# 6. Combination of methods

## 6.1. Introduction

In this chapter the use of a two-sided complementary approach to numerically model and experimentally measure seeing at a site is proposed. Seeing parameter values may be obtained from numerical modelling with LESNIC and also by experimental measurement with a seeing monitor. It should be possible to compare seeing values obtained by these two methods to verify whether modelled results obtained with LESNIC may be used in conjunction with measured results from the seeing monitor to predict the seeing at a site. Calibration of modelling will be accomplished by employing the measured results. The two-sided approach is an attempt at integrating methods from boundary layer meteorology and astronomical seeing. If seeing conditions could be connected to weather conditions, it would be possible to forecast seeing at a site. Experimental techniques alone cannot cover the almost infinite state of the PBL and also do not offer longer term prediction capability. On the other hand, LESNIC is based on prognostic equations and can thus be used as a predictive tool with due consideration of its limitations.

## 6.2. Proposed two-sided approach

To evaluate astronomical seeing conditions at a site, a two-sided approach is proposed – 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) while, on the other hand, obtaining quantitative seeing measurements with a seeing monitor. The latter should be used to verify and calibrate results produced by the LESNIC model.

Seeing monitor data should be compared with modelled results: (1) to determine whether LESNIC is suitable for modelling seeing conditions and, if so, (2) to fine-tune the model to make its seeing quality predictions more accurate and also (3) to calibrate the model. If a good correlation between actual seeing quality and the LESNIC model's predicted results can be found, it would be possible to employ meteorological data together with the

LESNIC model to select a suitable observing site as well as to forecast seeing quality at the site.

Seeing may be quantified in two ways: (1) theoretically, by making use of statistical parameters from the Kolmogorov model of turbulence (Kolmogorov, 1941) as developed by Tatarski (1961) and Fried (1965 & 1966) and (2) experimentally, by comparison of ideal and observed images.

An integrated approach should be followed to determine the seeing conditions at a site –

- On-site data collection with seeing monitor to provide seeing and Fried parameter values as follows:
    1. Capture image of bright star.
    2. Determine FWHM of star's intensity profile (PSF).
    3. Obtain seeing $\varepsilon_{FWHM}$ from FWHM using Equation (3.7a).
    4. Calculate Fried parameter $r_0$ from seeing $\varepsilon_{FWHM}$ by using Equation (3.7b).
- On-site data collection with Automatic Weather Station (AWS) to provide meteorological parameters such as temperature, pressure, humidity, wind speed etc. used as input into LESNIC model to obtain seeing and Fried parameter values from LESNIC as follows:
    1. Obtain $C_N{}^2(h)$ profile from Equation (2.13), where profiles of $C_T{}^2(h)$, $T(h)$ and $P(h)$ are provided by DATABASE64 using Equation (3.1) to Equation (3.4).
    2. Calculate Fried parameter $r_0$ from $C_N{}^2(h)$ profile using Equation (2.20).
    3. Calculate seeing $\varepsilon_{FWHM}$ from Fried parameter $r_0$ using Equation (2.21).
- Comparison of seeing results ($r_{0_\mathrm{L}}$, $\varepsilon_{FWHM_\mathrm{L}}$) calculated with LESNIC model with measured seeing results ($r_{0_\mathrm{SM}}$, $\varepsilon_{FWHM_\mathrm{SM}}$).
- Calibration of LESNIC model by using measured seeing data to improve on LESNIC model and its parameters.
- Use of LESNIC to accurately forecast seeing conditions.

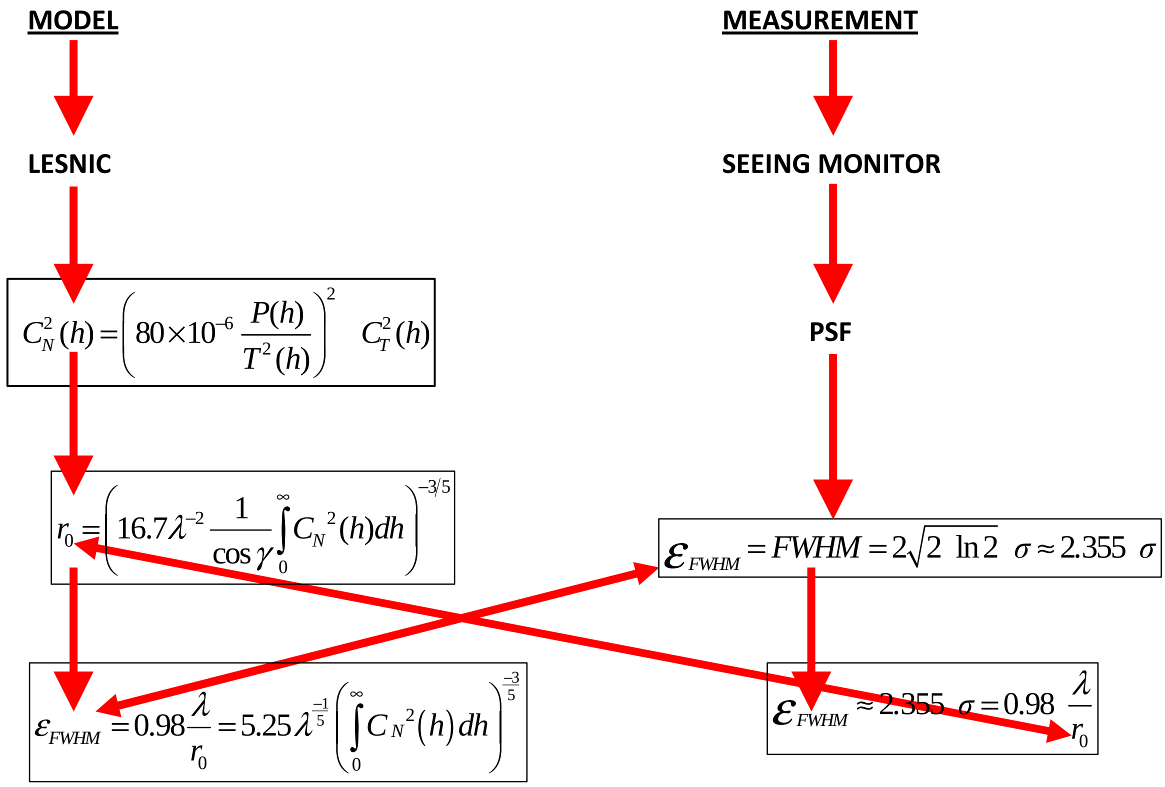


Figure 6.1. Comparison of modelled and measured Fried and seeing parameter results.

# 7. Conclusion

## 7.1. Summary

In summary, due to high atmospheric extinction, high levels of cloud cover and bad astronomical seeing, HartRAO as site is not suitable to collect LLR data from. It is therefore necessary to identify a new site for the location of a space geodetic observatory able to deliver data of international standard. The site must be suitable for hosting an LLR system. The LLR's laser beam is degraded by turbulence in the atmosphere, especially in the PBL. The LLR requires seeing conditions of at least 1"-2". A potential site must therefore be characterised with respect to seeing conditions. Measuring seeing at various locations on-site will assist in determining the most suitable location for the LLR. To determine seeing at a site, a two-pronged approach, combining methods from boundary layer meteorology and astronomical seeing, is envisaged. Atmospheric turbulence can be modelled with a turbulence-resolving model such as LESNIC. Optical seeing conditions can be measured quantitatively with a self-built seeing monitor. In conclusion, to follow, a discussion of the current situation, conclusions and future plans.

## 7.2. LESNIC

The effects of turbulence on the propagation of a laser beam from the Earth to the Moon and back again may be found by determining the vertical distribution of turbulence, the $C_N{}^2(h)$ profile. $C_N{}^2(h)$ profiles can be used to determine astronomical seeing conditions as part of site characterisation. *In situ* methods of determining astronomical seeing are difficult, time-consuming and costly in terms of equipment. In practical terms, it is impossible to carry out observations which cover all PBL conditions. Employing a turbulence-resolving model such as LESNIC, supported by measurement of meteorological parameters by means of meteorological instrumentation, would seem feasible for delivering and predicting $C_N{}^2(h)$ profiles.

The suitability of using LESNIC to model seeing conditions was investigated. The LESNIC model seems capable of reproducing observed $C_N{}^2(h)$ profiles and delivering seeing parameter values consistent with results from field campaigns as reported. Turbulence-resolving models, such as LESNIC, therefore show potential for delivering and predicting profiles and parameters to characterise astronomical seeing.

By making use of site-specific data for initial and boundary conditions as well as for topographic features and surface roughness, a turbulence-resolving model such as LESNIC may potentially be used to deliver and predict $C_N^{\,2}(h)$ profiles, which can then be used to determine astronomical seeing conditions as part of site characterisation. Numerical simulations will allow for determining conditions during specific observation periods and, more importantly, long-term seeing conditions as well.

## 7.3. Seeing monitor

Astronomical seeing parameters can also be measured by employing a seeing monitor on-site. Using the double star separation technique for verification and calibration purposes, and the PSF technique to measure the seeing $\varepsilon_{FWHM}$, the ideal PSF seeing monitor assembly must be able to deliver a resolution of better than 1 arc-second. The optimal combination of telescope, mount and CCD camera for the PSF technique was investigated. It resulted in the purchase of a second-hand 14" Meade LX200 GPS SCT with a computer-controlled heavy-duty alt-az fork-type mount as well as a Point Grey Grasshopper GRAS-20S4M CCD camera.

The newly acquired equipment and setup were tested during preliminary seeing measurements with the double star separation and PSF techniques outside the Matjiesfontein courthouse. The seeing monitor setup was verified by close agreement of an observed binary star separation and its stated value. Using the PSF technique, seeing was determined to be ~ 2", which agrees with previously determined seeing at Matjiesfontein.

Vibrations seem to be easily introduced to the fork-arm mount by any windy conditions and it takes a while for these vibrations to damp down. The alt-az fork-arm mount will have to be replaced with a GE mount eventually. The A-P 1600GTO GE mount was identified as the only mount with the required payload capacity. The 1600GTO is capable of carrying 90 kg. The added payload capacity may seem excessive, but wind loading also increases the effective load imparted to the mount. An enclosure would drastically reduce the wind load effect, and one of the smaller mounts listed in Table 4.1 may prove to be sufficient.

A Point Grey Grasshopper GRAS-03K2M-C CCD camera, together with Mac Mini, was also acquired with a view to adding the DIMM technique to the seeing monitor's repertoire. The DIMM technique is the standard technique used for site characterisation. SAAO has put their DIMM software, TimDIMM, at our disposal. All that is still required for the DIMM to be fully functional is a two-holed mask with wedge prism.

The intention is to also procure a PBL optical module and employ the PBL technique in future. The PBL technique's attraction lies in its making use of differential image motion of points along the Moon's limb. The LLR's laser beam is transmitted to, and reflected back from, retro-reflector arrays on the Moon. In the PBL configuration, the seeing monitor is therefore pointing in the same general direction and through a similar column of air as the LLR telescope. This would make it possible to model atmospheric refraction of the LLR's laser beam.

Immediate plans include a short seeing campaign using the PSF technique at the Matjiesfontein site. Setup for the DIMM technique - TimDIMM software and mask with wedge prism - should be completed by this time. Employing both the PSF and DIMM techniques would allow for cross-correlation of results and verification, validation and calibration of equipment.

The seeing monitor development will proceed at HartRAO as testing site. Control software and software for data processing and image analysis must be developed, streamlined and automated. The seeing monitor can be calibrated against the SALT MASS-DIMM at the SAAO site in Sutherland. The team from the University of Nice plans an extended seeing campaign using a PBL, GSM and LuSci, together with the SALT MASS-DIMM, at Sutherland in the near future. The possibility exists that the team would be able to fit in a short seeing campaign at Matjiesfontein. This would also present another opportunity to calibrate the self-built seeing monitor.

The short seeing campaign should give an indication of whether seeing conditions of better than the ~ 2", measured outside the Matjiesfontein courthouse, prevail at the site itself. For any potential site, though, site characterisation with respect to seeing will have to take place over a prolonged period of time to investigate seasonal variations in seeing. The best and the worst seeing conditions that can be obtained for a site will have to be investigated. Extended seeing campaigns should be planned at times when marked changes in meteorological conditions occur. Except for temporal variations in the seeing, spatial variations due to local topography dictate that seeing will have to be measured from various on-site locations and for different sectors of the sky. This would require the manufacture of a stable but portable steel pier to mount the seeing monitor on. The portable pier can then be bolted to foundations laid at the various on-site locations. During such campaigns, the seeing monitor will be protected from wind by screens, and from the rain by waterproof covering. Once the most suitable site and on-site location for the LLR have been identified, the seeing monitor will be set up as a permanent long-term site seeing monitor. It will be placed in an enclosure on a platform nearby the LLR.

## 7.4. Combination of methods

With the proposed two-pronged approach, the experimental results obtained with the on-site seeing monitor will be used to verify and calibrate the numerical results produced by the LESNIC model. Modelled results (with meteorological conditions as input) will be compared with quantitative seeing measurements to determine whether a good correlation exists between the LESNIC model's predicted results and actual seeing quality at a site.

Comparing observational data and modelled results will also give an indication of seeing quality's relation to meteorological conditions. If any relationship can be found, it would be possible to use existing meteorological data to select a suitable observing site and to forecast seeing quality at the site.

In order to connect LESNIC model results with seeing monitor results, the seeing monitor will have to collect data at a site for which vertical profiles of meteorological parameters are available, such as the SAWS site at Irene in Pretoria. The site-specific meteorological parameters will be used as input to the LESNIC model. Results obtained with the two methods can then be compared. Should the results show good agreement, the possibility exists that LESNIC can be utilised to build up a database of astronomical seeing conditions for any site on Earth.