EUROPEAN SOUTHERN OBSERVATORY

INTERNAL MEMORANDUM

M. Sarazin, May 14, 1996

Predicting $\tau 0$: the perspectives

What is $\tau 0$?

In the same way as $r0$ represents the spatial coherence of a wavefront at ground level after traveling through the atmosphere, $\tau 0$ is a statistical quantity describing its temporal coherence (not to be confused with the speckle boiling time, also often named $\tau 0$).

$\tau 0$ is entering the astronomical community with the arrival of new technology as $r0$ did in the seventies when the CCD came in: $\tau 0$ determines the time available for an adaptive optics correction system to sense and correct the wavefront. An AO system slower than the wavefront will degrade the image quality it was designed to improve.

How to compute $\tau 0$?

The atmospheric seeing, expressed as the FWHM of a long exposure image at an aberration free telescope (FWHM $\approx \lambda/r0$) is the cumulative effect of numerous *sheets* of refractive index perturbations all the way from about 20 km altitude down to the telescope enclosure (dome, mirror and instrument seeing are excluded from this memo as they will be from the VLT observatory!). Each turbulence sheet at altitude h has it's own $r0(h)$ and moves with the wind at a velocity $v(h)$ in the direction $\theta(h)$. If each sheet bears a fraction $\alpha(h)$ of the total turbulence (as $r0$ varies as the 3/5 power of the turbulence, we have $\alpha(h) = [\frac{r0}{r0(h)}]^{\frac{5}{3}}$), the resultant wavefront corrugations horizontal velocity at ground level is

$$V0 = [\sum \alpha(h) \vec{v}(h)^{\frac{5}{3}}]^{\frac{3}{5}} \tag{1}$$

and the coherence time will be proportional to the time needed for the wavefront to move by one coherence cell:

$$\tau 0 \approx 0.3 \frac{r0}{V0} \tag{2}$$

At a site which is not dominated by turbulence close to the ground and because of the 5/3 exponent on the wind speed (introduced for dimensional purposes) the slowest layers will not contribute much. The resultant wavefront corrugations will thus have a velocity and a direction merely determined by the fastest layers provided that they bear significant turbulence.

How much is $\tau 0$ at Paranal?

According to the previous remark, it would be enough to know, at a given site, the fraction α_{max} of the turbulence borne by the fastest layer, and its speed $Vmax$, to estimate the average wavefront velocity:

$$V0 \approx \alpha_{max}^{\frac{3}{5}} Vmax$$

From PARSCA measurements at Paranal (Topical Meeting on Adapt. Optics Proc. p 442, Oct. 1995), we find $Vmax/V0 \approx 3.5$ as averaged over 8 nights. This shows that the average wavefront velocity was, on the average, the same as if 1/8th of the turbulence was borne by the fastest layer. Now we assume that this particularity is roughly a constant of all good sites and extrapolate over the year.

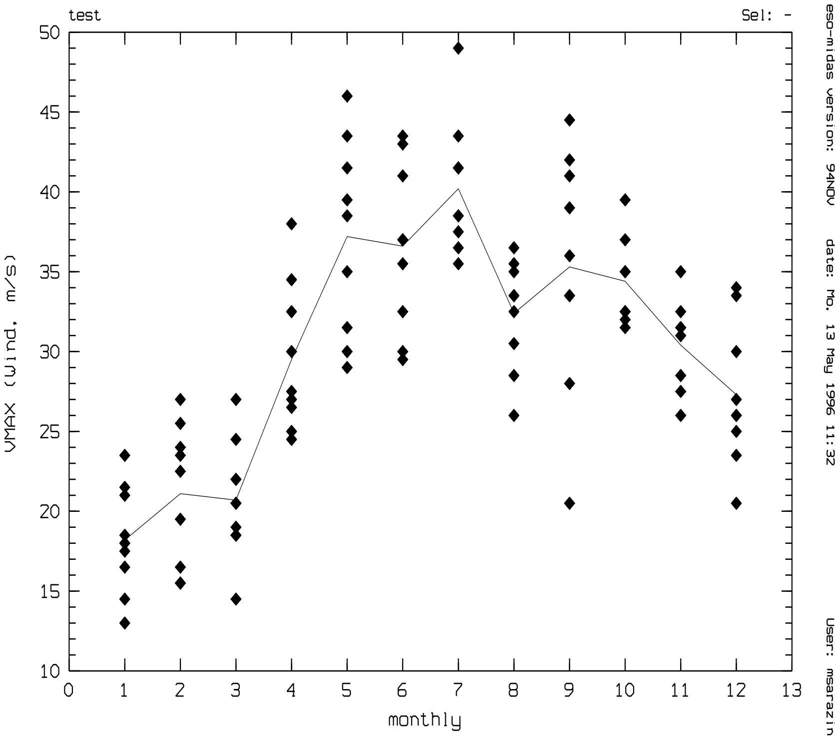

Figure 1: Monthly average wind speed at 200 mb (Antofagasta Radiosounding 1987-1996)

The yearly average velocity profile above Paranal has a maximum of 30 m/s at 200 mB (10-12 km above ground) and a secondary maximum of 7 m/s at 700 mB (corresponding to a few hundred meters above ground) which can be neglected. Applying the previous result on the 200 mB wind only, we obtain for Paranal a yearly average wavefront velocity of 8.6 m/s, and a median $\tau 0$ of 5.6 ms (for 0.65 " yearly median seeing).

We find incidentally the same yearly wind characteristics at Mauna Kea. Assuming the same vertical relative distribution $\alpha(h)$ of the turbulence, the median $\tau 0$ will increase like $r0$, up to 8 ms (for 0.45 " median seeing as reported by Keck I statistics on 1.8 m segments). Such conditions will happen only 10% of the time at Paranal.

About seasonal variations, the distribution of high altitude wind speed in the Paranal area given on Fig. 1 shows that the 10 years monthly average $Vmax$ decreases to 20 m/s in Summer and reaches 40 m/s in Winter. As seeing does not show noticeable seasonal trends, we conclude that the Paranal monthly median $\tau 0$ is expected to vary between 13 ms and 3.4 ms, with a 10 years average of 8.4 ms in Summer and 4.2 ms in Winter.

Why $\tau 0$ predictions ?

The previous discussion gives hints for establishing the specifications of an AO system, but is not sufficient for operation purposes. Again referring to the PARSCA data, we know that $\tau 0$ varies strongly (ranging from 1 to 15 ms) from night to night according to the position of the Jet Stream. However, the conditions remain fairly stable for several hours, due to the large spatial scales involved. To decide whether or not it makes sense scheduling AO assisted observations, the VLT flexible queue manager would benefit from a prediction for the beginning and the middle of the night.

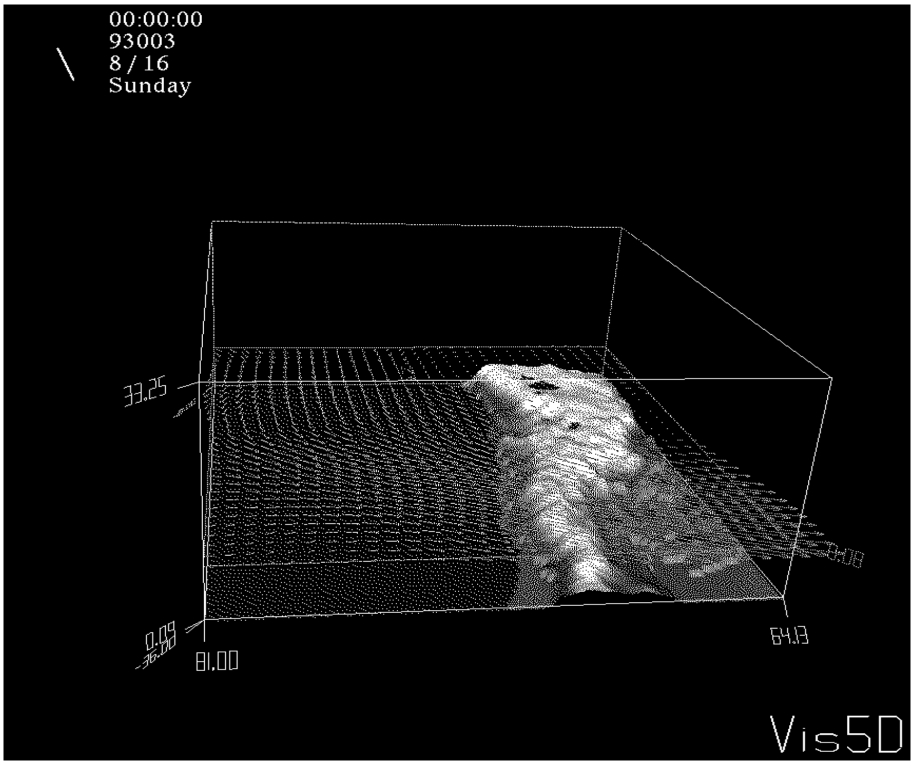

Figure 2: Wind Field at 500 mb over Northern Chile, ECMWF Prediction

How can $\tau 0$ be predicted ?
The 3D wind field is predicted all over the world on a 100x100 km grid by the European Center for Medium Range Forecast (ECMWF), an example is given on Fig 2. The resolution of ECMWF data is probably sufficient for the wind profile $V(h)$ but cannot depict the turbulence $\alpha(h)$.

The Dept. of Astrophysics of Nice University (author of the PARSCA campaign), in collaboration with the Mesoscale Research Dept. of Meteo France (Toulouse) have proposed to ESO a feasibility study for testing a newly developed numerical model (MESO-NH) capable to determine 3D turbulence profiles on a 500x500 m grid, using the ECMWF data as input and injecting the real terrain model of a 50 km area around Paranal.

The performances of the model will be estimated by running as test cases the ECMWF analyses of the nights of the PARSCA campaign and comparing the results to the PARSCA profiles.

In case of success of the study, an optimization of the model will allow to determine the cost of a real time prediction service for the VLT observatory (the CRAY CPU time needed for one prediction time strongly depends on the grid size and resolution needed).

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