AD-A167 567 DMA (DEFENSE MAPPING AGENCY) ORBIT DETERMINATION FOR 1/1
TRANSIT SATELLITES: 1985(U) DEFENSE MAPPING AGENCY
HYDROGRAPHIC/ TOPOGRAPHIC CENTER WASHINGTON DC
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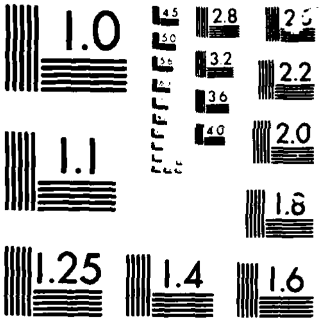

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SECURITY CLASSIFICATION OF THIS PA

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AD-A167 567

1a. REPORT SECURITY CLASSIFICATIO Unclassified

MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY N/A

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

AVAILABILITY OF REPORT
approved for public release
distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S) N/A

5. MONITORING ORGANIZATION REPORT NUMBER(S) N/A

DTIC ELECTE MAY 05 1986 S D D

6a. NAME OF PERFORMING ORGANIZATION Defense Mapping Agency Hydrographic/Topographic Ctr

6b. OFFICE SYMBOL (If applicable) HTC/STT

7a. NAME OF MONITORING ORGAN N/A

6c. ADDRESS (City, State and ZIP Code)
6500 Brookes Lane
Washington DC 20315-0030

7b. ADDRESS (City, State and ZIP C N/A

8a. NAME OF FUNDING/SPONSORING ORGANIZATION Defense Mapping Agency

8b. OFFICE SYMBOL (If applicable) DMAHQ/PA

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State and ZIP Code)
Bldg 56, US Naval Observatory
Wash, DC 20305-3000

10. SOURCE OF FUNDING NOS.

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
N/A	N/A	N/A	N/A

11. TITLE (Include Security Classification) DMA Orbit Determination for Transit Satellites: 1985

12. PERSONAL AUTHOR(S) Jesse Kenneth Murphy and Patrick J. Fell

13a. TYPE OF REPORT Final

13b. TIME COVERED FROM N/A TO

14. DATE OF REPORT (Yr., Mo., Day) 30 Apr 86

15. PAGE COUNT 14

16. SUPPLEMENTARY NOTATION

Presented at Foruth International Geodetic Symposium on Satellite Positioning, Austin, Texas, 28 Apr - 2 May 86

17. COSATI CODES

FIELD	GROUP	SUB. GR.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number) Orbit Determination; GPS

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

DTIC FILE COPY

86 5 2 063

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT N/A

UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS ☐

21. ABSTRACT SECURITY CLASSIFICATION N/A

22a. NAME OF RESPONSIBLE INDIVIDUAL Patrick J. Fell

22b. TELEPHONE NUMBER (Include Area Code) 202-227-2031

22c. OFFICE SYMBOL DMAHTC/STT

DD FORM 1473, 83 APR

EDITION OF 1 JAN 73 IS OBSOLETE.

SECURITY CLASSIFICATION OF THIS PAGE

DMA ORBIT DETERMINATION
FOR TRANSIT SATELLITES: 1985

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SUMMARY

Since 1975, the Defense Mapping Agency (DMA) has been computing precise orbits for the Navy navigation satellites, OSCAR series. In mid-1981, DMA began computing precise orbits for the NOVA-1 satellite and, in early 1985, for the NOVA-3 satellite. Currently, DMA determines precise orbits for the three OSCAR and two NOVA satellites which comprise the TRANSIT System.

This paper presents a comparison of computational results for these satellites with regard to orbit accuracy, time (oscillator) stability, and polar motion. The comparison is made for results obtained for 1985.

1.0 NAVY NAVIGATION SATELLITE ORBIT COMPUTATIONS AT THE DEFENSE MAPPING AGENCY

The Defense Mapping Agency Hydrographic/Topographic Center performs precise orbit computations for Navy navigation satellites using Doppler observations collected by a worldwide network of approximately 50 stations. Equipment at these sites is configured around either Tranet II or Magnavox 1502 DS receiver. Recorded Doppler counts, surface weather measurements, and other appropriate data are transmitted daily via satellite communications or over other telecommunication links to DMA for processing, time correction, and orbit determination. Data are accumulated for two days before precise orbit computations are performed for OSCAR satellites 30130, 30200, and 30110. For the NOVA satellites, data are currently processed every two days for NOVA-1, satellite 30480, and daily for NOVA-3, satellite 30500. During 1985, the NOVA processing interval varied based on availability of data from the network. For NOVA-1, two day processing occurred on days 001 through 036 and on days 187 through 365. For NOVA-3, two-day processing occurred on days 033 through 180. For all other days in 1985, data were processed on a daily basis. Table 1 provides information on satellites whose ephemerides were routinely computed during 1985.

TABLE 1: ACTIVE TRANSIT SATELLITE IN 1985

NSWC+ Number	APL++ Number	Name	Launch Year	Months Operational
59	30130	OSCAR-13	1967	222
77	30200	OSCAR-20	1973	145
93	30110	OSCAR-11	1977	97
105	30480	NOVA-1	1981	52
115	30500	NOVA-3	1984	12

\+ Naval Surface Weapons Center
++ Applied Physics Laboratory, Johns Hopkins University

Computation of TRANSIT satellite ephemerides is based on the CELEST computer program implementation of a batch least squares smoother. From Doppler range difference observations, dynamical and other model parameters are estimated to minimize the weighted sum square of Doppler residuals over the observation interval. The equations of motion include the NWL-10E1 gravity field with tracking station coordinates in the NSWC 9Z-2 Doppler system. The dynamical parameters in the orbit solution for each OSCAR satellite include an atmospheric drag scaling parameter for each day. NOVA satellites are modeled with an along-track thrust to compensate for calibration of the satellite drag compensation device. That device provides thrust-activated adjustments to maintain an orbit devoid of nonconservative along-track forces.

2.0 ORBIT COMPUTATION RESULTS FOR 1985

The following sections provide a summary of orbit computation results for the five active TRANSIT satellites tracked by the DMA network.

2.1 EPHEMERIDES

Orbits for the five active TRANSIT satellites were computed throughout 1985 on a one or two-day basis as previously discussed, using the CELEST orbit determination program. Ephemerides were not computed for the days provided in Table 2 due to several factors, including TRANSIT system implementation of the leap second adjustment and periods of satellite inoperability.

The orbit computation program provides sufficient diagnostic information to judge the overall quality of estimated ephemerides, the stability of satellite and tracking station clocks, and the performance of

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TABLE 2: TRANSIT EPHEMERIS NONAVAILABILITY LISTING 1985

APL NUMBER	EPHEMERIS NONAVAILABILITY 1985 DAY NUMBERS
30130	182-183
30200	139-140, 245-246
30110	20-21, 52-53, 134-135
30480	182, 183, 184, 223-224, 248-249, 266, 272, 333-334
30500	139, 250

the tracking network. One quantity compared within the CELEST program, used as a measure of ephemeris quality, is the station navigation solution. After the satellite ephemeris is estimated, each individual pass of Doppler data acquired during the fit span is used to adjust the geodetic coordinates of the tracking station in directions along the perpendicular to slant range vector of the satellite at its time of closest approach during the pass. These individual two-parameter station adjustments provide a measure of the consistency of the data with the estimated ephemeris. From these station navigation estimates, a weighted root mean square (RWS) is computed, where the weighting factor for each pass is chosen as the variance of the pass navigation solution.

Table 3 provides the average of the RWS station navigation results for all orbit determinations completed during 1985. These average values, labeled Tangential (along-track direction) and Radial (slant-range direction) are a measure of the internal consistency of computed ephemerides with the acquired Doppler data.

A measure of orbit repeatability can be obtained by comparing the estimated satellite position at the beginning of each fit span with the estimated position at the end of the previous span. These comparisons are made in the radial, tangential, and normal directions using the satellite position and velocity vectors to define the coordinate system. Averages for these quantities for the year 1985 are found in Table 3 under orbit consistency. Although the fit span used for NOVA data processing was one day for a significant number of days in 1985 (which may provide some advantage in orbit estimation when dynamic modeling error is present),

TABLE 3: SUMMARY OF EPHEMERIS QUALITY

	NOVA-1 SATELLITE 30500			NOVA-3 SATELLITE 30480			OSCAR-13 SATELLITE 30100			OSCAR-20 SATELLITE 30200			OSCAR-11 SATELLITE 30110		
	Tangential	Radial	Normal	Tangential	Radial	Normal	Tangential	Radial	Normal	Tangential	Radial	Normal	Tangential	Radial	Normal
Data Consistency	1.8m	1.2		1.4	1.3		1.9	2.3		2.0	2.4		2.4	2.0	
Orbit Consistency	2.3	0.7	1.9	2.1	0.6	1.2	2.8	0.7	1.3	3.4	1.0	1.4	5.9	3.8	1.0

these results indicate enhanced orbit quality for NOVA compared to the OSCAR series of satellites. The poorest performance is shown by OSCAR-11, satellite 30110. This satellite also demonstrates the worst frequency stability of the TRANSIT satellites (see Section 2.2). Based on these results, it can be concluded that on the average, precise orbit computations for TRANSIT, excluding satellite 93, are perhaps accurate to better than 3, 1, and 2 meters in the along-track, radial, and out-of-plane directions. Satellite 93 results are consistent with at least a 6, 4, and 1 meter capability.

2.2 FREQUENCY

Time stability for the Navy navigation satellite system is maintained through the operations of the Naval Astronautics Group at Point Magu, California. Time is maintained for OSCAR satellites through the deletion of cycle counts generated by a satellite crystal oscillator operating at a frequency slightly above a nominal frequency. Fractional frequency fluctuations are compensated for by estimating oscillator instability and by adjusting cycle counts appropriately. An actual time drift will still occur; however, the time error will be maintained within prescribed limits. For NOVA satellites time stability is maintained by varying the frequency of the satellite crystal oscillator. This frequency steering occurs daily, as necessary, for NOVA-3 but is not used on NOVA-1 due to a partial failure of the frequency steering mechanism.

As part of the DMA orbit determination solution, satellite frequency bias and drift are estimated. Frequency bias causes a time drift to occur equal to the ratio of the frequency bias to oscillator base frequency multiplied by the effective time span of the bias. Frequency drift causes a quadratic time error equal to the ratio of the frequency drift to oscillator base frequency multiplied by one-half the square of the effective time span of the drift. The long-term frequency stability for the Navy navigation satellites was calculated using the estimated daily frequency bias from CELEST orbit processing. Since this value is readily available on a one or two-day basis, long-term trends in frequency stability can be obtained. Figure 1 gives the plot of estimated frequency bias for OSCAR-13 fo 1985. Figure 2 gives similar results for NOVA-1. Based on these data an average frequency drift for the year was computed and is given in Table 4.

Figure 1: Satellite 30130 Frequency Error

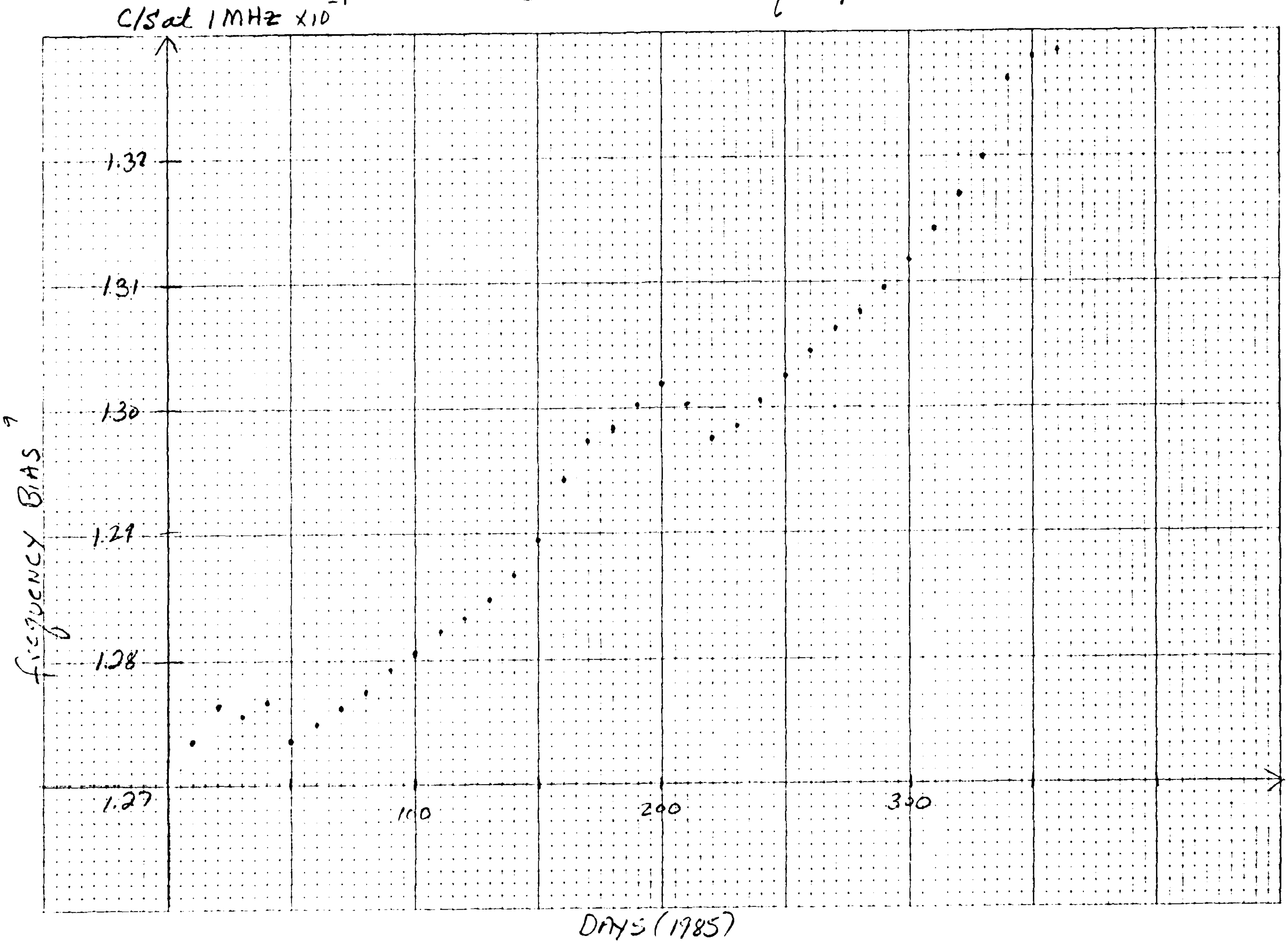
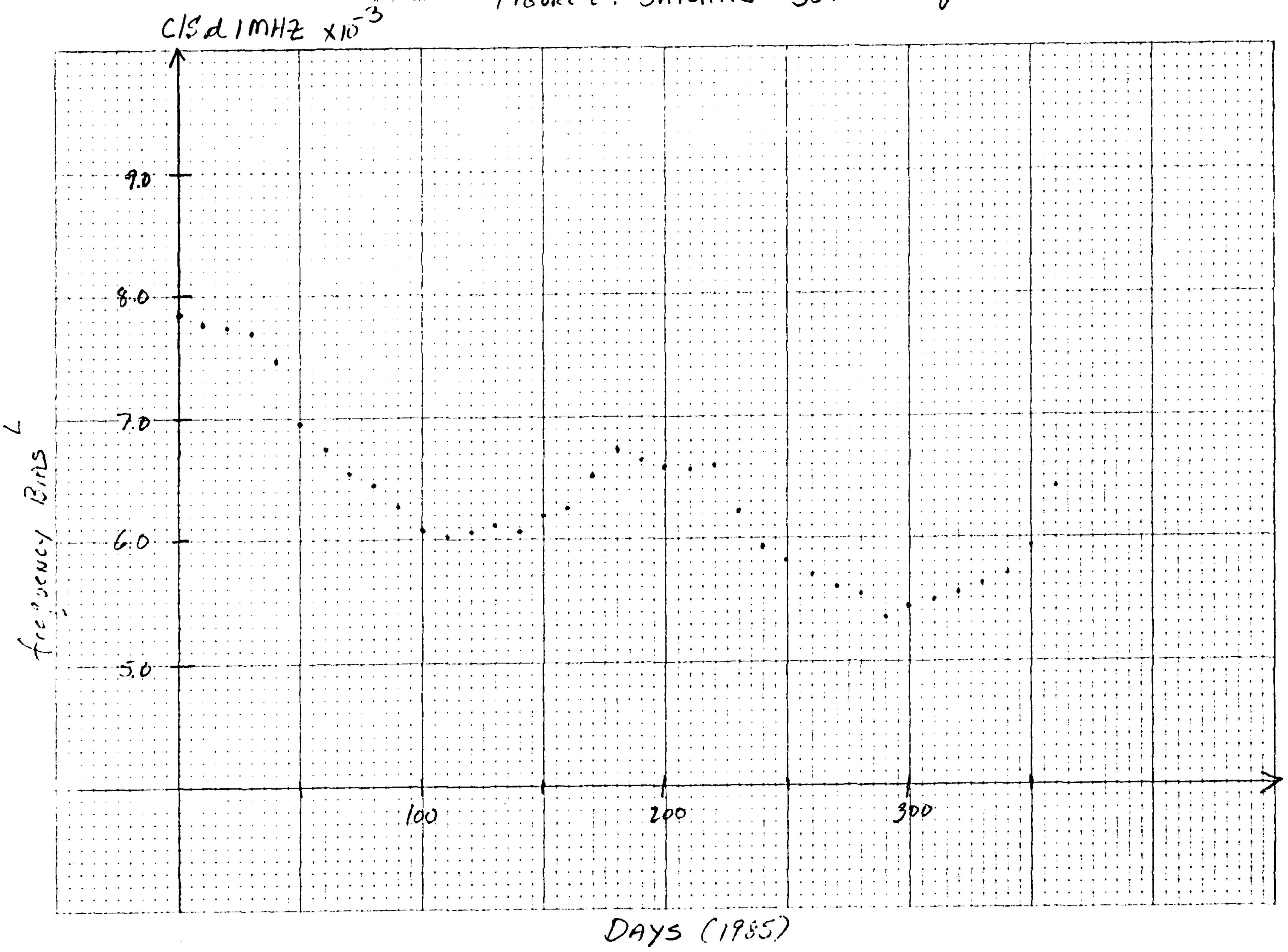


FIGURE 2: SATELLITE 30480 frequency ERROR



A comparison of these results demonstrates the relative stability of these crystal oscillators, with NOVA-1 and OSCAR-20 performing best. The frequency stability of OSCAR-11 is the poorest of the active TRANSIT satellites.

TABLE 4: MEAN FREQUENCY STABILITY

SATELLITE NAME		DAILY MEAN DRIFT+
	13	16×10^{-6}
OSCAR	20	7×10^{-6}
	11	37×10^{-6}
NOVA	1	4×10^{-6}
	3	++

\+ Units: cycles/sec per day at 1MHz
++ Stability maintained by active frequency steering.

2.3 POLAR MOTION

Included among parameters estimated in the orbit determination program is the position of the earth's spin axis with respect to the pole of the adopted NSWC 9Z-2 terrestrial frame. The scheme used to compute daily pole values is as follows: each satellite for which two-day spans of data are used for determination is designated to have an odd or even starting day number. Consequently, for each day of the year, pole positions are determined using less than five satellites. The fit span and two-day designator are provided in Table 5 for each satellite. Satellite data processed daily produce pole position estimates on both odd and even days.

TABLE 5: 1985 POLAR MOTION PROCESSING SCHEME

Satellite Number	PROCESSING INTERVAL (DAYS) One-Day	Two-Day	Designator
30130	-	001-365	Even
30200	-	001-365	Odd
30110	-	001-365	Even
30480	037-186	001-036, 187-365	Odd
30500	181-365	033-180	Odd

The 1985 Doppler pole solution were compared to five-day smoothed Circular D values published by the Bureau International de l'Heure (BIH). Where direct comparisons were not possible, interpolated BIH values were used. The polar motion solutions for 1985 are plotted with the BIH smoothed values in Figures 3 through 7. The differences, Doppler minus BIH, were used to compile Table 6, which provides the mean difference and standard deviation between Doppler results for each satellite and the BIH. The first half of the table provides results without consideration of processing interval; the second half provides comparisons of NOVA satellite results with BIH over processing spans of one and two days.

These results again demonstrate a systematic difference between Doppler and the BIH in the y coordinate (direction perpendicular to Greenwich Meridian positive to the west) of approximately one-half meter. However, there appears to be better consistency with BIH for this component when NOVA-3 (satellite 30500) data are processed using one-day spans. This, however, is not evident for NOVA-1 (satellite 30480). The interval consistency of the Doppler results appears to be on the order of .75 meter or less.

TABLE 6: COMPARISON OF DOPPLER AND BIH POLAR MOTION

Satellite Number	x Component Mean+	RMS	y Component Mean	RMS	Processing Span (Days)	Number of Spans
30110	-.033m	.661m	.521	.759	2	182
30200	.036	.637	.516	.754	2	182
30110	.071	.738	.440	.660	2	182
30480	.225	.615	.55	.767	1&2	215
30500	.534	.847	.184	.773	1&2	250
30480	.346	.556	.637	.580	1	139 (037-186)++
	-.258	.497	.576	.490	2	17 (001-036)
	.228	.462	.418	.238	2	59 (187-365)
30500	.379	.630	-.067	.594	1	180 (181-365)
	.961	.479	.831	.729	2	70 (041-180)

\+ Mean of Doppler minus BIH
++ 1985 Calendar day numbers

3.0 CONCLUSION

This paper has presented a summary of DMA orbit computation results for the Navy navigation satellite system for 1985. Ephemeris, frequency stability, and polar motion results were presented. The orbits computed for these five active satellites are used to support precise satellite positioning for a large community of geodetic users.

It is a pleasure to acknowledge the following people for their contributions to this report: Michael Kass, William Armour, and J. Milo Robinson.

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2. O'Toole, James W., 1976, CELEST Computer Program for Computing Satellite Orbits, Naval Surface Weapons Center Technical Report TR-3SCS.
3. Wooden, William H., 1986, Investigation of Polar Motion from Doppler Tracking of the Navy Navigation Satellite System During the Merit Campaign, Proceedings of the Fourth International Geodetic Symposium on Satellite, Austin, Texas.

FIGURE 3: BIH and Doppler (Satellite 59) Polar Motion Results from 1985.

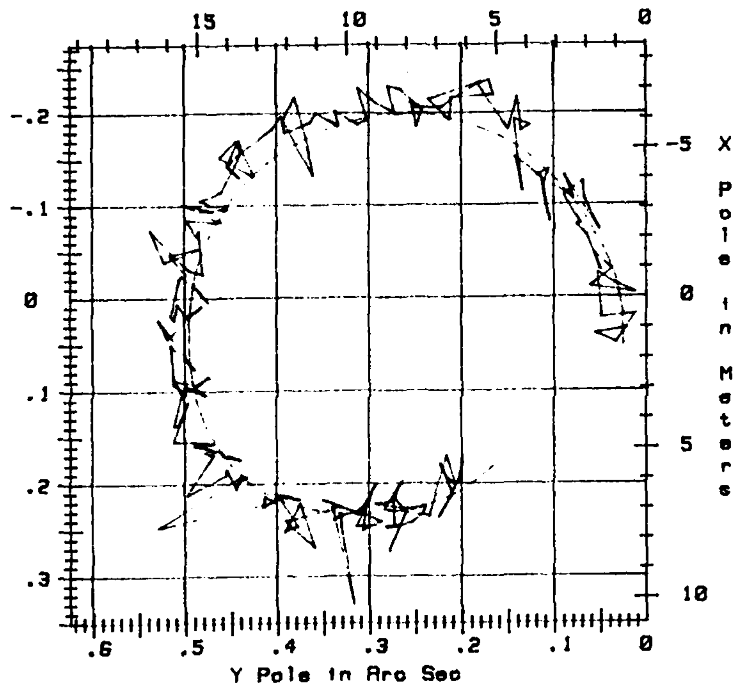


FIGURE 4: BIH and Doppler (Satellite 77) Polar Motion Results from 1985.

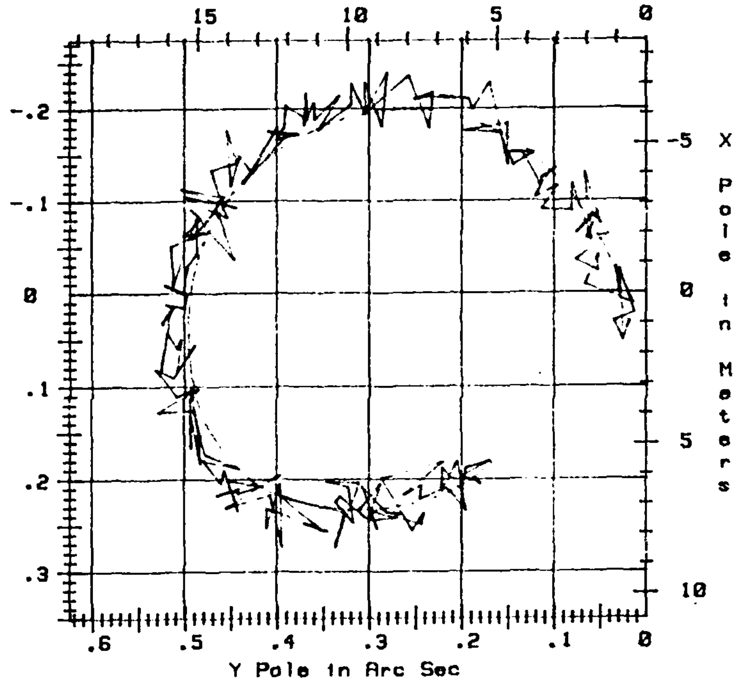


FIGURE 5: BIH and Doppler (Satellite 93)
Polar Motion Results from 1985.

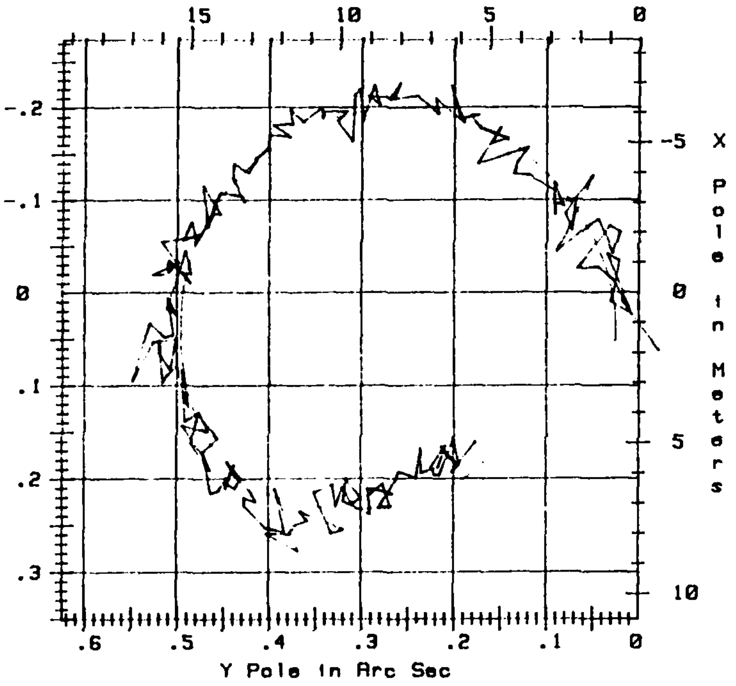


FIGURE 6: BIH and Doppler (Satellite 105)
Polar Motion Results from 1985.

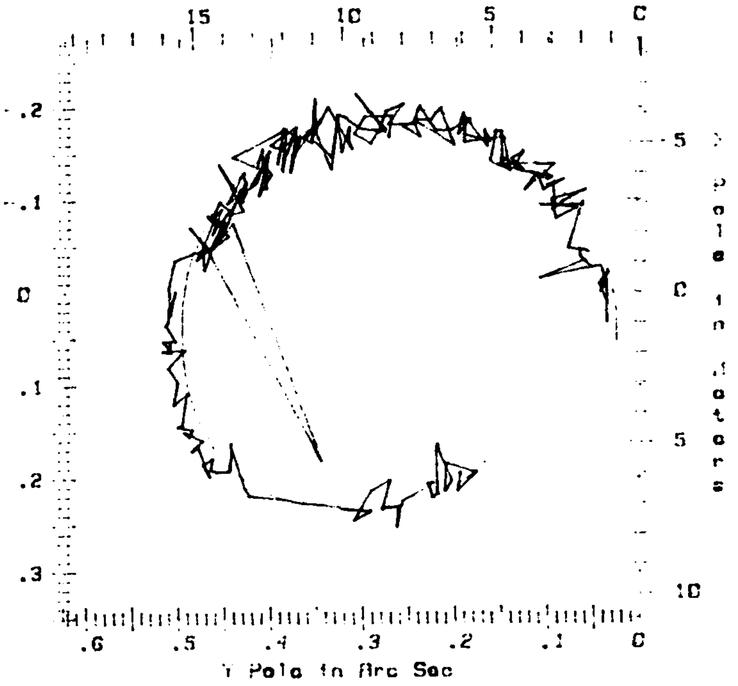
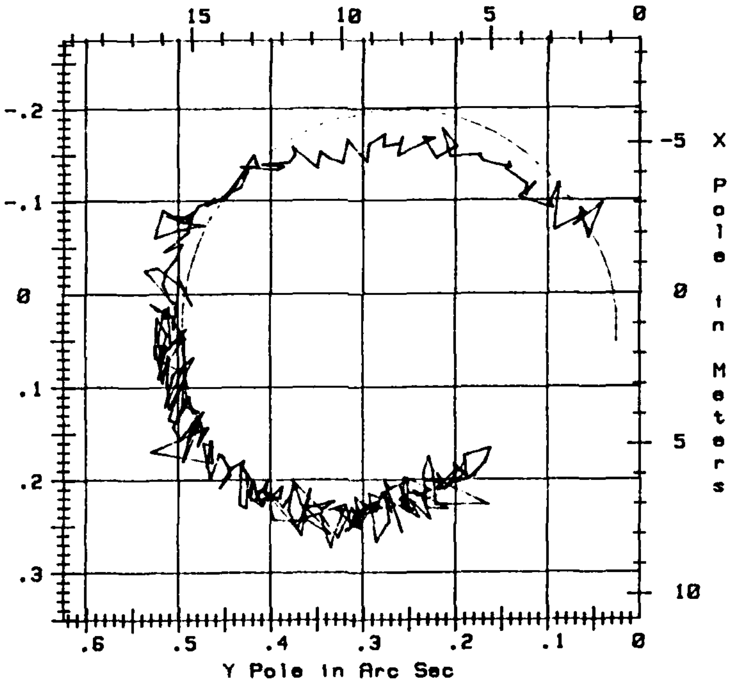


FIGURE 7 : BIH and Doppler (Satellite 115) Polar Motion Results from 1985.



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