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Astronomical seeing conditions as determined by turbulence modelling and optical measurement

by

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Astronomical seeing conditions as determined by turbulence modelling and optical measurement

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Abstract

Modern space geodetic techniques are required to provide measurements of millimetre-level accuracy. A new fundamental space geodetic observatory for South Africa has been proposed. It will house state-of-the-art equipment in a location that guarantees optimal scientific output. Lunar Laser Ranging (LLR) is one of the space geodetic techniques to be hosted on-site. This technique requires optical (or so-called astronomical) seeing conditions, which allow for the propagation of a laser beam through the atmosphere without excessive beam degradation. The seeing must be at ~ 1 arc second resolution level for LLR to deliver usable ranging data. To establish the LLR system at the most suitable site and most suitable on-site location, site characterisation should include a description of the optical seeing conditions. Atmospheric turbulence in the planetary boundary layer (PBL) contributes significantly to the degradation of optical seeing quality. To evaluate astronomical seeing conditions at a site, a two-sided approach is considered – on the one hand, the use of a turbulence-resolving numerical model, the Large Eddy Simulation NERSC (Nansen Environmental and Remote Sensing Centre) Improved Code (LESNIC) to simulate seeing results, while, on the other hand, obtaining quantitative seeing measurements with a seeing monitor that has been developed in-house.

Keywords: optical turbulence, astronomical seeing, large eddy simulation, seeing monitor, Lunar Laser Ranging (LLR).

List of Publications

The following contributions have been published in peer review journals or proceedings as part of this work or related to it.

1. **Nickola, M.**, Botha, R.C., Esau, I. and Djolov, G.D. and Combrinck, W.L. 2011. Site characterisation: astronomical seeing from a turbulence-resolving model. *South African Journal of Geology*, **114**(3-4): 581-584.
2. **Nickola, M.**, Esau, I. and Djolov, G. 2010. Determining astronomical seeing conditions at Matjiesfontein by optical and turbulence methods. *IOP Conference Series: Earth and Environmental Science*, **13**(1): 012010.
3. **Nickola, M.**, Botha, R. and Combrinck, W.L. 2009. Investigation of techniques to determine astronomical seeing conditions at Matjiesfontein. *Proceedings of the South African Geophysical Association 2009 Biennial Technical Meeting and Exhibition "Ancient rocks to modern techniques"*. Swaziland, 16-18 September 2009: 598-602.

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Declaration

I, Marisa Nickola, hereby declare that the work on which this thesis is based, which I hereby submit for the degree Master of Science, Faculty of Natural and Agricultural Sciences at the University of Pretoria, is my own work except where acknowledgements indicate otherwise. This work has not previously been submitted by me for another degree at this or any other tertiary institution.

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List of Abbreviations and Acronyms

AA	: Angle of Arrival
AC	: Achromatic
A/D	: Analogue to Digital
ADC	: Analogue-to-Digital Conversion
AGAP	: Astronomy Geographic Advantage Protection
alt-az	: altitude-azimuth
APO	: Apochromatic
APOLLO	: Apache Point Lunar Laser-ranging Operation
AWS	: Automatic Weather Station
C-BASS	: C-Band All Sky Survey
CCD	: Charge-Coupled Device
CFL	: Courant-Fridrihs-Levi
CO-SLIDAR	: COupled SLodar scIDAR
CRF	: Celestial Reference Frame
CTIO	: Cerro Tololo Inter-American Observatory
D/A	: Digital to Analogue
DB64	: DATABASE64
DC	: Direct Current
Dec	: Declination
DIMM	: Differential Image Motion Monitor
DNS	: Direct Numerical Simulation
Dobs	: Dobsonian
DORIS	: Doppler Orbitography and Radiopositioning Integrated by Satellite
EOP	: Earth Orientation Parameters
FF	: Full-Frame
FL	: Focal Length
FOV	: Field Of View
FWC	: Full-Well Capacity
FWHM	: Full Width at Half Maximum
G-SCIDAR	: Generalised SCIDAR
GE	: German Equatorial
GEM	: German Equatorial Mount
GNSS	: Global Navigation Satellite System

GPS	: Global Positioning Satellite
GSM	: Generalized Seeing Monitor
GUI	: Graphical User Interface
HartRAO	: Hartebeesthoek Radio Astronomy Observatory
HVR-GS	: High Vertical Resolution G-SCIDAR
IAC	: Instituto de Astrofisica de Canarias
IEEE	: Institute of Electrical and Electronics Engineering
IL	: InterLine
ING	: Isaac Newton Group of Telescopes
IPEV	: Institut Polaire Français Paul Emile Victor
KAT	: Karoo Array Telescope
LES	: Large Eddy Simulation
LESNIC	: Large Eddy Simulation NERSC Improved Code
LLR	: Lunar Laser Ranging
LOLAS	: Low Layer SCIDAR
LuSci	: Lunar Scintillometer
M-N	: Maksutov-Newtonian
MASS-DIMM	: Multi-Aperture Scintillation Sensor - Differential Image Motion Monitor
MeerKAT	: Karoo Array Telescope (larger array)
MLRO	: Matera Laser Ranging Observatory
MLRS	: McDonald Laser Ranging Station
NERSC	: Nansen Environmental and Remote Sensing Center
ORM	: Observatorio del Roque de los Muchachos
OCA	: Observatoire de la Côte d'Azur
OS	: Operating System
OTA	: Optical Tube Assembly
PBL	: Planetary Boundary Layer
PBL	: Profileur Bord Lunaire (or Lunar Limb Profiler)
PE	: Periodic Error
PEC	: Periodic Error Correction
PMT	: Photo-Multiplier Tube
PNRA	: Programma Nazionale di Ricerche in Antartide
PPEC	: Permanent Periodic Error Correction

PSF	: Point Spread Function
RA	: Right Ascension
RANS	: Reynolds-Averaged Navier-Stokes
RC	: Ritchey-Chrétien
RFI	: Radio Frequency Interference
RH	: Relative Humidity
S/LLR	: Satellite/Lunar Laser Ranging
S-N	: Schmidt-Newtonian
SAAO	: South African Astronomical Observatory
SALT	: South African Large Telescope
SAWS	: South African Weather Service
SBL	: Stably stratified planetary Boundary Layer
SCIDAR	: SCIntillation Detection And Ranging
SCT	: Schmidt-Cassegrain Telescope
SHABAR	: SHAdow BAnd Ranging
SI	: Scintillation Indice
SKA	: Square Kilometre Array
SLODAR	: SLOpe Detection And Ranging
SLR	: Satellite Laser Ranging
SNODAR	: Surface layer NOn-Doppler Acoustic Radar
SODAR	: SOnic Detection And Ranging
TRF	: Terrestrial Reference Frame
USB	: Universal Serial Bus
VLBI	: Very Long Baseline Interferometry
WF	: Weighting Function