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Accurate Orbit Determination Strategies for TOPEX/Poseidon Using TDRSS

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ACCURATE ORBIT DETERMINATION STRATEGIES FOR TOPEX/POSEIDON USING TDRSS*

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Abstract

Orbit determination results are obtained for the Ocean Topography Experiment (TOPEX)/Poseidon spacecraft by the Goddard Space Flight Center (GSFC) Flight Dynamics Division (FDD) using a batch-least-squares estimator available in the Goddard Trajectory Determination System (GTDS) to process Tracking and Data Relay Satellite (TDRS) System (TDRSS) measurements. TOPEX/Poseidon trajectories are estimated for the November 1992 and April 1993 timeframes using enhanced orbit determination techniques not currently used for TOPEX/Poseidon operational navigation support by the GSFC FDD. The quality of these solutions is assessed through comparisons with definitive precision orbit ephemerides (POEs), generated by the GSFC Space Geodesy Branch, which have a radial component accuracy requirement of 13 centimeters (1σ). The best root-mean-square (RMS) radial component difference between the GTDS solutions and the POEs is 24 centimeters.

1. Introduction

This study assesses the Ocean Topography Experiment (TOPEX)/Poseidon orbit determination accuracy of the Tracking and Data Relay Satellite (TDRS) System (TDRSS)-based orbit solutions using the Goddard Space Flight Center (GSFC) Flight Dynamics Division (FDD) operational batch-least-squares system.

The TOPEX/Poseidon spacecraft was launched on an Ariane 42P expendable launch vehicle in August 1992. In October 1992, maneuvers were completed that moved the spacecraft into its operational orbit, which is circular with an inclination of 66 degrees, an altitude of 1336 kilometers, a period of 112 minutes, and a 10-day ground track repeat period.

TDRSS is a geosynchronous relay satellite network; it currently consists of five geosynchronous spacecraft and a central command center called the White Sands Complex (WSC) at White Sands, New Mexico. Three of these TDRSs (TDRS-East, TDRS-West, and TDRS-Spare, located at 41 degrees, 174 degrees, and 171 degrees west longitude, respectively) actively support tracking of TDRSS-user spacecraft. Of the two remaining TDRSs, one (located at 275 degrees west longitude) is used only for spacecraft communications while the other (located at 46 degrees west longitude) is being reserved for future use. TDRSS can provide 85-percent to 100-percent coverage, depending on the spacecraft altitude.

The Bilateration Ranging Transponder System (BRTS) provides range and Doppler measurements for determining each TDRS orbit. The ground-based BRTS transponders are tracked as if they were TDRSS-user spacecraft. Since the positions of the BRTS transponders are known, their ranging data can be used to precisely determine the trajectory of the TDRSs.

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High-accuracy TDRSS-based orbit determination solutions are obtained for TOPEX/Poseidon using the batch-least-squares algorithm implemented in the Goddard Trajectory Determination System (GTDS). The TDRSS-based orbit solutions are compared with the high-precision orbit solutions obtained by the GSFC Space Geodesy Branch using laser and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) tracking measurements.[1] The accuracy requirements on the Space Geodesy Branch orbit determination solutions, which are used to analyze the sea surface height measurements obtained by the TOPEX/Poseidon radar altimeter, are extremely stringent. The definitive orbit determination requirements for the TOPEX/Poseidon mission science data include a maximum 13-centimeter (1σ) radial position error. The availability of the high-accuracy independent precision orbit determination ephemerides (POEs) generated by the Space Geodesy Branch provides a unique opportunity to evaluate the accuracy of the orbit determination systems used by the FDD for operational navigation and analysis support.

Section 2 presents the analysis procedures used in this study, and Section 3 describes the batch-least-squares solution evaluation results. Section 4 presents the conclusions of this study.

2. Analysis Procedures

The tracking measurements used in the batch-least-squares solutions are described in Section 2.1, and the orbit determination method and modeling are given in Section 2.2.

2.1 Tracking Measurements

Three distinct time periods were chosen for this study. The first time period covers 00:00 hours coordinated universal time (UTC) on 4 November 1992 through 00:00 hours UTC on 9 November 1992, which corresponds to the latter portion of the fifth TOPEX 10-day ground track repeat cycle, hereafter referred to as Cycle 5. This timeframe was chosen because this period was well characterized through previous analyses.[2] The second time period covers 20:00 hours UTC on 13 November 1992 through 16:30 hours UTC on 18 November 1992, which corresponds to the middle portion of Cycle 6. The third time period covers 22:00 hours UTC on 10 April 1993 through 22:00 hours UTC on 15 April 1993, which corresponds to the early portion of Cycle 21. The Cycle 6 and Cycle 21 timeframes were chosen because there was a minimal number of TDRS and TOPEX spacecraft attitude maneuvers during these periods.

Tracking measurements from TDRSS were used in GTDS to estimate the TOPEX and TDRS definitive ephemerides. The GTDS orbit solutions were obtained using two-way range and one-way return and two-way Doppler data from TDRSS in addition to two-way range data from BRTS. For Cycles 5 and 6, the tracking consisted of an average of 10 passes of one-way return Doppler measurements and 11 passes of two-way range and Doppler measurements per day, with the average pass lasting 40 minutes. For Cycle 21, the tracking consisted of an average of 17 passes of one-way return Doppler measurements and 4 passes of two-way range and Doppler measurements per day, with the average pass lasting 40 minutes. BRTS tracking coverage of each TDRS spacecraft typically consists of twelve to fifteen 5-minute passes per day.

2.2 Orbit Determination Method and Modeling

This section describes the orbit determination methods and modeling used to generate the batch-least-squares GTDS solutions.

2.2.1 GTDS Batch-Least-Squares Estimation

The weighted batch-least-squares orbit determination process in GTDS estimates, using the differential correction technique, a spacecraft state by minimizing the sum of the squares of the differences between the computed and observed spacecraft tracking measurements. The estimated spacecraft state typically consists of the position and velocity at a single time point (also known as the epoch), but can include other parameters related to the spacecraft accelerations and tracking measurements. The computed tracking measurements are calculated in GTDS using the spacecraft positions and velocities, generated by integrating the spacecraft equations of motion over a specified timespan, as input into a tracking measurement modeling scheme. In the weighted batch-least-squares process, the spacecraft state is iteratively estimated using the equation

$$\Delta X = (A^{\mathrm{T}}WA)^{-1}A^{\mathrm{T}}WR$$

where ΔX is the computed correction to the a priori spacecraft state for the current iteration at epoch, A is the matrix of partial derivatives of the tracking measurements with respect to the estimated state parameters, W is the measurement weight matrix, and R is the matrix of differences between the computed and observed tracking measurements based on the

solution from the previous iteration. The differential correction process continues until the changes in the weighted root-mean-square (RMS) of the R matrix elements are less than a specified tolerance.

The batch-least-squares estimation algorithm used by GTDS for this analysis is the same as that used for operational navigation support of the TOPEX mission by the GSFC FDD. The procedure used for operational support includes solving for the TOPEX spacecraft state, the onboard ultrastable oscillator (USO) frequency bias and drift parameters, and an along-track thrust estimation parameter using two-way and one-way return Doppler measurements. TOPEX range measurements are excluded from the solutions because covariance analysis shows no improvement in accuracy and to avoid operational limitations in solving for uncorrected biases, which have been found to reduce the orbit solution quality. TDRS spacecraft trajectories are determined separately using the BRTS ranging measurements.

The modeling and state estimation parameters used for this analysis were improved to provide more accurate results and to take advantage of techniques not currently in operational use. Specifically, the solutions in this analysis use the full 70×70 or truncated 50×50 Joint Gravity Model-2 (JGM-2) geopotential model for TOPEX. The operational TOPEX solutions use the JGM-2 model truncated at 20×20. The TDRS solutions in this analysis use the truncated 20×20 JGM-2 model, while the operational solutions use the JGM-2 model truncated at 8×8. Furthermore, the TOPEX state space was expanded to include estimation of the coefficient of solar radiation pressure and multiple along-track thrust parameters that were intended to compensate for an anomalous acceleration acting on the spacecraft. Analysis of the operational TOPEX orbit solutions indicated the presence of an unmodeled spacecraft body-fixed force with a day-to-day variability that occurred immediately after the mission orbit was achieved; this behavior became the subject of intense further analysis. In addition to the force modeling and estimated parameters, the procedure for estimating the TOPEX and TDRSs orbits in this analysis are also modified from the current operational procedure. For operational support, the TOPEX orbits are estimated using pregenerated TDRS orbits as input. For this analysis, the TOPEX and TDRS orbits are estimated simultaneously.

2.2.2 TDRS/TOPEX Orbit Determination Procedure

TDRS spacecraft trajectories were estimated simultaneously with TOPEX using both BRTS range and TOPEX two-way range and two-way and one-way return Doppler data to determine the best possible TDRS trajectories. A new technique developed for obtaining more accurate TDRS orbit solutions using GTDS, referred to as the analytic calibration of biases (ACB) technique, involves performing a series of simultaneous TDRS/TOPEX solutions to calibrate a set of relative range measurement biases for each source of range measurement error in the TDRSS.[3] The TOPEX and TDRS ACB standard force modeling and parameters used in this study are provided in Table 1. The data spans for each of the orbit determination arcs in Cycles 5, 6, and 21 were 5 days in length, with one thrust correction factor estimated per day in the simultaneous TDRS/TOPEX solutions and three thrust correction factors per 5-day arc in the TOPEX-only solutions. The simultaneous TDRS/TOPEX solution arcs were selected to avoid all maneuvers and TDRS angular momentum unloads, where possible, while maintaining the longest possible data spans. In addition, central angle editing was used to mitigate the effects of ionospheric refraction on the TDRS-to-TOPEX tracking link. The central angle chosen was designed to eliminate all data below the TOPEX local horizon. Note that the Cycle 5 results use the full 70×70 JGM-2 geopotential model, while the Cycle 6 and 21 solutions use a truncated 50×50 JGM-2 geopotential model. At the time the Cycle 6 and 21 analyses were performed, the full 70×70 model was not available in GTDS. Analyses for the Cycle 6 and 21 data spans using the 70×70 geopotential model are currently underway.

The ACB technique estimates, in a methodical manner, a set of relative range measurement biases for each source of range measurement error within the TDRSS. In the standard ACB technique, a total of six solutions are generated. The first five solutions are simultaneous TDRS/TOPEX solutions used to obtain the best possible TDRS trajectories. The final solution is a TOPEX-only solution that uses the best-estimated TDRS trajectories determined from the previous simultaneous solutions.

Table 1. Standard ACB Parameters and Options Used in the GTDS Solutions

Orbit Determination Parameter or Option	GTDS Values*	
	TOPEX	TDRSs
Estimated parameters	Orbital state, thrust coefficients, coefficient of solar radiation pressure (C_R), USO bias and drift	Orbital state, coefficient of solar radiation pressure (C_R), spacecraft transponder delay, BRTS transponder delays
Integration type	Cowell 12th order	Cowell 12th order
Coordinate system of integration	Mean-of-J2000.0	Mean-of-J2000.0
Integration step size (seconds)	60 seconds	600 seconds
Tracking measurements	TDRSS two-way Doppler TDRSS one-way return Doppler TDRSS two-way range	BRTS two-way range
Measurement span	See text	See text
Data rate	1 per minute	1 per 20 seconds
Differential correction (DC) convergence parameter	0.00005	0.00005
Editing criterion	3σ	3σ
Ionospheric editing criterion	Central angle greater than 79.48 degrees	–
Measurement weight sigmas	Doppler: 10 millihertz Range: 1.5 meters	2 meters
Satellite area model	Variable mean area model	Constant, 40 meters^2
Satellite mass	2417.2 kilograms	TDRS-5: 1973.1 kilograms TDRS-4: 1853.6 kilograms
Geopotential model	Cycle 5: 70 × 70 JGM-2 Cycle 6: 50 × 50 truncated JGM-2 Cycle 21: 50 × 50 truncated JGM-2	20 × 20 JGM-2
Atmospheric density model	Jacchia-Roberts	N/A
Solar and lunar ephemerides	DE-200	DE-200
Coefficient of drag (C_D)	2.3 applied	N/A
Ionospheric refraction correction Ground-to-spacecraft Spacecraft-to-spacecraft	 Yes No (central angle edit instead)	 Yes N/A
User-spacecraft antenna offset correction	Constant radial, along-track, cross-track	No
Tropospheric refraction correction	Yes	Yes
Polar motion correction	Yes	Yes
Solid Earth tides	Yes	Yes

* DE = Developmental Ephemeris (Jet Propulsion Laboratory); JGM = Joint Gravity Model; N/A = not applicable

The first solution determines, through analysis of the BRTS range residuals, which BRTS transponders have range biases relative to the TDRSS range measurements for the TOPEX. The second solution estimates a pseudo TDRSS-user transponder delay through the estimation and differencing of BRTS and TOPEX range measurement biases. The next three solutions determine the best possible TDRS orbits using the information obtained from the first two simultaneous solutions and iteratively estimating the BRTS, pseudo TDRSS-user and TDRS transponder delays. The final solution is a TOPEX-only solution using the trajectories of the TDRSs obtained from the final iterative simultaneous solution.

The details of the standard ACB technique are described in Table 2. The ACB procedure is depicted schematically in Fig. 1.

Table 2. ACB Procedure Solution Description

Solution	Purpose	Solution Type	Tracking Measurements	Range-Measurement-Related Parameters
(1)	Determines which BRTS transponders appear to have biases in the range tracking measurements relative to the TDRSS range measurements of TOPEX, which is accomplished through examination and analysis of the BRTS range residuals resulting from the solution. This information will be used in Solution (3).	Simultaneous TOPEX/ TDRSs	BRTS range measurements for the TDRSs and TDRSS range and two-way and one-way return Doppler for TOPEX	Estimate range measurement biases on the TOPEX range measurements at the White Sands ground antennas
(2)	Determines a pseudo TOPEX transponder delay. This information will be used in Solution (3).	Same as Solution (1)	Same as Solution (1)	Estimate range measurement biases on the TOPEX range measurements at the White Sands ground antennas. Estimate range measurement biases on the BRTS range measurements at the White Sands ground antennas. Determine the pseudo TOPEX transponder delay by differencing the BRTS range bias and the TOPEX range bias for each White Sands ground antenna and then averaging these differences to obtain a single average White Sands ground antenna range bias. This average White Sands ground antenna bias serves as an approximation for the TOPEX transponder delay.
(3a)	Solutions (3a), (3b), and (3c) use the information from Solution (1) and Solution (2) to obtain the best possible TDRS orbits for use in Solution (4). Solution (3a) is the first iteration for estimating the best possible TDRS orbits.	Same as Solution (1)	Same as Solution (1)	Estimate the BRTS transponder delays for the biased BRTS transponders identified in Solution (1). Apply the average White Sands ground antenna bias (pseudo TOPEX transponder delay) determined in Solution (2) to each White Sands ground antenna. Estimate the TDRS transponder delays for each TDRS.
(3b)	Solution (3b) is the second step in the iterative process to obtain the best possible TDRS orbits.	Same as Solution (1)	Same as Solution (1)	Apply the BRTS transponder delays determined in Solution (3a) to the corresponding biased BRTS transponders. Estimate the White Sands ground antenna biases (pseudo TOPEX transponder delay) for each White Sands ground antenna. Apply the TDRS transponder delays determined in Solution (3a) to the corresponding TDRS.
(3c)	Solution (3c) is the final step in the iterative process to obtain the best possible TDRS orbits.	Same as Solution (1)	Same as Solution (1)	Same as Solution (3a), except apply the individual White Sands ground antenna biases (pseudo TOPEX transponder delay) determined in Solution (3b) to each corresponding White Sands ground antenna.
(4)	Solution (4) uses the TDRS orbits obtained from Solution (3c) to determine the best possible TOPEX orbit solution.	TOPEX-Only	TDRSs two-way and one-way return Doppler for TOPEX	Not applicable. Range measurements eliminated to minimize the effect of TOPEX range measurement bias modeling errors on the TOPEX trajectory

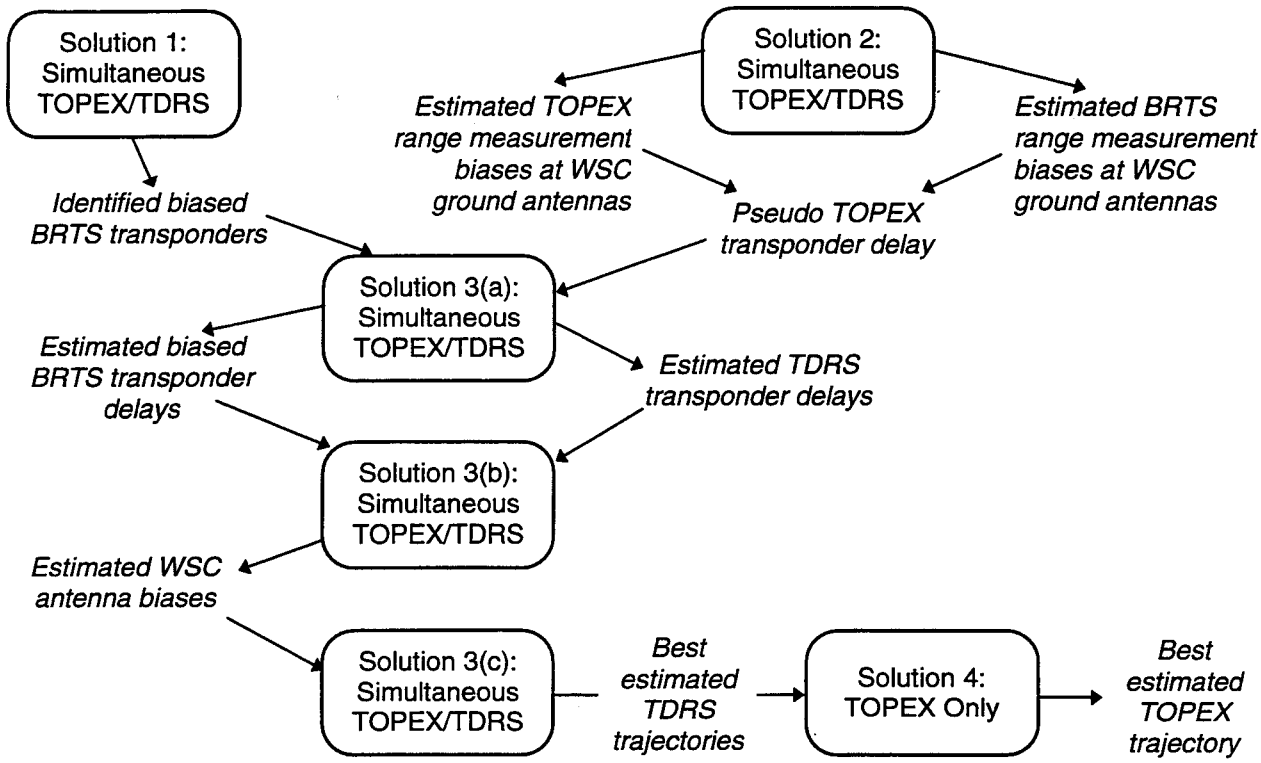

Fig. 1. A Schematic of the ACB Procedure

3. Analysis Results

The following sections present high-accuracy GTDS orbit solution results for the TOPEX/Poseidon spacecraft. All the results are derived using the standard ACB method described in Section 2.2. Section 3.1 shows results for Cycle 5. Next, results for Cycle 6 and Cycle 21 are shown in Sections 3.2 and 3.3, respectively. The specific timespans covered in each of these cases can be found in Section 2.1. Finally, Section 3.4 discusses issues common to all three timespans.

The accuracy of the TOPEX/Poseidon orbit determination solutions generated in this study is assessed through comparisons with high-accuracy TOPEX/Poseidon precision orbit ephemerides (POEs) generated by the Precision Orbit Determination (POD) team within the Space Geodesy Branch located at GSFC. The POEs are generated with the Geodynamics (GEODYN) orbit determination system using laser ranging and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) tracking measurements. The definitive orbit determination requirements for the TOPEX/Poseidon POEs include a maximum 13-centimeter (1σ) radial position error. The estimated accuracy of the TOPEX/Poseidon POEs is less than 6 centimeters on the radial component and less than 50 centimeters in total position. The availability of the independent orbit determination solutions generated by the Space Geodesy Branch provides a unique opportunity to evaluate the accuracy of the orbit determination systems used by the FDD for operational navigation and analysis support.

3.1 Cycle 5 ACB Results

This section presents the high-accuracy GTDS orbit solution results for the TOPEX/Poseidon spacecraft using tracking measurements from Cycle 5. The root-sum-square (RSS) comparison differences with the POE over the whole 5-day solution arc can be seen in Fig. 2. Here the root mean square of the RSS differences is 1.07 meters with a maximum RSS difference (Diff) of 2.24 meters. The radial and along-track components have RMS values of 0.24 meter and 0.72 meter, respectively, while the cross-track component has an RMS value of 0.76 meter. The maximum differences are 0.43, 1.85, and 1.81 meters

for the radial, along-track, and cross-track components, respectively. The radial, along-track and cross-track components of the differences between the final ACB TOPEX/Poseidon solution and the TOPEX/Poseidon POE can be seen in Fig. 3 for 1 day of the solution arc.

In addition to the tracking measurement reduction solutions, GTDS orbit determination solutions have been obtained using state vectors from the Cycle 5 POE as the measurements. This form of orbit determination solution eliminates all measurement and TDRS spacecraft dynamical force modeling, thereby making it possible to estimate the amount of error resulting from the dynamical modeling used in GTDS for TOPEX. This solution span, which is 4 days long, begins on 00:00 hours UTC on 7 November 1992 and ends on 00:00 hours UTC on 11 November 1992; and it used POE state vectors at 12-minute intervals. The mean RSS position difference between this special solution and the Cycle 5 POE is 0.4 meter, with a maximum difference of 1.1 meters. The maximum radial, along-track, and cross-track differences are 0.4 meter, 0.9 meter, and 1.0 meters, respectively. These differences reflect the force modeling differences between the GTDS dynamical force modeling and the Cycle 5 POE.

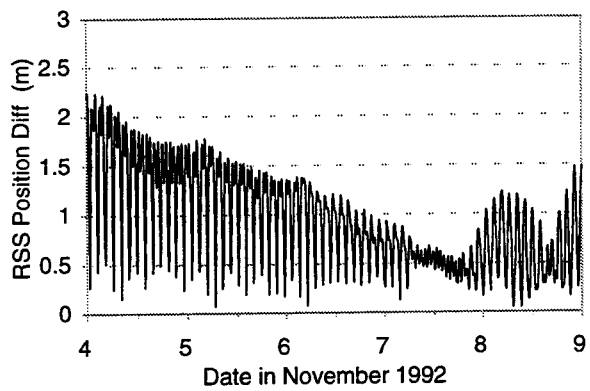

Fig. 2: RSS Position Difference Between the POE and ACB Ephemerides for Cycle 5

3.2 Cycle 6 ACB Results

This section reports on the accuracy of TOPEX/Poseidon solutions derived with the ACB method with tracking measurements from Cycle 6. The RSS of the comparison of the GTDS solution with the TOPEX/Poseidon POE can be seen in Fig. 4. The RMS value is 1.60 meters, with a maximum value of 2.30 meters. The RMS and maximum value of the radial component are 0.46 and 0.85 meter, respectively. The RMS values of the along-track and cross-track components are 1.02 meters and 1.15 meters, respectively, with the corresponding maximum values of 2.02 meters and 1.74 meters.

Notice that the results for Cycle 6 are slightly worse than the results for Cycle 5, even though the length of the timespan, the types of tracking measurements, and the number of TDRS momentum unloads are similar. The results for Cycle 6 should improve when the geopotential modeling is improved from the truncated 50×50 JGM-2 model to the full 70×70 JGM-2 model which was used for the Cycle 5 GTDS solutions.

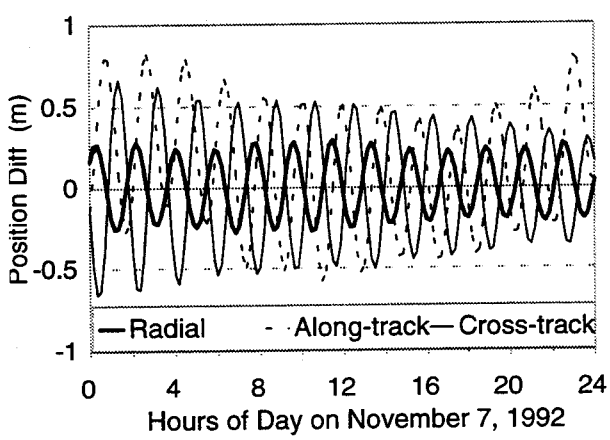

Fig. 3: Position Differences by Component Between the POE and ACB Ephemerides for November 7, 1992

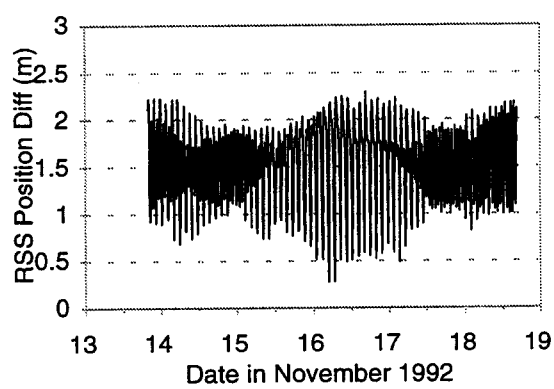

Fig. 4: RSS Position Difference Between the POE and ACB Ephemerides for Cycle 6

3.3 Cycle 21 ACB Results

This section presents TOPEX/Poseidon solution accuracy results using tracking measurements from Cycle 21. The comparison of the GTDS solution with the TOPEX/Poseidon POE can be seen in Fig. 5, which shows the RSS difference values for the whole solution arc. The RMS value is 3.06 meters, with a maximum value of 4.74 meters. The RMS values of the radial and cross-track components are 0.31 meters and 1.22 meters, respectively, with the corresponding maximum values of 0.55 meters and 2.16 meters. Notice that these values are not radically different from those in the previous two cycles. In contrast, the RMS and maximum value of the along-track component are 2.79 and 4.53 meters, respectively. Thus, the difference in this component dominates the total position difference. The average value of the along-track difference is –2.69 meters. This implies the along-track difference has a sizable bias, which can be seen in Fig. 6.

The major difference between the Cycle 21 timespan and the preceding Cycle 5 and Cycle 6 timespans is the marked difference in the proportion of one-way return and two-way Doppler measurement types. The earlier cycles have an almost equal mixture of one-way and two-way measurements, while Cycle 21 is dominated by the one-way measurements. Although a number of additional solutions with varying proportions of one-way and two-way measurements with various relative measurement weights failed to improve the solutions, the lack of two-way Doppler measurements remains the best candidate for explaining the poor results from Cycle 21. It is important to note that the orbit determination solutions derived with this tracking measurement distribution easily meet the requirements for operational navigation support; only the precision work may require that the additional two-way measurements be included.

3.4 Remarks

This section discusses several issues common to all three of the previously discussed timespans. Some of the difference in the along-track component between the GTDS solutions and the POEs is probably due to differences in the modeling of the along-track accelerations. The POEs estimate a daily once-per-revolution along-track acceleration, consisting of two estimated parameters per day, and a daily constant along-track acceleration to accurately model the effects of the anomalous spacecraft forces as well as atmospheric drag perturbations.[1] The GTDS TOPEX/Poseidon-only solution, however, only estimates three thrust correction factors to characterize the along-track forces. Similarly, the POEs estimate a daily once-per-revolution cross-track acceleration, consisting of two solved-for parameters per day, to characterize the cross-track accelerations, while the GTDS solutions estimate no cross-track accelerations because of software limitations. Some differences can, in part, also be attributed to the differences in the modeling of the attitude changes resulting from the yaw-steering feature. These differences would affect both the measurement modeling and the atmospheric drag and solar radiation pressure force modeling. The POEs model the instantaneous changes in the spacecraft cross-sectional areas for drag and solar radiation pressure evaluation resulting from the yaw steering. The GTDS TOPEX/Poseidon solution uses the variable mean area model, which provides mean orbital values of the drag and solar radiation pressure cross-sectional areas.

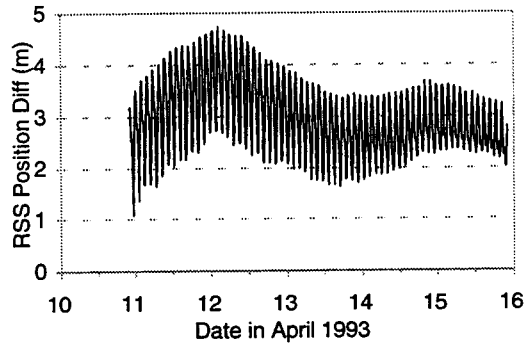

Fig. 5: RSS Position Difference Between the POE and ACB Ephemerides for Cycle 21

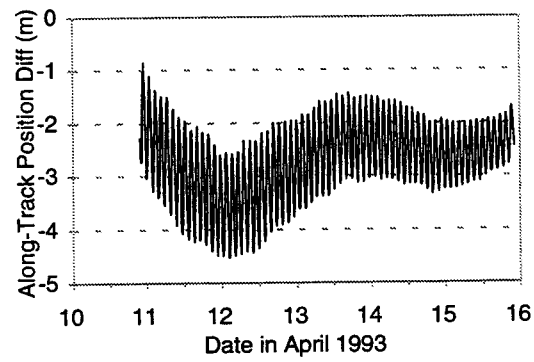

Fig. 6: Along-Track Position Difference Between the POE and ACB Ephemerides for Cycle 21

The remaining differences between the GTDS trajectories and the POEs may be caused largely by differences in force modeling. A number of force modeling enhancements to GTDS should improve the GTDS solutions and narrow the differences with the POEs. These enhancements include improved spacecraft area models for both the TDRSs and the user spacecraft, dynamic polar motion, generalized acceleration models, an improved Earth shadow model, an Earth radiation pressure model, and an ocean tides model. The ability to estimate TDRS trajectories through maneuvers and momentum unloads should also improve the GTDS solutions.

Earlier covariance analysis identified three areas as major error sources in TOPEX analyses. Because the ACB solution technique is quite involved, the procedures to mimic a covariance analysis that matches exactly the ACB orbit determination technique do not exist. The dominant error sources were geopotential error associated with the Goddard Earth Model-T3 (GEM-T3), measurement biases in the various range measurements in the TDRSS system, and ionospheric refraction effects. The geopotential error was reduced by using the more sophisticated JGM-2 geopotential model. The ACB method of estimating relative biases is designed to model and account for most of the remaining bias uncertainty in the range measurements. The ionospheric refraction effects remain as a possible large error source.

It is important to note that TDRSS tracking does not have a requirement to yield orbit solutions with accuracy comparable to laser-tracked orbit solutions. However, a major objective of this work is to assess the achievable TDRSS orbit determination accuracy. It is also worth noting that supporting spacecraft with the TDRS system has several advantages over similar support with the Global Positioning Satellite (GPS) system. First of all, the TDRS system, in addition to tracking and navigation support, also provides communications services to the user spacecraft; this is not possible with the GPS system. Additionally, the turnaround time for a high-accuracy solution is much faster for the TDRS system than in the GPS system. The ACB solution method described here can be accomplished in less than half a day. With the GPS system, the downgrading of the tracking measurements under selective availability requires that measurements from a number of ground stations be collected and then analyzed. This collection and subsequent analysis can be fairly time consuming, possibly requiring several days or longer. This is relatively long in contrast to the near-real-time solutions available from the TDRS system.

4.0 Conclusions

This study analyzed the TDRSS-user orbit determination accuracy using a batch-least-squares estimation method. The estimated orbits for three separate timespans were compared with the POEs. The radial component in the best timespan compared within 24 centimeters RMS, less than two times the 13-centimeter (1σ) POE accuracy requirement. These solutions compared with the POE within 1.1 meters RMS difference. The other timespans gave slightly worse results, but should improve with better modeling. Dynamical TOPEX/Poseidon modeling errors in GTDS caused a maximum of 1 meter of the observed error in the solutions. Given the observed residuals and the known level of dynamical mismodeling in the current GTDS solutions, it has been shown that the TDRSS tracking measurement data have sufficient quality to support orbit determination to levels better than 24 centimeters in radial accuracy and 2 meters in total position accuracy, provided issues of sufficient tracking coverage and accurate orbit determination force modeling are addressed.

The reduction of the differences, as compared with an earlier analysis, was the direct result of the use of the improved TDRS orbits obtained from the TOPEX/Poseidon/TDRS simultaneous solutions. This demonstrates that the treatment of the relay orbit determination has a significant impact on high-accuracy orbit determination in the TDRSS environment.

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