Optical Turbulence

The influence of the atmosphere on ground-based astronomy

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Abstract

The optical turbulence is responsible for the distortion of the images taken by ground-based telescopes. In this study the mesoscale non-hydrostatic model Meso-NH is used to characterize the optical turbulence at Mt Graham International Observatory (AZ, USA). The simulations are compared to measurements of the vertical distribution of the optical turbulence performed with a Generalized Scidar. These measurements cover 41 nights which are evenly distributed over different seasons of the year so we can better evaluate the performance of the model.

The Meso-NH model is shown to be able to describe the vertical distribution of the optical turbulence from the ground up to 20 km as well as the total integrated value with reasonable, small discrepancies from the measurements. Improvements can be done in the reconstruction of the seasonal variation trend of the vertical distribution of the optical turbulence.

Introduction

The optical turbulence (OT) is a very small-scale phenomena that is caused by the fluctuations in the index of refraction of the air. When the wavefront from a distant star reaches the upper atmosphere of the Earth, it is perfectly flat. Then, as it passes through the atmosphere, it becomes perturbated and the image of the scientific object taken with the telescope becomes blurry. (See Fig. 1.)

The most obvious solution to overcome the OT is to put the telescope in orbit around the Earth, thus completely eliminating the influence of the atmosphere. However, space telescopes are very expensive, the mirror of the telescope is comparatively small and any repairs or upgrades require space missions so the life-time of the space telescope is much shorter than for a ground-based telescope.

The other solution is to build the telescope on the ground in a location where the influence of the atmosphere is as small as possible and then correct for the OT using adaptive optics.

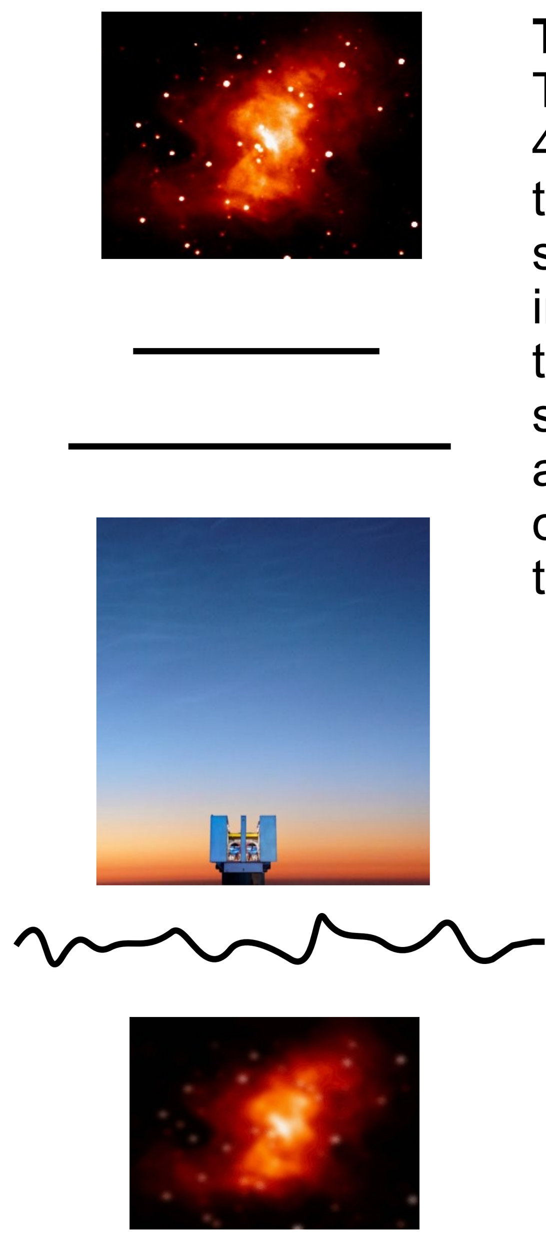

Figure 1: An illustration of the distortion caused by the optical turbulence in the atmosphere. The image shows the Crab nebula.

What is Optical Turbulence?

The OT is formed in the presence of dynamical turbulence, created by the wind shear, and a thermally stable stratification of the atmosphere. The vertical distribution of the OT is described by the structure function Cn2. The most intense OT is found near the surface, and a second weaker maximum can be found near the the jet-stream, at ~12 km above sea level.

The seeing (ε) describes the quality of the observation or more technically, the apparent angular diameter of a point source. It is calculated using the following equation, where λ is the wavelength and h is height above the surface:

$$\varepsilon = 0.58\,\lambda^{-1/5}\left(\int C_N^2(h)\,dh\right)^{3/5}$$

Using meteorological models in site testing

Numerical atmospheric models can provide useful information as a tool for site characterization. Unlike measurements, models can provide a complete 3D maps of all parameters, not just in a single point. Models can be used to characterize any site on the Earth for any given time period (provided there are initialization data).

Meso-NH simulations at Mt Graham

Meso-NH was developed by the CNRM/LA team, Toulouse, France [1]. The package to calculate the optical turbulence and derived astroclimatic parameters has been developed by Masciadri et al. 1999 [2].

The Meso-NH model is run in a grid-nesting mode using three imbricated models, see Fig. 2, centred on the Mt Graham Observatory. The model is run for the 41 nights during different seasons of the year for which we have measured the vertical profile of the optical turbulence with a Generalized Scidar (GS) [3]. This is the largest sample of measurements of the vertical distribution of the OT that has been used to evaluate the performance of a meteorological model in simulating the OT [4].

The model is run in two different versions, v23 and v24, following two different approaches to the calibration procedure.

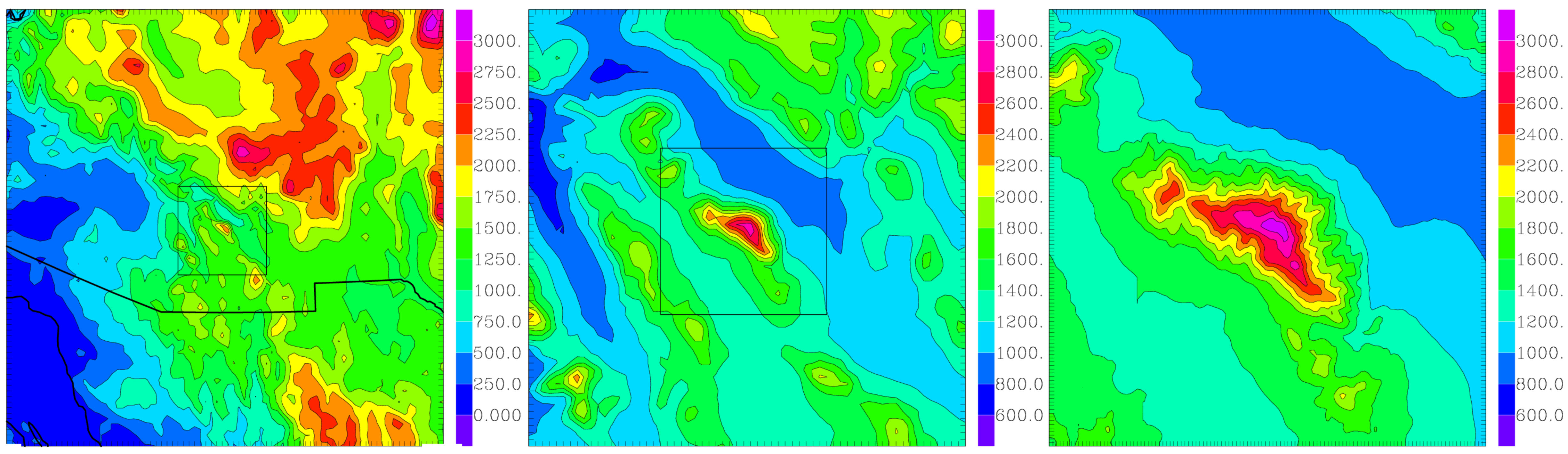

Figure 2: The model domains

	Model 1	Model 2	Model 3
Δx	10 km	2.5 km	0.5 km
Grid points	80x80	64x64	120x120
Surface	800x800 km	160x160 km	60x60 km
Time step	30 s	6 s	3 s

Table 2: Resolution of the different models.

The seeing at Mt Graham

The seeing from the Meso-NH model is compared to the measurements with the GS in Table 1 and Fig. 3 using two different versions of the model (v23 and v24). The seeing is divided into total seeing (0-20 km), boundary layer seeing (the first km) and free atmosphere seeing (1-20 km). The model agrees well with the GS near the surface, where most of the OT is formed. In the free atmosphere the model shows a much smaller variability in the seeing than the GS-data.

Average seeing	ε_{tot}	ε_{BL}	ε_{FA}
GS	0.77	0.58	0.45
MNH v23	0.89	0.67	0.49
MNH v24	0.82	0.64	0.42

Table 1: The average seeing for all 41 nights at Mt Graham, from measurements and simulations

The vertical distribution of the Optical Turbulence

The average profiles of the Cn2 from all nights are shown in Fig. 4 (top). The Meso-NH is well correlated to the measurements in the boundary layer as well as in the free atmosphere. If the sample is divided by season the situation changes slightly. During the summer (bottom left) the simulations agree very well with the measurements near the surface. In the upper atmosphere the simulations are correctly showing the secondary peak at a higher altitude than during the winter, but the strength of the Cn2 is overestimated. During the winter (bottom right) performs well, but the Cn2 is underestimated in the upper atmosphere.

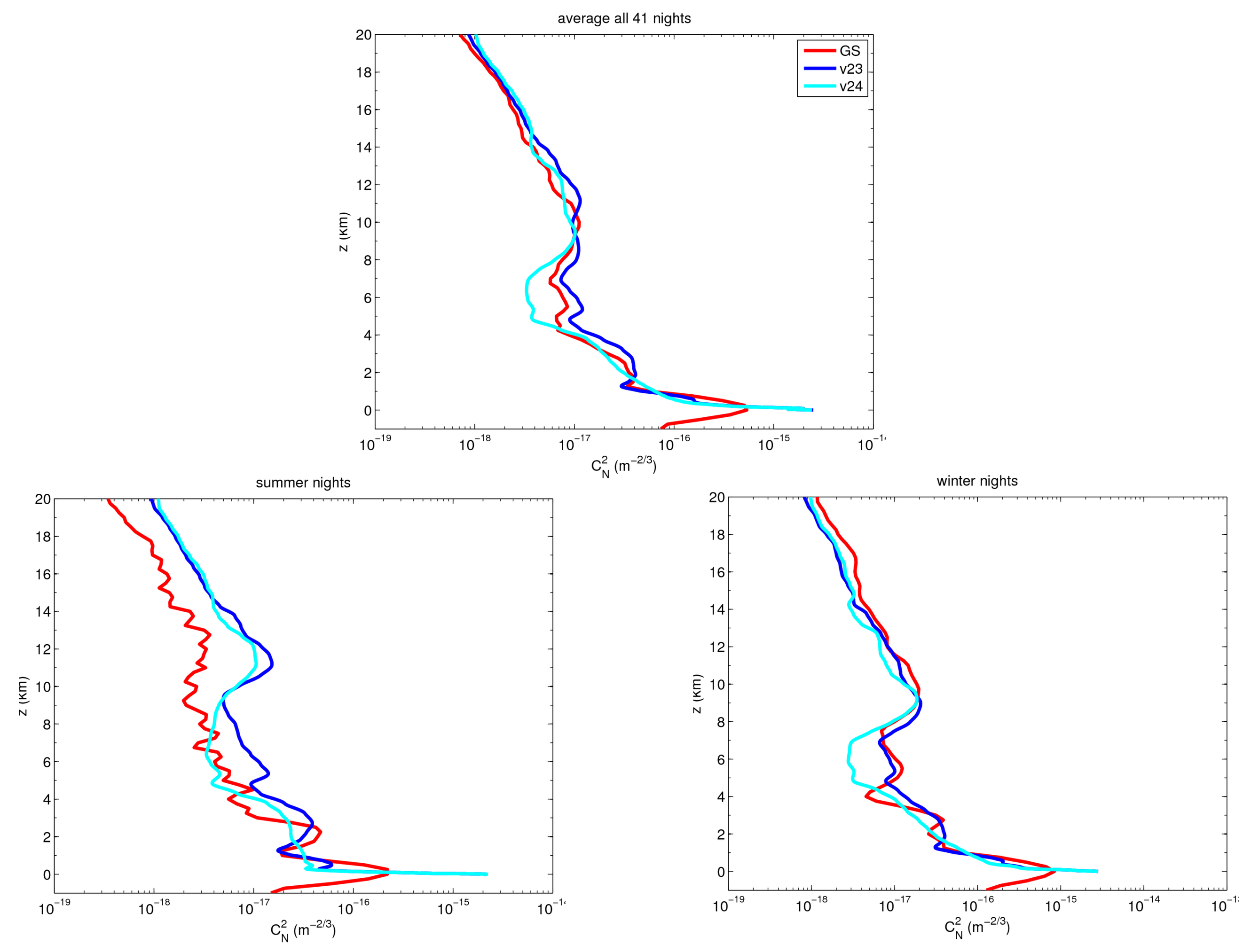

Figure 4: The average Cn2 from the measurements (red) and the simulations (blues) for all nights (top), summer (bottom left) and winter (bottom right).

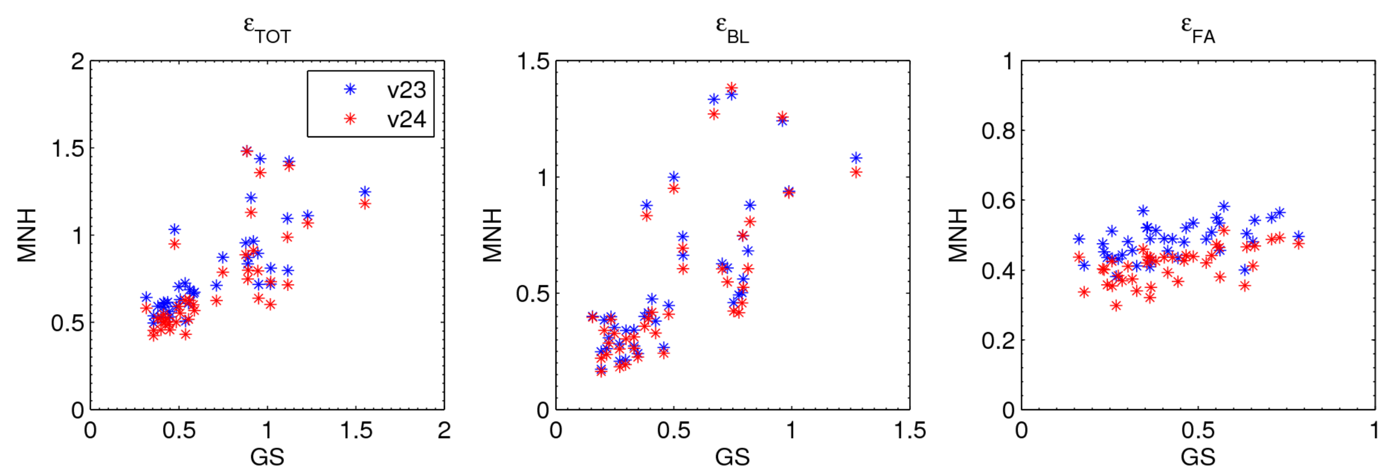

Figure 3: The nightly seeing from the Meso-NH model plotted against the GS measurements.

Conclusions

We have demonstrated the capabilities of the Meso-NH model to simulate the OT at Mt Graham. Looking at the average of all nights (41 nights distributed over different seasons) the simulated Cn2 and seeing match well with what is measured by the GS. If the sample is divided into seasons the Cn2-profile is still matching the measurements well below 4 km from the surface. Above this height, because of the inertia of the model, the Cn2 is overestimated during the summer and somewhat underestimated during the winter. This is also reflected in the seasonal seeing values (not shown here, see [4]). However, the Meso-NH is capable of discriminating the season with the calmest conditions (summer) from the season with the most turbulent conditions (winter).

References

[1] Lafore, J. P. et al., 1998, Annales Geophysicae,16,90

[2] Masciadri, E., Vernin, J., Bougeault, P., 1999a, A&ASS, 137, 185

[3] Masciadri, E., Stoesz, J., Hagelin, S., Lascaux, F., 2010, MNRAS, 404, 144

[4] Hagelin, S., Masciadri E., Lascaux, F., 2010, MNRAS, in preparation

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