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### Title

**Defense Mapping Agency**

**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

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

+ 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
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 2 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>
<thead>
<tr>
<th></th>
<th>NOVA-1 SATELLITE 30500</th>
<th>NOVA-3 SATELLITE 30480</th>
<th>OSCAR-13 SATELLITE 30100</th>
<th>OSCAR-20 SATELLITE 30200</th>
<th>OSCAR-11 SATELLITE 30110</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tangential Radial Normal</td>
<td>Tangential Radial Normal</td>
<td>Tangential Radial Normal</td>
<td>Tangential Radial Normal</td>
<td>Tangential Radial Normal</td>
</tr>
<tr>
<td>Data Consistency</td>
<td>1.8m 1.2</td>
<td>1.4 1.3</td>
<td>1.9 2.3</td>
<td>2.0 2.4</td>
<td>2.4 2.0</td>
</tr>
<tr>
<td>Orbit Consistency</td>
<td>2.3 0.7 1.9</td>
<td>2.1 0.6 1.2</td>
<td>2.8 0.7 1.3</td>
<td>3.4 1.0 1.4</td>
<td>5.9 3.8 1.0</td>
</tr>
</tbody>
</table>
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

C/Sat 1 MHz x 10^-1

Days (1985)
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>
<thead>
<tr>
<th>SATELLITE NAME</th>
<th>DAILY MEAN DRIFT+</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>16 x 10^{-6}</td>
</tr>
<tr>
<td>OSCAR 20</td>
<td>7 x 10^{-6}</td>
</tr>
<tr>
<td>11</td>
<td>37 x 10^{-6}</td>
</tr>
<tr>
<td>NOVA 1</td>
<td>4 x 10^{-6}</td>
</tr>
<tr>
<td>3</td>
<td>++</td>
</tr>
</tbody>
</table>

+ 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.
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 5: 1985 POLAR MOTION PROCESSING SCHEME

<table>
<thead>
<tr>
<th>Satellite Number</th>
<th>PROCESSING INTERVAL (DAYS)</th>
<th>Designator</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One-Day</td>
<td>Two-Day</td>
</tr>
<tr>
<td>30130</td>
<td>-</td>
<td>001-365</td>
</tr>
<tr>
<td>30200</td>
<td>-</td>
<td>001-365</td>
</tr>
<tr>
<td>30110</td>
<td>-</td>
<td>001-365</td>
</tr>
<tr>
<td>30480</td>
<td>037-186</td>
<td>001-036, 187-365</td>
</tr>
<tr>
<td>30500</td>
<td>181-365</td>
<td>033-180</td>
</tr>
</tbody>
</table>
### TABLE 6: COMPARISON OF DOPPLER AND BIH POLAR MOTION

<table>
<thead>
<tr>
<th>Satellite Number</th>
<th>x Component Mean</th>
<th>x Component RMS</th>
<th>y Component Mean</th>
<th>y Component RMS</th>
<th>Processing Span (Days)</th>
<th>Number of Spans</th>
</tr>
</thead>
<tbody>
<tr>
<td>30110</td>
<td>-0.033 m</td>
<td>0.661 m</td>
<td>0.521 m</td>
<td>0.759 m</td>
<td>2</td>
<td>182</td>
</tr>
<tr>
<td>30200</td>
<td>0.036 m</td>
<td>0.637 m</td>
<td>0.516 m</td>
<td>0.754 m</td>
<td>2</td>
<td>182</td>
</tr>
<tr>
<td>30110</td>
<td>0.071 m</td>
<td>0.738 m</td>
<td>0.440 m</td>
<td>0.660 m</td>
<td>2</td>
<td>182</td>
</tr>
<tr>
<td>30480</td>
<td>0.225 m</td>
<td>0.615 m</td>
<td>0.55 m</td>
<td>0.767 m</td>
<td>1&amp;2</td>
<td>215</td>
</tr>
<tr>
<td>30500</td>
<td>0.534 m</td>
<td>0.847 m</td>
<td>0.184 m</td>
<td>0.773 m</td>
<td>1&amp;2</td>
<td>250</td>
</tr>
<tr>
<td>30480</td>
<td>0.346 m</td>
<td>0.556 m</td>
<td>0.637 m</td>
<td>0.580 m</td>
<td>1</td>
<td>139 (037-186)**</td>
</tr>
<tr>
<td></td>
<td>-0.258 m</td>
<td>0.497 m</td>
<td>0.576 m</td>
<td>0.490 m</td>
<td>2</td>
<td>17 (001-036)</td>
</tr>
<tr>
<td></td>
<td>0.228 m</td>
<td>0.462 m</td>
<td>0.418 m</td>
<td>0.238 m</td>
<td>2</td>
<td>59 (187-365)</td>
</tr>
<tr>
<td>30500</td>
<td>0.379 m</td>
<td>0.630 m</td>
<td>-0.067 m</td>
<td>0.594 m</td>
<td>1</td>
<td>180 (181-365)</td>
</tr>
<tr>
<td></td>
<td>0.961 m</td>
<td>0.479 m</td>
<td>0.831 m</td>
<td>0.729 m</td>
<td>2</td>
<td>70 (041-180)</td>
</tr>
</tbody>
</table>

**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.
4.0 REFERENCES


Figure 4: DHI and Doppler (SARellite 37)

Figure 3: DHI and Doppler (SARellite 90)

Polar Motion Results from 1985.