean circulation to be obtained. Thus, the accuracy of the TOPEX orbit is critical, and this implies the use of an accurate gravity field model for the Earth in the orbit determination procedure.

A large data base of satellite tracking data exists at GSFC. An effort has been made to collect and process this data for use in the derivation of an improved model for the Earth's gravity field, GEM-T1 (Marsh et al., 1988). Doppler tracking data for the NOVA-1 satellite will be part of the data base for the next solution, GEM-T2.

The NOVA-1 spacecraft is shown in Figure 1 (Eisner et al., 1982). Its orbital characteristics are as follows:

Semimajor axis = 1.184 earth radii	Eccentricity = 0.0011
Inclination = 89.96 degrees	Perigee height = 1164 km.
Apogee height = 1181 km.	Period = 1.815 hrs.
Perigee period = 130.5 days	Nodal period = 2706 years
Beat period = 5.5 days	

Since NOVA-1 is a polar satellite, it senses the entire gravity field of the Earth. In addition, it is equipped with a DISCOS drag compensation system which serves to correct nonconservative force effects such as atmospheric drag. Orbit determination of satellites not so equipped necessitates the estimation of atmospheric drag coefficients which may have gravity information aliased into them. Part of this study is to ascertain whether any along-track nonconservative force effects remain in the data, and to model these effects. A similar study was done by William D. Tepper, then of the Center for Space Research, University of Texas at Austin (Tepper, 1987).

NOVA-1 DOPPLER TRACKING DATA

The NOVA-1 data used in this analysis are a result of Project MERIT—more specifically, that portion of the project called MERITDOC. The data spanned 95 days, from 3/30/84 to 7/2/84, and were obtained from the Center for Space Research, The University of Texas at Austin. Sixteen stations were involved in tracking during this time period. Table 1 (Tepper, 1987) shows the tracking complement, along with the useful data span for each station. Figure 2 is a map of the station locations, also giving the 5-degree elevation visibility boundaries. Table 2 gives the initial coordinates for the stations—the NOVA-1 tracking network is tied to the very large Lageos laser tracking network.

The receivers tracking NOVA-1 produced data at a 4.6-second sampling rate, which results in a very large range rate data set requiring a large amount of computer time for analysis. Also, additional range rate noise is caused by the discretization of the doppler interval (Tepper, 1987). Consequently, the data received from the University of Texas had been averaged over about 23 seconds by combining five counts of the 4.6-second intervals. This resulted in less noise and a significant lowering of the computational costs for the analysis.

DATA REDUCTION PROCEDURE

Editing of the data was done by converging the orbit using short arcs in order to reduce the orbit residual errors to a reasonable level. The first step in the procedure was to catalog the data and divide it into 6-day arcs for processing, which resulted in a total of 16 arcs over the time period. The orbit determination was done using the GEODYN orbit determination and parameter estimation computer program, which uses Cowell's method of integrating the orbit and a Bayesian least squares statistical estimation procedure for parameter estimation.

The gravity field used was GEM-T1 (Marsh et al., 1988), which is the initial gravity model produced by Goddard Space Flight Center for the TOPEX project. The parameters estimated in the procedure included the initial state vector, one solar radiation parameter per arc, one range rate bias per pass, and selected station positions. In addition, in order to account for along-track nonconservative forces which might not be entirely negated by the DISCOS system, it was decided to initially solve for one air drag coefficient per arc. Also, it became necessary to estimate timing biases for the Buenos Aires and Rio Grande stations.

Dynamic editing of observations was performed in GEODYN based upon a 4-sigma criterion and a 10-degree elevation angle cutoff. Additional editing was done in a post-GEODYN residual analysis program using a 3-sigma criterion and a 5-degree elevation angle cutoff. Also in this residual analysis procedure, individual passes were edited on the basis of a maximum allowable RMS, a maximum timing bias, a minimum number of observations, and a maximum elevation angle. Finally, hand editing of observations and passes was done to eliminate obvious outliers which escaped the previous editing.

This initial data processing resulted in RMS of fits for the 16 arcs considerably less than 1 cm/sec. However, it was necessary to estimate positions for certain of the stations, notably the North American stations. In addition, both the Buenos Aires and the Rio Grande stations in South America had apparently significant timing biases which were estimated in the data reduction procedure. Also, much of the data from the Huahine station in the Society Islands were unusable—estimation of the station position and measurement and timing biases did little to improve the situation.

Figure 3 shows the residuals from a typical "good" pass of data—in this case: Herstmonceux, England. The residuals are all significantly less than 1 cm/sec, and there is very little discernible pattern in them. Figure 4 presents the residuals from a troublesome Buenos Aires pass in an arc where a timing bias had to be applied for the station. There are some residuals above the 1 cm/sec level, and a secular trend still appears. Finally, Figure 5 shows one of the better Huahine passes in which a clear secular trend is apparent.

NONCONSERVATIVE FORCE EFFECTS

In these initial orbit fits, one drag coefficient (C_D) was estimated for each arc. These coefficients were negative and were small in magnitude (<2), which indicates that the DISCOS system was operating and the uncorrected error was in the positive along-track direction (Tepper, 1987). To further investigate this problem, two arcs were chosen for which the following parameters were estimated in place of the one C_D:

1) One C_D per day, or

2) One along-track acceleration parameter (ACC) per arc, or

3) One ACC per day.

Orbit differences were computed among selected pairs of the orbit determinations and the results studied to ascertain the best parameterization for the observed uncorrected along-track effects. These results, along with the orbit fits for the four cases, are presented in Tables 3 and 4. As might be expected, the orbit fits are slightly better with the daily parameterizations, whether drag or along-track acceleration. The orbit comparisons show that the position differences are almost all along-track with a small difference occurring between C_D/day and ACC/day.

Figure 6 provides a history of along-track force biases estimated by the Navy Astronautics Group for NOVA-1 during 1984 (Tepper, 1987). The values for the ACC/day parameters estimated in the previous experiment are in excellent agreement with the corresponding along-track force bias values determined from Figure 6. Therefore, it was decided to use the more correct ACC/day parameterization for the along-track effects.

FINAL ORBIT FITS

The final data reduction computer runs were made solving for ACC/day parameters along with other parameters previously mentioned. Then, the matrices of normal equations were created for inclusion in the solution for the gravity model GEM-T2. The resulting orbit fits are shown in Table 5 along with the overall weighted RMS of fit. The results are quite consistent from arc to arc, with most of the RMS values under 0.5 cm/sec. Table 6 presents the results on a station-by-station basis which clearly shows the more consistent stations and those which were troublesome. In particular, the problems with the Huahine, Buenos Aires, and Rio Grande stations result in larger than average RMS values for those stations.

CONCLUSIONS

Doppler tracking data for the NOVA-1 satellite have the potential for contributing significantly to Earth gravitational studies because of the polar orbit of the satellite and its near independence from nongravitational force effects. This data will be used in the derivation of an improved model GEM-T2 for the gravity field of the Earth in a continuing attempt to provide a sufficiently accurate model for the TOPEX project.

The data to be included in this gravity field solution spans the period between 3/30/84 and 7/2/84 and comes from 16 stations around the globe. The data set, after editing, contains 73,239 observations averaged over 23-second intervals. This data was divided into 6-day arcs resulting in 16 arcs over the 95-day span.

The GEM-T1 gravity field model was chosen as the nominal field in the orbit determination and data reduction procedure. In addition, arc parameters solved for include solar radiation pressure coefficients and along-track acceleration. These along-track acceleration parameters represent forces which agree quite closely with the along-track force biases estimated by the Navy Astronautics Group for the same period in 1984.

Coordinates for some of the stations had to be estimated in the data reduction procedure—in particular, for the North American stations. Also, timing biases were solved for in the case of Buenos Aires and Rio Grande. Most of the observations for Huahine had to be discarded as unusable—the few passes that were retained had consistently high RMS values compared with the other stations.

The observation residuals which remained resulted in quite consistent RMS values for the 16 arcs, typically around 0.5 cm/sec. There was more variability among the RMS values for the 16 stations, ranging from a low of 0.3954 cm/sec (9192 observations) for Effelsburg, West Germany, to a high of 0.7342 cm/sec (1112 observations) for Huahine, Society Islands.

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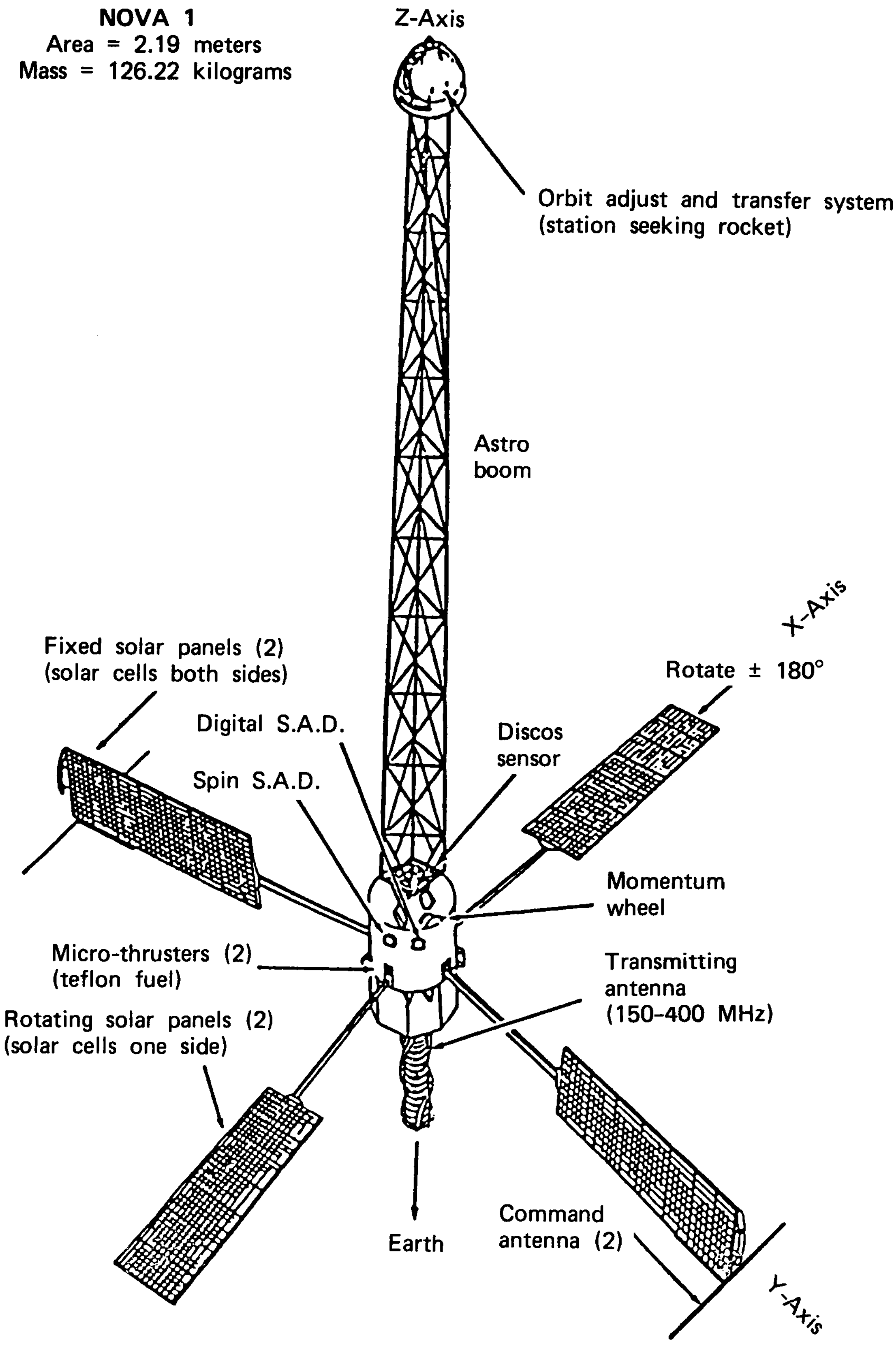

Figure 1. The NOVA-1 spacecraft.

Table 1. NOVA-1 Tracking Network.

Station Number	Location	Receiver Type	Useful Data Span
3041	Dionysos, Greece	MX1502	4/2–7/1/84
3061	Madrid, Spain	JMR-1	3/30–6/29/84
3091	Simosato, Japan	MX1502	3/30–7/2/84
3101	Canberra, Australia	MX1502	4/25–7/2/84
3111	Huahine, Society Islands	JMR-1	4/19–6/29/84
3121	Potsdam, East Germany	JMR-4A	3/30–7/2/84
3131	Herstmonceux, England	MX1502	3/30–5/27/84
3141	Effelsburg, West Germany	MX1502	4/4–6/23/84
3161	Haystack, Massachusetts	MX1502	4/14–7/2/84
3171	Fort Davis, Texas	MX1502	4/10–6/13/84
3181	Platteville, Colorado	MX1502	4/14–6/26/84
3711	Paris, France	JMR-1	6/15–6/25/84
3721	Grasse, France	JMR-1	3/30–5/21/84
3791	Buenos Aires, Argentina	JMR-1	5/2–6/9/84
3811	Rio Grande, Argentina	JMR-1	5/2–5/31/84
3831	Penc, Hungary	JMR-4A	3/30–7/2/84

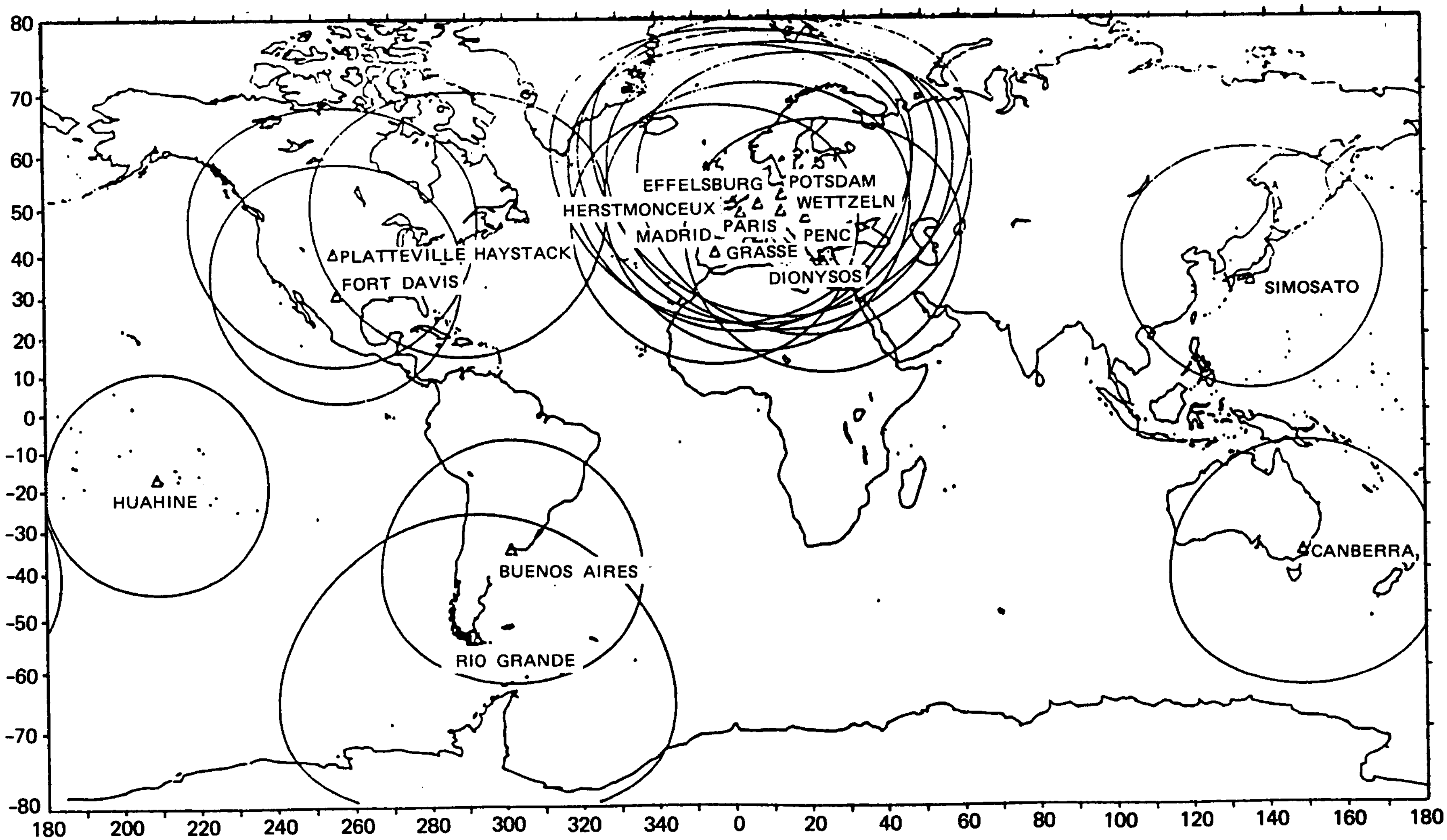

Figure 2. NOVA-1 Doppler Tracking 3/30/84–7/2/84
5-Degree Visibility Masks.

Table 2. Coordinates for Doppler Tracking of the NOVA-1 Satellite.

Station Number	X (meters)	Y (meters)	Z (meters)	σ_x (cm)	σ_y (cm)	σ_z (cm)	σ (cm)	Coordinate Source
3041	4595216.945	2039473.414	3912615.760	7.5	13.0	5.2	15.8	Estimated
3061	4849196.853	-360288.268	4114925.899	5.3	14.1	4.9	15.9	Estimated
3091	-3822388.309	3699380.477	3507565.502	10.4	10.8	4.6	15.7	Estimated
3101	-4446492.361	2678116.898	-3696281.458	10.3	15.7	6.1	19.7	Estimated
3111	-5345888.122	-2958246.443	-1824597.229	27.7	37.6	19.4	50.6	Estimated
3121	3800591.631	881925.934	5028906.315	4.7	11.0	4.2	12.7	Estimated
3131	4033590.810	24250.988	4924211.709	N/A	N/A	N/A	N/A	Survey
3141	4029171.946	490761.765	4904010.002	4.2	11.2	4.1	12.7	Estimated
3161	1492411.818	-4457291.863	4296820.802	12.8	6.5	5.0	15.2	Estimated
3171	-1324192.243	-5332061.739	3232044.561	21.0	11.8	9.4	25.9	Estimated
3181	-1240628.358	-4720491.033	4094464.981	14.3	6.7	5.4	16.6	Estimated
3711	4201867.703	177906.914	4779204.391	11.0	23.2	10.7	27.8	Estimated
3721	4588035.868	556448.260	4381665.815	N/A	N/A	N/A	N/A	Survey
3791	2745505.971	-4483584.164	-3599098.084	32.9	27.4	18.3	46.5	Estimated
3811	1429903.917	-3495341.762	-5122712.877	32.3	23.6	19.8	44.6	Estimated
3831	4052450.028	1417640.980	4701413.606	6.8	12.3	5.3	15.0	Estimated

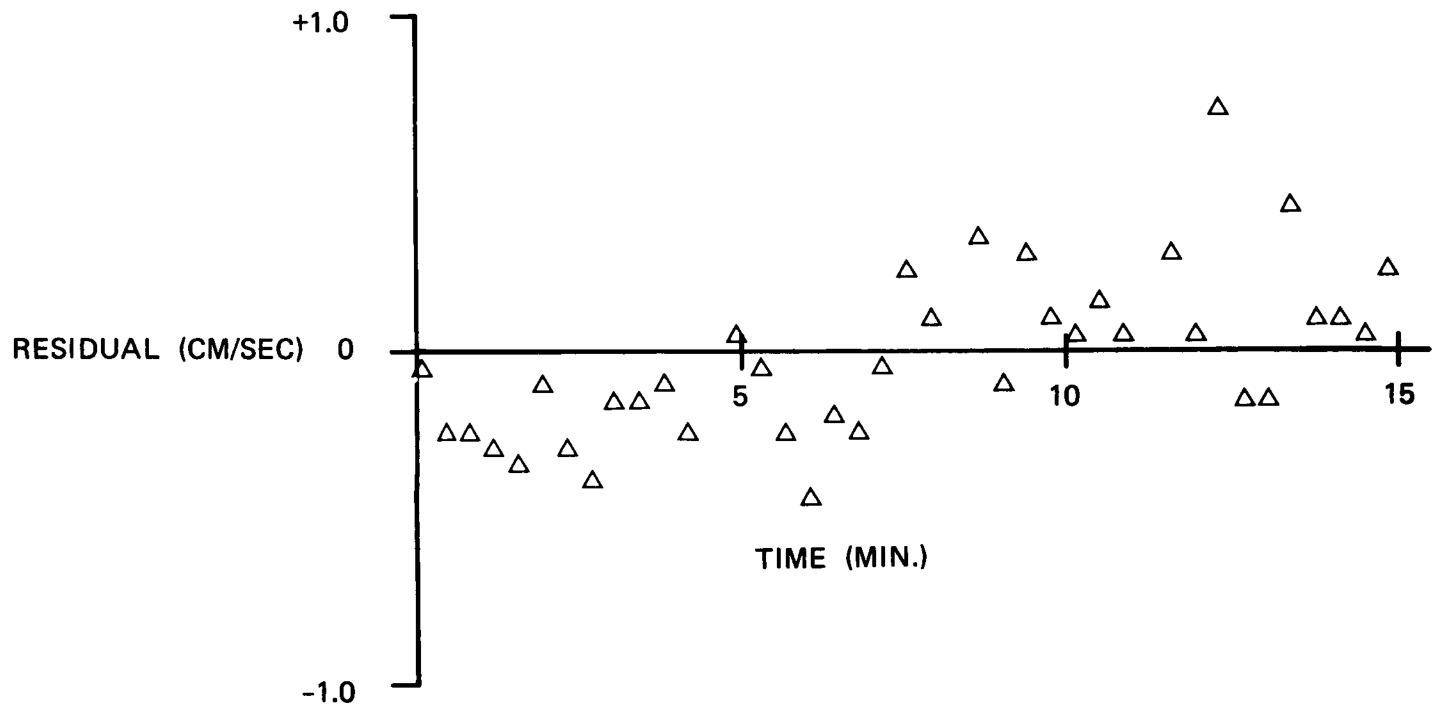

Figure 3. NOVA-1 Doppler Residuals
Herstmonceux, England.

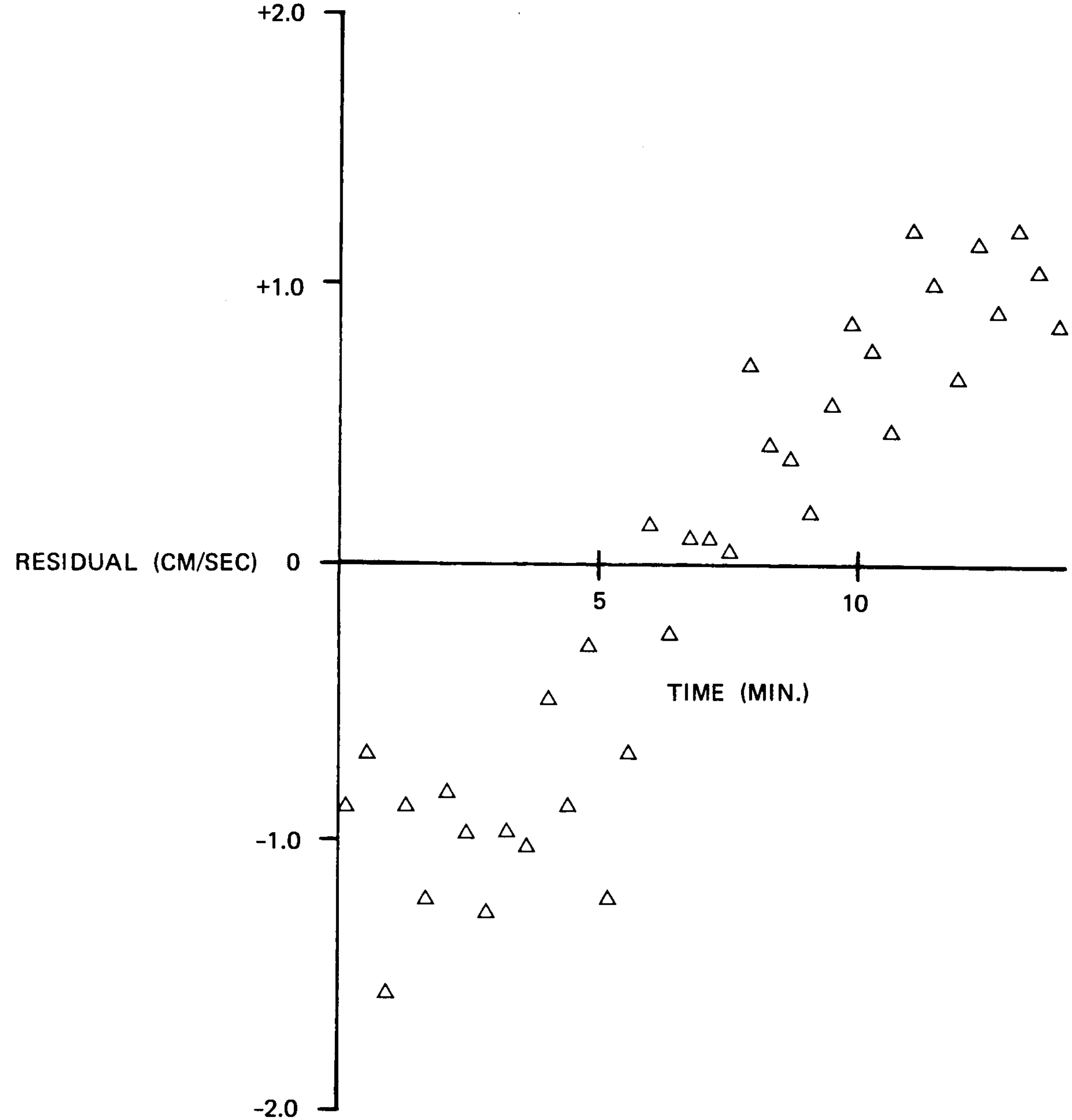

Figure 4. NOVA-1 Doppler Residuals
Buenos Aires, Argentina

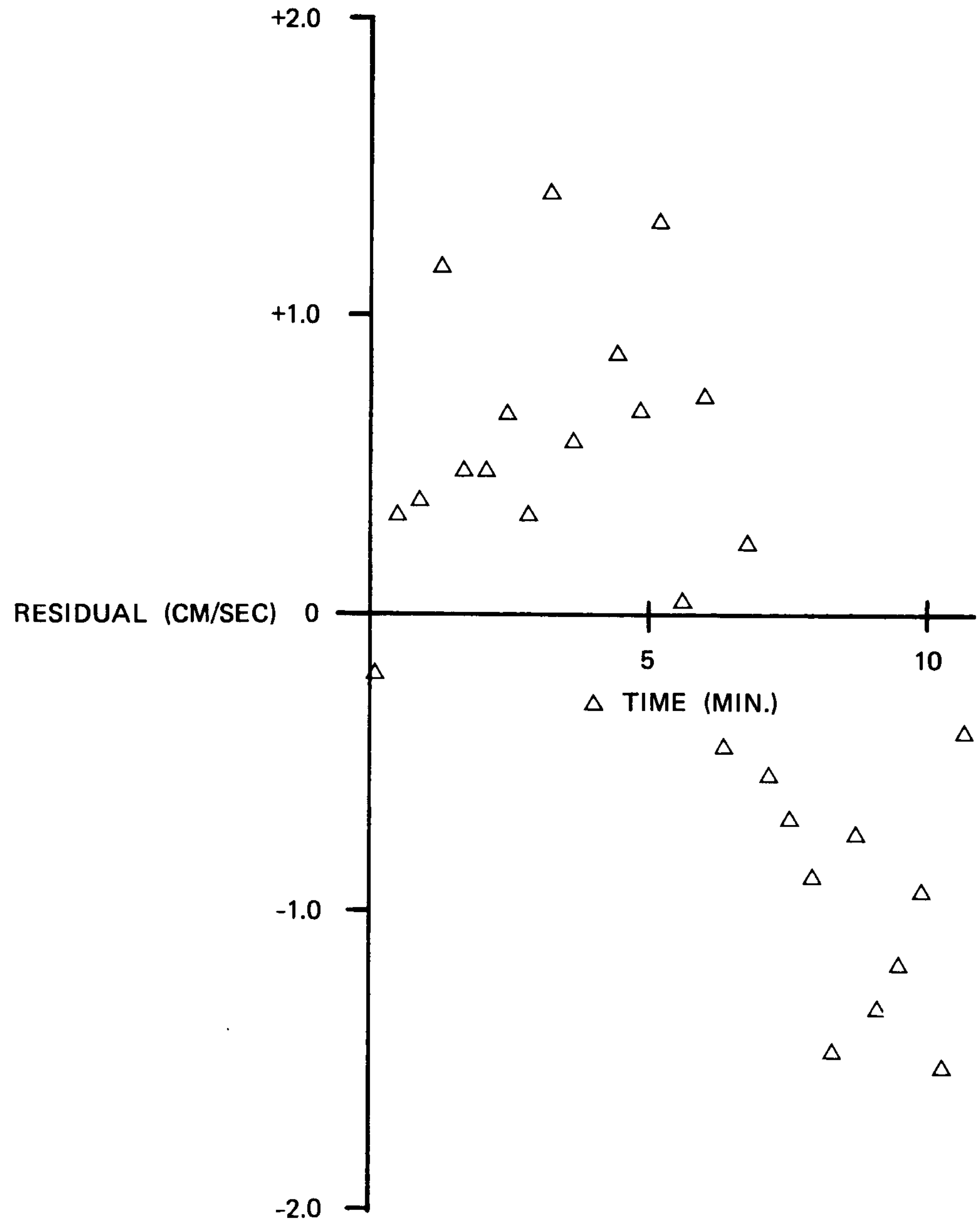

Figure 5. NOVA-1 Doppler Residuals
Huahine, Society Islands.

Table 3. ARC 840417
ORBIT FITS

	C_D	C_D/DAY	ALONG-TRACK ACCEL.	ALONG-TRACK ACCEL./DAY
RMS(cm/sec)	0.4690	0.4349	0.4572	0.4363

POSITION DIFFERENCES

	ALONG-TRACK DIFFERENCE(m)		POSITION DIFF. RMS(m)	
	MAX.	MIN.	ALONG-TRACK	TOTAL POS.
C_D vs ACCEL	1.175	-2.203	0.7303	0.7338
C_D vs C_D/DAY	2.733	-6.200	1.7309	1.7322
ACC vs ACC/DAY	2.208	-4.694	1.4167	1.4175
C_D/DAY vs ACC/DAY	0.435	-0.758	0.1786	0.1865

Table 4. ARC 840511
ORBIT FITS

	C_D	C_D/DAY	ALONG-TRACK ACCEL.	ALONG-TRACK ACCEL./DAY
RMS(cm/sec)	0.5368	0.5094	0.5347	0.5095

POSITION DIFFERENCES

	ALONG-TRACK DIFFERENCE(m)		POSITION DIFF. RMS(m)	
	MAX.	MIN.	ALONG-TRACK	TOTAL POS.
C_D vs ACCEL	0.577	-1.272	0.3389	0.3413
C_D vs C_D/DAY	2.756	-4.836	1.3221	1.3268
ACC vs ACC/DAY	2.520	-3.799	1.3460	1.3498
C_D/DAY vs ACC/DAY	0.233	-0.334	0.0829	0.0871

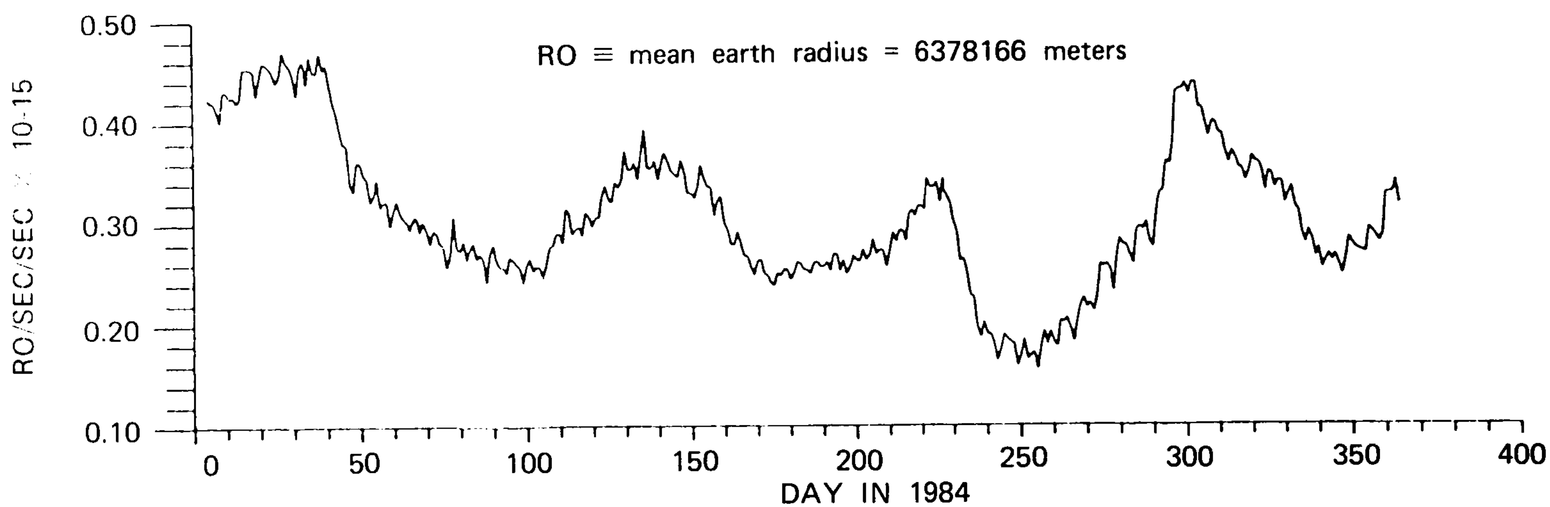

Figure 6. NOVA-1 Along-Track Force Biases for Year 1984 as Estimated by the Navy Astronautics Group.

Table 5. NOVA-1 Data Reduction
(6-day arcs).

YYMMDD	NO. OBS.	RMS(cm/sec)
840330	2854	0.4587
840405	4218	0.4376
840411	4528	0.4561
840417	5402	0.4369
840423	5528	0.4529
840429	6036	0.4591
840505	6240	0.4841
840511	6402	0.5168
840517	5178	0.5146
840523	5030	0.4847
840529	3930	0.4885
840604	3909	0.5153
840610	3317	0.4757
840616	4239	0.5037
840622	4069	0.4642
840628	2359	0.4773
TOTALS	73239	0.4692

Table 6. NOVA-1 Station Summary.

STATION	NO. OBS.	RMS(cm/sec)
DIONYSOS	6087	0.4947
MADRID	6241	0.5085
SIMOSATO	6660	0.5201
CANBERRA	3088	0.5875
HUAHINE	1112	0.7342
POTSDAM	8914	0.4376
HERSTMON.	6859	0.4314
EFFELSB.	9192	0.3954
HAYSTACK	6430	0.4700
FORT DAV.	1506	0.4745
PLATTEV.	4748	0.4533
PARIS	1063	0.6407
GRASSE	1674	0.5357
B. AIRES	1536	0.6597
RIO GR.	2068	0.5451
PENC	6061	0.3271
TOTALS	73239	0.4692

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16. Abstract

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