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HISTORICAL MOBLAS SYSTEM CHARACTERIZATION

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Abstract – This paper is written as a direct response to the published NASA LAser GEOdynamic Satellite (LAGEOS) orbital solution SL7.1 [*Smith et al.*, 1991], in order to close the data information loop with an emphasis on the NASA MOBile LAser Ranging System's (MOBLAS 4,5,6,7,8) LAGEOS fullrate data since November 1, 1983. A preliminary analysis of the supporting information (i.e. satellite laser ranging system eccentricities and system dependent range and time bias corrections) contained in SL7.1 indicated CentiMeter (cm) level discrepancies. In addition, a preliminary analysis of the computed monthly MOBLAS range biases from SL7.1 appear to show cm level systematic trends, some of which appear to be "real", particularly in the 1984 to 1987 time period. This paper is intended to be a reference document for known MOBLAS systematic errors (magnitude and direction) and for supporting MOBLAS information (eccentricities, hardware configurations, and potential data problem periods). Therefore, this report is different than your typical system characterization report [*Pearlman*, 1984], but will be more valuable to the user. The MOBLAS error models and supporting information contained in this paper will be easily accessible from the Crustal Dynamics Data Information System (CDDIS).

1. INTRODUCTION

In the late 1970's, NASA developed five, second generation mobile laser ranging systems in support of the SEa Altimeter SATellite (SEASAT) mission. The goal of the SEASAT mission was to map the surface of the oceans using the onboard satellite altimeter. Satellite Laser Ranging (SLR) data was used to calibrate the SEASAT altimeter. During the 1980's, the MOBLAS systems underwent an extensive upgrade program that improved the data accuracy and precision an order of magnitude, from the 100 MilliMeter (mm) to the 10 mm level. Since the mid-1980's, LAGEOS data has been compressed into 2 minute bins (normal points), which statistically reduces the single shot precision level [*Smith et al.*, 1985]. MOBLAS LAGEOS normal point precision levels have been at the 1-2 mm level since the late-1980's.

During the 1980's, cm level systematic biases were discovered through special and collocation analysis techniques developed by Bendix in support of the Goddard Laser Tracking Network (GLTN) and the Crustal Dynamics Satellite Laser Ranging (CDSLR) mission contracts. When centimeter level systematic errors were discovered in NASA SLR data, the NASA management philosophy was to identify the source of the bias; to eliminate or model the bias; and to document the nature of the bias. Due to cost considerations, historical NASA SLR data were not repaired (in most cases) to remove known cm level systematics. In addition, the documentation of these bias problems was not maintained in a central database and had a limited distribution. The intent of this paper is to provide one reference source for known <u>uncorrected</u> MOBLAS (LAGEOS) systematic errors that will be available from the CDDIS.

The original MOBLAS major hardware components were the General Photonics (GP) q-switched laser, the Amperex dynode-chain PhotoMultiplier Tube (PMT), the Ortec 934 discriminator, and the Hewlett Packard (HP) 5360 time interval counter. In the 1983-1984 time frame, the largest systematic unrecoverable error source, the GP laser, was replaced with a Quantel mode-locked laser. The HP5370 counter was usually incorporated as part of the Quantel laser upgrade. In the 1986-1987 timeframe, the largest systematic error source, the Amperex 2233B and Ortec discriminator, was replaced with the ITT F4129 gated three-stage Micro-Channel Plate (MCP)PMT and Tennelec TC454 discriminators. The systematic error sources associated with the hardware components mentioned above are discussed in *Degnan* [1985] and *Varghese* [1985].

It is virtually impossible to recover any hardware related systematic errors in the GP laser era due to the domination of "wavefront-distortion" errors [*Degnan*, 1985]. In the Quantel laser pre-MCPPMT era, the largest recoverable systematic hardware related error source was signal strength (0-30mm) of the returning pulse [*Heinick*, 1984]. Discriminator and PMT "timewalk" characteristics, coupled with calibration signal strengths not distributed the same as LAGEOS signal strengths induced a systematic bias. The magnitude and direction of the bias was system dependent, and decreased in magnitude as calibration methods improved. A model has been developed to recover this error based on the review of historical calibration and LAGEOS "timewalk" curves. Unfortunately, only a small sample of these curves ever existed. Signal strength effects did vary from pass-to-pass and within a pass. The MCPPMT and dual Tennelec discriminators package developed by *Varghese*, coupled with proper calibration techniques essentially eliminated signal strength as a bias source at the mm level.

In 1988, another recoverable hardware systematic error source was discovered by *See and Sneed*. They discovered the measurement of the laser transmit delay (TDEL) was in error, because the TDEL electronics did not measure the cable delay ($\leq$0.5 microseconds) between the time code generator and the system computer. In addition, they and *McCollums* discovered that the TDEL electronics had other TDEL sub-microsecond accuracy ambiguities, which would have masked this bias. In the 1989-1990 timeframe, the TDEL electronics were modified to remove these sub-microsecond ambiguities. The cable delay has been measured in MOBLAS-4,7,8 and is being modelled in the pre-processing. As of this writing, the MOBLAS-5 and 6 cable delays have not been measured.

Other mm level hardware errors are known to exist in the current MOBLAS hardware (i.e. HP5370 [*Selden*, 1992] and optical path changes as a function of pointing angle [*McCollums*, 1986]), but are presently unrecoverable. Not all systematic error sources in SLR systems are hardware related. Survey of ground targets, survey of monument offsets, atmospheric modelling, data pre-processing, and orbital modelling are other SLR error sources. Fortunately, many of these errors sources can be recovered to the 10-20mm level, using historical processing results.

In the GP laser era, calibration targets were large boards at distances of 2-3 KiloMeters (Km). These boards were mounted on metal poles which were guyed. The height of these poles was system dependent. Cube corners also existed and were mounted on various structures and in most cases were in close proximity (a few meters) to the calibration boards. The reason calibration boards were used versus cube corners was to average the "wavefront-distortion" effects of the GP laser. Historical ground tests results [*Brogdon et. al.*] indicated up to 20cm and 60cm differences in system delay between the board and cube corner, and as a function of pointing angle, respectively. When the mode-locked (Quantel) lasers were installed, ground tests results were dramatically improved, and for the first time, 10-20mm survey errors to the ground targets and 10-20mm ground target movement could be detected [*Wroe et. al.*]. Within a few months of the MCPPMT's (1986-1987) being installed, the primary calibration targets became the original cube corners. In the 1988-1989 timeframe, long (2-3Km) Nelson piers became the primary calibration targets. In the 1991-

1992 timeframe, the primary targets became short (100-200 meters) Nelson piers with the advent of the translator and the short target ranging electronics [*Eichinger et. al.*, 1990].

In the early to mid 1980's, cm level movement of the original targets, coupled with survey uncertainties and infrequent surveys, severely limited the absolute accuracy of MOBLAS data. "Average" target movement and survey uncertainties, in most cases, is recoverable to the 10-20mm level using historical ground test results. In the mid-1980's, surveying equipment and frequency of surveying was improved, but the problem still existed with unstable targets. In the late-1980's, the target stability problem was minimized to the millimeter level, when the current day target calibration structure, the Nelson pier, were used as the primary calibration target.

The MOBLAS eccentricity measurement techniques were improved in the mid-1980's [*Nelson*, 1986]. The infrequency of eccentricity surveys was a mm level systematic error source, because long term temporal changes in the eccentricity data were at this level. Some of these errors are traceable based on MOBLAS log records or special analysis techniques.

Neutral Density (ND) filters have always been used during calibration to attenuate the signal. During satellite ranging the filters were removed, thus inducing a difference in the "effective" calibration and satellite optical paths [*Crawford*, 1985]. This difference was not modelled, but is recoverable to the 1mm level. In 1991-1992 the Optical Attenuation Mechanisms (OAM) [*Silva et. al.*, 1991] were installed in the MOBLAS, which minimizes the use of ND filters. The ND filter bias is currently being modelled in the pre-processing.

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS elevation encoder measurements. These measurements could be in error by a few millidegrees and would thus induce a systematic error in the tropospheric refraction correction [*Husson et. al.*, 1987]. This correction could be in error up to 20mm. The error was system and satellite dependent, but is fully recoverable to the sub-mm level. To remove this error in pre-1988 MOBLAS data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle. All MOBLAS data taken after January 1, 1988, were pre-processed using the computed elevation angle from a short arc fit to the ranges.

LAGEOS orbital modelling errors have improved significantly over the last 12 years along with the quality of SLR data [*Smith et. al.*, 1991]. Orbital modelling is limited by the quality and distribution of the global SLR dataset, but in some instances, is the only hope for recovering the "net" historical SLR biases.

In the remainder of this article, each MOBLAS system is addressed individually. Each system's eccentricities and recoverable bias sources are discussed and summarized in tables, which are contained at the end of this article. The bias model tables include the major system configuration changes (laser, PMT, discriminators, counter) and important pre-processing information (i.e. calibration target and calibration range). The tables and this article will be available from the CDDIS.

2. MOBLAS-4

2.1 MOBLAS-4 Eccentricities

Since August 15, 1983, MOBLAS-4 has only occupied one monument/marker (7110). Prior to August 1983, 7110 was occupied by MOBLAS-3. There exists 5 sets of MOBLAS-4 eccentricities and 10 MOBLAS-4 Site Occupation Designators (SOD's) at 7110. SOD's 71100402, 71100403, and 71100410, each have two sets of eccentricities.

The 3mm change in the Up ecc., between the 1985 and 1988, surveys could be caused by settlement of the pad and monument [*Nelson,* 1988]. There were no measurements of the eccentricities between 1985 and 1988. The MOBLAS-4 mount was releveled twice in 1988 (June 16 and December 13), but apparently there was no change in eccentricities, based on the April 1988 and November 1989 surveys. In February 1992, the eccentricities were remeasured prior to the removal of the mount. There was a 2mm unexplained change in the North ecc. In March 1992, the MOBLAS-4 mount was removed from system to be refurbished, and in April 1992, the refurbished mount was re-installed and the ecc. were remeasured. Table 1 contains the recommended set of MOBLAS-4 eccentricities with their corresponding SOD(s) and effective starting dates.

2.2 MOBLAS-4 LAGEOS Biases

The net MOBLAS-4 recoverable biases (range and time) are presented in Table 2. To correct MOBLAS-4 LAGEOS data, the known range and time biases (in Table 2) should be subtracted from the LAGEOS range and timetags, respectively. Any time there is the potential for a change in the bias(es), even though the bias(es) did not change, a new entry has been added. A component breakdown of the biases is presented, followed by a section describing known problem data, and followed by a section describing potential problem data.

2.2.1 MOBLAS-4 ND filters

MOBLAS-4 LAGEOS data was biased short by 3mm ± 1 and 1mm ± 0mm from August 15, 1983 through January 17, 1992, and from January 18 through May 31, 1992, respectively, due to ND filters. On January 18, 1992, the OAM was installed in MOBLAS-4 reducing the ND filter bias. After June 1, 1992, this bias has been removed through modelling.

2.2.2 MOBLAS-4 signal strength

MOBLAS-4 LAGEOS data was biased long by 20mm ± 10, 10mm ± 5, 6mm ± 3, and 4mm ± 2 from August 15, 1983 through June 30, 1984; July 1, 1984 through August 31, 1984; September 1, 1984 through July 31, 1985; and August 1, 1985 through November 19, 1986; respectively, due to signal strength. This bias would vary from pass-to-pass and would have a slight elevation dependence. Low elevation data would be biased longer by several mm than high elevation data. Signal strength effects were reduced as the MOBLAS-4 calibration techniques improved, and were eliminated when the MCPPMT package was installed on November 20, 1986.

2.2.3 MOBLAS-4 elevation angles

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS-4 encoder measurements. To remove this error in pre-1988 MOBLAS-4 data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle.

2.2.4 MOBLAS-4 calibration targets/distances

MOBLAS-4 has used 4 different calibration targets (1 board and 3 cube corners) at marker 7110. From August 15, 1983 through December 31, 1987; from January 1, 1987 through January 28, 1988; from January 29 through April 29, 1988; from April 29, 1988 through December 5, 1991; and from December 6, 1991 to the present; the MOBLAS-4 primary calibration targets were the 2Km board, the 2Km cube corner, the 2Km board, the 2Km Nelson pier, and the 200m Nelson pier, respectively.

MOBLAS-4 has been surveyed 5 times (1983, 1985, 1988, and twice in 1992) at marker 7110. Sometime between the 1983 and the 1985 surveys, vandals removed the bracing support of the MOBLAS-4 calibration board tower [*Nelson*, 1985], which could explain the 13mm difference between the 1983 and 1985 calibration board distances. When the new calibration board values were used in data processing, there would be an automatically induced 13mm discontinuity in the MOBLAS-4 range bias. The new board values were used with all data taken after June 20, 1985. Data just prior to June 20, 1985 would have been biased longer by 13mm than data after June 20, 1985 (This 13mm change does not appear in the range bias model, because the exact date of the change is unknown). The cube corner became the operational target in January 1987 (The exact day is unknown at this time).

The distance (2Km) and the design/stability of the original MOBLAS-4 targets (a calibration board mounted on a tower and a cube corner mounted on wooden posts) were limiting factors to surveying accuracy and MOBLAS-4 data accuracy. The survey accuracy of these original targets was at the 10-15mm level [*Nelson*]. Historical ground test results indicate up to 20mm differences in "apparent" system delays between the MOBLAS-4 calibration board and the cube corner, which indicates both targets could move at least 10mm in either direction from month-to-month and from day-to-day. LAGEOS orbital analysis appears to be the only viable means for recovering the "true" average MOBLAS-4 monthly target distance to better than 20mm in the October 1983 to April 1988 timeframe.

Between November 1, 1987 and January 28, 1988, the MOBLAS-4 operational calibration target, cube corner, was very unstable, which caused unusual changes (up to 90mm) in the "apparent" system delay. Individual MOBLAS-4 LAGEOS passes could be biased long (up to 90mm) during this period. *Eanes* [1987] originally discovered this data problem. The bias could change (up to 30mm) from pass-to-pass and from day-to-day. The problem was eliminated when the previous calibration target (board) was used starting January 29, 1988. On April 30, 1988, the MOBLAS-4 calibration target became the 2Km Nelson pier.

2.2.5 MOBLAS-4 TDEL

All MOBLAS-4 data between January 5, 1990 and May 31, 1992 contains a time bias of -0.4 microseconds. To correct this time bias, add +0.4 microseconds to each observation's timetag. This correction is only valid after January 5, 1990, because on this date, the MOBLAS-4 TDEL electronics were modified to eliminate other TDEL sub-microsecond accuracy ambiguities, which would have masked this bias. This bias has been eliminated through modelling, effective June 1, 1992.

2.2.6 MOBLAS-4 known problem data

Between April 12, 1984 and May 24, 1984, individual MOBLAS-4 passes contained discontinuities (100mm up to 600mm) due to the range gate window being changed during the pass. The magnitude of the discontinuities depends upon where the return occurred in the range gate window [*Varghese*, 1985]; therefore, data during this period should not be used. This problem was originally detected by *Eanes* [1985] and was resolved when the system adhered to standard tracking procedures.

2.2.7 MOBLAS-4 potential problem data

Between December 29, 1988 and January 27, 1989, MOBLAS-4 LAGEOS data is questionable due to a bad time interval unit (HP5370). The RMS scatter of this data was cyclic and dependent upon the LAGEOS range [*Heinick et. al.*, 1989]. The data is believed to be unbiased and just systematically noisy. This problem was resolved by replacing the HP5370.

3. MOBLAS-5

3.1 Eccentricities

Since July 1, 1979, MOBLAS-5 has only occupied one monument/marker (7090). There exists only 3 unique sets of MOBLAS-5 eccentricities and 12 MOBLAS-5 SOD's at 7090. SOD 70900508 has 2 sets of eccentricities.

The MOBLAS-5 mount was releveled on September 5, 1985. No survey was performed after the releveling til 1987. The 8mm change in the Up ecc., between the 1979 and 1987 surveys, remains unexplained. It is not known how far back the 1987 Up ecc. can be backdated. The MOBLAS-5 mount was also releveled on August 5, 1989, but the eccentricities were not remeasured. In January 1992, the mount was re-installed and the eccentricities were remeasured. Table 3 contains the recommended set of MOBLAS-5 eccentricities with their corresponding SOD(s) and effective starting dates.

3.2 MOBLAS 5 LAGEOS Biases

The net MOBLAS-5 recoverable biases (range and time) are presented in Table 4. To correct MOBLAS-5 LAGEOS data, the known range and time biases (in Table 4) should be subtracted from the LAGEOS range and timetags, respectively. Any time there is the potential for a change in the bias(es), even though the bias(es) did not change, a new entry has been added. A component breakdown of the biases is presented, followed by a section describing known problem data, and followed by a section describing potential problem data.

3.2.1 MOBLAS-5 ND filters

Prior to June 1, 1992, MOBLAS-5 LAGEOS data was biased short by 3mm $\pm$ 1 due to ND filters. After June 1, 1992, this bias has been removed through modelling.

3.2.2 MOBLAS-5 signal strength

MOBLAS-5 LAGEOS data was biased short by 3mm $\pm$ 2 from July 27, 1983 through April 22, 1987, due to signal strength. This bias would be fairly constant from pass-to-pass. This bias was eliminated when the MCPPMT package was installed in MOBLAS-5 on April 23, 1987.

3.2.3 MOBLAS-5 elevation angles

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS-5 encoder measurements. To remove this error in pre-1988 MOBLAS-5 data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle.

3.2.4 MOBLAS-5 calibration targets/distances

MOBLAS-5 has used 4 different calibration targets (2 boards and 2 cube corners) at marker 7090. From August 1, 1979 through June 7, 1980; from June 8, 1980 through May 31, 1987; from June 1 through July 31, 1987; from August 1 through August 25, 1987; and from August 26, 1987 through June 30, 1992; the MOBLAS-5 primary calibration targets were the 2Km calibration board, the 3Km calibration board, the 1Km cube corner, the 3Km calibration board, and the 3Km Nelson pier, respectively.

MOBLAS-5 has been surveyed only 3 times in 13 years (1979/80, 1987, & 1992) at marker 7090. Between the 1979/80 and 1987 surveys, the 1Km cube corner and the 3Km board ranges changed by +30mm and -9mm, respectively. The 2Km board was never resurveyed and the 3Km board blew away in August 1987. In early January 1992, the mount was replaced and a new survey was performed.

The system delay differences obtained from the 1Km cube corner and the 3Km board in historical minico tests since June 1985 were 39mm ± 5 and 0mm ± 5 [*Husson and Wroe,* 1987] using the 1980 and 1987 surveys, respectively. Therefore, the 1987 survey values can be backdated to at least June 1985, which means MOBLAS-5 data between June 1985 through May 31, 1987 (all board calibrated data) was biased long by 9mm ±5mm. All data since June 1, 1987, until the mount replacement in 1992, was processed with the 1987 surveyed ranges and should be bias free. Research into minico results prior to June 1985 still needs to be performed.

3.2.5 MOBLAS-5 TDEL

The MOBLAS-5 cable delay causing this bias has not been measured as of this writing. On January 30, 1990, the MOBLAS-5 TDEL electronics were modified to eliminate other TDEL sub-microsecond ambiguities.

3.2.6 MOBLAS-5 PMT Gating

Prior to June 8, 1980, MOBLAS-5 LAGEOS data was biased short by 20mm±5 due to calibration data falling in a non-linear region of the Amperex 2233B PMT gate. This bias was characterized by *Varghese* [1985]. This bias was eliminated, effective June 8, 1980, when a longer calibration board (>3Km) was used.

3.2.7 MOBLAS-5 known problem data

Between December 19, 1991 and January 3, 1992, MOBLAS-5 data quality was degraded due to a stuck bit. The bit was stuck low (100 picosec.) for LAGEOS. It does not appear that this data is recoverable, because of it's unknown effect on calibration data.

3.2.8 MOBLAS-5 potential problem data

Between August 12, 1988 and January 31, 1989, MOBLAS-5 system delays and pre-to-post calibration shifts were erratic [*Heinick et al.*, 1989]. Therefore, the uncertainty in the system delay is increased during this period; however, this should be a random error than should average over several passes. This problem disappeared during February 1989.

4. MOBLAS-6

4.1 MOBLAS-6 Eccentricities

Since March 3, 1983, MOBLAS-6 has only occupied one monument\marker (7122). There exists 4 sets of MOBLAS-6 eccentricities and 9 MOBLAS-6 SOD's at 7122. SOD 71220604 has two sets of eccentricities.

The May 1988 survey sheet had the <u>wrong sign</u> for the East ecc. It should be negative, not positive. Based on the 1991 survey, there was no apparent change in the eccentricities when the MOBLAS-6 mount was releveled on August 5, 1989. Table 5 contains the recommended set of MOBLAS-6 eccentricities with their corresponding SOD(s) and effective starting dates.

4.2 MOBLAS-6 LAGEOS Biases

The net MOBLAS-6 recoverable biases (range and time) are presented in Table 6. To correct MOBLAS-6 LAGEOS data, the known range and time biases (in Table 6) should be subtracted from the LAGEOS range and timetags, respectively. Any time there is the potential for a change in the bias(es), even though the bias(es) did not change, a new entry has been added. A component breakdown of the biases is presented, followed by a section describing known problem data, and followed by a section describing potential problem data.

4.2.1 MOBLAS-6 ND filters

All MOBLAS-6 LAGEOS data was biased short by 3mm ± 1 due to ND filters.

4.2.2 MOBLAS-6 signal strength

MOBLAS-6 LAGEOS data was biased long by 12mm ± 4, 10mm ± 3, and 4mm ± 2 from May 1, 1984 through March 31, 1986; from April 1 through August 31, 1986; and September 1, 1986 through January 27, 1987; respectively, due to signal strength. This bias would vary slightly (several mm) from pass-to-pass and would have a slight elevation dependence. Low elevation data would be biased longer than high elevation data. Signal strength effects were reduced as system calibration techniques improved, and were eliminated when the MCPPMT package was installed in MOBLAS-6 on January 28, 1987.

4.2.3 MOBLAS-6 elevation angles

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS-6 encoder measurements. To remove this error in pre-1988 MOBLAS-6 data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle.

4.2.4 MOBLAS-6 calibration targets/distances

MOBLAS-6 has used 4 different calibration targets (1 board and 3 cube corners) at marker 7122. From May 1, 1983 through March 26, 1987; from March 27, 1987 through August 16, 1988; from August 17, 1988 through October 3, 1989; and from October 4, 1989 through April 30, 1991; the MOBLAS-6 primary calibration targets were the 2Km calibration board, the 2Km cube corner, the first 2Km Nelson pier, and the second 2Km Nelson pier, respectively.

MOBLAS-6 was surveyed 4 times in 8 years (1983, 1988, 1989, & 1991) at marker 7122. In October 1983, several months after the first survey, a hurricane passed through the site. Between the 1983 and 1988 surveys, the ranges to the 2Km cube corner and the 2Km board changed by +6mm and -17mm, respectively. The system delay differences obtained from the these two targets in historical minico tests, since the Quantel laser installation (July 1984), were 33mm ± 15 and 10mm ± 15 [*Husson and Wetzel*, 1987] using the 1983 and 1988 surveys, respectively. The 1988 surveyed target ranges for the cube corner and the board are only accurate to the 10mm level. The 10mm difference which remains in the historical minico results can be attributed to survey. Making this assumption and distributing the 10mm difference equally to both targets, the 1988 survey (with adjustment) can be backdated to the hurricane (October 1983). This means MOBLAS-6 data from October 1, 1983 through March 26, 1987; from March 27, 1987 through May 2, 1988; and from May 3 through August 16, 1988; is biased long by 22mm ± 10, short by 11mm ± 10, and short by 5mm ± 10, respectively.

In 1988, the first Nelson pier was built; however, the pier foundation was not built to specifications. The pier moved 14mm between 1988 and 1989 due to a poor foundation and being on a steep slope [*Nelson*, 1989]. *Nelson* believes this movement would have been linear over the 13 months between the 1988 and 1989 surveys. MOBLAS-6 data between August 17, 1989 and June 23, 1989, was biased long by 4mm $\pm$ 1mm/month. On October 4, 1989, the primary MOBLAS-6 calibration target became the second Nelson pier, which eliminated target movement as a MOBLAS-6 systematic bias source.

4.2.5 MOBLAS-6 TDEL

The MOBLAS-6 cable delay causing this bias has not been measured as of this writing. On January 11, 1990, the MOBLAS-6 TDEL electronics were modified to eliminate other TDEL sub-microsecond ambiguities.

4.2.6 MOBLAS-6 known problem data

All MOBLAS-6 satellite RMS's between February 1 and March 1, 1984, were high caused by a bad distribution amplifier [*Oldham*]. Data during this period should not be used. On March 2, 1984, the distribution amplifier was replaced which eliminated the problem.

4.2.7 MOBLAS-6 potential problem data

All MOBLAS-6 data between February 8 and May 12, 1989, was affected by a bad Setra barometer. Setra barometric data was in error by up to 30 millibars. All MOBLAS-6 data during this interval was corrected and believed to be accurate to at least 3 millibars.

All MOBLAS-6 calibration data between April 1 and September 26, 1990, was unusually noisy (twice the normal RMS). The LAGEOS data during this period is suspected to be bias free. The calibration data returned to normal when some adjustments were performed on the HP5370 in late September [*MOBLAS-6*, 1990].

5. MOBLAS-7

5.1 MOBLAS-7 Eccentricities

Since January 1, 1981, MOBLAS-7 has only occupied one monument/marker (7105); however, two other laser systems (TLRS-2, 71051206, and MOBLAS-2, 71050207) have been referenced to marker 7105. There exists 14 sets of MOBLAS-7 eccentricities and 21 MOBLAS-7 SOD's at 7105.

The reason for the 5mm change in the east ecc. between the 1981 and 1984 survey is assumed to be caused by movement of the survey monument to the East or by movement of the MOBLAS support pad to the West [*Nelson*, 1984].

During the 1985 pre-collocation survey of MTLRS-1 and MOBLAS-7, a 2 cm discrepancy was found in the 7105 Up eccentricity [*Nelson*, 1985]. The original determination of the Up eccentricity is suspected to be in error [*Nelson*, private communication]; and therefore, the 1985 Up eccentricity can be backdated to Jan 1, 1981.

Prior to the TLRS-1 and MOBLAS-7 collocation in 1986 [*Nelson*, 1986], MOBLAS-7 eccentricities were measured on three different occasions, once in December 1985 and twice in January 1986 (before and after the MOBLAS-7 mount was releveled on January 18, 1986). There were millimeter level changes between these surveys. This would give SOD 71050709 five unique sets of eccentricities.

During October 1989, a 1-2 cm bias existed between MOBLAS-7 and TLRS-3 [*Varghese and Husson*, 1989] and a follow-up survey indicated cm level movement of the MOBLAS-7 reference point. Polyquick collocation analysis revealed that the movement appeared to have occurred in August 1989; therefore, the October 12, 1989 survey can be backdated to August 25, 1989.

MOBLAS-7 was down for approximately 6 months in early-1990 due to a major slip ring failure. During this period that the slip rings were being repaired, MOBLAS-7 was removed from it's pad in order that the pad could be reinforced. Prior to ranging and after MOBLAS-7 re-occupied marker 7105, the eccentricities were remeasured. Table 7 contains the recommended set of MOBLAS-7 eccentricities with their corresponding SOD(s) and effective starting dates.

5.2 MOBLAS-7 LAGEOS Biases

The net MOBLAS-7 recoverable biases (range and time) are presented in Table 8. To correct MOBLAS-7 LAGEOS data, the known range and time biases (in Table 8) should be subtracted from the LAGEOS range and timetags, respectively. Any time there is the potential for a change in the bias(es), even though the bias(es) did not change, a new entry has been added. A component breakdown of the biases is presented, followed by a section describing known problem data, and followed by a section describing potential problem data.

5.2.1 MOBLAS-7 ND filters

All MOBLAS-7 LAGEOS data was biased short by 3mm ± 1,1mm ± 1,3mm ± 1, and 1mm ± 1 from January 1, 1981 through July 9, 1991; from July 10 through 23, 1991; from July 24 through October 17, 1991; and from October 18, 1991 through May 31, 1992; respectively, due to ND filters. The OAM was installed on July 10, 1991, removed on July 24, 1991, and reinstalled on October 18, 1991. After June 1, 1992, this bias has been removed through modelling.

5.2.2 MOBLAS-7 signal strength

MOBLAS-7 LAGEOS data was biased long by 30mm ± 15, 4mm ± 2, 7mm ± 3, 30mm ± 10, 5mm ± 3, 3mm ± 2, and 4mm ± 2 from August 22, 1983 through February 29, 1984; from March 1 through July 31, 1984; from August 1 through September 30, 1984; from October 1, 1984 through January 25, 1985; from January 26, 1985 through March 31, 1985; from April 1, 1985 through March 30, 1986; and from February 1, 1988 through April 30, 1988; respectively, due to signal strength. This bias would vary slightly (several mm) from pass-to-pass and would have a slight elevation dependence. Low elevation data would be biased longer than high elevation data. Signal strength effects were reduced as system calibration techniques improved, and were eliminated when the MCPPMT package was installed in MOBLAS-7 on March 31, 1986.

5.2.3 MOBLAS-7 elevation angles

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS-7 encoder measurements. To remove this error in pre-1988 MOBLAS-7 data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle.

5.2.4 MOBLAS-7 calibration targets/distances

MOBLAS-7 has used 3 different calibration targets (1 board and 2 cube corners) at marker 7105. From January 1, 1981 through September 19, 1986; from September 20 through December 5, 1986; and from December 6, 1986 to the present; the MOBLAS-7 primary calibration targets were the 3Km board, the second 3Km cube corner, and the 200m Nelson pier, respectively.

MOBLAS-7 has been surveyed at least once per year since January 1984. The February 1981 and the June 1981 surveyed board ranges were incorrect, causing all MOBLAS-7 data from March 1 through June 30, 1981 and from July 1 through December 31, 1981 to be biased long by 49mm $\pm$ 20 and 22mm $\pm$ 20, respectively.

Between the 1984 and 1985 surveys, the board range changed by 17mm, however; historical minico results support the 1984 survey value [*Heinick*, 1985] for the board range (not the 1985 value). On February 7, 1986, the guy wires were tensioned on the calibration board before the board was resurveyed (12mm change); however, the new surveyed calibration board range was not used until March 2, 1986. Therefore, all MOBLAS-7 LAGEOS passes from August 1, 1985 through February 6, 1986, and from February 7 through March 1, 1986, is biased long by 17mm $\pm$ 20 and short by 12mm $\pm$ 20, respectively, except for the LAGEOS passes in Table 9. Occasionally due to ground fog conditions, the board could not be ranged, so the secondary calibration target, the 3km cube corner, was used. All passes in Table 9 were calibrated using the original 3Km cube corner and are believed to have the correct calibration distance. Between the January and October 1989 surveys, the Nelson pier target range changed by 15mm due to movement of the MOBLAS-7 reference point. Apparently, the MOBLAS-7 reference point moved around August 25, 1989 based upon intercomparison with TLRS-3 [*Varghese and Husson*, 1989]. All MOBLAS-7 data from August 25 through October 11, 1989 is biased short by 15mm.

5.2.5 MOBLAS-7 TDEL

All MOBLAS-7 data from July 13, 1989 through September 27, 1990, and from September 28, 1990 through May 31, 1992 contains a time bias -0.5 and -0.3 microseconds, respectively. This correction is only valid after July 13, 1989, because on this date, the MOBLAS-7 TDEL electronics were modified to eliminate other TDEL sub-microsecond accuracy ambiguities, which would have masked this bias. On September 28, 1990, the cable length causing this bias was shortened, which caused a decrease in the magnitude of the bias. This bias has been eliminated through modelling, effective June 1, 1992.

5.2.6 MOBLAS-7 known problem data

All MOBLAS-7 data between January 13 through January 17, 1986, has a reference frequency problem and should not be used. The HP5370 frequency was on internal frequency during this period of time.

5.2.7 MOBLAS-7 potential problem data

All MOBLAS-7 LAGEOS data between June 7 and June 13, 1984 was noisy (100-130mm) and should be used with caution. The cause of the high noise is unknown.

All MOBLAS-7 LAGEOS data between September 25 and October 5, 1984 was noisy (80-120mm) and should be used with caution. The cause of the high noise is unknown.

6. MOBLAS-8

6.1 MOBLAS-8 Eccentricities

Since October 1, 1981, MOBLAS-8 has only occupied one monument/marker (7109). In July 1982, the MOBLAS-4 and MOBLAS-8 moms vans were switched. There exists 9 sets of MOBLAS-8 eccentricities, and 15 MOBLAS-8 SOD's at 7109.

On August 4, 1982 the system was releveled, but there was not a follow-up survey until 1984, which indicated a 17mm change in the Up ecc. *Nelson* [1984] recommends that the 1984 survey be backdated to 1982. There was a 4mm change in the Up ecc between 1985 and 1988, possibly due to settlement of the laser support slab [*Nelson* ,1985]. Table 10 contains the recommended set of MOBLAS-8 eccentricities with their corresponding SOD(s) and effective starting dates.

6.2 MOBLAS-8 LAGEOS Biases

The net MOBLAS-8 recoverable biases (range and time) are presented in Table 11. To correct MOBLAS-8 LAGEOS data, the known range and time biases (in Table 11) should be subtracted from the LAGEOS range and timetags, respectively. Any time there is the potential for a change in the bias(es), even though the bias(es) did not change, a new entry has been added. A component breakdown of the biases is presented and followed by a section describing known problem data.

6.2.1 MOBLAS-8 ND filters

All MOBLAS-8 LAGEOS data was biased short by 3mm $\pm$ 1 and 1mm $\pm$ 1 from September 1, 1981 through April 7, 1992, and from April 8, 1992 through May 31, 1992, respectively, due to ND filters. On April 7, 1992, the OAM was installed in MOBLAS-8 reducing the ND filter bias. After June 1, 1992, this bias has been removed through modelling.

6.2.2 MOBLAS-8 signal strength

MOBLAS-8 LAGEOS data was biased long by 5mm $\pm$ 3, 10mm $\pm$ 5, 6mm $\pm$ 3, and 3mm $\pm$ 2 from August 4, 1982 through December 31, 1983; from January 1 through March 31, 1984; April 1 through July 31, 1984; and from August 1, 1984 through September 25, 1986; respectively, due to signal strength. This bias would vary slightly (several mm) from pass-to-pass and would have a slight elevation dependence. Low elevation data would be biased longer than high elevation data. Signal strength effects were reduced as system calibration techniques improved, and were eliminated when the MCPPMT package was installed in MOBLAS-8 on September 26, 1986.

6.2.3 MOBLAS-8 elevation angles

Prior to January 1, 1988, the tropospheric range correction applied to the fullrate data was computed based on the MOBLAS-8 encoder measurements. To remove this error in pre-1988 MOBLAS-8 data, the applied tropospheric refraction must be removed and reapplied using the computed elevation angle.

6.2.4 MOBLAS-8 calibration targets/distances

MOBLAS-8 has used 5 different calibration targets (2 boards and 3 cube corners) at marker 7109. From September 1, 1981 through August 19, 1985; from August 20, 1985 through December 31, 1986; from January 1, 1987 through March 22, 1989; from March 23, 1989 through April 7, 1992; and from April 8, 1992 to the present; MOBLAS-8 primary calibration targets were the original 2Km board, the second 2Km board, the second 2Km cube corner, the 2Km Nelson pier, and the 200m Nelson pier, respectively.

MOBLAS-8 was surveyed 7 times (1981, 1982, 1984, 1985, 1988, and twice in 1991) at marker 7109. During August 1985, new calibration targets (a 2Km board and 2Km cube corner) were built to replace the vandalized 2Km board and 2Km cube corner [*Nelson*, 1985]. The guy wires had been cut on both targets. The newly constructed board became the operational target, effective August 20, 1985. The preliminary board range and the final surveyed board range published in the November 1985 survey sheet were different by 10mm. It is not known at this writing when the "official" number was used for fullrate data processing. Sometime between October 1986 and January 1987, the cube corner became the operational target. In December 1988, these targets were resurveyed along with a newly constructed 2Km Nelson pier. Between the 1985 and 1988 surveys, the board and cube corner ranges changed by 14mm and 11mm, respectively. Historical minico results, since January 1987, suggest that 1985 and 1988 cube corner surveyed ranges were in error by -20mm and -9mm, respectively. Therefore, MOBLAS-8 data was biased long by 20 ± 15 and 9 ± 10mm from January 1, 1987 through December 11, 1988, and from December 12, 1988 through March 22, 1989, respectively. More research is needed into data processing results prior to January 1987.

6.2.5 MOBLAS-8 TDEL

All MOBLAS-8 data from November 22, 1989 through May 31, 1992, contains a time bias of +0.3 microseconds. This correction is only valid after November 22, 1989, because on this date, the MOBLAS-8 TDEL electronics were modified to eliminate other TDEL sub-microsecond accuracy ambiguities, which would have masked this bias. This bias has been eliminated through modelling, effective June 1, 1992.

All MOBLAS-8 data from August 4, 1982 (the date of the moms van swap with MOBLAS-4) through October 26, 1986 was biased late depending on the interval of a second the laser was fired [*MOBLAS-8 crew and Heinick*, 1986]. The transmit delays (TDEL) on the .0, .2, .4, .6, .8 second intervals were reading high by 0.0, 3.2, 6.4, 9.6, and 11 microseconds, respectively, due to a wiring problem. Since MOBLAS-8 data was equally distributed in these different time intervals, a mean offset of 6.0 microseconds can be post-applied to the data. The TDEL wiring problem was fixed on October 27, 1986.

6.2.6 MOBLAS-8 known problem data

All MOBLAS-8 data between January 1 through March 4, 1982, exhibited very high RMS's (300-600mm) due to poor hardware performance. This data probably contains significant biases and should not be used. The hardware was repaired on March 5, 1982, and the RMS's returned to nominal levels.

7. CONCLUDING REMARKS

The present article has been the first attempt to characterize known biases contained in historical MOBLAS LAGEOS data; however, more research into historical ground test results and calibration processing information is needed to resolve potential biases. These bias models and eccentricity information should improve the quality of the historical MOBLAS LAGEOS dataset. We encourage other global data producing centers to characterize their historical biases.

In the 1980-1983 timeframe, the laser was the dominant MOBLAS systematic error source. In the 1984-1986 timeframe, target stability, survey related issues, and signal strength effects were the dominant error sources. In the 1987-1988 timeframe, target stability and survey related issues were the dominant error sources. In the 1989-1992 timeframe, the HP5370 counter and ND filters appear to have been the dominant error sources. Some of the above mentioned systematic errors are recoverable (to some level) using historical processing results; however, orbital analysis may be the only way to unravel the "net" biases in the global SLR dataset to the 10mm level. These bias models will evolve as historical SLR data is better understood by close cooperation of the data producer and the data user.

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Table 1. MOBLAS-4 Eccentricities for SOD 711004xx

Occ. No.	Start Date	North (M)	East (M)	Up (M)	Revis. Date	Comments
2	08/15/83	-0.033	-0.015	3.209	01Aug92	First survey
2-3	06/20/85	-0.033	-0.015	3.210	01Aug92	1mm change in Up
3-10	04/27/88	-0.033	-0.016	3.213	01Aug92	1 & 3mm change in East and Up
10	02/01/92	-0.031	-0.016	3.213	01Aug92	2mm change in North, no survey sheet published
11	04/21/92	-0.026	-0.019	3.189	01Aug92	Mount replacement

Table 2. MOBLAS-4 LAGEOS Biases at 7110

Time Span	Range Bias(mm)	Time Bias(us)	Revis. Date	Comments
08/15/83 - 04/11/84	17	0	01Aug92	Quantel, 2233B, 5370, Ortec, & board (1954.6037m)
04/12/84 - 05/24/84	17	0	01Aug92	Gating problem causing discontinuous data, see 2.2.6
05/25/84 - 06/30/84	17	0	01Aug92	Data quality returned to normal
07/01/84 - 08/31/84	7	0	01Aug92	Improvement in amplitude modelling
09/01/84 - 06/19/85	3	0	01Aug92	Improvement in amplitude modelling
06/20/85 - 07/31/85	3	0	01Aug92	New target range (1954.5910m), see 2.2.4 para. 2
08/01/85 - 11/19/86	1	0	01Aug92	Improvement in amplitude modelling
11/20/86 - 12/31/86	-3	0	01Aug92	MCP & Tennelec disc. installed
01/01/87 - 10/31/87	-3	0	01Aug92	Cube corner (1955.469m)
11/01/87 - 12/31/87	-3	0	01Aug92	Unstable cube corner, see 2.2.4 para. 4
01/01/88 - 01/28/88	-3	0	01Aug92	Computed angles used, see 2.2.3, unstable cube corner, see 2.2.4 para. 4
01/29/88 - 04/29/88	-3	0	01Aug92	Cal. board (1954.5910m)
04/30/88 - 12/28/88	-3	0	01Aug92	Long Nelson pier (1955.2677m)
12/29/88 - 01/27/89	-3	0	01Aug92	Questionable data, bad counter, see 2.2.7
01/28/89 - 11/06/89	-3	0	01Aug92	New counter installed
11/07/89 - 11/11/90	-3	0	01Aug92	New range (1955.2682m), cube replaced
11/12/90 - 01/04/90	-3	0	01Aug92	Cube vandalized and replaced (1955.2600m)
01/05/90 - 12/05/91	-3	-0.4	01Aug92	Transmit delay modification see 2.2.5
12/06/91 - 01/17/92	-3	-0.4	01Aug92	Translator installed, short Nelson pier (186.9920m)
01/18/92 - 04/20/92	-1	-0.4	01Aug92	OAM installed
04/21/92 - 05/31/92	-1	-0.4	01Aug92	Mount replaced, new target range (186.9986m)

Table 3. MOBLAS-5 Eccentricities for SOD 709005xx

Occ. No.	Start Date	North (M)	East (M)	Up (M)	Revis. Date	Comments
1-8	08/01/79	0.003	0.011	3.185	01Aug92	First survey
8-10	10/15/87	0.003	0.010	3.177	01Aug92	1mm & 8mm change in East and Up
11-12	01/12/92	-0.011	0.020	3.181	01Aug92	Mount replaced

Table 4. MOBLAS-5 LAGEOS Biases at 7090

Time Span	Range Bias(mm)	Time Bias(us)	Revis. Date	Comments
08/01/79 - 06/07/80	-23	0	01Aug92	GP laser, 2233B, 5360, Ortec, & board (2065.491m), gating problem see 3.2.6
06/08/80 - 07/26/83	-3	0	01Aug92	New board (3100.2532m) used
07/27/83 - 05/31/85	-6	0	01Aug92	Quantel & 5370 installed
06/01/85 - 04/22/87	3	0	01Aug92	Suspect 9mm error in target range, see 3.2.4
04/23/87 - 05/31/87	6	0	01Aug92	MCP & Tennelec disc. installed
06/01/87 - 07/31/87	-3	0	01Aug92	Cube corner (1257.9630m) used
08/01/87 - 08/25/87	-3	0	01Aug92	Board (3100.2442m) used
08/26/87 - 12/31/87	-3	0	01Aug92	Long Nelson pier (3116.8969m) used
01/01/88 - 08/11/88	-3	0	01Aug92	Computed angles used, see 3.2.3
08/12/88 - 01/31/89	-3	0	01Aug92	High cal. shifts, see 3.2.8
02/01/89 - 01/29/90	-3	0	01Aug92	Cal. shifts return to normal
01/30/90 - 07/22/90	-3	0	01Aug92	Transmit delay modification, see 3.2.5
07/23/90 - 12/18/91	-3	0	01Aug92	New range (3116.8974m), cube replaced
12/19/91 - 01/03/92	-3	0	01Aug92	Bad data, stuck bit see 3.2.7
01/04/92 - 01/11/92	-3	0	01Aug92	Stuck bit repaired
01/12/92 - 05/31/92	-3	0	01Aug92	Mount replaced, new survey (3116.9047m)

Table 5. MOBLAS-6 Eccentricities for SOD 712206xx

Occ. No.	Start Date	North (M)	East (M)	Up (M)	Rev. Date	Comments
1-4	05/01/83	0.001	-0.007	3.182	01Aug92	First survey
4-7	05/03/88	0.002	-0.006	3.181	01Aug92	1mm change in all eccs., see 4.1
8-9	06/23/89	0.002	-0.006	3.181	01Aug92	No change
9	04/30/91	0.002	-0.006	3.181	01Aug92	No change, final survey

Table 6. MOBLAS-6 LAGEOS Biases at 7122

Time Span	Range Bias(mm)	Time Bias(us)	Revis. Date	Comments
05/01/83 - 09/30/83	-3	0	01Aug92	GP laser, 2233B, 5360, Ortec, & Board (2229.1998m)
10/01/83 - 01/31/84	19	0	01Aug92	Hurricane, suspect target movement, see 4.2.4, para 2
02/01/84 - 03/01/84	19	0	01Aug92	Bad distribution amplifier, see 4.2.6
03/02/84 - 04/30/84	19	0	01Aug92	Distribution amplifier replaced
05/01/84 - 03/31/86	31	0	01Aug92	Quantel laser and HP5370 installed
04/01/86 - 08/31/86	29	0	01Aug92	Improvement in amplitude modelling
09/01/86 - 01/27/87	23	0	01Aug92	Improvement in amplitude modelling
01/28/87 - 03/26/87	19	0	01Aug92	MCP and Tennelec installed
03/27/87 - 12/31/88	-14	0	01Aug92	Cube corner used (2229.4086m)
01/01/88 - 05/02/88	-14	0	01Aug92	Computed angles used, see 4.2.3
05/03/88 - 08/16/88	-8	0	01Aug92	New cube corner range used (2229.4150m)
08/17/88 - 08/31/88	1	0	01Aug92	First Nelson pier used (2229.2215m)
09/01/88 - 09/30/88	2	0	01Aug92	Nelson pier movement, see 4.2.4 para 3
10/01/88 - 10/31/88	3	0	01Aug88	Nelson pier movement
11/01/88 - 11/30/88	4	0	01Aug92	Nelson pier movement
12/01/88 - 12/31/88	5	0	01Aug92	Nelson pier movement
01/01/89 - 01/31/89	6	0	01Aug92	Nelson pier movement
02/01/89 - 02/28/89	7	0	01Aug92	Nelson pier movement, bad barometric data
03/01/89 - 03/31/89	8	0	01Aug92	Nelson pier movement, bad barometric data
04/01/89 - 04/30/89	9	0	01Aug92	Nelson pier movement, bad barometric data
05/01/89 - 05/12/89	10	0	01Aug92	Nelson pier movement, bad barometric data
05/13/89 - 05/31/89	10	0	01Aug92	Barometer repaired
06/01/89 - 06/22/89	11	0	01Aug92	Nelson pier movement
06/23/89 - 11/16/89	-3	0	01Aug92	Second Nelson pier used (2232.7419m)
11/17/89 - 01/10/90	-3	0	01Aug92	New range (2232.7447m), cube replaced
01/11/90 - 03/31/90	-3	0	01Aug92	Transmit delay modification
04/01/90 - 09/26/90	-3	0	01Aug92	Calibration RMS's are high
09/27/90 - 04/30/91	-3	0	01Aug92	Calibration RMS's return to normal levels

Table 7. MOBLAS-7 Eccentricities for SOD 710507xx

Occ. No.	Start Date	North (M)	East (M)	Up (M)	Rev. Date	Comments
1-4	01/01/81	0.016	-0.026	3.169	01Aug92	First survey, Up was in error
5	03/22/84	0.017	-0.031	3.169	01Aug92	1 & 5mm change in North & East
8	05/07/85	0.017	-0.031	3.169	01Aug92	No change
9	07/29/85	0.017	-0.032	3.169	01Aug92	1mm change in East
9	12/13/85	0.017	-0.032	3.170	01Aug92	1mm change in Up
9	01/17/86	0.016	-0.031	3.168	01Aug92	1, 1 and 2mm changes in North, East, and Up
9	01/22/86	0.017	-0.031	3.168	01Aug92	1mm change in North
9-10	03/17/86	0.017	-0.031	3.168	01Aug92	No change
10-11	10/06/86	0.017	-0.031	3.168	01Aug92	No change
11-12	06/18/87	0.017	-0.031	3.168	01Aug92	No change
13	01/09/89	0.017	-0.031	3.168	01Aug92	No change
15-16	08/25/89	0.035	-0.040	3.162	01Aug92	System moved, 18mm, 9mm, 6mm changes in North, East, and Up
17-18	07/25/90	-0.014	-0.033	3.153	01Aug92	Relocation
19-23	12/10/90	-0.014	-0.033	3.153	01Aug92	No change

Table 8. MOBLAS-7 LAGEOS Biases at 7105

Time Span	Range Bias(mm)	Time Bias(us)	Revis. Date	Comments
01/01/81 - 06/30/81	46	0	01Aug92	GP laser, 2233B, 5360, Ortec, & board (3225.460m)
07/01/81 - 12/31/81	19	0	01Aug92	Slyvania laser installed, board (3225.433m)
01/01/82 - 01/31/83	-3	0	01Aug92	Board (3225.411m)
02/01/83 - 08/21/83	-3	0	01Aug92	HP5370 counter installed
08/22/83 - 02/29/84	27	0	01Aug92	Quantel laser installed
03/01/84 - 03/21/84	1	0	01Aug92	Improvement in amplitude modelling
03/22/84 - 06/06/84	1	0	01Aug92	New board (3225.421m)
06/07/84 - 06/13/84	1	0	01Aug92	Data suspect, high RMS's, see 5.2.7
06/14/84 - 07/31/84	1	0	01Aug92	RMS's return to normal
08/01/84 - 09/24/84	4	0	01Aug92	Increase in amplitude dependence
09/25/84 - 09/30/84	4	0	01Aug92	Data suspect, high RMS's, see 5.2.7
10/01/84 - 10/05/84	27	0	01Aug92	Increase in ampl. dependence, high RMS's
10/05/84 - 01/25/85	27	0	01Aug92	RMS's return to normal
01/26/85 - 03/31/85	2	0	01Aug92	Improvement in amplitude modelling
04/01/85 - 07/31/85	0	0	01Aug92	Improvement in amplitude modelling
08/01/85 - 01/12/86	17	0	01Aug92	New range (3225.438m), see 5.2.4 & Table 9
01/13/86 - 01/17/86	17	0	01Aug92	5370 on internal frequency, see 5.2.6
01/18/86 - 02/06/86	17	0	01Aug92	5370 put back on external frequency
02/07/86 - 03/01/86	-12	0	01Aug92	Guy wires on board tensioned, Secondary cal. target new cube corner (3482.552m)
03/02/86 - 03/30/86	0	0	01Aug92	New board range (3225.450m)
03/31/86 - 09/30/86	-3	0	01Aug92	MCP and Tennelec disc. installed
10/01/86 - 12/05/86	-3	0	01Aug92	Cube corner used (3482.547m)
12/06/86 - 12/31/87	-3	0	01Aug92	Nelson pier used (223.385m), antiparallax hardware installed
01/01/88 - 01/31/88	-3	0	01Aug92	Computed angles used 5.2.3
02/01/88 - 04/30/88	1	0	01Aug92	Amplitude dependence (+4mm)
05/01/88 - 01/08/89	-3	0	01Aug92	Elimination of amplitude dependence
01/09/89 - 06/14/89	-3	0	01Aug92	New range (223.3868m)
06/15/89 - 07/12/89	-3	0	01Aug92	New antiparallax hardware installed
07/13/89 - 08/02/89	-3	-0.5	01Aug92	Transmit delay modification, see 5.2.5
08/03/89 - 08/24/89	-3	-0.5	01Aug92	Original antiparallax hardware installed
08/25/89 - 10/11/89	-18	-0.5	01Aug92	Apparent movement of system, see 5.2.4
10/12/89 - 07/23/90	-3	-0.5	01Aug92	New range (223.4018m)
07/24/90 - 09/27/90	-3	-0.5	01Aug92	New range (223.3922m), cube replaced
09/28/90 - 12/09/90	-3	-0.3	01Aug92	TDEL cable shortened, see 5.2.5
12/10/90 - 07/09/91	-3	-0.3	01Aug92	New antiparallax hardware installed
07/10/91 - 07/23/91	-1	-0.3	01Aug92	OAM installed
07/24/91 - 10/17/91	-3	-0.3	01Aug92	OAM removed
10/18/91 - 05/31/92	-1	-0.3	01Aug92	OAM reinstalled

**Table 9. MOBLAS-7 Cube Corner Calibrated LAGEOS Passes
(The range biases for these passes would be 0)**

Date	Time
08/09/85	5:20
08/09/85	8:51
08/14/85	5:51
08/28/85	4:11
08/29/85	6:16
08/29/85	9:42
08/30/85	8:30
08/31/85	7:08
09/04/85	5:10
09/04/85	8:36
09/06/85	5:55
09/06/85	9:22
09/07/85	4:35
09/07/85	8:03
09/10/85	3:59
09/10/85	7:31
09/11/85	2:52
09/11/85	6:15
09/11/85	9:37
09/17/85	5:04
09/18/85	10:38
09/20/85	8:01
09/21/85	9:59
10/01/85	10:22
10/07/85	12:49
10/08/85	11:24
10/16/85	11:34
10/17/85	13:22
12/03/85	21:32
12/04/85	0:59
02/13/86	22:07

Table 10. MOBLAS-8 Eccentricities for SOD 710908xx

Occ. No.	Start Date	North (M)	East (M)	Up (M)	Rev. Date	Comments
1	09/01/81	0.012	0.011	3.225	01Aug92	First Survey
1	07/22/82	-0.029	0.011	3.124	01Aug92	M8 & M4 mom's van swap
1-2	08/04/82	-0.029	0.011	3.141	01Aug92	System releveled, 17mm change in Up, based on 84 survey
2-3	09/24/84	-0.029	0.011	3.141	01Aug92	No survey sheet
3-5	08/20/85	-0.029	0.011	3.142	01Aug92	1mm change in Up
6-11	12/12/88	-0.027	0.012	3.138	01Aug92	2, 1, & 4mm change in North, East, and Up
12	12/01/91	-0.019	0.005	3.184	01Aug92	Mount replacement
13-15	12/12/91	-0.035	-0.003	3.184	01Aug92	System releveled, 16 & 8mm change in North and East

Table 11. MOBLAS-8 LAGEOS Biases at 7109

Time Span	Range Bias(mm)	Time Bias(us)	Revis. Date	Comments
09/01/81 - 12/31/81	-3	0	01Aug92	GP laser, 2233B, 5360, Ortec, & board (2394.087m)
01/01/82 - 03/04/82	-3	0	01Aug92	Very high RMS's (300-600mm), see 6.2.6
03/05/82 - 08/03/82	-3	0	01Aug92	Hardware repaired, data nominal
08/04/82 - 12/31/83	2	+6.0	01Aug92	M4/M8 van switch, Quantel, HP5370, transmit delay problem see 6.2.5, board (2394.120m)
01/01/84 - 03/31/84	7	+6.0	01Aug92	Increase in amplitude dependence
04/01/84 - 07/31/84	3	+6.0	01Aug92	Improvement in amplitude modelling
08/01/84 - 08/19/85	0	+6.0	01Aug92	Improvement in amplitude modelling
08/20/85 - 09/25/86	0	+6.0	01Aug92	New board used (2389.506 or 2389.496m), see 6.2.4
09/26/86 - 10/26/86	-3	+6.0	01Aug92	MCP & Tennelec disc. installed
10/27/86 - 12/31/86	-3	0	01Aug92	Transmit delay wire connected, see 6.2.5
01/01/87 - 12/31/87	17	0	01Aug92	Cube corner used (2389.519m), see 6.2.4
01/01/88 - 12/11/88	17	0	01Aug92	Computed angles, see 6.2.3
12/12/88 - 03/22/89	6	0	01Aug92	New cube corner range (2389.508m)
03/23/89 - 11/06/89	-3	0	01Aug92	Nelson pier used (2401.1450m)
11/07/89 - 11/21/89	-3	0	01Aug92	New range (2401.1458m), cube replaced
11/22/89 - 11/30/91	-3	-0.3	01Aug92	Transmit delay modification, see 6.2.5
12/01/91 - 12/11/91	-3	-0.3	01Aug92	Mount re-installed, Nelson pier (2401.1392m)
12/12/91 - 04/06/92	-3	-0.3	01Aug92	Mount releveled, Nelson pier (2401.1576m)
04/07/92 - 05/31/92	-1	-0.3	01Aug92	Short range Nelson pier used (207.4742m), OAM installed

Multiwavelength

Ranging/Streak Cameras