ATMOSPHERIC CONTRIBUTION TO THE LASER RANGING JITTER

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Abstract

We are reporting on the theory and experiments related to the atmospheric fluctuations and their contribution to the laser ranging jitter. The millimeter precision ground target laser ranging at the 2 kHz repetition rate enabled us to reveal the short period atmospheric fluctuations contribution to the laser ranging error budget. The amplitude and the time spectrum have been investigated for the first time on the picosecond resolution level. The relation of this effect to the seeing conditions has been investigated.

Goals

- Investigate contribution of rapid atmospheric fluctuations (turbulence) to the laser ranging error budget
- Correlate the measured turbulence contribution with instantaneous atmospheric conditions (seeing)
- Investigate the time spectrum of the observed fluctuations
- Prove the existing theory by the first direct experiment

Philosophy

- Enjoy the high repetition rate, millimeter precision laser ranging station Graz, Austria
- Determine the turbulence contribution to the overall ranging jitter by numerical analysis of the raw ranging data
- Parallel measurement of astronomical seeing to determine the turbulence strength along the beam path
- Compare the results to theoretical predictions - correlation

Theoretical Background

- Turbulent mixing of air of different temperatures → random fluctuation of refractive index along the beam path → random changes of the measured range

- Gardner (1976) derived analytical formula for prediction of the turbulence-induced ranging jitter:

$$RMS = 5.1\, L_0^{5/6} \sqrt{\int_0^L C_n^2(x)\,dx}$$

(Greenwood-Tarazano spectral model used)

L_o .... outer scale of turbulence
$C_n^2(x)$ ... turbulence strength along the beam path
L .... target distance

GARDNER, C. S. *Effects of random path fluctuations on the accuracy of laser ranging systems*. Applied Optics, 1976, vol. 15, no. 10, p. 2539–2545.

Obtaining the Model's Parameters

- L_o ... size of the largest turbulent eddies
  - horizontal path: L_0 is between $h/2$ and h, where h is the beam height above the surface*
  - slant path to space: L_0 generally unknown, existing estimates from 5 up to 300 meters, varies with height

- C_n^2 ... turbulence strength
  - its integral along the beam path can be determined from the seeing measurement on the same path

* *Handbook of Optics*, McGraw-Hill, 1992. Vol. 1, Chapter 44, Atmospheric Optics.

Laser Ranging Experiment Setup I

- Satellite laser station Graz, altitude 500 m above sea
- laser 2 kHz @ 532 nm, 8 ps
- detector: C-SPAD, ET timing, precision 1 mm RMS

The laser telescope in Graz

Mask for ground target ranging

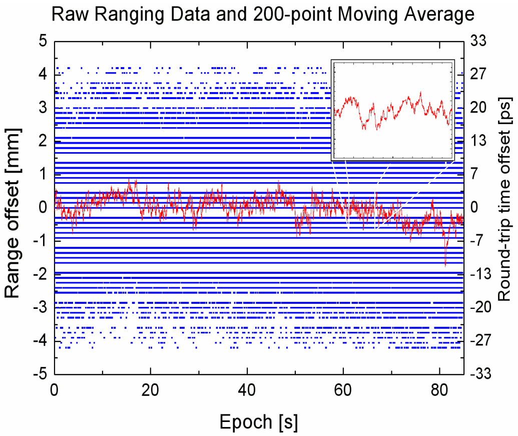
Laser Ranging Experiment Setup II

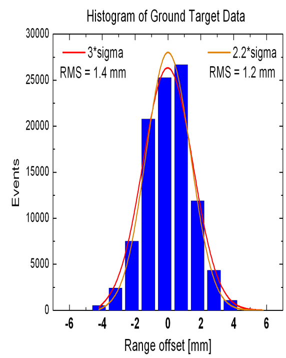
- Targets:
  - ground-based retroreflector installed 4.3 km from the observatory; average beam height ~ 50 m above ground
  - satellites with low signature and high return energy (ERS-2, Envisat, pass segments selected)

4.3 km distant retroreflector illuminated by the laser

Ground Target Ranging

Graz, 2004-05-10, 09:30 UTC, 1.2 kHz return rate





Ground Target Ranging

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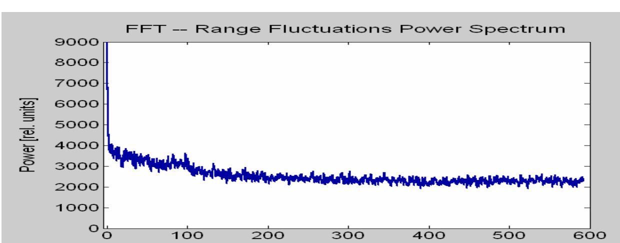
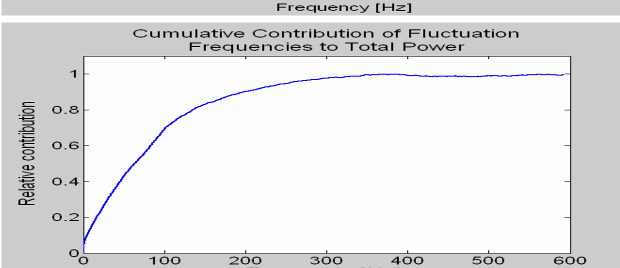




Ground Target Ranging – Results

Graz, 2004-05-10, 09:30 UTC, 1.2 kHz return rate

Results of numerical analysis:

Overall jitter

1.4 mm RMS

=

Instrumental noise + Turbulence-induced jitter

1.2 mm RMS 0.6 mm RMS

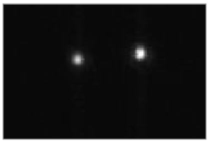
Extraction of turbulence contribution from the raw data:

- Much higher sampling rate (>1 kHz) than maximum frequencies of turbulent fluctuations (<200 Hz)
- Instrumental noise is random shot-to-shot */ turbulent fluctuations are correlated within several shots ("waves")*

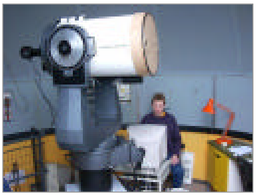
➔ moving averaging

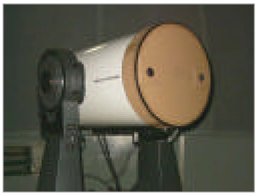
Seeing Measurement

- DIMM (Differential Image Motion Monitor)
  – standard astronomical site-testing technique
- Statistics of mutual movement of 2 images of a distant source
- Short exposure times 5 ms
- Hartmann mask + slightly defocused telescope (MEADE 16'')
- Targets 1) 2.8 km distant red bulb (day + night)
  2) bright star (night only)

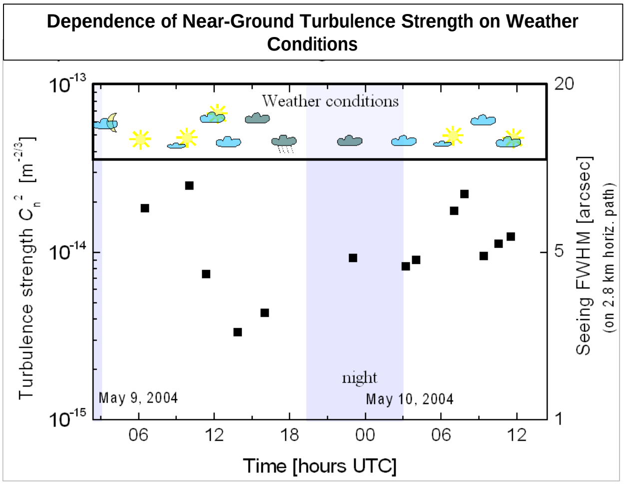


Bulb, FOV 2 arcmin,
1 arcsec/pixel,
seeing 4.6 arcsec

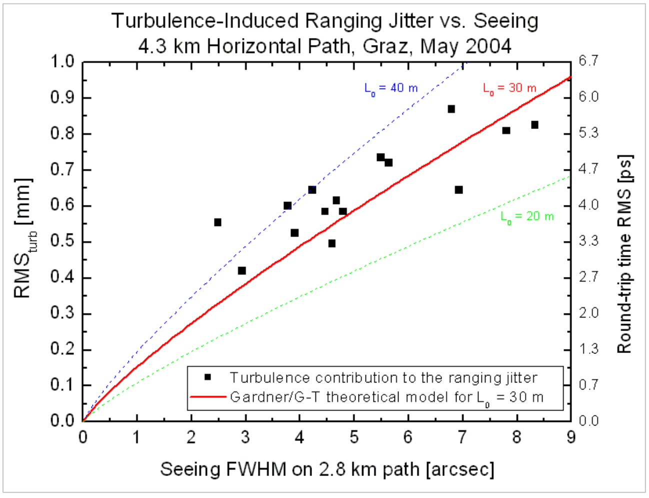




Seeing Measurement - Results



Comparison of Theory and Experiment Horizontal Path



Satellite Laser Ranging Results

- Typical seeing measured on a star: 2 arcsec → Gardner's theory ~ 0.3 mm RMS for L_0 = 100 m
- Measurement → turbulence contribution 2 arcsec seeing ~ 0.3 mm RMS (good agreement)
- The major observed range fluctuations are completely random shot-to-shot → not caused by turbulence

Conclusion

- Atmospheric turbulence contribution to the laser ranging jitter has been proved and directly measured
- Observed contribution: RMS 0.4–0.9 mm 4.3 km horiz. path
~ 0.3 mm for satellites
- Maximum frequencies of atmospheric fluctuations: ~200 Hz
- Correlation between atmospheric conditions and turbulence-induced ranging jitter was found (good agreement with Gardner)
- Further measurements under various atmospheric conditions are planned to improve the statistics