3.4.2 International Laser Ranging Service (ILRS)

Introduction

The International Laser Ranging Service (ILRS), established in 1998, is responsible for the coordination of SLR/LLR missions, technique development, network operations, data analysis and scientific interpretation. Here we summarize the status and developments in 2010.

Network

The network of SLR/LLR stations, under the aegis of the ILRS, has been subject to change over the years. From a technical perspective, the quality of the observations has improved drastically during the past decade. At this moment, the single-shot precision of an average station is better than 10 mm (for the best stations this number is a few millimeters). The absolute quality of the individual observations is at the 10 mm level, with a significant number of stations doing significantly better. The geometry of the SLR network has been a point of concern over the years (cf. Figure 1). However, the network has improved slightly in recent

Fig. 1: The global network of SLR stations (status early 2011).

years. NASA's next generation SLR system is in the final stages of development, and it is expected to reach completion by next year. The switching to high repetition rate systems at a number of sites has increased productivity and improved data quality. This evolution will slowly lead us to the GGOS-era network as described in their GGOS2020 document.

The network sustained a major disruption on February 27, when a "megaquake" of magnitude 8.8 with a duration of about 2.5 minutes, hit the Concepción area in Chile. All geodetic instruments at the site were affected and SLR operations were suspended. The coseismic relocation of the site by more than 3 m required tremendous effort from the local crew to bring the systems back up to normal operations. Surprisingly, SLR was up by mid-April and tracking successfully by late April in operational mode. Because of the ILRS network's poor station distribution, particularly in the southern hemisphere, the loss of this site was reflected immediately in the quality of the products delivered while the Concepción SLR was inoperable.

Statistics of the data collected as pass segments during the calendar year 2010 are summarized in Table 1. For each of the contributing stations the tracked passes are broken down in three categories of tracked targets: Low Earth Orbiters (LEO), LAGEOS 1 & 2, and the High Earth Orbiters (HEO) which include the GPS, GLONASS, ETALON and GIOVE-A/B satellites (GALILEO test s/c), as well as a number of recently launched Beidou satellites, part of the Chinese Navigation Constellation COMPASS/Beidou.

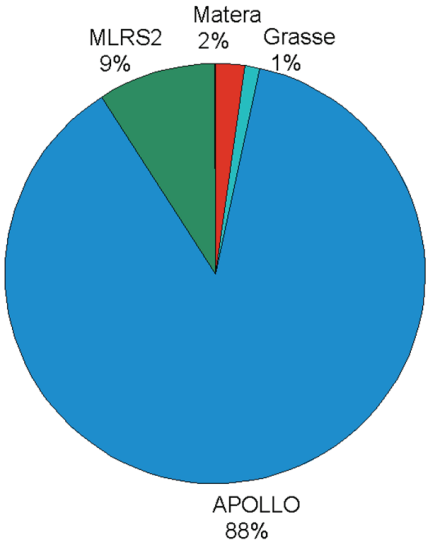

Fig. 2: Observatory statistics in 2010.

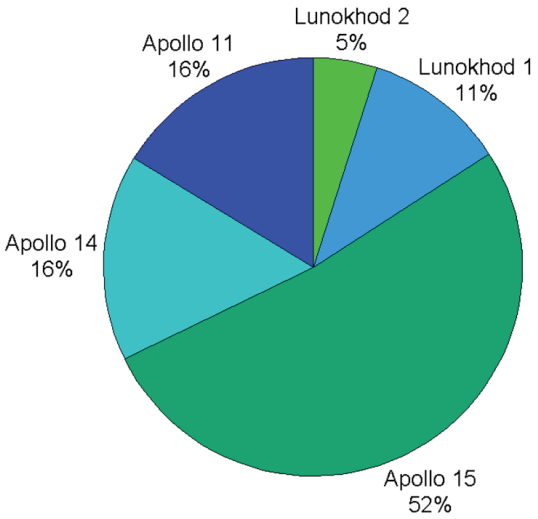

Fig. 3: Reflector statistics in 2010.

Table 1: ILRS Network Tracking Statistics for 2010.

Site Name	Station	Number of Passes			Total
		Low	LAGEOS	High	
Altay	1879	137	176	238	551
Arequipa	7403	1,503	91	0	1,594
Beijing	7249	341	51	30	422
Borowiec	7811	61	11	0	72
Changchun	7237	6,474	817	455	7,746
Concepcion	7405	1,873	591	273	2,737
Grasse	7845	1,534	658	1,148	3,340
Graz	7839	4,757	670	546	5,973
Greenbelt	7105	1,510	334	322	2,166
Haleakala	7119	1,413	404	0	1,817
Hartebeesthoek	7501	1,196	262	168	1,626
Herstmonceux	7840	3,862	754	1,306	5,922
Katzively	1893	1,288	203	151	1,642
Kiev	1824	680	129	30	839
Koganei	7308	1,058	291	374	1,723
Koganei	7328	38	18	0	56
Komsomolsk-Na-Amure	1868	43	139	120	302
Matera	7941	4,266	1,686	2,018	7,970
McDonald	7080	1,142	446	247	1,835
Monument Peak	7110	2,781	829	1,013	4,623
Mount Stromlo	7825	6,420	1,068	521	8,009
Potsdam	7841	2,319	390	58	2,767
Riga	1884	1,187	133	4	1,324
Riyadh	7832	843	220	73	1,136
San Fernando	7824	2,709	288	44	3,041
San Juan	7406	2,739	492	839	4,070
Shanghai	7821	1,905	343	409	2,657
Simeiz	1873	1,103	333	9	1,445
Simosato	7838	871	345	28	1,244
Tahiti	7124	553	168	8	729
Tanegashima	7358	362	162	91	615
Wettzell	8834	1,598	330	198	2,126
Yarragadee	7090	15,289	3,329	4,733	23,351
Zimmerwald	7810	5,151	1,009	1,112	7,272
Totals	34 stations	79,006	17,170	16,566	112,742

From all of the ILRS observatories (about 35), only a few laser ranging systems are technically equipped to track retro-reflector arrays on the surface of the Moon or spacecraft orbiting around the Moon. The active Lunar Laser Ranging (LLR) sites in 2010 were the three well-known observatories: the McDonald Observatory in Texas, USA, the APOLLO site in New Mexico, USA, and the Observatoire de la Côte d' Azur, France. In addition, the Matera Laser Ranging station in Italy showed its lunar capability for the first time providing a few normal points. Finally, the German Geodetic Observatory at Wettzell worked on its system to soon join the LLR tracking network. The measurement statistics of 2010 (Figure 2) clearly shows that most of the data have been collected at the APOLLO site.

Figure 3 illustrates the statistics for the observed reflectors: The good distribution among all reflectors is mainly due to the APOLLO site contribution, which gets a relatively strong signal even from the smaller reflectors. The most remarkable event on the LLR reflector side was the re-discovery of the Lunokhod 1 reflector that was taken to the Moon by the unmanned Soviet mission Luna 17 (Figure 4). The exact position of the Lunokhod 1 rover was unknown for nearly 39 years, before it was observed by LRO in March 2010. Initial laser measurements were a few days later carried out by the APOLLO site. The LLR data showed the reflector in a good condition with a strong signal. Due to its close position to the lunar limb, the Lunokhod 1 reflector has a high sensitivity to the orientation of the Moon, it helps to obtain a better determination of lunar libration in longitude and latitude.

Today, the LLR results are considered among the most important science return of the Apollo era. It has continuously provided range data for about 40 years, generating about 16800 normal points by 2010. Based on appropriate modeling and sophisticated data analysis, LLR determines many parameters of the Earth–Moon dynamics like lunar ephemeris, lunar physics, the Moon's interior, reference frames and Earth orientation parameters.

LLR has also become a strong tool for testing Einstein's theory of general relativity in the solar system. By extending the standard solution, it is possible to solve for parameters related to gravitational physics, like the temporal variation of the gravitational constant, metric parameters as well as the strong equivalence principle and preferred-frame effects. As one example of a recent study see Hofmann et al. (2010). So far, all LLR-based relativity tests have confirmed Einstein's theory of gravitation.

In 2010, an ISSI (International Space Science Institute, Berne, Switzerland) workshop series has been started dedicated on "Theory and model for the new generation of the Lunar Laser Ranging data", where experts from various disciplines discuss future challenges in LLR observation, modeling and analysis.

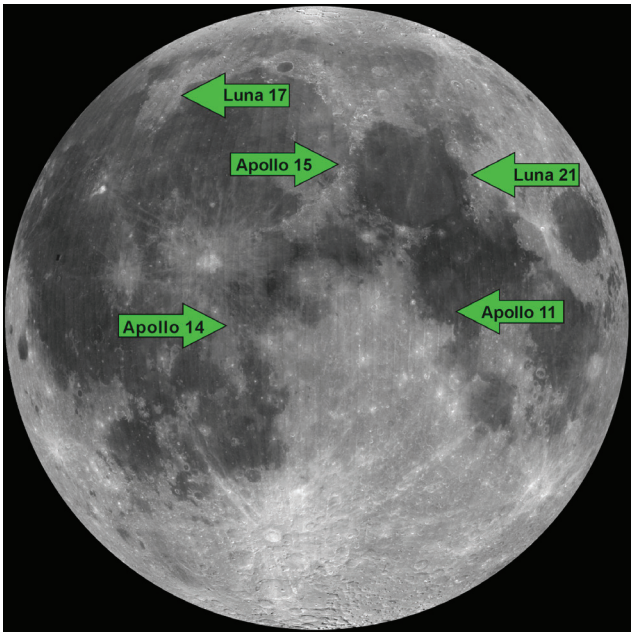

Fig. 4: Retro-reflector sites on the Moon, Luna 17 has not been successfully tracked until 2010.

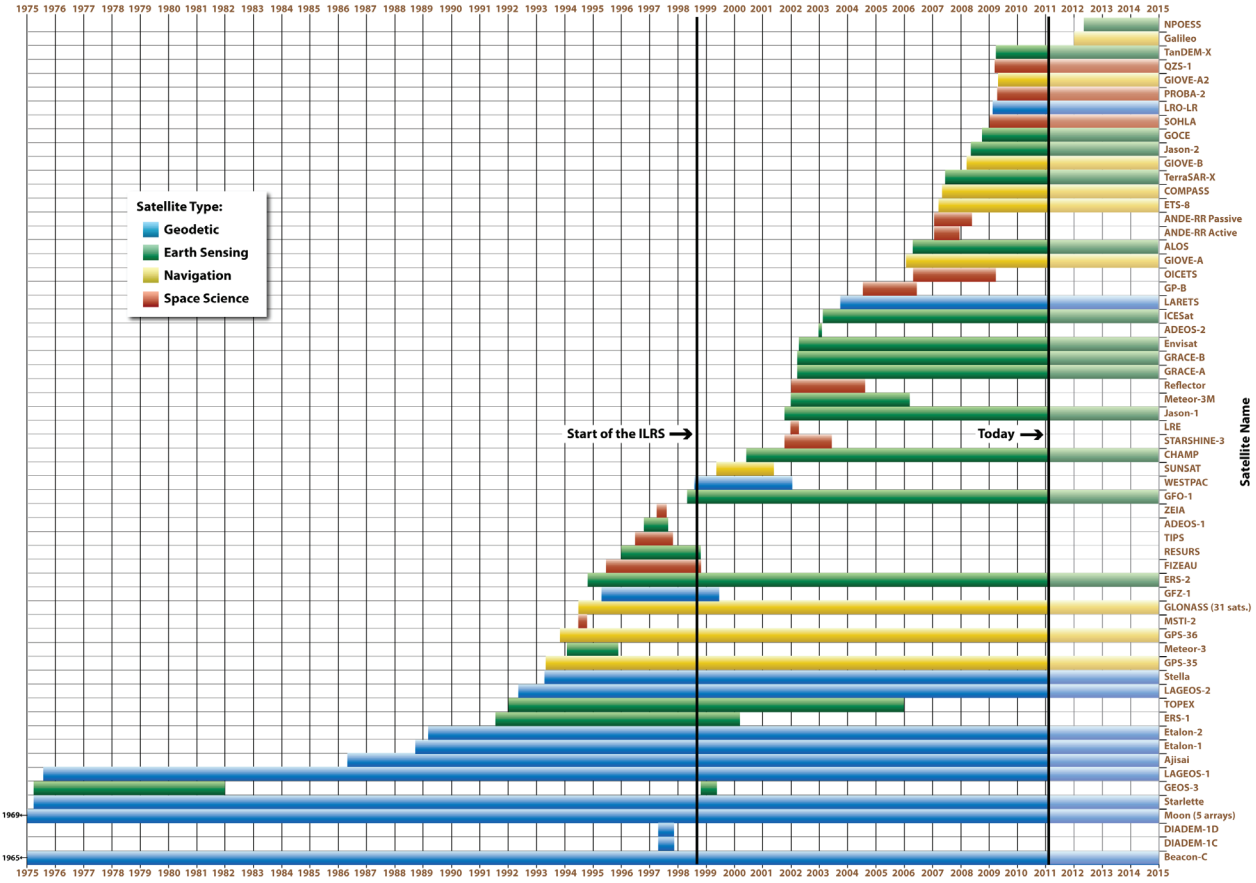

Fig. 5: The currently tracked SLR missions (status early 2011).

Missions

In 2010, a total of ~30 satellites (including the Moon) were being tracked by laser (Figure 5). Of these, only about 1/3 are geodetic type targets (cannonball satellites), the rest are mainly Earth Observation missions and navigation satellites, along with a small number of experimental space science missions. During 2010 we had six successful launches of satellites carrying LRAs, listed in Table 2. The first one, COMPASS-G1 is a geostationary member of the COMPASS/Beidou Constellation, launched by China. Cryosat-2, the second launch, is an ESA mission for observation of the cryosphere and the oceans with radar altimeters and Synthetic Aperture Radar (SAR). The third mission, TanDEM-X, is a German DLR mission to complete the imaging pair with TerraSAR-X, launched back in 2007. QZS-1 is the fourth mission and the first of a Japanese Navigation Constellation that intends to improve navigation in urban areas of Japan and the surrounding regions. There were also two multi-payload launches from Russia, each one placing in orbit three new GLONASS satellites, 119-120-121 and 122-123-124. The new GLONASS-M satellites carry improved LRAs and ILRS initiated tracking campaigns to evaluate the effectiveness of the new design. The group of GLONASS spacecraft tracked by ILRS was changed to substitute older spacecraft with the recently launched. Some ILRS stations begun tracking a larger number of GLONASS satellites in order to gain experience in handling a large number of HEO targets, something ILRS will have to contend with once GLONASS, Galileo, COMPASS/Beidou, etc. become fully operational and request tracking support.

A number of missions completed their operations in 2010 (Table 3). The pair of ANDE spacecraft Pollux and Castor completed successfully their mission in late March. ETS-8 collected its last observations in late July, and ICESat in the beginning of August. The first geopotential mapping mission CHAMP collected its last observation on September 4, and after a successful 10-year

Table 2: ILRS Supported Missions Launched in 2010.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (Seconds)	Altitude (Km)	Inclination (deg)	First Data Date
COMPASS-G1	1000101	2002	36287	9	300	42,164	55.5	28-Apr-12
Cryosat-2	1001301	8006	36508	3	15	720	92	20-Apr-10
TanDEM-X	1003001	6202	36605	1	5	514	97.44	21-Jun-10
QZS-1	1004501	1581	37158	9	300	32,000-40,000	45	11-Sep-10
GLONASS-119	1000701	9119	36400	9	300	19,140	65	
GLONASS-121	1000702	9121	36401	9	300	19,140	65	12-Apr-10
GLONASS-120	1000703	9120	36402	9	300	19,140	65	12-Apr-10
GLONASS-124	1004101	9124	37137	9	300	19,140	65	11-Oct-10
GLONASS-123	1004102	9122	37138	9	300	19,140	65	7-Oct-10
GLONASS-122	1004103	9122	37139	9	300	19,140	65	6-Oct-10

Table 3: Missions that ended their operations in 2010.

Satellite Name	Satellite ID	SIC Code	NORAD Number	NP Indicator	Bin Size (Seconds)	Altitude (Km)	Inclination (deg)	First Data Date	Last Data Date
ANDE Pollux	903805	1074	35693	1	5	350	51.6	4-Aug-09	16-Mar-10
ANDE Castor	903806	1073	35694	1	5	350	51.6	4-Aug-09	1-Apr-10
ETS-8	605901	1579	29656	9	300	36,000	0	10-Mar-07	29-Jul-10
ICESat	300201	8201	27642	1	5	600	94	5-Mar-03	2-Aug-10
CHAMP	3902	8002	26405	1	5	474	87	1-Jan-00	4-Sep-10

mission, it entered the atmosphere for a final trajectory on September 20.

Analysis and science

The main topic on which most of the Analysis Centers focused their work during 2010 was the evaluation and validation of ITRF2008 candidate models. Two such TRFs were produced and delivered to the Services for evaluation: ITRF2008P from the French/IGN ITRS CC and ITRF2008D from the German/DGFI CC. The two models were made available in early April and the intention was to complete their evaluation by the Services so that a final model could be adopted for official release during a dedicated meeting (REFAG 2010) in Paris, in early October 2010. The general consensus amongst the Analysis Working Group (AWG) was that the two models performed very similarly and were both an improvement upon ITRF2005. When compared in 3-D station positions and network scale, we can see a slight (but throughout consistent) preference for the ITRF2008D model, at the few tenths of a millimeter level (Fig. 6).

	vs SLRF2005		vs ITRF2008		vs ITRF2008D	
	<WRMS> [mm]	σWRMS [mm]	<WRMS> [mm]	σWRMS [mm]	<WRMS> [mm]	σWRMS [mm]
All Sites	13.21	18.80	10.93	18.43	10.48	18.54
Core Sites	8.44	5.79	7.13	4.99	6.89	5.12

Fig. 6: Weighted RMS statistics of X, Y, and Z coordinates of stations in the ILRS network with respect to the old ITRF2005 (SLRF2005 version of ILRS) and the two new candidate models ITRF2008 (IGN) and ITRF2008D (DGFI). Statistics are shown for the entire network (top line) and the Core sites only (bottom line). The comparison spans the entire period covered by SLR observations (1983.0 – 2009.0).

The most significant difference between the two candidate models was their scale definition. Although ITRF2008P is a clear improvement over the ITRF2005, the SLR data clearly prefer the scale

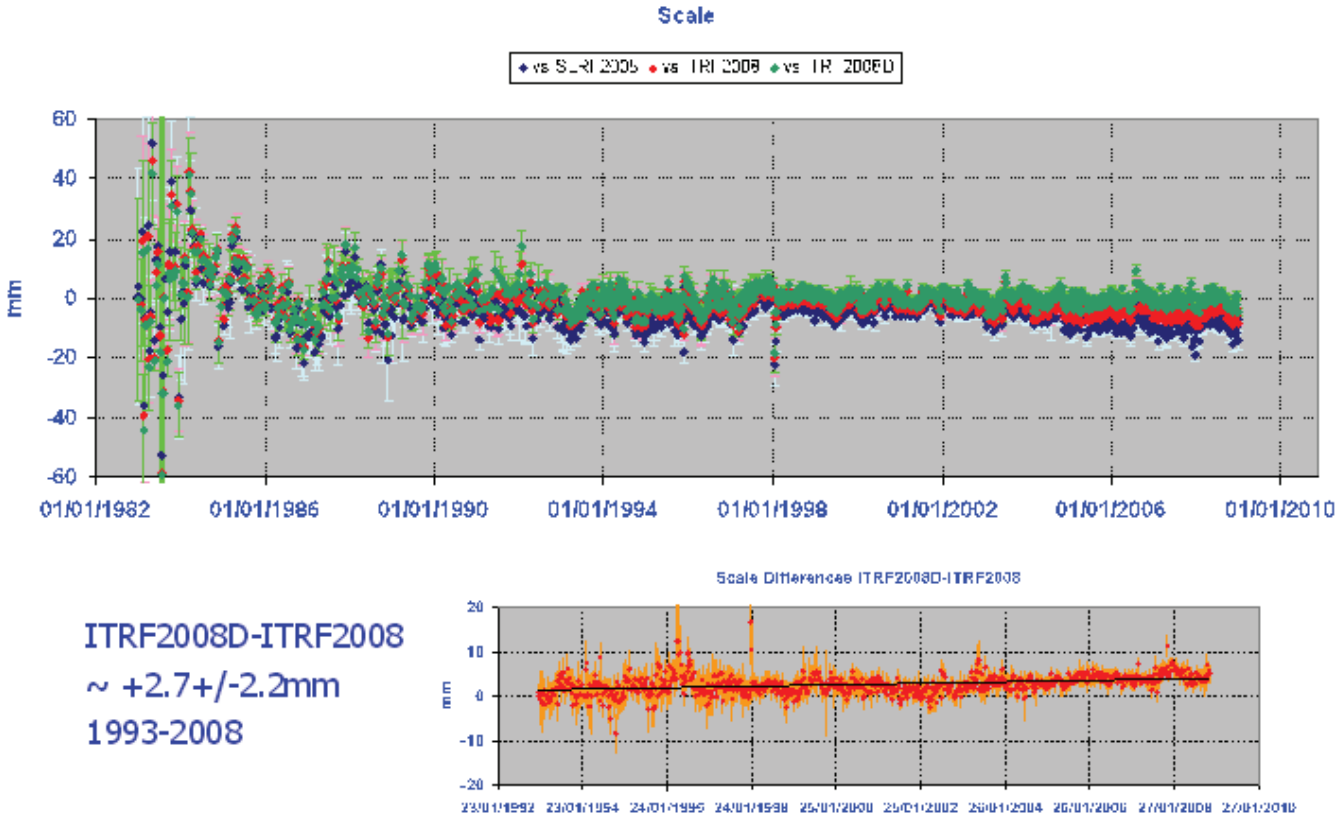

Fig. 7: Weekly ILRS product comparison in scale with respect to the old ITRF2005 (SLRF2005 version of ILRS) and the two new candidate models ITRF2008 (IGN) and ITRF2008D (DGFI). The systematic difference between ITRF2008 and ITRF2008D is shown in the second graph.

definition of ITRF2008D. This results in a trendless evolution of the scale as seen from the weekly ILRS products for the 1983.0 to 2009.0 period (Fig. 7). The two frames differ in scale systematically by 2.7 ± 2.2 mm/y over the 1993–2008 period, when the SLR data are of the highest quality. While the stability (rate) of the scale is –0.18 mm/y for ITRF2008P, for ITRF2008D is only –0.04 mm/y, both having a sigma of 0.01 mm/y.

Following the development of ITRF2005 ILRS' AWG took extreme care to eliminate systematic effects in the data, by resolving their source and correcting for them or by allowing for the estimation of appropriate parameters during the data reduction process. The primary concern of all AC analysts treating the same data with exactly the same measurement biases was also addressed and the AWG adopted the establishment and the maintenance of a "Data Handling" file in a quasi-SINEX format (machine readable), either known from engineering tests or detected during the analysis. With the accuracy of the results reaching a few millimeters at worst, even small biases of comparable magnitude cause discontinuities in the TRF and force the introduction of ad hoc "breaks" in the

series which must be avoided at all costs since they cause instability in the end-product. The “Data Handling” must be interrogated every time one analyzes SLR data since it is updated frequently. To aid users a “version” and date of last update are included in the file, and they are changed when a new entry is inserted. This file is maintained by DGFI and can be accessed from:

<http://ilrs.dgfi.badw.de/data_handling/ILRS_Data_Handling_File.snx>

A similarly formatted file called the “Discontinuities File” has been established in order to keep track of the various events at each site of the network that mark the different periods of operation of each site between changes (that result in a functionally/operationally different system). This file is also maintained by DGFI and can be accessed from:

<http://ilrs.dgfi.badw.de/data_handling/ILRS_Discontinuities_File.snx>

The “Discontinuities File” is of more interest to the ITRF developers and users, rather than to the SLR analysts.

During 2009 the European Space Agency Space Operations Center (ESOC) underwent benchmark activities to become an official ILRS Analysis Center under the codename “ESA”. Most of the testing formalities were successfully completed at the end of 2009, and ESA joined the ILRS AWG as the ninth AC in early 2010.

Meetings

The ILRS held a number of meetings in 2010. The first one was the Governing Board meeting at the EGU in Vienna, Austria, followed by meetings of various Working Groups including the AWG. There was no International Laser Workshop in 2010, nor a Technical Workshop, however, in the fall, in conjunction with the IAG Commission 1 Symposium on Reference Frames for Applications in Geosciences, in Marne-la-Vallee, France, October 04–08, 2010, we held a second ILRS Analysis Working Group Meeting, on October 01, 2010. In addition to these two main events, the ILRS participated in several international meetings and held several internal meetings of its Central Bureau (<http://ilrs.gsfc.nasa.gov/about_ilrs/meetings.html>).

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