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# VERIFICATION OF THE COHERENCE TIME PRODUCED BY THE MASS-DIMM TURBULENCE PROFILER IN CHILE

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RESUMEN

La base de datos de MASS-DIMM en Paranal y Armazones ha sido reprocesada con la última versión del software de reprocesamiento ATMOS. La constante de tiempo atmosférico $\tau_0$ es calculada combinando los perfiles de $C_n^2$ de MASS con los perfiles de la velocidad del viento obtenidos a partir del análisis de un modelo meteorológico global. Estos se comparan con los resultados obtenidos del reprocesamiento de los datos MASS para los modelos de 6 y 13 niveles.

ABSTRACT

The MASS-DIMM database at Paranal and Armazones has been reprocessed with the latest version of the ATMOS reprocessing software. The atmospheric time constant $\tau_0$ is calculated combining MASS $C_n^2$ profiles with wind velocity profiles from global meteorological model analyses. It is then compared to the reprocessed MASS output for 6 and 13-layers models.

*Key Words:* atmospheric effects — instrumentation: photometers — methods: data analysis — methods: observational — site testing



## 1. INTRODUCTION

The MASS principle was introduced in 2001 (Kornilov & Tokovinin 2001) and the first portable MASS prototype started operation at ESO Observatories in 2003. The instrument has been optimized since then and combined with a DIMM channel (Kornilov et al. 2007). The MASS-DIMM associated to a robotized telescope has become the key instrument within the community of astronomical site testing. Several MASS-DIMM units are in regular operation at large observatories for supporting science operation with adaptive optics. The MASS-DIMM delivers profiles of $C_n^2$ (index of refraction structure constant) above 250 m height. It has a lower vertical resolution than the SCIDAR (Scintillation Detection and Ranging) but has the advantage to require only a small portable telescope.

In addition to the turbulence profiles, MASS produces estimates of the turbulence coherence time $\tau_0$. However until recently MASS was estimating only a value proportional to the coherence time from the variance of the logarithm of the intensity ratio for different exposure times (1 and 3 ms) and a linear adjustment was needed a posteriori[4]. An independent study was conducted in the frame of the TMT site selection process (Travouillon et al. 2009) using wind velocity profiles from NCEP/NCAR reanalysis dataset consisting of a 2.5 deg × 2.5 deg global grid of weather parameters covering 17 pressure levels, combined with the MASS turbulence profiles to compute the characteristic velocity of the turbulence. This study led to a calibration coefficient about 40% larger than initially proposed and pointed out the need for a revision of the MASS processing software.

Thanks to the dedication of the MASS team, a new version of the processing software has been made available aiming at providing absolute values of the coherence time (Kornilov 2011) and also allowing to increase the number of layers from 6 to about 13 (Kornilov & Kornilov 2011). We propose to repeat the work by (Travouillon et al. 2009) to check the accuracy of the new processing. Two periods have been selected for this purpose, June 2009 and July 2010, when MASS instruments were operated simultaneously at the sites of Paranal (VLT) and Armazones (E-ELT) and when wind profiles with the highest vertical resolution are available. The version 2.97.3 of ATMOS reprocessing software has been used, where the user is free to choose the layer central altitude distribution. Within each layer, the

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[4]`http://www.ctio.noao.edu/~atokovin/profiler/timeconst.pdf`.

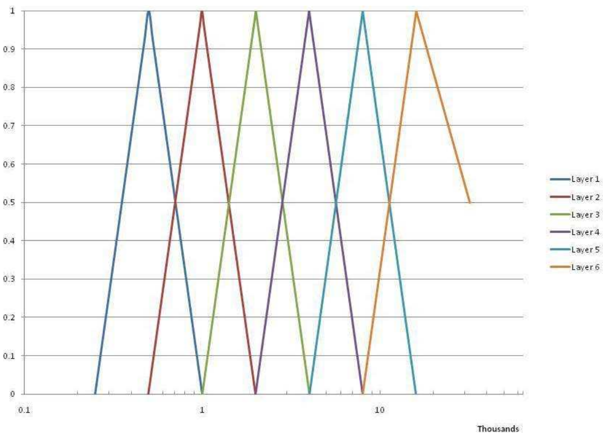


Fig. 1. MASS 6-layer weighting function used to constrain the wind velocity vertical profiles. The horizontal axis is the decimal log of the altitude above ground. The sensitivity is maximum at respectively 0.5, 1, 2, 4, 8 and 16 km and falls to zero at the peak of the neighboring layer.

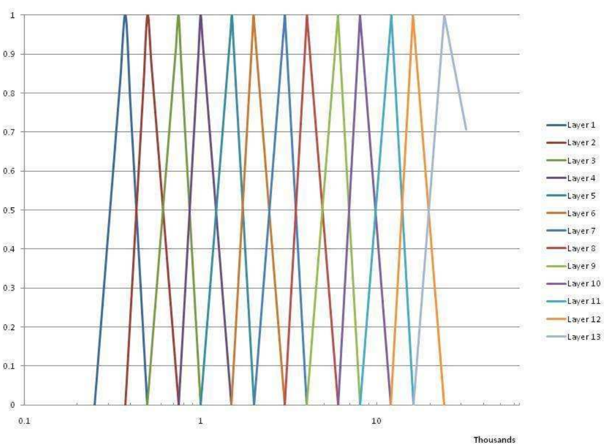


Fig. 2. MASS 13-layer weighting function used to constrain the wind velocity vertical profiles. The horizontal axis is the decimal log of the altitude above ground. The sensitivity is maximum at respectively 0.375, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, 8, 12, 16 and 24 km and falls to zero at the peak of the neighboring layer.

MASS sensitivity weighting function versus altitude can be approximated in a logarithmic scale to a triangle falling to zero at the peak of the neighboring layer. The 6-layer model (Figure 1) is the one originally proposed by the MASS developer, arguing that only 6 fully independent scintillation measurements (absolute and differential) can be performed with a 4 pupil instrument. The 13-layer model (Figure 2) is deliberately oversampled to make use of the full resolution of the instrument.

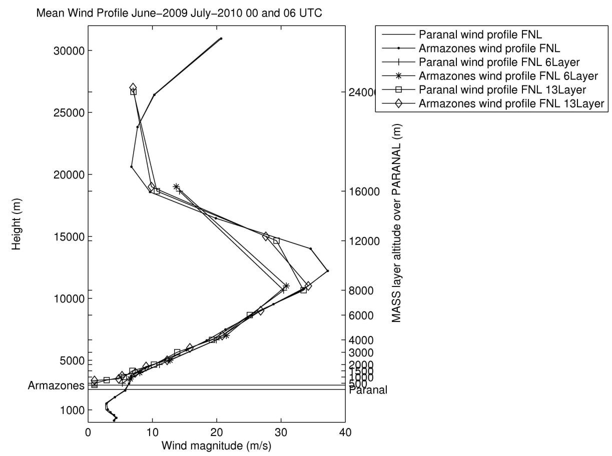


Fig. 3. Original mean FNL wind velocity vertical profile and after averaging with the MASS weighting functions described in Figures 1 and 2. The vertical scale on the left is the height above sea level.

The coherence time measured by MASS is identical in both models. The integrated MASS seeing in the 13-layer model is only about 2% higher than in the 6-layer model. The new ATMOS data reduction software delivers two estimates of $\tau_0$ without using any fudge factor. The original one, so called "DESI", is based on differential indices as in the former versions but after some errors have been fixed. The second estimate, so called "Weight", is based on the new algorithm described in (Kornilov 2011). Although both estimates have comparable median values, in line with the conclusions of (Travouillon et al. 2009), $\tau_0$ "DESI" distribution has an unusually long tail at large $\tau_0$. We chose to use in this paper the new $\tau_0$ "Weight" which has a more physical distribution at $\tau_0 > 5$ ms.

## 2. WIND VELOCITY

The meteorological product used in this work is the FNL with 26 vertical levels between 1000 to 10 HPa and 1 degree horizontal resolution[5]: the NCEP FNL (Final) Operational Global Analysis is produced with the same model which NCEP uses in the Global Forecast System (GFS), but the FNLs are prepared about an hour or so after the GFS is initialized. While the GFS operational model has only 13 pressure levels, 1.5 degree of horizontal resolution and forecast of 96 hours, the FNLs are delayed so that more observational data can be used and are performed every 6 hours from 00 UT.

The wind velocity vertical profile over each site is obtained from a bilinear interpolation of the hori-

[5]http://dss.ucar.edu/datasets/ds083.2/.

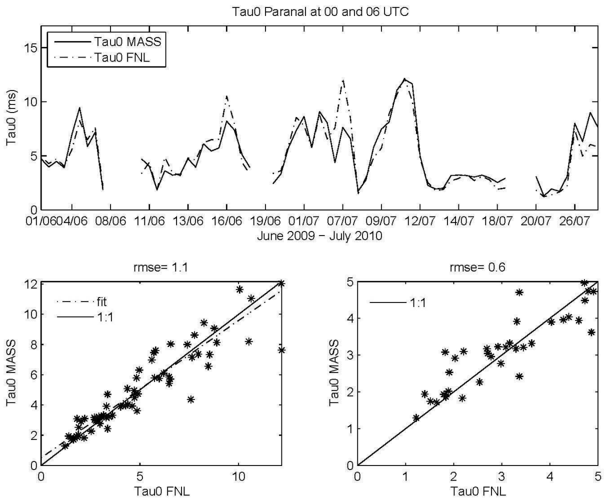


Fig. 4. Comparison of the coherence time computed from MASS $C_n^2$ and wind velocity profiles with MASS-DIMM output at Paranal in June 2009 and July 2010, 6-layer model: time series (top), regression for all data (bottom left) and for $\tau_{0\mathrm{FNL}} < 5$ ms.

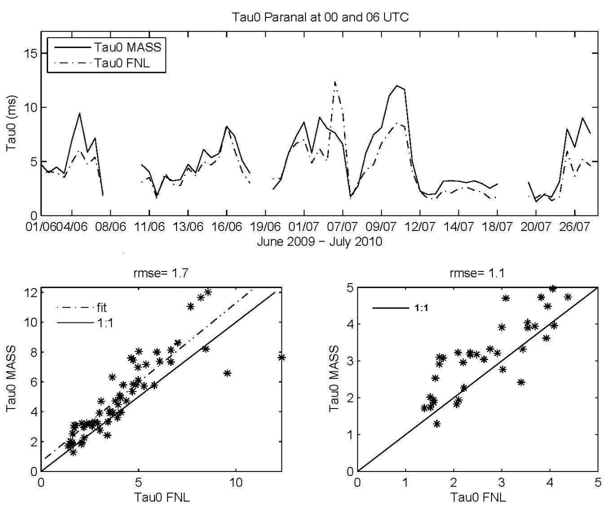


Fig. 5. Comparison of the coherence time computed from MASS $C_n^2$ and wind velocity profiles with MASS-DIMM output at Paranal in June 2009 and July 2010, 13-layer model: time series (top), regression for all data (bottom left) and for $\tau_{0\mathrm{FNL}} < 5$ ms.

zontal grid. The altitude is assimilated to the geopotential height. The wind velocity is then binned into the MASS triangular weighting functions shown in Figures 1 and 2 to be combined with the $C_n^2$ profile measured within a few minutes of the analysis time following the method described in (Travouillon et al. 2009). Figure 3 shows that the 6-layer model strongly under-estimates the contribution of the jet

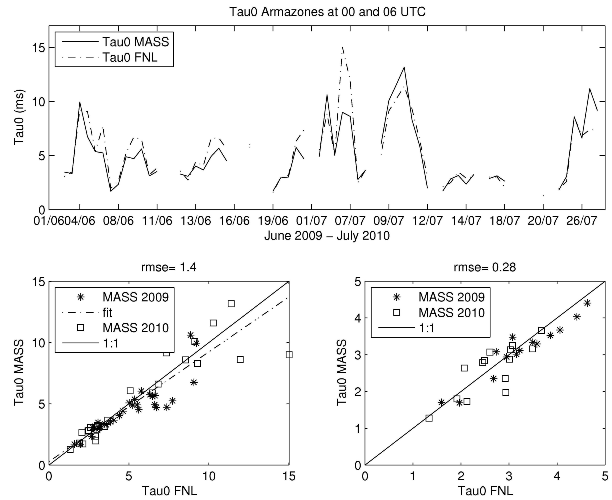


Fig. 6. Comparison of the coherence time computed from MASS $C_n^2$ and wind velocity profiles with MASS-DIMM output at Armazones in June 2009 (TMT data) and July 2010 (ESO data), 6-layer model: time series (top), regression for all data (bottom left) and for $\tau_{0\mathrm{FNL}} < 5$ ms.

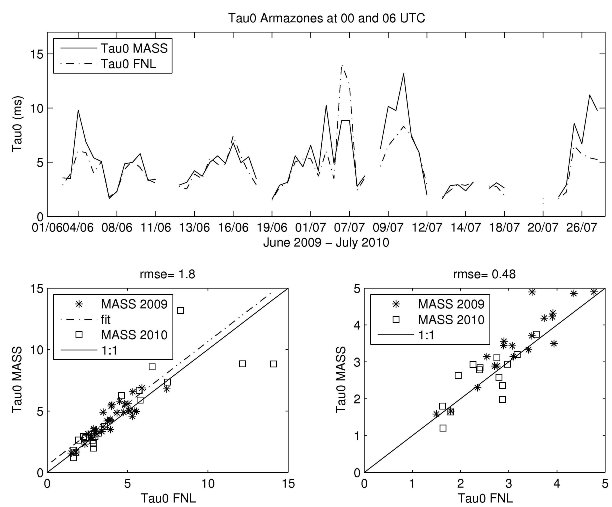


Fig. 7. Comparison of the coherence time computed from MASS $C_n^2$ and wind velocity profiles with MASS-DIMM output at Armazones in June 2009 (TMT data) and July 2010 (ESO data), 13-layer model: time series (top), regression for all data (bottom left) and for $\tau_{0\mathrm{FNL}} < 5$ ms.

stream at the tropopause level, this is one of the main incentive for increasing the number of layers. Note that the original profiles are basically identical for both sites separated by 20 km, a value ≈7 times smaller than the horizontal resolution of the FNL.

## 3. VERIFICATION

The atmospheric coherence time delivered by the MASS is compared to the value computed from

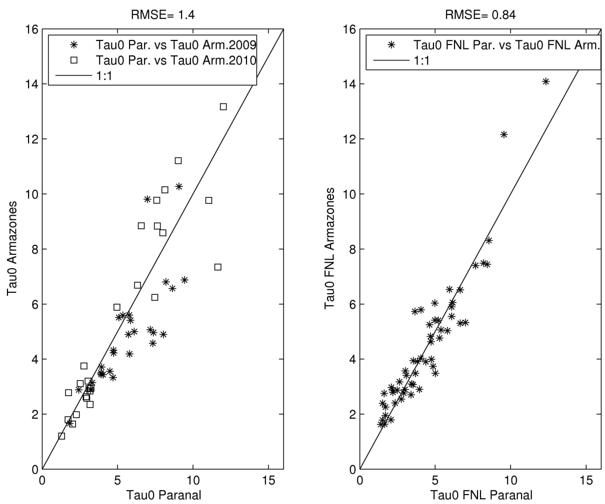


Fig. 8. Comparison of the coherence time at Paranal and Armazones computed from MASS $C_n^2$ and wind velocity profiles (right) to the direct MASS-DIMM output (left) for simultaneous measurements in June 2009 and July 2010, 13-layer model.

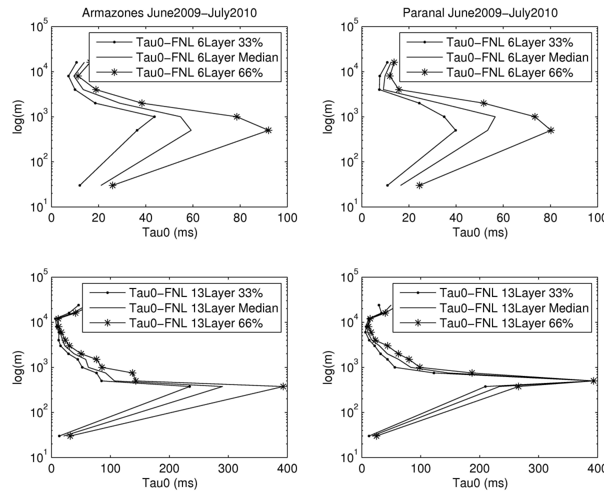


Fig. 9. Terciles and median vertical profiles of $\tau_0$ measured at Armazones and Paranal during June 2009 and July 2010, 6 and 13-layer models with ground layer.

MASS $C_n^2$ profiles and FNL wind speed properly binned into the MASS weighting functions as described in § 2. The results for both models are presented separately for each sites because MASS geometrical parameters are different at Paranal and at Armazones: Paranal MASS-LITE (Figures 4 and 5) uses a refractor with 92 mm diameter outer pupil while TMT T2 at Armazones 2009 and ESO MD31 at Armazones 2010 (Figures 6 and 7) use reflectors with respectively 90 mm and 80 mm outer diameters. In all cases the agreement is satisfactory with a linear fit close to 1 and a full scale rms dispersion of about 1.5 ms which can be lower than 0.3 ms if only values of $\tau_0$ below 5 ms are considered. The 13-layer model which delivers as expected smaller values for $\tau_{0\mathrm{FNL}}$ presents a slight offset although the slope of the linear fit is closer to 1. The large $\tau_0$ are better depicted while the dispersion in the short $\tau_0$ range is twice that of the 6-layer model probably due to the uncertainty in modelling the jet stream velocity above the sites. This could indicate that the improvement in vertical resolution requires a better spatial resolution and will be the object of further studies: operational models are currently capable to run down to 0.125 degree in their latest version.

## 4. RESULTS

Figure 8 confirm that the coherence time at the two summits distant of 20 km is strongly correlated. The lower dispersion in the $\tau_{0\mathrm{FNL}}$ is an artifact due to the coarse horizontal resolution of the model. However while MASS can only produce integrated value of $\tau_0$, the knowledge of the vertical profile of the wind velocity allows to compute the coherence time of each individual layer as shown on Figure 9. There, a lower level has been added, composed of the turbulence in the ground layer not seen by MASS (difference of DIMM and MASS total $C_n^2$) combined to the wind velocity measured at 30 m above ground by the local meteorological station.

## 5. CONCLUSION

The coherence time provided by the new MASS reprocessing software agrees well with meteorological wind profiles, in global agreement with the conclusions of (Travouillon et al. 2009). The higher resolution of MASS $C_n^2$ profiles combined to meteorological model wind velocity allows a better representation of the coherence time at the tropopause level.

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