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Revealing the onset of free convection in terrestrial planet atmospheres

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Abstract. The site testing program for the Thirty-Meter-Telescope (TMT) is monitoring the seeing conditions above several mountains. Observations are presented which show that the ground layer seeing (0 m–500 m above the ground) is influenced by the onset of free convection. It is shown that under radiation dominated conditions, indicating free convection of the atmosphere above the site, the occurence of the very best seeing conditions is supressed. A quantitative threshold for these conditions is given, allowing to estimate the shortterm future stability of the ground layer seeing.

Keywords. Atmospheric effects, convection, turbulence, Earth

1. Introduction

One of the most important parameters indicating the quality of a potential astronomical site is *seeing*. The standard instrument measuring the integrated seeing through the entire atmosphere above the telescope level is the Differential Image Motion Montior (DIMM, Tokovinin 2002). In recent years the Multi Aperture Scintillation Sensor (MASS, Tokovinin *et al.* 2003) has been developed allowing to measure $C_N^2(h)$ turbulence profiles on a routine basis. The site testing campaign for the TMT employs a combined MASS-DIMM device on their site testing telescopes, mounted $z = 7$ m above the ground. The TMT site testing equipment also consists of a meteorological station measuring basic atmospheric parameters as temperature T, relative humidity, atmospheric pressure P, wind speed v and direction at an elevation of $z = 2$ m (Skidmore *et al.* 2004). Additional instrumentation, in part installed temporarily, consists of all-sky cameras (Walker *et al.* 2006), SODAR (Travouillon 2006) and sonic anemometers (Skidmore *et al.* 2006).

2. Seeing and convection of the first 500 m

The TMT MASS delivers the seeing as measured above $z = 500$ m. From the simultaneously obtained MASS and DIMM seeing measurements (s_M, s_D, respectively) it is possible to compute the seeing within the first 500 m above the ground by $s_{GL} = (s_D^{5/3} - s_M^{5/3})^{3/5}$, which we will refer to as groundlayer GL. As pointed out by Els & Vogiatzis (2006) the energy flux emerging from the ground prevents the groundlayer seeing to reach its very best values. Here we make use of the ground heat flux, as measured a few cm within the ground and the net radiation flux measured 2 m above the surface. The difference H of these two values gives the energy deposited into the air just above the ground. In the following, data are shown which have been collected between November 2004 and August 2006 at Cerro Armazones (3064 m ASL) in northern Chile. In Fig. 1

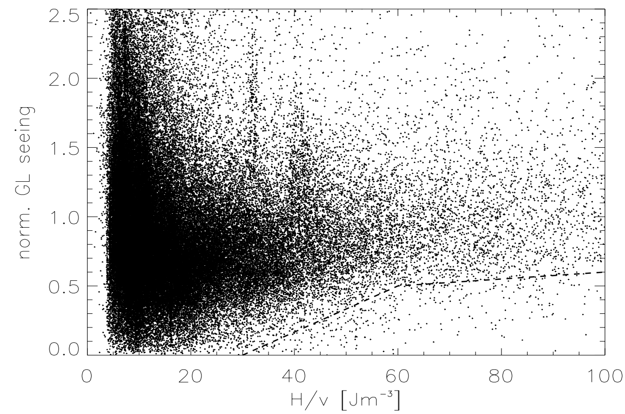

Figure 1. Normalized groundlayer seeing ($s_{GL}/\bar{s}_{GL}$) versus H/v ($z = 2$ m). The occurence of the best seeing values is suppressed beyond $H/v \gtrsim 30$ Jm^{-3}; the dashed line approximately outlines this trend.

the dependence of s_{GL} (normalized by the average $\bar{s}_{GL}$) on the quotient H/v ($z = 2$ m) is shown. In the region H/v ($z = 2$ m) $\gtrsim 30$ Jm^{-3} the very best values ($s_{GL} \lesssim 0.3 \cdot \bar{s}_{GL}$) are not reached. The seeing in this region is just about (and slightly better) than the overall average value $\bar{s}_{GL}$. In order to investigate whether this effect is due to free convection the Monin-Obukhov length $L_\star = -\frac{u^3 T \rho c_p}{\kappa g Q_H}$ is used (Monin & Obukhov 1954). Where $Q_H = H/(c_p \rho)$ is the sensible heatflux from the ground, ρ the atmospheric density and c_p the heat capacity of air. u is the friction velocity $u = v(z)/ln(z/z_0)$. With v measured at $z = 2$ m and an assumed roughness of $z_0 = 0.005$ m, corresponding to surface features of about 5 cm in size. $-L_\star$ gives the height above ground at which the turbulent energy production rate of the dynamic interaction of the air with the ground is equal to turbulent energy production rate due to buoyancy. In Fig. 2 the groundlayer seeing s_{GL} versus $L_\star$ is shown for data for which H/v ($z = 2$ m) $\gtrsim 30$ Jm^{-3}. All of these data fall at $-L_\star < 8$ m, and mostly $-L_\star < 1$ m. Therefore the condition for free convection, $z/L_\star < -1$, is fulfilled already very close to the ground.

3. Summary and conclusion

It was shown that the occurence of optimal (much better than average) GL seeing is supressed under atmospheric conditions in agreement with free convection at the telescope level. The extension of the dynamic layer of the atmosphere above the telescope is thus necessary to obtain the best possible seeing conditions. Future measurements of the 3D wind speeds and temperature profiles at several elevations using a 30 m tower, installed in the vicinity of the telescope, will allow to improve the measurement of $L_\star$. The easy to measure quotient of H/v might be used as an indicator for the stability of the atmospheric conditions and can therefore be employed to estimate the forthcoming shortterm seeing conditions above a site. This work did not take any effects of potential structures surrounding the telescope (i.e., dome, trees) into account and to make use of that parameter on other astronomical sites requires a proper calibration for such effects. Whether a modification of the surroundings of the telescope (i.e., painting of the surface) is sufficient to decrease the occurance of free convection remains to be seen during future investigations.

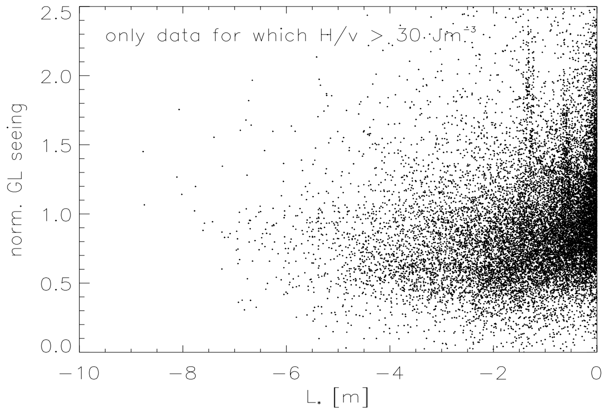

Figure 2. Normalized groundlayer seeing versus the Monin-Obukhov length $L_\star$ only for data which fall beyond H/v ($z = 2$ m) $\gtrsim 30$ Jm^{-3} in Fig. 1. All data fall at $-L_\star \lesssim 8$ m and most of them even $-L_\star \lesssim 3$ m, indicating that the conditions for an unstable or free convective atmosphere, $z/L < -1$, are reached very close to the ground.

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