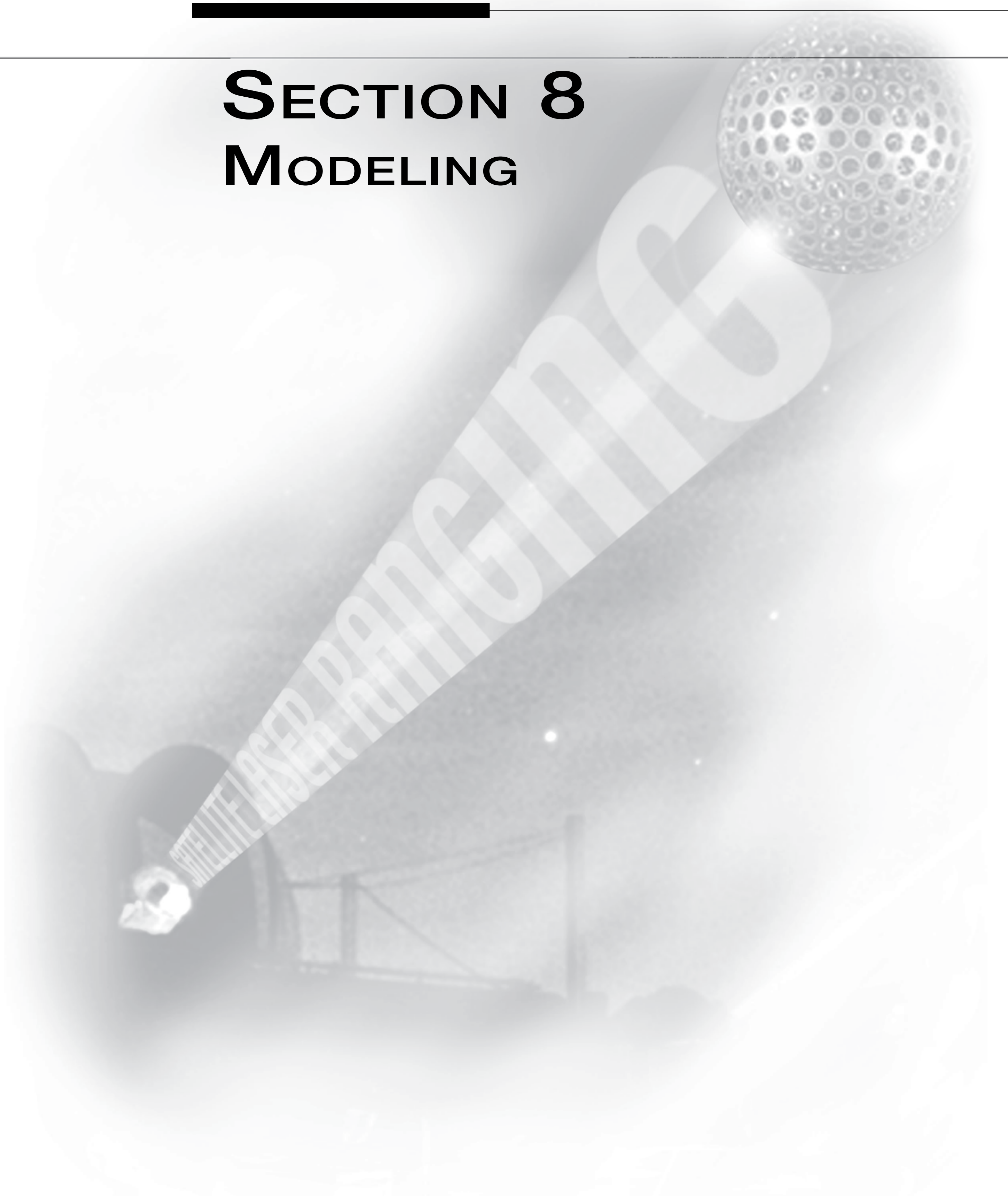
Section 8
Modeling



Section 8

Modeling

Vincenza Luceri/e-GEOS S.p.A., Centro di Geodesia Spaziale and Erricos C. Pavlis/JCET

Improved Measurement Bias Modeling

The first reanalysis of the ILRS data for ITRF2005 indicated that the new models we use in the reduction process are now sensitive enough to allow us to fit the LAGEOS data with an RMS of a few millimeters, consistently below one centimeter. These improved fits revealed the existence of station biases that were previously undetected and made it clear that in order to benefit from the improvement of the background models, we would have to address seriously the measurement bias issue.

Lists of data editing and corrections (october 2007; REVISED 090118)

Those lists have been proposed by ASI at the AWG meeting in Grasse (September 2007) and accepted by the ILRS/AWG for the generation of the ILRS official products.

LIST OF DATA TO BE DELETED

Site No.	Wav	Core NonCore in V50	Solve ?	Model ?	bias in sol V50	SOLUTION PROPOSAL	Source
1863	G	NC	NO	NO	--	data before 1994.0	
1873	G	NC	NO	NO	--	data before 1995.0	
1884	G	NC	NO	NO	1993.0 ->	data before August 1994	
1893	G	NC	NO	NO	--	data before 1998.0	CDDIS
7112	G	NC	NO	NO	--	data before 1985.0	
7123	G	NC	NO	YES	--	data from 25 to 30 August, 1988 (3 m bias) data on May 12, 1993 (> 500 meter bias)	
7236	G	NC	NO	NO	--	data after 1998.0 (a few acquisitions)	
7237	G	NC	NO	NO	--	data before 1996.0	
7249	G	NC	NO	NO	--	data before 1999.0	
7355	G	NC	NO	NO	--	use only data in 2003	
7510	G	NC	NO	NO		data from 920623 to 920930 to be deleted	CDDIS
7585	G	NC	NO	NO		data from 920623 to 920930 to be deleted	CDDIS
7810	B	C	NO	YES	--	data from Dec 18, 1996 to Dec 29, 1997	
7811	G	NC	NO	YES	1993.0 -1994.0	data before 1993:202	CDDIS
7820	G	NC	NO	NO	--	data before 2000:291	CDDIS
7824	G	NC	NO	NO	--	data before 1996	
7831	G	NC	NO	YES	--	data before 1984	
7832	G	C	NO	NO	__	data before 1998	
7835	G	NC	NO	YES	--	data before Oct 1988	
7837	G	C	NO	NO	__	data before 1990	
7841	G	NC	NO	NO	--	data before Feb 19, 2004	

LIST OF SITES WITH BIAS ESTIMATION

Site No.	Wav	Core NonCore in V50	Solve ?	Model ?	bias in sol V50	SOLUTION PROPOSAL
1864	G	NC	YES	NO	1993.0 ->	bias to be estimated over all the period
1868	G	NC	YES	NO	1993.0 ->	bias to be estimated over all the period
1953	G	NC	YES	NO	--	bias to be estimated over all the period
7548	G	NC	YES	NO	--	bias to be estimated over all the period
7308	G	NC	YES	NO	--	bias to be estimated over all the period
7548	G	NC	YES	NO	--	bias to be estimated over all the period
7810	I	C	YES	NO	--	bias to be estimated over all the period
7845	G	NC	YES	NO	--	bias to be estimated over all the period (bad for EOP referencing)

LIST OF SITES WITH RANGE BIAS APPLICATION

The range correction should be subtracted from the data and is one-way

Site No.	Wav	Core NonCore in V50	Solve?	Model?	bias in sol V50	SOLUTION PROPOSAL			Bias Source
						Start Date	End Date	Correction	
1873	G	C	NO	YES	__	1995	2000	-270 mm	Analysis
7080	G	C	NO	YES	__	Jan 1, 1988	Dec 15, 1989	-40 mm	Analysis
						April 4, 1990	Jan 31, 1993	25 mm	CDDIS
								Correction to be added to the pressure values	
						March 6, 1995	Jan 26, 1996	2.1 mB	CDDIS
						Jan 26, 1996	April 25, 1996	10.3 mB	CDDIS
						April 25, 1996	May 8, 1996	9.7 mB	CDDIS
7109	G	NC	NO	YES		Jan 9, 1997	Jan 18, 1997	164.9 mm	CDDIS
7110	G	C	NO	YES	__	Jan 01, 1984	May 15, 1984	30 mm	Analysis
						Oct 27, 1987	Jan 25, 1988	30 mm	Analysis
						Aug 27, 1996	Oct 3, 1996	163,6 mm	CDDIS
7122	G	NC	NO	YES		May 1984	Mar 15, 1987	30 mm	Analysis
7123	G	NC	NO	YES		July 14, 1987	Oct 9, 1987	-30 mm	CDDIS
7210	G	NC	NO	YES	1993 -2005	1983.0	Sep 12, 1987	25 mm	Analysis
						Sep 12, 1987	Jan 21, 1994	-37 mm	Analysis
						Jan 21, 1994	2000	-11 mm	Analysis
7237	G	NC	NO	YES		1996.0	1998.0	20 mm	Analysis
						1998.0	June 24, 2002	-20 mm	Analysis
7512	G	NC	NO	YES		Mar 1992	May 1992	-30 mm	Analysis
7517	G	NC	NO	YES		June 1992	August 1992	-94 mm	Analysis
7525	G	NC	NO	YES		March 1992	June 1992	11 mm	CDDIS
7544	G	NC	NO	YES		Sept 1992	Dec 1992	-85 mm	Analysis
7545	G	NC	NO	YES		Oct 1993	Mar 1994	15 mm	Analysis
7580	G	NC	NO	YES		Nov 1992	Jan 1993	68 mm	Analysis
7587	G	NC	NO	YES		Aug 1992	Oct 1992	30 mm	Analysis
7810	B	C	NO	YES	__	May 24, 1988	Sept 30 1989	50 mm	Analysis
						Jan 1998	May 29, 2002	-26 mm	Analysis
						May 29, 2002	Dec 28, 2004	-20 mm	Analysis
						Dec 28, 2004	Feb 6, 2006	-26 mm	Analysis
7811	G	NC	NO	YES	1993 -1994	Jul 20, 1993	May 19, 1998	-50 mm	Analysis
						May 19, 1998	Mar 28, 2003	-35 mm	Analysis
7831	G	NC	NO	YES		1987	June 1990	+85 microsec	CDDIS
7834	G	NC	NO	YES		Mar 11, 1985	Jul 18, 1986	-30 mm	Analysis
7835	G	NC	NO	YES	1993 - 1998	Sep, 1991	Sept 9, 1997	25 mm	Analysis
7836	G	NC	NO	YES		Jan 1, 1994	Oct 12, 1994	18.45 mm	CDDIS
7839	G	C	NO	YES	93.0 to 09/96	1983	Sept 28, 1996	-22 mm	Analysis
~~7840~~*	G	~~C~~	~~NO~~	~~YES~~	__	~~Jan 1984~~	~~Dec 1984~~	~~30 mm~~	~~Analysis~~
						~~Sep 15, 1988~~	~~Dec 1992~~	~~Bias drift~~	~~Analysis~~
						~~Oct 1, 1994~~	~~Feb 1, 2002~~	~~-2.5 mm~~	~~Appleby~~
						~~Feb 1, 2002~~	~~Feb 10, 2007~~	~~5.5 mm~~	~~Appleby~~
8834	G	C	NO	YES	1993 - 1997	1990	Nov 1, 1992	-35 mm	CDDIS
						Nov 1, 1992	April 15, 1996	40 mm	Analysis
						April 15, 1996	Oct 13,2000	5 mm	Analysis

* Consult new (separate) table of corrections for 7840

Figure 8-1. The three lists of data handling to account for known or suspected measurement biases for the entire ILRS network.

The first step in this direction was to scrutinize and document thoroughly all events at each site that could potentially lead to a measurement bias. The sources for this information are the station reports, SLRmail-reported events, and personal communications with station engineers. The result of these initial inquiries was a number of lists (Figure 8-1) that identified stations and time periods over which their data were to be either deleted from any analysis, corrected with bias estimates provided by the local engineering team, or flagged to have mandatory biases estimated during any analysis.

Determining a complete and accurate set of station biases and corrections based on the above was augmented and verified with the analysis of long-term solutions that decorrelate the biases from the station height estimates. Figure 8-2 shows an example of one site before and after the application of biases identified by this process. It is evident that without accounting for these biases, the otherwise high quality data from the station at Zimmerwald, Switzerland, would be wasted, and the contribution of the station in the overall development of the product significantly diminished.

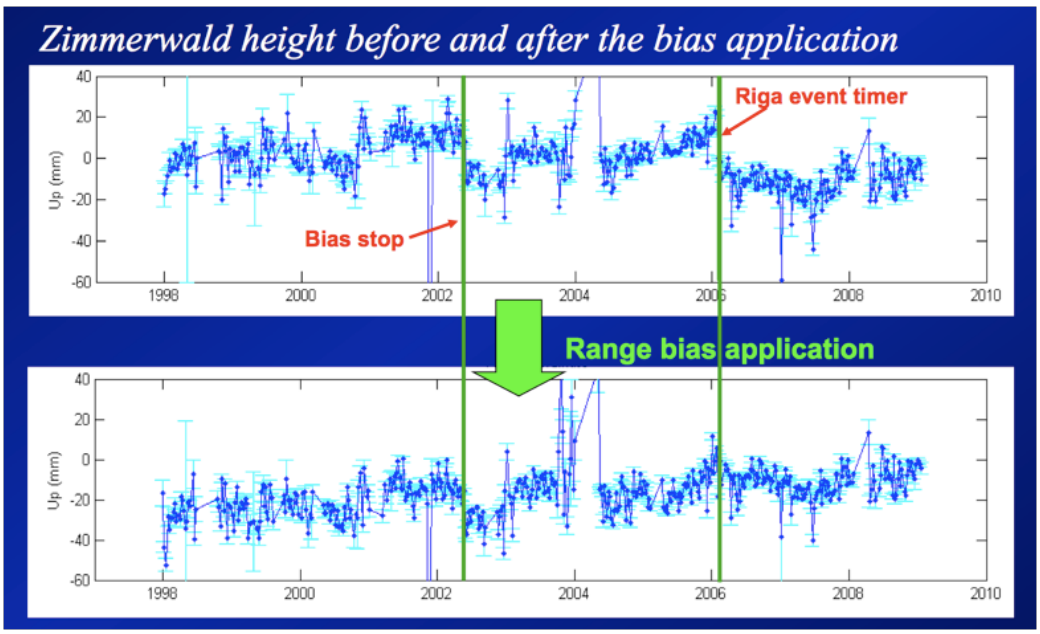


Figure 8-2. Biweekly height variation at Zimmerwald, Switzerland with respect to a long-term height estimate. Solid lines indicate known events that could cause biases in the data. The top panel shows the time series before the application of the biases, the bottom one after correcting for these biases, indicating a much improved, flatter evolution of the station height.

The bias validation and documentation effort led to a rather complete set of biases and corrections that after several iterations and tests were adopted to be used by all ACs. The process was complicated by the fact that part of the data corrections reported in these lists were due to Stanford counter non-linearity, for several sites that used these counters. A major effort at Herstmonceux attempted to estimate these corrections using the experience, data, and hardware that were still available at the site, and once validated, to extend this process to other sites of the network where the counters were no longer available [Appleby et al., 2007]. Unfortunately, the process of post-calibrating these systems proved ineffective, delivering rather arbitrary and at times even opposite sign estimates, so the effort was abandoned and it was decided instead to estimate biases from the data itself, using the long-term solutions.

The list of all (accepted) reported and estimated biases was published on the ILRS webpages, to be used by all ACs in the reanalysis for the ITRF2008. A parallel effort compiled all of this information in a SINEX-like format that is machine-readable and allows the automatic use of the information in any analysis environment. SLR data users in the future will be directed to access this file when analyzing data in order to ensure the best and most consistent results for any application. The file will be kept up to date and extended as new information becomes available. At the moment the final version of this file is pending release, awaiting the release of the final list of possible biases in the data, from the final combination of the ILRS submission to ITRS with those from other techniques.

The process of improved bias handling was presented at various conferences [Bianco et al., 2008], [Luceri et al., 2009] and workshops [Appleby, 2007], [Luceri, 2007], [Appleby et al., 2008], [Ries, 2007] in order to give users a clear view of the underlying mechanism used to decide the biases and to assure the users of ILRS products (e.g., ITRS) that this process used reliable and valid information that would result in far more stable products in the future.

Cannonball Spacecraft Center-of-Mass Offset Modeling

Graham Appleby/NERC, Toshimichi Otsubo/Hitotsubatshi University (HIT-U) and Erricos C. Pavlis/JCET

SLR measurements are in principle unbiased and provide an absolute measure of the distance between the ground system reference point and the Effective Reflecting Plane (ERP) of the Laser Reflector Array (LRA) on the spacecraft. This, however, requires that we have predetermined, through theoretical studies and very accurate measurements, the geometry of that ERP with respect to the center-of-mass (CoM) of the spacecraft. The problem is obviously more complicated for active satellites with moving appendages, variable attitude orientation, thrusters that consume fuel, etc. For the purely geodetic, cannonball shape passive satellites the situation is by far simpler although not entirely so. This has been identified as one of the limiting sources of error in breaking the millimeter barrier in the accuracy of ILRS products, so it has attracted a lot of attention lately, primarily from the dedicated Working Group (Signal Processing WG), but also from a newly formed ILRS "Task Force" that involved more than SPWG engineers.

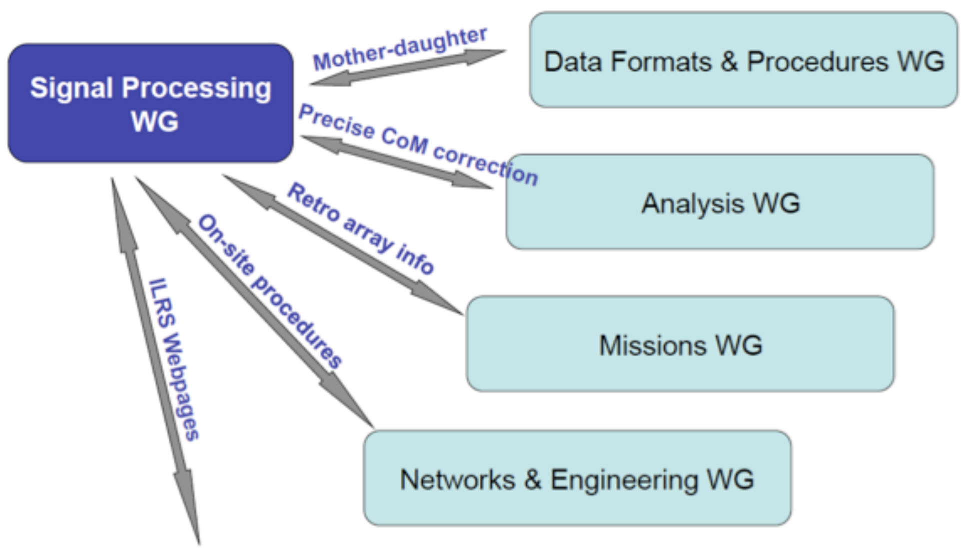


Figure 8-3. The interaction between the Signal Processing WG and other ILRS bodies.

The primary concern of that group was to prepare the best possible CoM tables for the ILRS network, considering the variety of ground systems and operating modes of the stations. The first priority for tackling this was for the LAGEOS spacecraft since they are the basis for the official ILRS products, followed next by the Etalon satellites. The fact that this group exchanges information with many of the ILRS components further underscores the importance of these measurements (Figure 8-3).

Table 8-1. Ground-system dependence for LAGEOS' CoM correction and adopted standard.

Stn pad ID	Name	Pulse length (ps)	Detector	Regime (single, few, multi)	Editing Level (×σ)	Calib. St. error (mm)	LAGEOS St. error (mm)	LAGEOS CoM range (mm)	LAGEOS CoM ADOPTED (mm)
1873	Simeiz	350	PMT	No CNTL	2.0	60	70	248-244	246
1884	Riga	130	PMT	CNTLD s->m	2.0	10	15	252-248	250
7080	McDonald	200	MCP	CNTLD s->m	3.0	8.5	13	250-248	249
7090	Yaragadee	200	MCP	CNTLD f->m	3.0	4.5	10	250-248	249
7105	Greenbelt	200	MCP	CNTLD f->m	3.0	5	10	250-248	249
7110	Mon. Peak	200	MCP	CNTLD f->m	3.0	5	10	250-248	249
7124	Tahiti	200	MCP	CNTLD f->m	3.0	6	10	250-248	249
7237	Changchung	200	CSPAD	CNTLD s->m	2.5	10	15	250-245	248
7249	Beijing	200	CSPAD	No CNTL, m	2.5	8	15	255-247	251
7355	Urumqui	30	CSPAD	No CNTL	2.5	15	30	255-247	251
7405	Conception	200	CSPAD	CNTLD s	2.5	15	20	246-245	246
7501	Harteb.	200	PMT	CNTLD f->m	3.0	5	10	250-244	247
7806	Metsahovi	50	PMT	?	2.5	15	17	254-248	251
7810	Zimmerwald	300	CSPAD	CNTLD s->f	2.5	20	23	246-244	245
7811	Borowiec	40	PMT	No CNTL f	2.5	16	23	256-250	253
7824	San Fernando	100	CSPAD	No CNTL s->m	2.5	30	25	252-246	249
7825	Stromlo	10	CSPAD	CNTLD s->m	2.5	4	10	257-247	252
7832	Riyadh	100	CSPAD	CNTLD s->m	2.5	10	15	252-246	249
7835	Grasse	50	CSPAD	CNTLD s->m	2.5	6	15	255-246	250
7836	Potsdam	35	PMT	CNTLD s->m	2.5	10	20	256-252	254
7838	Simosato	100	MCP	CNTLD s->m	3.0	20	40	252-248	250
7839	Graz	35	CSPAD	No CNTL m	2.2	3	9	255-250	252
7839	Graz kHz	10	CSPAD	No CNTL s->f	2.2	3	9	255-250?	252
7840	Herstmonceux	100	CSPAD	CNTLD s	3.0	6	15	246-244	245
7840	Hx kHz	10	CSPAD	CNTLD s	-1.5,+2.5	3	9	245	245
7841	Potsdam 3	50	PMT	CNTLD s->f	2.5	10	18	254-248	251
7941	Matera	40	MCP	CNTLD m	3.0	1	5	252-248	250
8834	Wettzell	80	MCP	No CNTL f->m	2.5	10	20	252-248	250

One of the complications of determining an accurate CoM correction for each target satellite derives from the fact that this correction depends not only on the spacecraft and LRA geometry, but also to a large extent on the type of ranging and detection system that is used at the tracking ground station. This dependence has been known for a long time now, but it has been applied explicitly by the analysts only in the case of the single-photon system at Herstmonceux, UK, while a single CoM offset was used for all other sites and satellites. Over the past years it became obvious that unless this correction was applied with the utmost accuracy possible, SLR would suffer from increased jitter in its scale definition and poor fits to the tracking data. With scale being one of the most important SLR contributions to ITRF, the improved handling of this correction is now one with the highest priority.

During the past two years the SPWG has generated a table that provides the most accurate values for the CoM correction for LAGEOS-1 and -2, for all active stations of the ILRS network and for all of their operating modes (Table 8-1). Although this has been published already on the ILRS webpages:
http://ilrs.gsfc.nasa.gov/stations/site_info/data_correction/nsgf_iCoM_LAGEOScorrections.html

it was decided that the official ILRS products would adopt these new CoM corrections after the contribution to ITRF2008 is finalized, during the next reanalysis phase. At the same time, using similar procedures, a second table with the appropriate CoM for the two Etalon spacecraft was developed and finalized (Table 8-2), which will also become the standard at the same time as the previous one for LAGEOS. However, it should be understood that in general it is not possible to determine CoM corrections accurate at the mm-level for these large spherical satellites. This fact has been recognized in what is considered a realistic range of CoM values for each tracking station and for each satellite and given in these tables along with the adopted single value that should be used by analysts. It should also be pointed out that although in most cases the discrepancy from an overall mean value is only a few millimeters and well below most stations' noise levels, the fact that this is a systematic error affecting directly the SLR-implied scale of the network, makes it extremely important for the development of the ITRF. It is therefore the first "improvement" to be adopted immediately next when the Analysis WG enters a new phase of data reanalysis.

Both tables are "live" documents, being kept up-to-date as stations change operating modes or as new stations join the network. It is thus advised that users should query the ILRS pages often in order to be sure that they use the latest version. It is highly likely that before these tables become effective in the day-to-day analyses, a machine-readable version will be placed online so that analysts can link directly to it on the fly.

Table 8-2. Ground-system dependence for Etalon CoM correction and adopted standard.

Stn pad ID	Name	Pulse length (ps)	Detector	Regime (single, few, multi)	Editing Level (×σ)	Calib. St. error (mm)	ETALON CoM range (mm)	ETALON CoM ADOPTED (mm)
1873	Simeiz	350	PMT	No CNTL	2.0	60	593-603	598
1879	Altay	150	PMT	No CNTL	2.5	20	600-610	605
1884	Riga	130	PMT	CNTLD s->m	2.0	10	602-612	607
7080	McDonald	200	MCP	CNTLD s->m	3.0	8.5	598-608	603
7090	Yaragadee	200	MCP	CNTLD f->m	3.0	4.5	598-608	603
7105	Greenbelt	200	MCP	CNTLD f->m	3.0	5	598-608	603
7110	Mon. Peak	200	MCP	CNTLD f->m	3.0	5	598-608	603
7119	Haleakala	200	MCP	CNTLD f->m	3	4.5	598-608	603
7124	Tahiti	200	MCP	CNTLD f->m	3.0	6	598-608	603
7237	Changchung	200	CSPAD	CNTLD s->m	2.5	10	570-580	575
7249	Beijing	200	CSPAD	No CNTL, m	2.5	8	570-580	575
7355	Urumqui	30	CSPAD	No CNTL	2.5	15	576-586	581
7358	Tanegashima	50	MCP	No CNTL	3	1.3	602-612	607
7405	Conception	200	CSPAD	CNTLD s	2.5	15	573-577	575
7406	San Juan	40	CSPAD	No CNTL	2.5	8	576-586	581
7501	Harteb.	200	PMT	CNTLD f->m	3.0	5	598-608	603
7806	Metsahovi	50	PMT	?	2.5	15	602-612	607
7810	Zimmerwald	300	CSPAD	CNTLD s->f	2.5	20	570-574	572
7811	Borowiec	40	PMT	No CNTL f	2.5	16	602-612	607
7824	San Fernando	100	CSPAD	No CNTL s->m	2.5	30	573-583	578
7825	Stromlo	10	CSPAD	CNTLD s->m	2.5	4	576-586	581
7832	Riyadh	100	CSPAD	CNTLD s->m	2.5	10	573-583	578
7835	Grasse	50	CSPAD	CNTLD s->m	2.5	6	604-613	609
7836	Potsdam	35	PMT	CNTLD s->m	2.5	10	604-613	609
7838	Simosato	100	MCP	CNTLD s->m	3.0	20	602-612	607
7839	Graz	35	CSPAD	No CNTL m	2.2	3	569-579	574
7839	Graz kHz	10	CSPAD	No CNTL s->f	2.2	3	571-577	574
7840	Herstmonceux	100	CSPAD	CNTLD s	3.0	6	563-567	565
7840	Hx kHz	10	CSPAD	CNTLD s	-1.5,+2.5	3	563-567	565
7841	Potsdam 3	50	PMT	CNTLD s->f	2.5	10	606-612	609
7941	Matera	40	MCP	CNTLD m	3.0	1	607-613	610
8834	Wettzell	80	MCP	No CNTL f->m	2.5	10	603-613	608

Advanced Refraction Modeling

Erricos C. Pavlis/JCET and Glynn Hulley/JPL

SLR is an optical technique and as such it is not affected greatly by atmospheric refraction as other space geodetic techniques operating in the microwave region of the spectrum. Nevertheless, since we strive for mm-level accuracy, even the otherwise small effects of horizontal gradients in the lower atmosphere must be accounted for. One proven way to do this is to compute refraction corrections along the laser beam path directly from three-dimensional ray tracing (3D ART) through the meteorological fields that are now routinely available. This method was pioneered and tested with the analysis of two years of SLR data by Hulley and Pavlis [2007a, b, c, d]. The concept is described in the graphic and equations shown in Figure 8-4. As discussed in [ibid], the SLR data for 2004-2005 were corrected using refraction corrections obtained using the 3D ART approach, based on three different global fields: ECWMF, NCEP and the satellite observations from the AIRS instrument on board the Aqua NASA platform.

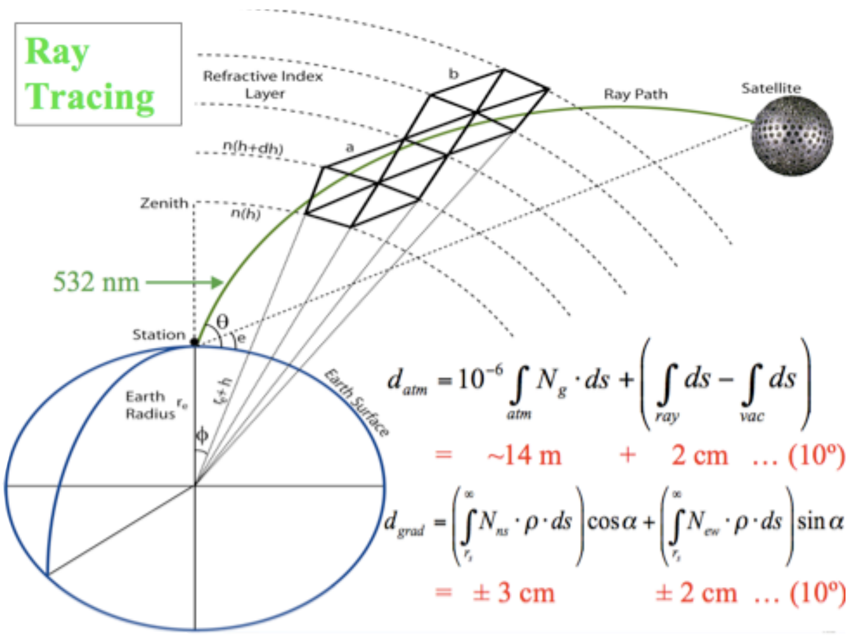


Figure 8-4. The three-dimensional ray tracing approach to computing the total atmospheric delay along the path of a SLR range observation.

The comparison of atmospheric gradient variations obtained from the three sources agreed in generally very well, however, it is quite apparent when one looks at the results shown in Figure 8-5 for the Herstmonceux site, that AIRS and ECMWF are in much better agreement than any other pair. After applying these corrections to the SLR data, the RMS residual fits improve considerably, indicating the importance of these corrections for future analyses. Statistics of these comparisons are shown in Table 8-3. From these results it is evident that 3D ART with AIRS-observed meteorological fields is the best approach, explaining almost 25% of the residual variance. An alternate approach where the isotropic delay is modeled through the analytical model of [Mendes and Pavlis, 2004] and the gradients are obtained from 3D ART is not as effective, explaining only 14% of the variance for the same data.

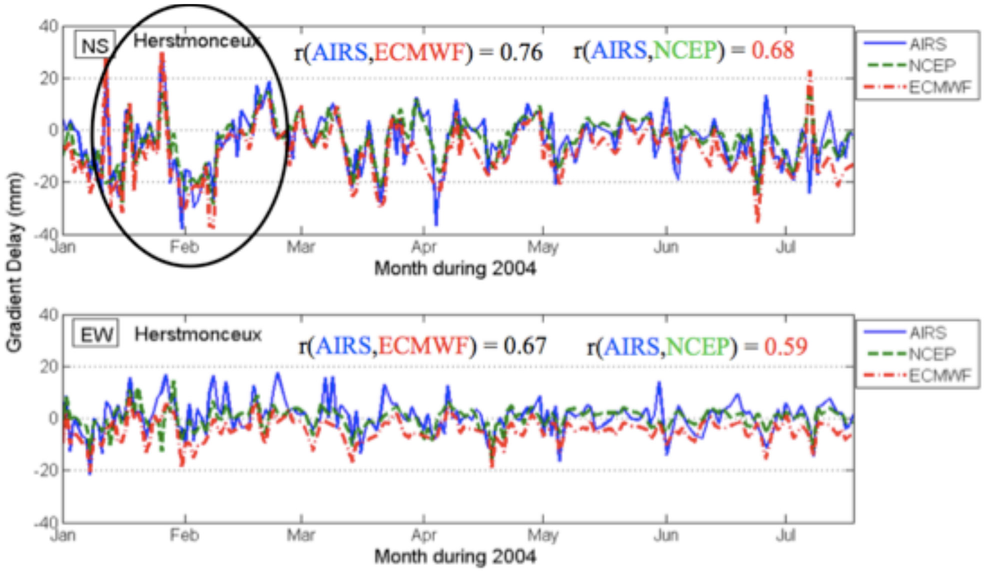


Figure 8-5. Atmospheric gradients at Herstmonceux during 2004, from three different source fields (AIRS, NCEP and ECMWF).

At this point there is no routine computation of refraction corrections in an operational way, so the above 3D ART approach will have to await until someone can commit to produce these corrections as part of a service to the ILRS. When available, their utilization in the data analysis process will be a rather trivial matter. The results of this investigation were presented at ILRS workshops, the AGU and published in refereed journals [Hulley and Pavlis, 2007a, b, c, d].

Table 8-3. Residual statistics of SLR data corrected with 3D ART atmospheric delays.

Method	ΔBias (mm)	Δσ (%)
AIRS		
RT_{grad}	0.3 ± 0.3	14.0
RT_{3D}	0.9 ± 1.1	24.8
ECMWF		
RT_{grad}	0.1 ± 0.5	10.8
RT_{3D}	0.6 ± 1.2	22.5

Atmospheric Loading Modeling

Erricos C. Pavlis, Magdalena Kuzmicz-Cieslak, and Peter Hinkey/JCET

The effect of atmospheric circulation (mass redistribution) is currently not modeled during the reduction of SLR data for official ILRS products. This is because IERS requires that this effect be applied to products by all of the services simultaneously, to avoid a mixed result. During the GGOS Unified Analysis Workshop of 2007 (UAW 2007), each of the Technique Analysis Coordinators were tasked to perform some limited testing to determine the level of impact this new model will have on their products. In the case of ILRS the modeled effect applies to the orbit as well as the loading effect that modifies primarily the tracking sites' height. Using the meteorological global fields of ECMWF we can derive a correction to each station's position due to this loading effect. This has been provided as a service for a few years now [Petrov and Boy, 2004], and results are available for various operational and experimental fields from ECMWF (versions v0, v1 and v2), as well as from NCEP:

"v0": 1970/01 - 2002/08: ECMWF Reanalysis (ERA40), with a spatial resolution of 1.125 degrees
"v1": 2000/12 - 2006/12: ECMWF Operational, with a spatial resolution of about 0.350 degrees
"v2": 2005/10 –present: ECMWF Operational, with a spatial resolution of about 0.250 degrees

Because of the existence of these multiple versions of the ECMWF fields, we chose to analyze SLR data in 2001 and 2006, so that we can test the maximum possible set of these fields. The results obtained from these tests were compared to those obtained without atmospheric modeling, and the statistics of their differences are summarized in Table 8-4.

Table 8-4. Statistics of RMS differences (in mm) for the 2001 & 2006 LAGEOS SLR data reductions with atmospheric loading modeling from various ECMWF releases.

Test Case	Points (weeks)	Mean	Median	RMS	Std Deviation
ΔRMS v0-NO*	52	3.4	2.7	4.45	2.87
ΔRMS v1-NO	104	2.9	2.1	4.31	3.16
ΔRMS v2-NO	52	2.7	1.7	4.09	3.08
ΔRMS v1-v0	52	0.4	0.0	0.92	0.82
ΔRMS v2-v1	52	1.7	1.4	2.58	1.96

*NO indicates no atmospheric loading modeling

The top three rows of Table 8-4 show that any of the three versions of ECMWF fields, when used to derive loading at the tracking sites improves the results with an average reduction in the overall RMS of fit of the order of 3 mm in the mean (or 2 mm median difference), and a similar magnitude of variation about the mean over the tested weeks.

The last two rows compare the three variations of the ECMWF released fields, as "seen" through the orbit filter controlled by SLR tracking data. Evidently, the difference between v0 and v1 is insignificant given the magnitude of the mean and the corresponding RMS. Apparently, going from 1°.125 resolution down to 0°.350 is not making a huge difference. On the other hand, the difference between v1 and v2 is much larger, although that one does not seem statistically significant either when one considers the scatter associated with it. Additionally, the comparison of v1 and v2 is over 2006, when the data that are used to form the ECMWF fields are quite different from those used in 2001 (when we compared the v1 to v0), dominated by global fields obtained from satellite missions. Irrespective of which ECMWF product one uses, it is evident that there is a significant change (improvement) in the fits to SLR data and if one compares this change to the present day state-of-the-art results, the conclusion is that we can no longer afford to not model such effects if our goal is to achieve millimeter or better geodesy.

It is expected that following the completion of the reanalysis effort for the ITRF2008 development, the ILRS AWG will conduct internal tests to verify the consistent application of atmospheric effects and include it as part of the standard model for the next reanalysis. The results from these tests were presented at various conferences [Pavlis, 2007], [Boy et al., 2008], ILRS workshops [Pavlis et al., 2008] and a dedicated EGU session [Boy et al., 2008].

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