

Atmospheric Contribution to the Laser Ranging Jitter

Lukas Kral, Ivan Prochazka (1)

Georg Kirchner, Franz Koidl (2)

Wolfgang Voller (3)

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(1) Czech Technical University in Prague, Czech Republic

(2) Satellite Laser Station Graz Lustbuehel, Graz, Austria

(3) Austrian Academy of Sciences

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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:

$$RMS = 5.1 L_0^{5/6} \sqrt{\int_0^L C_n^2(\square) d\square}$$

(Greenwood-Tarazano spectral model used)

L_0 outer scale of turbulence

$C_n^2(\square)$... 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_0 ... 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)

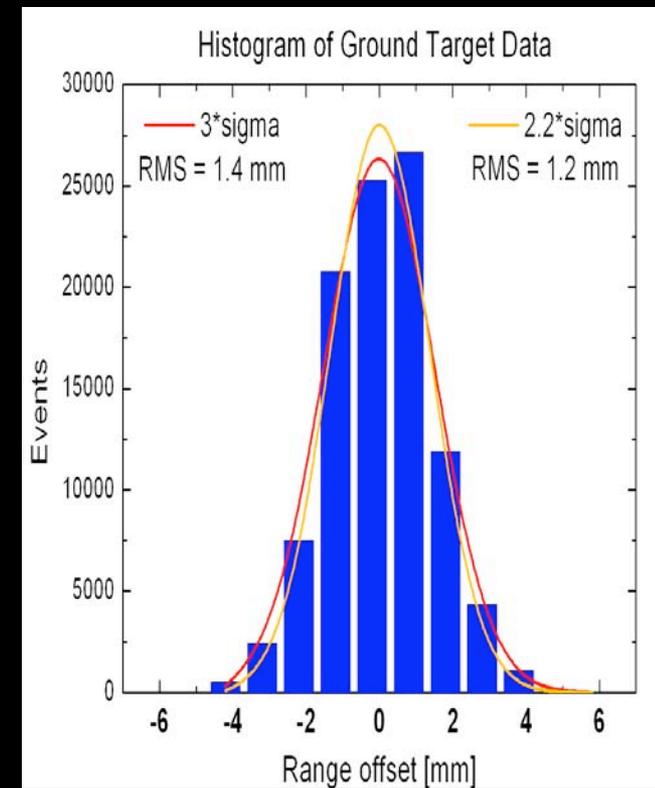
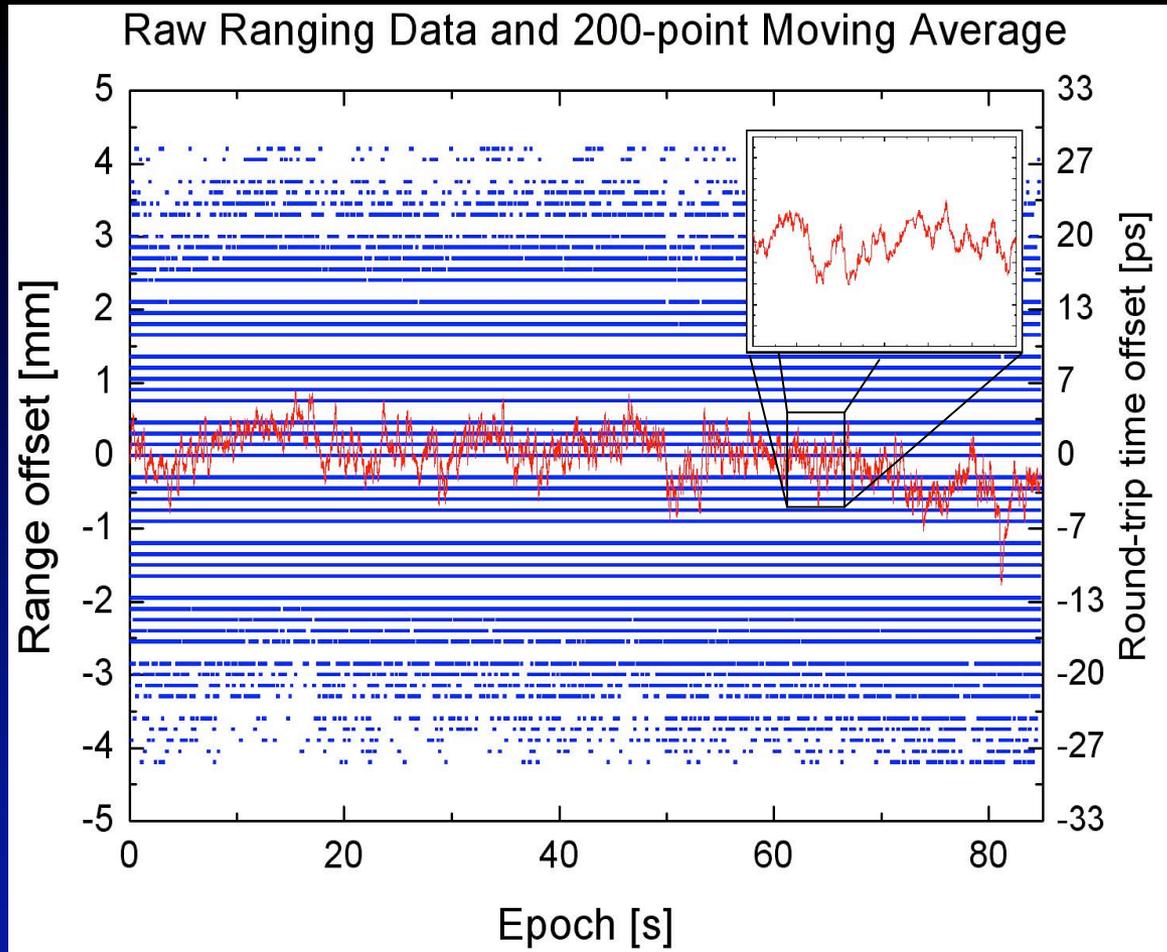


4.3 km distant retroreflector illuminated by the laser

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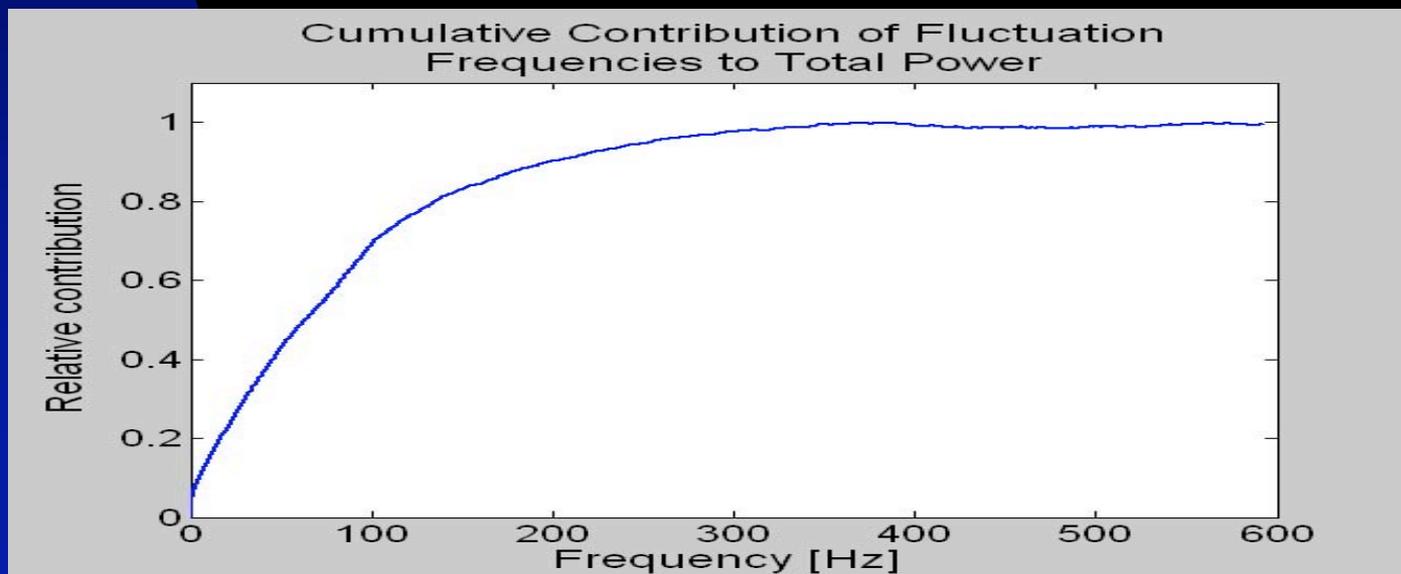
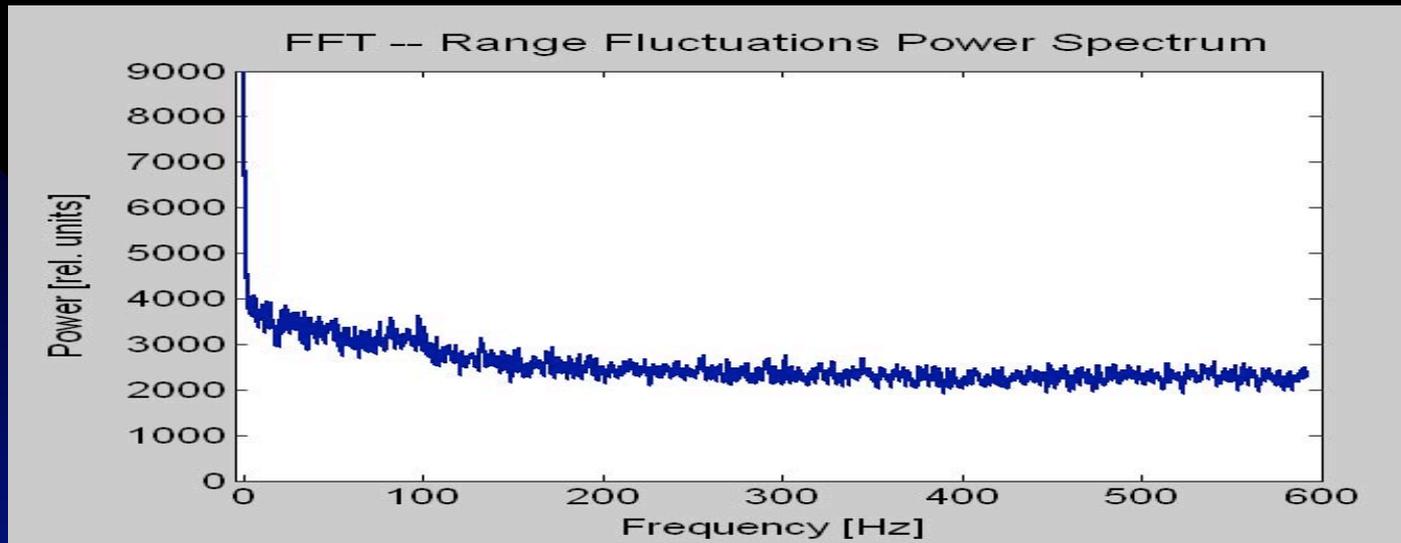
Ground Target Ranging

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



Ground Target Ranging

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



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

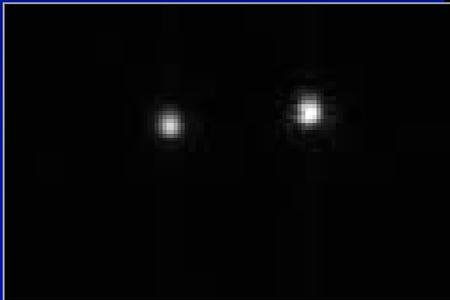
0.6 mm RMS

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)

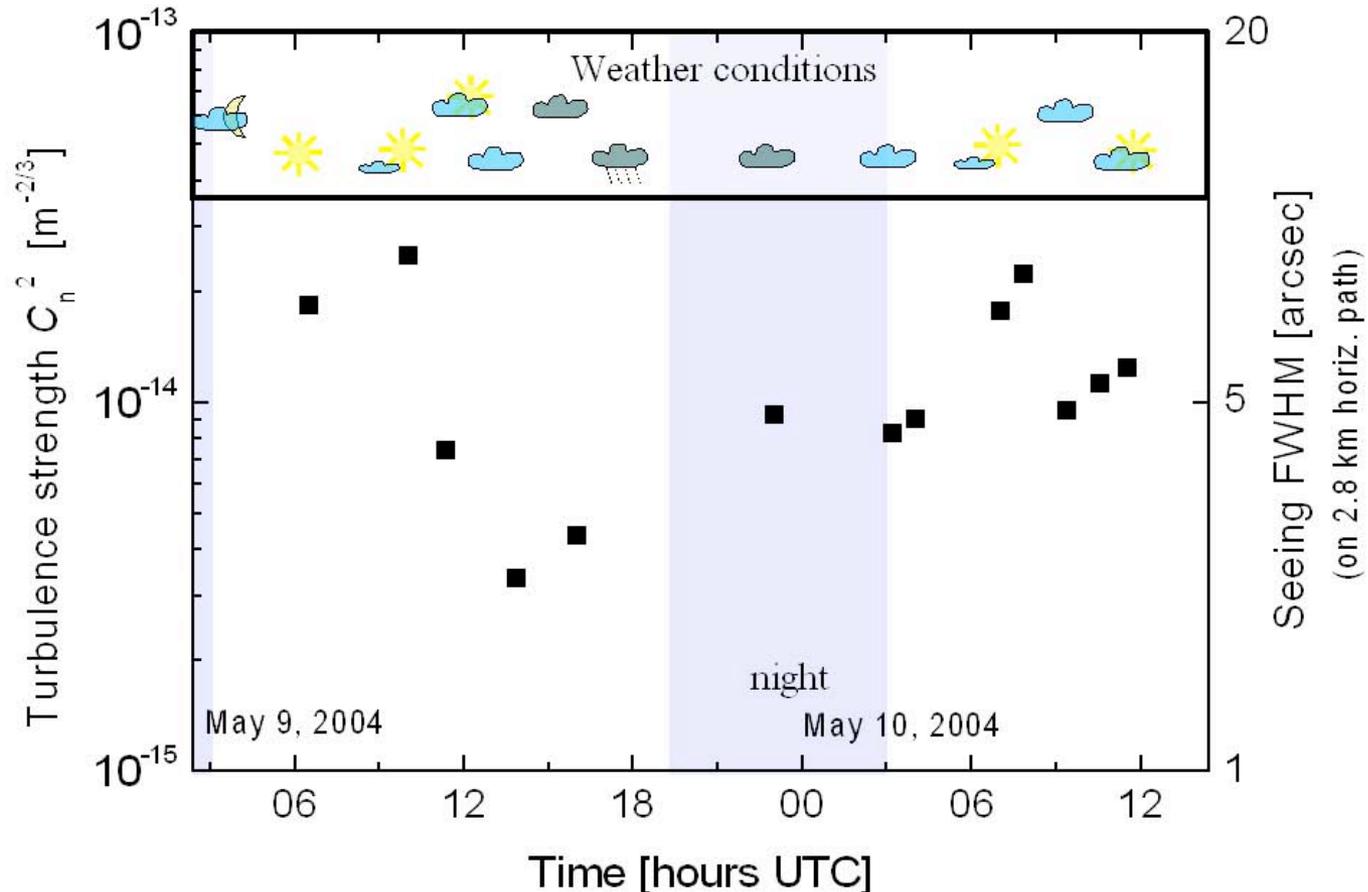


Bulb, FOV 2 arcmin,
1 arcsec/pixel,
seeing 4.6 arcsec

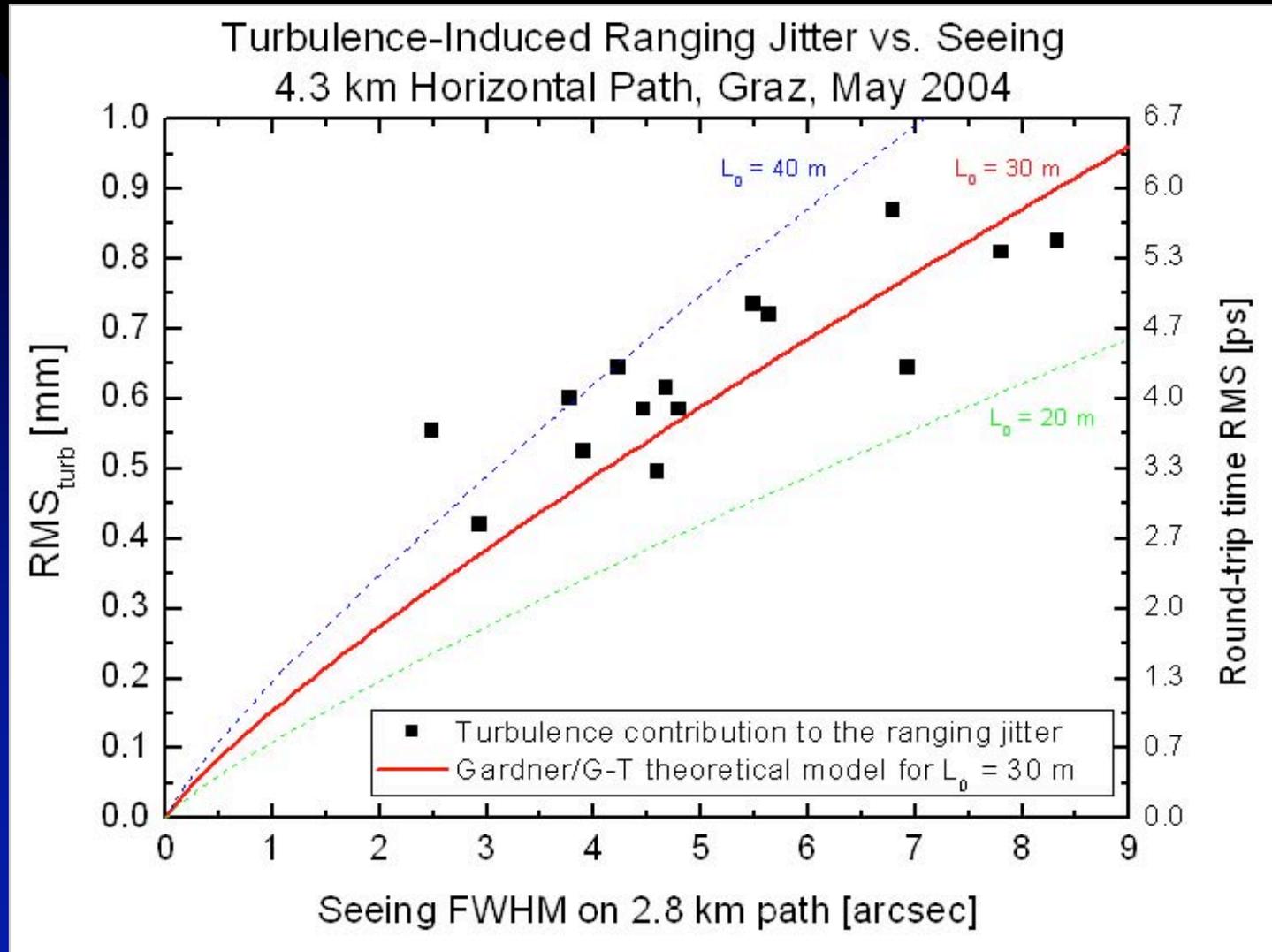


Seeing Measurement - Results

Dependence of Near-Ground Turbulence Strength on Weather Conditions



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
- The “1 = > 3 mm” error source is not the atmosphere