Coherence time and turbulence velocity at the Roque de los Muchachos Observatory from G-SCIDAR.

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ABSTRACT

The coherence time (τ_0) is one of the relevant atmospheric optical parameters for the design of AO systems, being directly related with the band width and the stability requirements. A proper retrieval of τ_0 implies the combination of vertical turbulence and wind profiles. In this work we have used 140 nights of G-SCIDAR $C_n^2(h)$ turbulence profiles obtained at the Roque de los Muchachos Observatory (ORM) and wind profiles from simultaneous operational radiosounding balloons launched from the neighbour island of Tenerife ($\sim$ 155 km distant) at midnight by the Spanish Meteorological Agency (AEMet). The wind data have been processed to retrieve the average velocity of the turbulence (V_0) for each night. Here we present the statistical results of τ_0 and V_0 for the ORM and median monthly vertical profiles of wind speed for the Canary Islands. The median τ_0 is 4.9 ms, with quartiles P25=2.9 ms and P75=6.5 ms. The same values for V_0 are 6.2, 9.5 and 12.4 m/s for P25, P50 and P75, respectively. The average wind profile shows a maximum driven by the Tropopause at an altitude ranging from 10 to 12 km over the Observatory.

Keywords: Coherence time, average velocity of turbulence, turbulence profile, wind speed profile, Roque de los Muchachos Observatory, La Palma, SCIDAR, radiosounding balloon

1. INTRODUCTION

The coherence time (τ_0) is the time lapse that the light crossing the Earth atmosphere maintains a near-constant phase relationship, both temporally and spatially. Its value impacts on the design and operation of AO systems, being directly related with the band width and the stability requirements. Assuming the Taylor hypothesis, changes in the pattern of turbulence of an air parcel occur much slower than the time it takes for the parcel to pass through the aperture of the telescope pushed by the wind. In such a case, τ_0 can be expressed as a function of the Fried parameter, r_0 (coherence radius), and the average velocity of the turbulence V_0 as:

$$\tau_0 = 0.314 \frac{r_0}{V_0} \tag{1}$$

Both, r_0 and V_0, can be obtained from the refractive-index structure constant profile of the turbulence, $C_n^2(h)$, with height, h, as follows:

$$r_0 = \left[0.423\ k^2 \int dh\ C_n^2(h) \right]^{-3/5} \tag{2}$$

$$V_0 = \left[\frac{\int dh\ C_n^2(h)\ V(h)^{5/3}}{\int dh\ C_n^2(h)} \right]^{3/5} \tag{3}$$

where k is the optical wave-number and $V(h)$ is the wind speed vertical profile. Therefore, vertical turbulence and wind profiles[1] are needed to get τ_0.

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In this work we calculate the coherence time through the combination of 140 nights of almost simultaneous wind speed and $C_n^2(h)$ turbulence profiles. The turbulence data were obtained at the Roque de los Muchachos Observatory (ORM, Canary Islands) with the G-SCIDAR technique (Generalized-SCIntillation Detection And Ranging). G-SCIDAR[2–5] has proved to be the most reliable technique to retrieve C_n^2 profiles. The wind profiles, $V(h)$, were obtained from the operational radiosounding balloons launched from the neighbour island of Tenerife ($\sim$ 155 km distant) at midnight (Güímar AEMet station - WMO 60018).

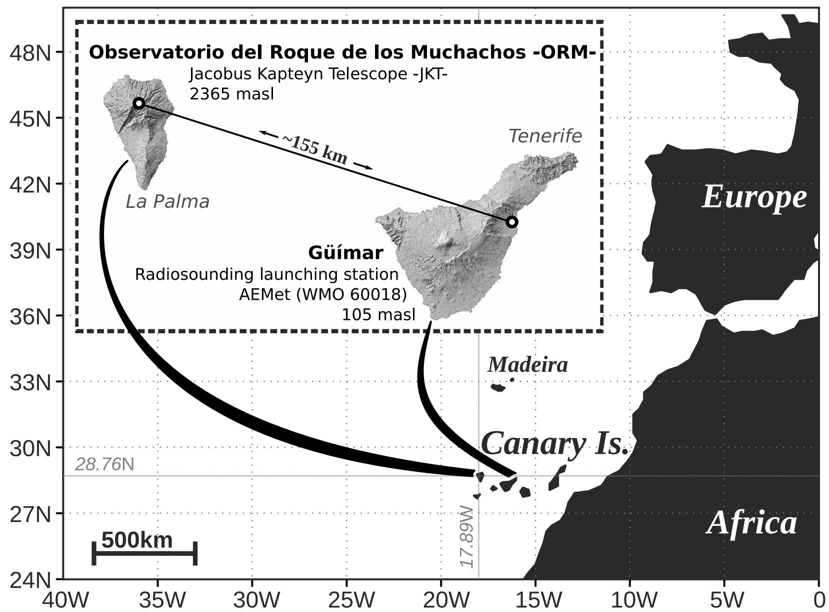

Figure 1. Location map.

2. LOCATION

The Roque de los Muchachos Observatory (ORM) is located on the island of La Palma, in the Canary Islands, Spain (see Fig. 1). It is one of the best locations for astronomy on Earth. ORM hosts, among others, the currently largest optical-IR telescope in the World, the 10.4m Gran Telescopio Canarias (GTC) and will host the future Cherenkov Telescope Array (CTA) for the northern hemisphere.

The lower troposphere of the Canary Islands shows an almost constant vertical thermal inversion layer (IL), as a consequence of their latitude, the Azores anticyclone and the cold Atlantic stream. The altitude of the IL ranges from 800 m in summer to 1600 m in winter, well below the altitude of the Observatories.[6] The IL separates the moist marine boundary layer and the dry free atmosphere, inducing a dry and stable atmosphere above it.

3. RESULTS

3.1 Canary Islands night time wind profile

The wind profiles have been obtained from operational radiosounding balloons launched by the Spanish meteorological service (AEMet) from the Güímar station (WMO-60018) in the neighbour island of Tenerife ($\sim$ 155 km from the ORM; see Fig. 1). We have used the 00UT low resolution profiles from the repository of the Department of Atmospheric Sciences of the University of Wyoming.

Fig. 2 shows the monthly average wind speed vertical profile for the full database. The period covers 10 years, spanning from 2004 to 2013, that includes the ones of the G-SCIDAR campaigns at ORM. We selected the wind profiles with a minimum top height of 20 km and at least 80 sampled levels, resulting in 3088 profiles. The average night time wind speed profile shows a maximum driven by the Tropopause at an altitude ranging

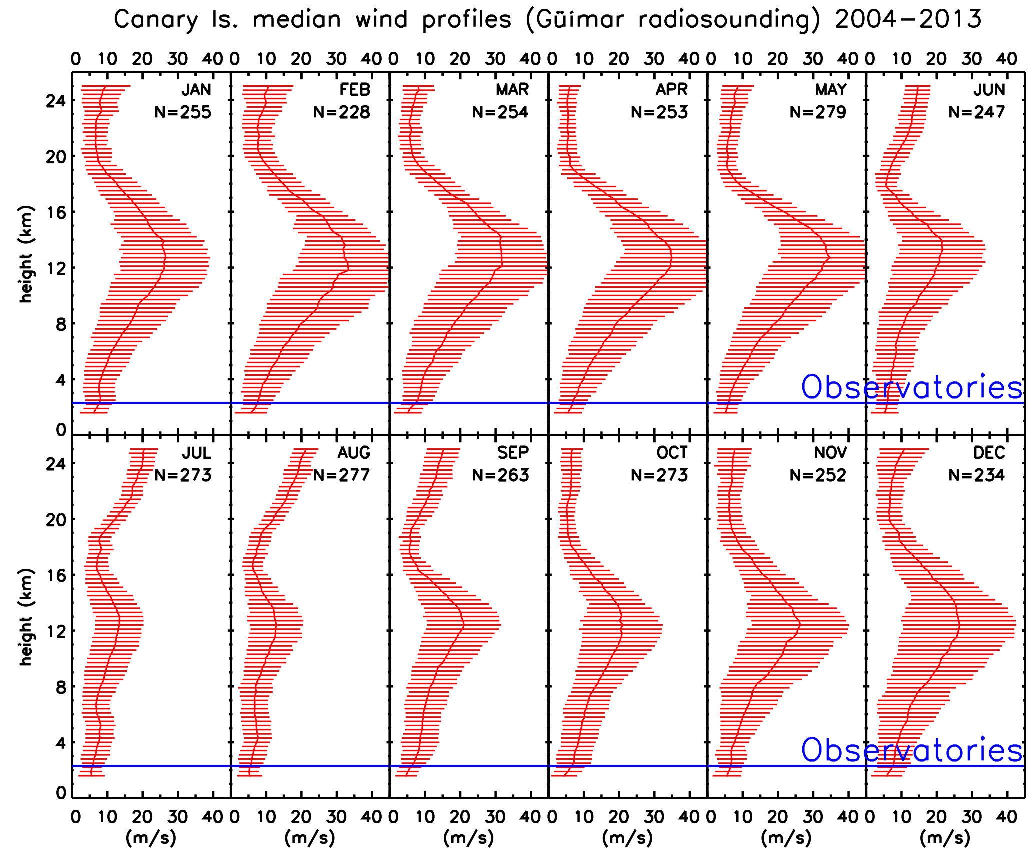

Figure 2. Night time average wind speed profile for the Canary Islands. The sample includes 3088 radiosounding balloon profiles at 00UT spanning from 2004 to 2013. The balloons were released from the Güímar operational station in the island of Tenerife (see Fig. 1). The blue line labelled as 'observatories' indicates the altitude of the astronomical observatories in the Canary Islands, ORM and Teide.

from 10 to 12 km over the Observatory level, with some weak influence of the jet stream in the summer months (Jun-Sep).

3.2 Turbulence profile

The C_n^2 turbulence profiles have been obtained at the ORM by the High Spatial Resolution Group of the Instituto de Astrofísica de Canarias (IAC), leaded by J.J. Fuensalida, with the instrument 'cute-SCIDAR'[7,8] installed at the 1 m Jacobus Kapteyn Telescope of the Isaac Newton Group. The full database covers more than 200,000 profiles from 212 nights at ORM.[9] The median and mean monthly turbulence profiles for ORM with the full database are shown in Fig. 3

The C_n^2 profiles were calculated from the normalized autocovariances derived from 1000 images of scintillation patterns in a displaced pupil plane, following the G-SCIDAR technique.[4,5] Each detector pixel covers a square of 1.935 cm on the JKT pupil. The dome turbulence was removed.[10] The data were recalibrated[11] and codified to 79 vertical levels spanning from the ground to 26 km in steps of $\sim$ 300 m.

To match with the simultaneous radiosounding balloon flights, the turbulence profiles were 1h median averaged, that approximates the time of flight of the balloon (between 00UT and 01UT). Only nights with a minimum of 60 individual turbulence profiles in this time period were considered, resulting in 140 nights (join with the conditions imposed in Sec. 3.1).

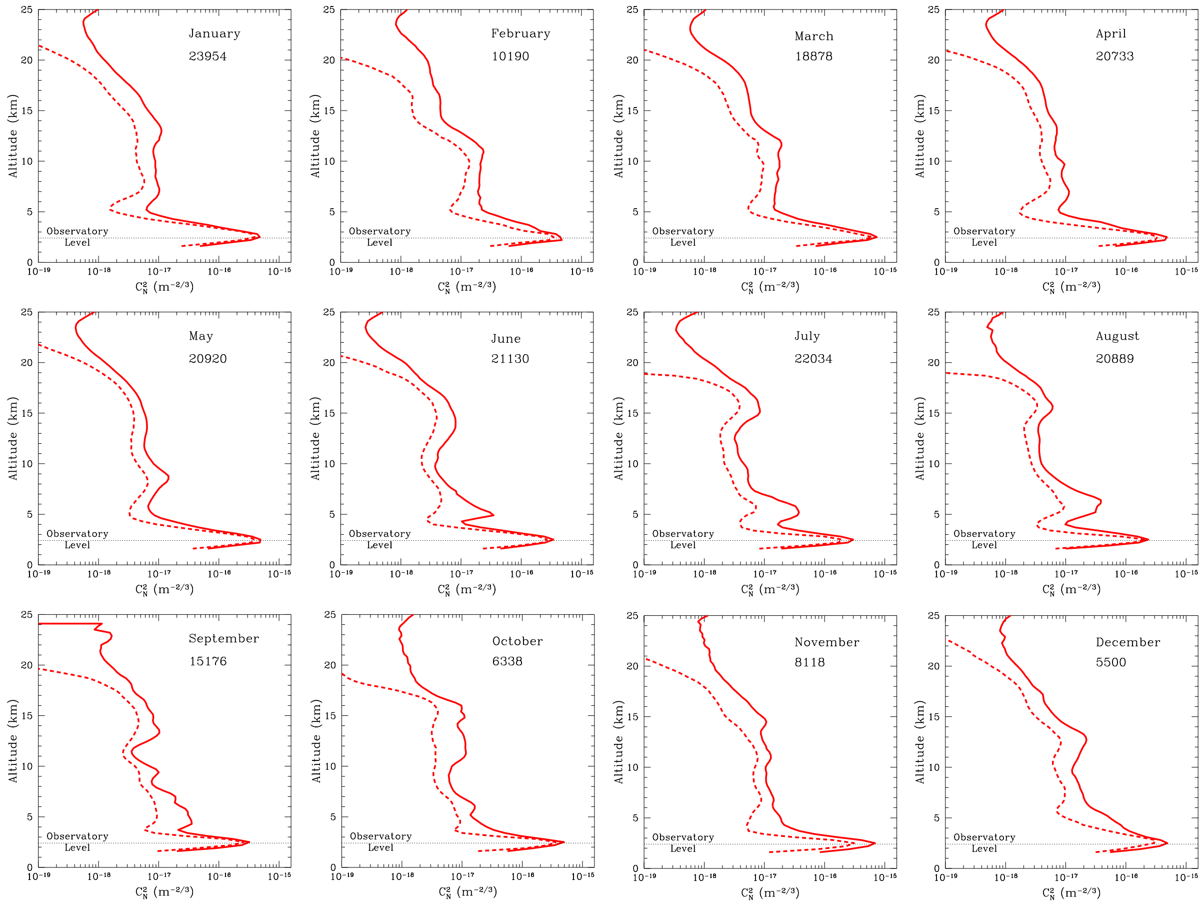

Figure 3. Monthly mean (continuous line) and median (dashed line) C_n^2 vertical profiles at ORM from the full database of G-SCIDAR measurements for a period spanning from 2003 to 2009 (212 nights). The number of individual profiles included is labelled for each month.

3.3 Average velocity of the turbulence

The V_0 has been calculated applying the Eq. 3 to the 140 simultaneous* G-SCIDAR $C_n^2(h)$ profiles at ORM and radiosounding $V(h)$ profiles at Güímar, cut off to the altitude of the Observatory. We assumed spatial correlation between both locations as they are in the same mesoscale climatological area and our results come from large sampled medians. We applied a 5% edge trimming to the sample to increase the statistical robustness of the results, avoiding punctual de-correlations.

The results are shown in the Fig. 4. The quartiles, including the median (P50) value, are P25= 6.2 m/s, P50=9.5 m/s and P75=12.4 m/s. Therefore, V_0 has low values at ORM with large dispersion, being σ=3.9 m/s.

3.4 Coherence time

After applying Eq. 1 with the V_0 obtained in Sec. 3.3, τ_0 values are derived. The statistical results for this parameter are in Fig.5. As in the previous section, we have applied a 5% edge trimming of the sample looking for statistical robustness. The quartiles for τ_0 at ORM are P25= 2.9 ms, P50=4.9 ms and P75=6.5 ms. These results confirm the excellent conditions of the ORM for AO.

*We must remark the meaning of simultaneous we are using here. Both, $C_n^2(h)$ and $V(h)$ were obtained at the same time, but 155 km apart. The first as an average of profiles between 00UT and 01UT, and the latter as a point measure of radiosonde, over the same hour, in a single balloon flight.

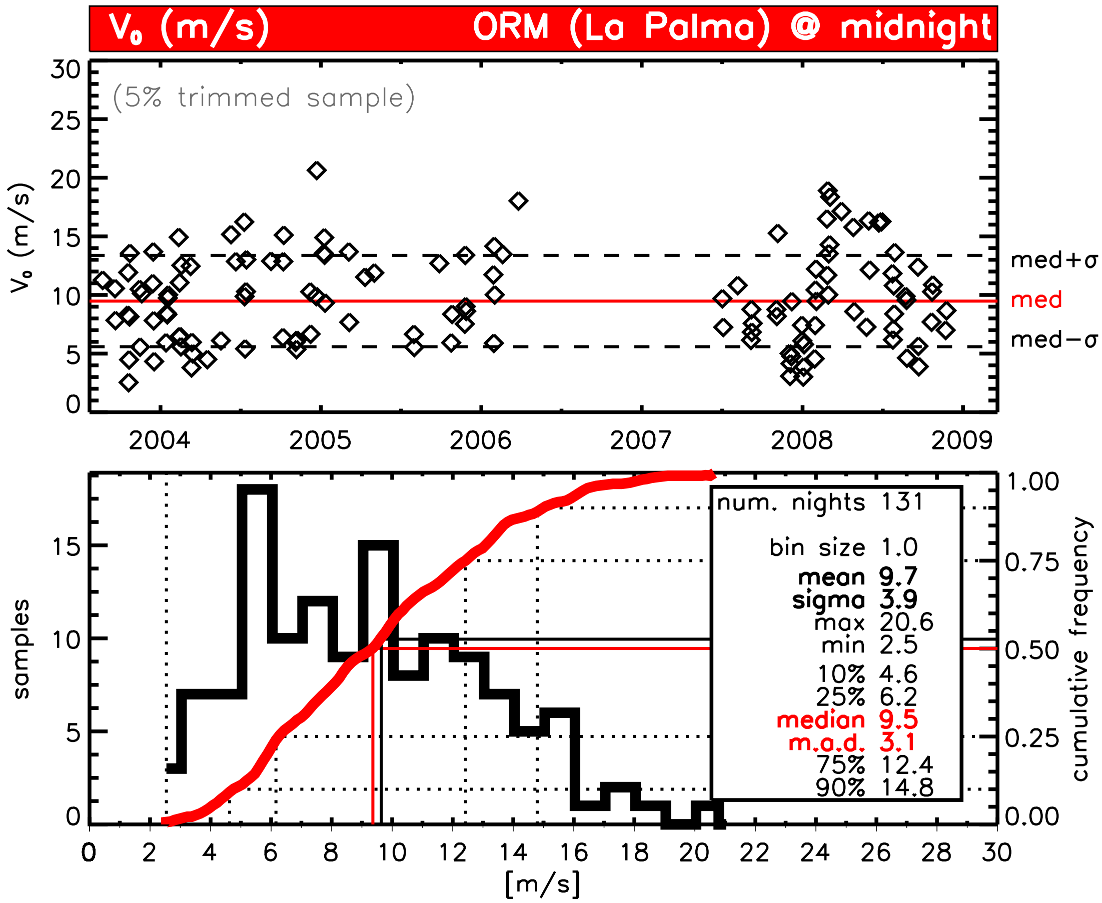

Figure 4. Average turbulence velocity V_0 statistical results for the ORM (time series on the top and statistical distribution and results on the bottom). The red line on the bottom panel is the cumulative distribution. The robust median absolute deviation (m.a.d.) is included in the box with the results.

The τ_0 distribution is slightly double peaked, with the second peak centred around 11 ms. Fifteen percent of the time, τ_0 is between 6.5 and 10.9 ms. These are outstanding conditions for AO and other high spatial resolution techniques.

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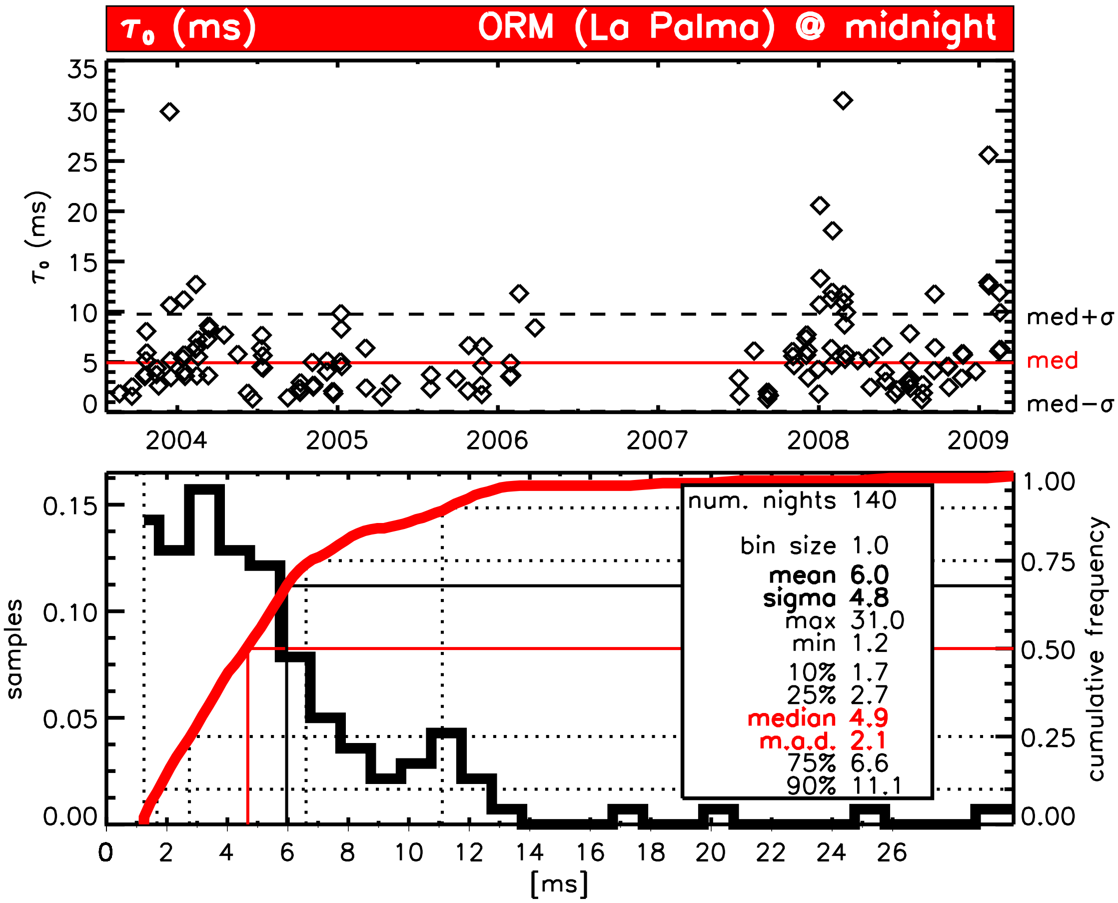

Figure 5. Coherence time τ_0 statistical results for the ORM (time series on the top and statistical distribution and results on the bottom). The red line on the bottom panel is the cumulative distribution. The robust median absolute deviation (m.a.d.) is included in the box with the results.

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