The new satellite laser ranging system at Metsähovi

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Abstract.

The new satellite laser ranging system at Metsähovi began regular operation in January 1998. During the first year 369 passes with 54 424 accepted observations from 13 satellites were obtained. The mean precision of the range measurements for the near-Earth satellites was 31 mm and for Lageos 25 mm. This report reviews briefly the instrumental status and performance of the new satellite laser.

Introduction

Satellite range measurements at the Metsähovi Geodetic Observatory were initiated in 1978 with the use of a ruby satellite laser. The pulse length of the Q-switched ruby laser was 20 ns, and the ranging precision achieved was about 0.5 m [1]. As a partial upgrade the laser pulse length was shortened to 4.5 ns by an electro-optical shutter in 1985 [2]. In 1993, a 4-ns Nd:YAG laser was taken into use, which has allowed ranging measurements of about 10-cm precision [3]. As a further improvement, construction of a new satellite laser was launched in 1993. A 1-m laser telescope from the Latvian University at Riga was installed in November 1994. Some development of mode-locked Nd:YAG laser technology resulting in 50-ps pulses was done previously. After some principal modifications of the telescope, preliminary operational status was achieved in August 1997. During 1998 both the old (7805) and new (7806) systems have been in regular use. Preliminary evaluation of the ranging data shows a precision of about 25 mm, which is 20 times better than the initial precision 20 years ago and about 5 times better than that of the old system.

Equipment

The main specifications of the new satellite laser are given in Table 1. A passively Q-switched and mode-locked Nd:YAG laser with a self-filtering unstable resonator [4,5] was installed in the instrument room near the new telescope upon an iron table. The initial model used cavity dumping, a method that efficiently produces a single pulse. Unfortunately the Pockels cell was slowly damaged by the high internal power density. A different variant, in which the laser power is coupled continuously out, was then used. This method results in a comblike pulse train, about 5–10 short pulses separated by the round-trip travel time of the resonator (13.436 ns, corresponding to twice the 2.014-m optical length of the resonator). From this train an electro-optical shutter passes about half the trailing pulses, the so-called semitrain containing 3–4 pulses. The semitrain goes through a double-pass amplifier and is finally converted to green clour (532 nm) by a potassium titanyl phosphate (KTP) second harmonic crystal. The pulse length is nominally 50 ps, the pulse energy is limited to 10 mJ and the pulse rate is 1 Hz.

The laser telescope has 1-m diameter Cassegrain-Mangin optics, used in common for the transmitted and received beams. At the Metsähovi scheme an aperture-sharing method is used, in which the transmitted beam is shifted from the optical axis and passes unobstructedly between the primary and secondary mirrors. Beam divergence can be changed by moving the negative input lens. The receiver path goes outside the transmitter 45-degree mirror through the field-limiting aperture and an interference filter to the photomultiplier. In this case the effective receiver area is decreased by about 15% from the original model, in which two rotating mirrors were used to separate the beams. The tracking is controlled by a PC. The telescope also has a visual channel separated from the receiving channel by a dichroic mirror. An image amplifier, a CCD camera and a PC are used to monitor the satellite, when visible, during tracking. The mount accuracy with error modelling is better than 30 arcsec (rms).

In the receiver a fast photomultiplier is used as the detector. Pulse timing is done with a fast constant-fraction timing discriminator. The time interval is measured by an event timer measuring the delay with 20-ps precision and also the transmit epoch with 400-ns precision. The system time is syncronized with a second tick from the GPS station clock. A third PC is used to control the time interval counter and range gating and to calculate the predicted orbits. The start pulse is formed by channelling a small sample from the transmitted beam to the receiving channel. In the scheme employed, a common detector is used for start and stop pulses. Although use of the common detector is a good preventive measure against drifts [6], its use is rare. The system delay was determined by measuring laser time intervals to the external calibration prisms at distances of 320.700 m and 11.236 m. An electronic calibrator was used to monitor the status of the time interval counter. Weather data are taken once during the pass.

Satellite ranging results

The following 13 satellites were observed in 1998: TOPEX, ERS-2, Stella, Ajisai, ERS-1, GFO-1, Lageos-1, Geos-3, Starlette, Resurs, Westpac, Fizeau, and Lageos-2. The number of passes and observations with their mean rms precisions are given in Table 2. Data preprocessing is more complicated than with single pulses due to the possible presence of multiple levels at the ranges measured (Figure 1). In this plot the time bias is adjusted and the mean observed deviation from the predicted orbit is removed. The levels are combined with the main track in the folding process, which adjusts the subranges by 2.014 m or its multiples (Figure 2). The observations are then screened by analytical Kepler (Sterne) orbit fitting or by polynomial fitting to the observed range deviations with respect to the calculated ranges using automatic adaptive median filtering of the deviations [7] (Figure 3). Finally, the field generated normal points, i.e. representative single range measurements over specified averaging times (120 s for Lageos, 15 s for remote sensing satellites and 30 s for the other neare-Earth satellites), are formed and sent to the Eurolas Data Centre in Germany. The precision of the normal points have been 5–10 mm (Figure 4). Weekly reports from the University of Texas at Austin/Center for Space Research indicate that the possible range bias is quite stable and may be within 20 mm.

Future work

Tracking of near-Earth satellites and Lageos at night-time has been nearly satisfactory, but the tracking capability in daylight or tracking of far-orbiting satellites is still missing. The transmitted energy can be simply boosted several times by an added laser preamplifier. Installation of a parallel laser system using a 150-ps, 50-mJ Nd:YAG laser, working on the Brillouin pulse compression principle, is also under preparation. Daylight tracking needs improvements in the accuracy of the mount and installation of the existing narrow band (0.3 nm) holographic filter. The receiving efficiency can be improved 3–4 times by introduction of a photon counting mode avalanche photodiode detector.

Table 1. Specifications of the new Metsähovi satellite laser ranging system

Laser	Nd:YAG oscillator with polarization-coupled self-filtering unstable resonator, passive dye Q-switching and mode-locking, external semitrain gating (3–4 pulses), double-pass amplifier, KTP second harmonic crystal (60% eff.), wavelength 532 nm
Pulse duration	50 ps nominal (not measured)
Laser energy	10 mJ at 532 nm (first pulse), 25 mJ overall maximum
Repetition rate	1 Hz
Receiving and transmitting optics	1-m diameter Cassegrain-Mangin, focal length 11.6 m, secondary mirror 0.25 m dia., receiving beam angle 30-120 arcsec, transmitting beam in off-axis position, exit beam diameter 30 cm, beam angle variable 5-40 arcsec, static mirrors only
Visual optics	visual channel in common with the main optics, dichroic mirror, image amplifier, CCD camera controlled by PC-No. 3
Telescope mount	Azimuthal, model TPL-1 by the Latvian University, Riga, step motor-driven, one step equal to 1 arcsec, controlled by PC-No. 1 with hardware and software from Riga, manual offsets, electromechanical shutters protecting photomultiplier and image amplifier
Detector	Hamamatsu R4998 photomultiplier, quantum efficiency 8% Start and stop pulses have common photomultiplier and timing discriminator
Preamplifier	Gain 5 V/V, 1-GHz bandwidth
Interference filter	3-nm bandwidth
Time interval counter	COMTIS 911E from Riga, 20 ps rms, includes epoch registering and range gate, uses PC-No. 2, external frequency from a hydrogen maser or BVA crystal oscillator
Timing processor	Ortec 9307 pico–Timing discriminator
Time syncronization	TRAK Systems 8810 GPS Station Clock
Calibration	External corner cubes, distances 320.700 m and 11.236 m Counter calibrated by external electric double pulses
Range noise	30 mm (rms) to close-Earth satellites 25 mm (rms) to Lageos (measured range 8612 km) 12 mm (rms) at laser calibration
Weather instruments	Pressure sensor Vaisala PTB200A, accuracy 0.2 hPa Temperature sensor Vaisala HMP35D, accuracy 0.2 K Humidity sensor Vaisala HMP35D, accuracy 3%

Table 2. Satellite observations with the new laser in 1998

Satellite	Passes	Observations	RMS (m)
TOPEX/Poseidon	96	22928	0.038
ERS-2	64	6231	0.025
Stella	56	5550	0.026
Ajisai	34	4478	0.036
ERS-1	29	2267	0.032
GFO-1	22	1831	0.025
Lageos-1	21	6702	0.025
Geos-3	19	3337	0.048
Starlette	11	433	0.025
Resurs	6	210	0.023
Westpac	5	91	0.020
Fizeau	4	113	0.016
Lageos-2	2	253	0.023
Total	369	54424	

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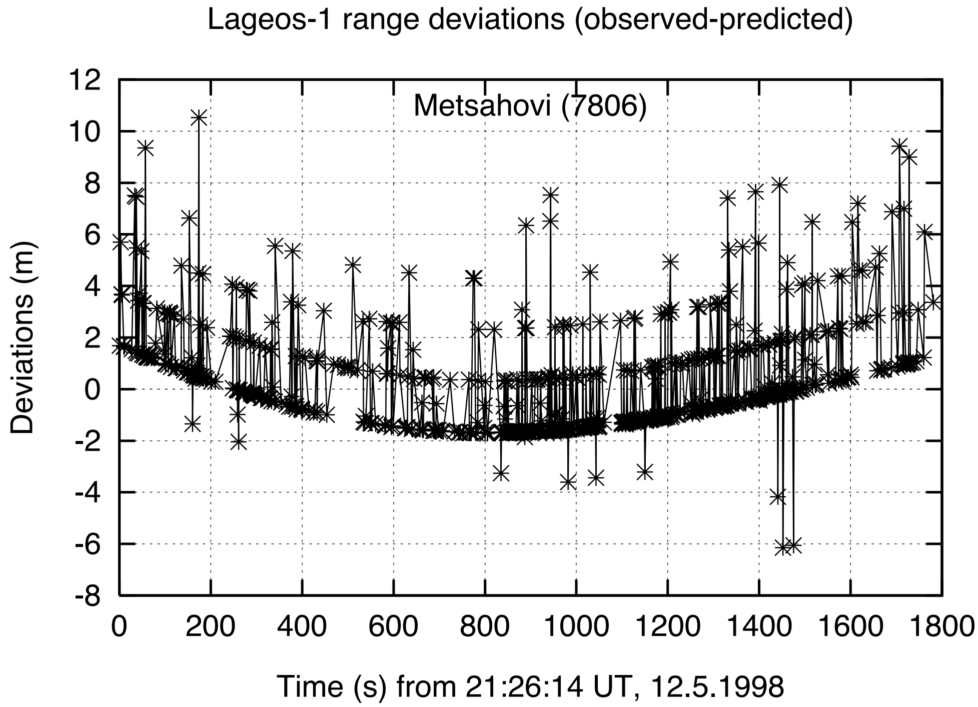

Figure 1: Raw observed range deviations

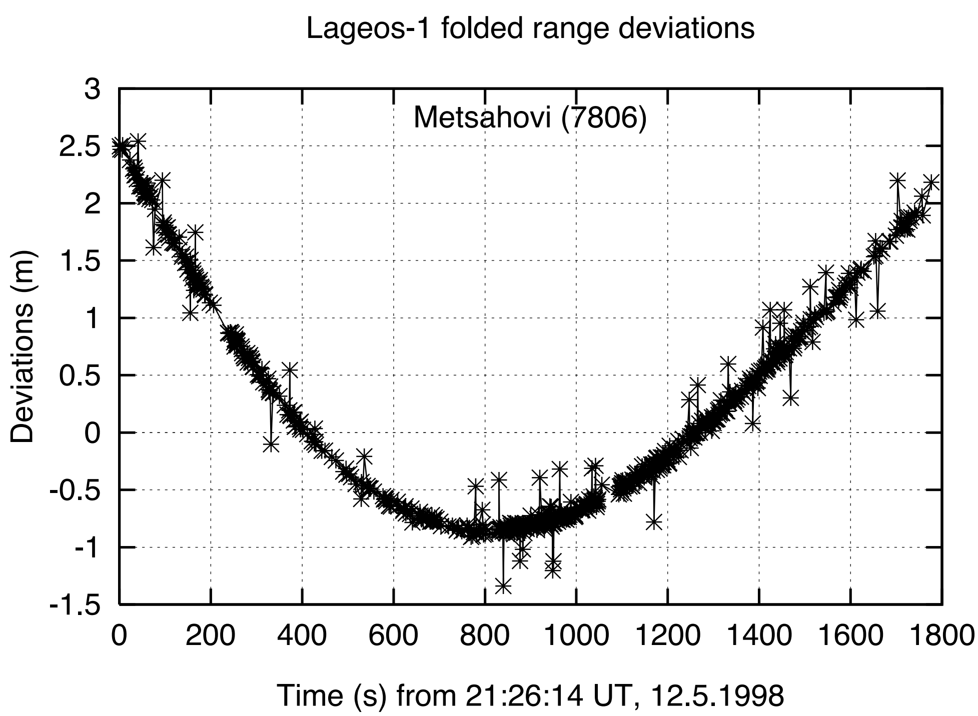

Figure 2: Range deviations after folding

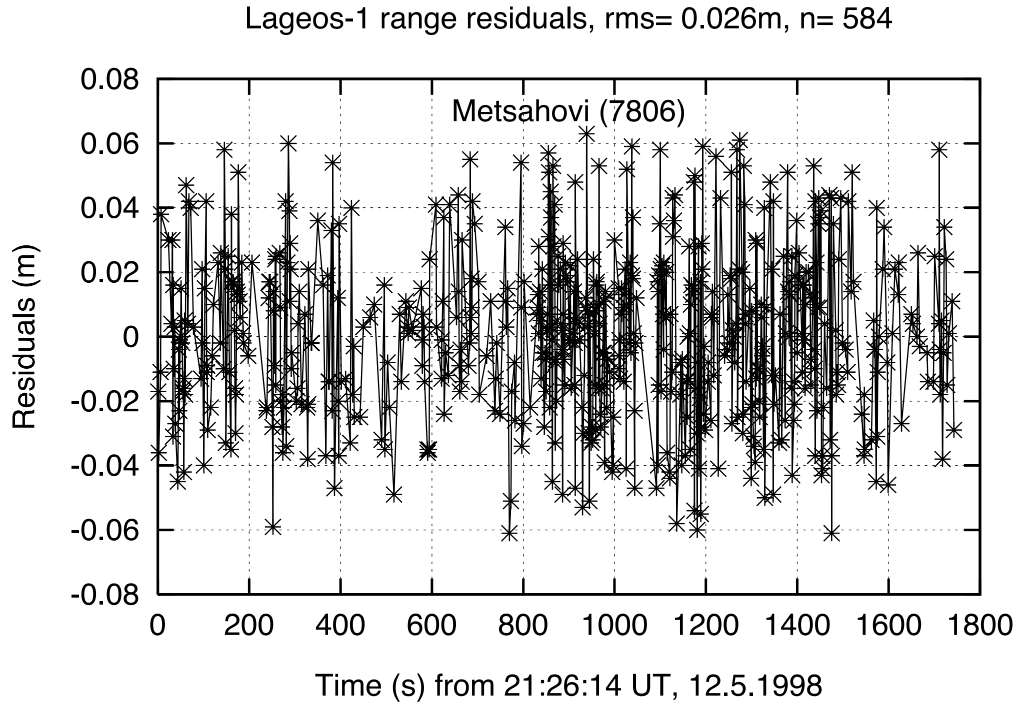

Figure 3: Filtered range residuals

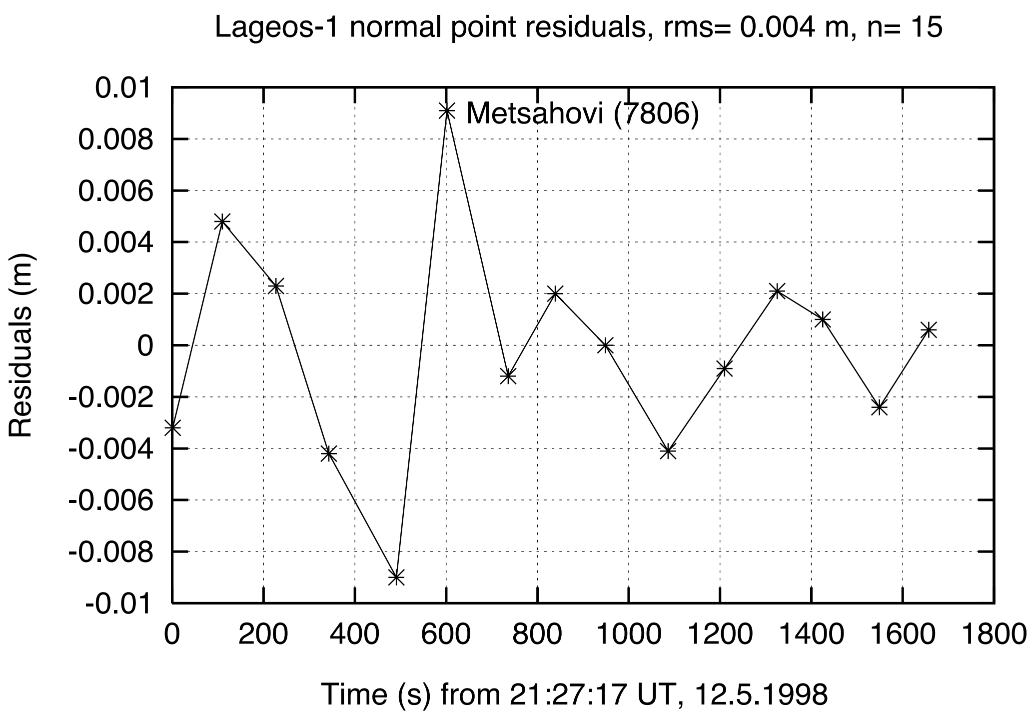

Figure 4: Normal point (120 s) range residuals