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NEAR GROUND WIND SIMULATIONS BY A MESO-SCALE ATMOSPHERICAL MODEL FOR THE EXTREMELY LARGE TELESCOPES SITE SELECTION

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RESUMEN

Las intensidades del viento que se obtienen de los modelos de circulación general de los centros meteorológicos (como el ECMWF) no son confiables para la selección de un sitio óptimo para grandes telescopios, debido a su baja resolución horizontal ($2° - 2.5°$). En este trabajo probamos la capacidad de un modelo no hidrostático de escala media (Meso-Nh) con una resolución horizontal de 1 km para reconstruir la intensidad del viento cerca del suelo (NGW) medida en Paranal (Chile) y Maidanak (Uzbekistan), y para distinguir entre ambos. Las mediciones muestran diferencias típicas entre las velocidades del viento de 4 – 5 m/s. En este trabajo, se comparan mediciones del NGW hechas durante 20 – 25 noches en cada sitio, y se analizan estadísticamente. Nuestra conclusión es que el modelo Meso-Nh puede discriminar entre ambos sitios. Por el contrario, los modelos de circulación general no son capaces de hacerlo. Discutimos también las limitaciones de este estudio, y sugerimos algunos procedimientos para superarlos.

ABSTRACT

Currently, many Extremely Large Telescopes (ELTs: [30 – 100] m size) projects exist. Because of the huge size of such instruments, the selection of an optimal site having a low wind intensity at ground level is a fundamental priority to assure the telescope stability. Wind intensity estimations provided by the general circulation models of the meteorological world centres (such as the ECMWF) are not reliable, because of their low horizontal resolution ($2° - 2.5°$). In this paper we test the ability of a non-hydrostatic meso-scale model (Meso-Nh), having a horizontal resolution of 1 km, in reconstructing the near ground wind intensity (NGW) measured at Paranal, Chile and Maidanak, Uzbekistan, and the ability of the model to discriminate between the two sites. Measurements of the NGW taken during some years at the two sites show a typical wind speed difference of 4 – 5 m/s. In this paper, NGW measurements from $20 - 25$ nights at each site are compared with simulations and a statistic analysis is made. Our conclusion is that the Meso-Nh model can discriminate between the two sites. On the contrary, the analyses and/or forecasts provided by the general circulation models cannot. The limitations of this study are discussed, and some procedures to by-pass these limitations are suggested.

Key Words: **ATMOSPHERIC EFFECTS — METHODS: NUMERICAL — SITE TESTING**

1. INTRODUCTION

One of the principal goal of *site testing* in astronomy is the selection of the optimum site for the telescopes (Stock 1964). One of the pioneering studies in this domain is the site testing campaign for the VLT interferometer concluded at the beginning of the nineties (Ardeberg, Lindgren, & Lundström 1986, 1990; Sarazin 1986, 1990a). A set of parameters, including the altitude and latitude of the site, the sky brightness, the precipitable water vapour, the cloud cover, the relative humidity and the optical turbulence were identified as the discriminatory parameters for the selection of the best sites in the world. A few instruments and some techniques were developed in the past 20 years in order to characterize and monitor the astronomical sites. A huge improvement in the science of *site testing* was attained with the development of the physics that relate the turbulence with the wavefront propagation and the image quality at the focus of a telescope. A few instruments were built in order to measure the integrated quantity of the turbulence: the Differential Image Motion Monitor - DIMM (Sarazin & Roddier 1990b), the Generalized Seeing Monitor - GSM (Martin et al. 1998), and a few were built to measure the vertical distribution of the turbulence: the Classical Scidar (Vernin & Azouit 1983a, 1983b), the Generalized Scidar (Fuchs, Vernin, & Tallon 1998) and the Multi Aperture Scintillation Sensor - MASS (Tokovinin 2002). Today, many projects of Extremely Large Telescopes (ELTs) with diameters of the order of $30-100$ m exist . Because of the huge size of such telescopes, the characterization of a further (with respect to the parameters already listed) and fundamental parameter is mandatory for the selection of the sites: the near ground wind intensity (NGW). It is indeed necessary to limit the potential vibrations produced by the interaction between the wind and the mechanical and optical structure of the telescope in order to assure the stability of the telescope and a good image quality. The only existing (and free of charge) wind intensity estimations extended over the whole world are those provided by the general circulation models of the meteorological world centres (such as the European Centre for Medium Weather Forecasts (ECMWF)) and those provided by NASA's surface meteorology data that are the result of a spatio-temporal interpolation of measurements provided by satellites. Both of these data have a low horizontal resolution ($2°-2.5°$) and they cannot characterize the wind intensity with the required precision. Indeed, the orographic effects, fundamental in the reconstruction of the atmospheric flow near the ground, are not well described by these data because of the low horizontal resolution. It is known that the meso-scale meteorological models give reliable NGW estimations with horizontal resolution of a few kilometers (generally of at least 10 km) and over inhomogeneous geographic regions (Hanna & Yang 2001; Bergström 1996; Cox, Bauer, & Smith 1998). The astronomical applications present some particular aspects that can justify a deeper study in order to test the usefulness of the meso-scale models for the selection of the best site for the ELTs, namely the following:

(a) The astronomical sites are all situated in mountainous regions having a high degree of topographic inhomogeneity that can force the wind to high values. The applications of meso-scale models found in the literature are more frequently over rural regions characterized by a more uniform atmospheric flow near the ground and by low wind intensity (rarely larger than 10 m/s). Moreover, the astronomical sites are found, in general, in low populated regions in the world or near the sea. In many of these regions, the quality of the initialization 'real' data (analysis and/or forecasts) is intrinsically worse (Deidda, Marrocu, & Speranza 1997) than in highly populated regions such as the United States or Europe. The reason is the following: the initialization 'real' data depends on a spatio-temporal interpolation of the radiosoundings (i.e., measurements) launched four times each day from meteorological stations distributed over the world. The distribution of these meteorological stations is not uniform and so the interpolation is more reliable in regions with a high density of meteorological stations. This means that the effective usefulness of the meso-scale models for these applications is not *a priori* evident.

(b) Most applications of meso-scale models found in the literature are carried out during the day-time. We are interested in wind estimates during the night-time, when the atmosphere is characterized typically by a strong thermal stability and a temperature inversion near the ground. The estimate of the energy budgets near the ground is fundamental to reconstruct how fast or slow is the air mixing in the boundary layer, and the wind intensity can be affected by this energetic balance. The physics of the energy transfer near the ground is less well-known for night-time conditions than for day-time conditions (Hanna & Yang 2001; André et al. 1978). This means that the results obtained until now are not necessarily representative for astronomical applications.

(c) We do not want simply to estimate the wind intensity of a site but we want to discriminate between sites with different mean wind values. This means that the measurements uncertainty has to be smaller than the difference that we want to detect.

(d) The meso-scale models are frequently used, at least in meteorological applications, in a grid-nesting configuration (i.e., the use of different models having different resolutions extended over different volumes, which are joined as Russian dolls). This allows a description of the atmospheric flow with a higher resolution but in a limited region of the computational domain. The limitation of such a configuration is that it can be extremely expensive and, in general, needs a great amount of CPU time. The model runs over different computational domains forced by a sequence of input data that are forecasts at different time steps. In our study, we intend to choose and test an extremely simplified configuration formed by a single computational domain with a fixed horizontal resolution, in order to apply the model to a huge number of potential astronomical sites and for a large number of nights.

In this paper we use the non-hydrostatic meso-scale model Meso-Nh developed by the Centre National des Recherches Meteorologiques and the Laboratoire d'Aerologie (Toulouse) (Lafore et al. 1998; Cuxart, Bougeault, & Redelsperger 2000; Belair et al. 1998; Bechtold et al. 2001; Koffi et al. 2000). In the past few years Meso-Nh was adapted to simulate the optical turbulence above astronomical sites (Masciadri, Vernin, & Bougeault 1999a, 1999b, 2001; Masciadri 2001b; Masciadri & Jabouille 2001; Masciadri & Garfias 2001), so it seems a good candidate to simulate the NGW in an astronomical site.

In § 2 we describe the intent of this paper. In § 3 we present the preliminary results that we obtained aiming to define the best model configuration in order to do a more detailed statistic analysis. In § 4 we present the statistical results obtained by comparing simulations with measurements, and in § 5 we discuss the abilities and the limitations of the proposed technique. Finally, we suggest some procedures in order to by-pass the detected limitations.

2. DEFINITION OF THE PROBLEM

We intend to test the ability of the Meso-Nh model in reconstructing the NGW at precise sites and its ability to discriminate between the wind intensities of different astronomical sites. We apply the model to two astronomical sites whose mean wind values near the ground are substantially different: Cerro Paranal (Chile) (24.61 S, 70.40 W), the site

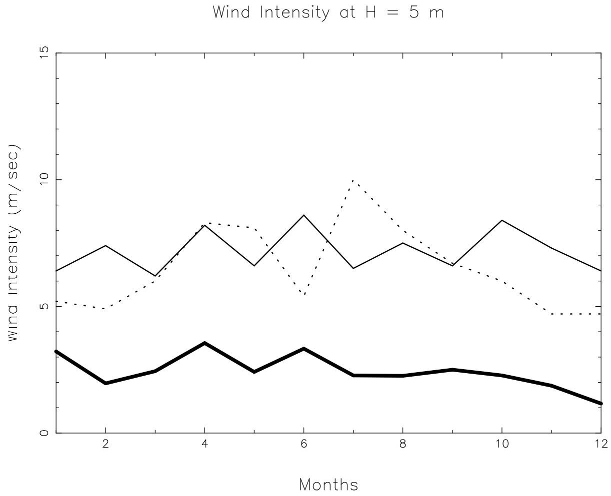

Fig. 1. Mean values of the near ground wind measured above Maidanak (bold line) and Paranal (thin line and dotted line) for all the months of a year. The full and the dotted thin lines show mean values calculated in different ranges of years above Paranal (see the text).

of the VLT interferometer, and Maidanak (Uzbekistan) (38.67 N, 66.88 E), a site known for its extremely low wind near the ground. The first step of our study was the estimation of the mean difference of the NGW between the two sites. Indeed, to test the capabilities of the model, it is fundamental to prove that it can discriminate between two sites whose NGW characteristics are known.

We analyzed NGW measurements taken systematically during the past years over the two sites. The NGW was measured with an anemometer placed at a 5 m height at Maidanak and at 10 m in Paranal. We extrapolated the wind at 5 m in Paranal using the empirical and logarithmic formula (Holton 1992) valid in the surface layer:

$$u = \frac{u_*}{K} \ln\left(\frac{z}{z_0}\right) , \qquad (1)$$

where z_0 is the surface roughness, $K = 0.4$ is the Von Karman constant and u_* is the friction velocity. We took the typical value of $u_* = 0.3$ m/s (Holton 1992) and a minimum (0.1 m) and a maximum (0.4 m) value for z_0. These values were chosen since the Paranal surface is characterized by small stones. We calculated the velocity versus altitude for the two z_0 values. A difference in velocity Δu of about 0.5 m/s ($z_0 = 0.1$ m) and 0.7 m/s ($z_0 = 0.4$ m) is calculated between 5 and 10 m. We therefore subtracted a mean value of 0.6 m/s from all the Paranal measurements. Figure 1 shows the mean value of the NGW measured above Maidanak (bold line) in the range [August 1996−October 1999] for all the

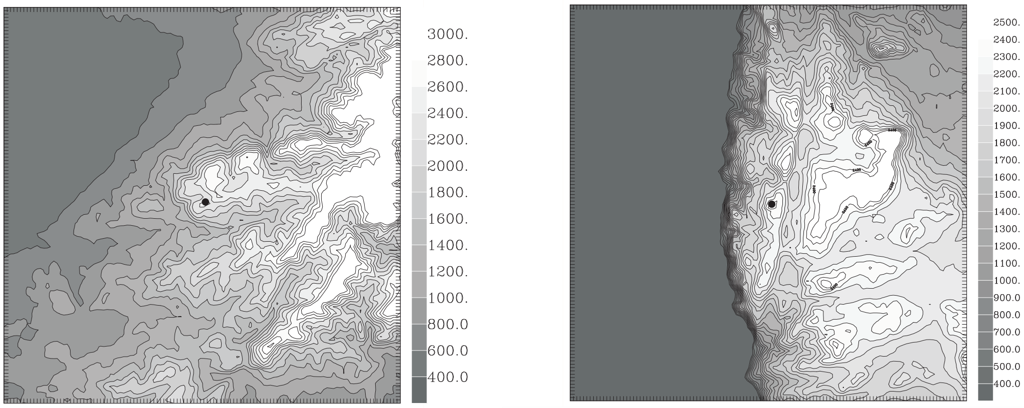

Fig. 2. Orographic models extended over a surface of 120 km × 120 km and with a horizontal resolution of 1 km centred over the Maidanak (Uzbekistan - on the left) and Paranal (Chile - on the right) astronomical sites. The geographic coordinates are, respectively: (38.67 N, 66.88 E) and (24.61 S, 70.40 W).

months of a year (Table 5 of Ehgamberdiev 2000). The thin lines (full and dotted) show the mean value of the NGW measured above Paranal (the full thin line is a mean calculated in the years [1998 – 2000]; the dotted thin line shows the values reported in Sarazin 1990a (p. 90) for the year 1986). We calculate a difference in velocity between Maidanak and Paranal of $\Delta v = 4.74$ m/s in the first case (bold and full thin line) and of $\Delta v = 4.05$ m/s in the second case (bold and dotted thin line). The maximum root-mean square deviation is 0.74 m/s. This means that, although some variations during the years are observed, the statistical difference between the two sites is, at least, of 4 m/s. We note that the choice of the extrapolation (from 10 to 5 m) is absolutely arbitrary and we should have chosen an extrapolation from 5 to 10 m. The goal is simply to compare measurements taken at the same altitude.

Figure 2 shows the orographic models of the two astronomical sites implemented in the Meso-Nh model. The surface is 120 km×120 km and the horizontal resolution is 1 km. This is the maximum resolution for which orographic models for every place in the world are provided free of charge. This resolution is higher than the typical resolution ($\sim$ 10 km) used in equivalent studies done in rural places and it seems more suitable for describing the effect of the irregular orography of mountain regions. We intend to do a set of simulations over the two sites using the same model configuration and extended over 3 hours. The model is initialized with analyses provided by ECMWF and calculated at 00:00 U.T. These are *fully 3D fields analyses* that extend over the whole surface. We underline that, since our simulations are not forced continuously by sequential initial conditions as in an operational forecasting model, the simplified procedure that we are using is not literally a 'forecasting' but rather an adaptation of the atmospheric flow to the ground, and the simulation results are to be interpreted as a mean estimation of the wind in the night. This means that there is no one-to-one correlation between the simulation time and the instant at which the wind was measured.

3. PRELIMINARY RESULTS

Here we report the results of some preliminary tests done in order to select the best model configuration for the statistical analysis. In order to select which size of the first vertical grid point better reproduces the wind intensity above the ground we simulated the NGW above Maidanak and Paranal using three different vertical grid samples. All three grid samples have the first grid point above the ground at z_0 m (z_0 different for each vertical grid), an increasing logarithmic stretching until 3000 m and a constant grid size of 600 m above 3000 m. The first vertical grid sample has $z_0 = 5$ m, the second one has

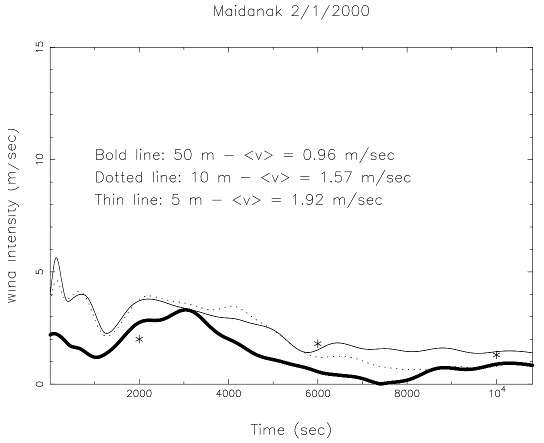

Fig. 3. Maidanak 2/1/2000: simulations extended over 3 hours of the NGW obtained with different z_0. The first grid point z_0 is at 50 m (bold line), at 10 m (dotted line) and at 5 m (thin line) from the ground. The asterisks are the measurements of the NGW done during the same night above the site.

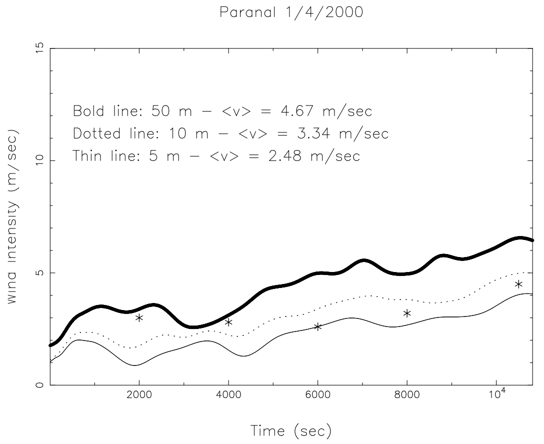

Fig. 4. Paranal 1/4/2000: the same as Fig. 3.

z_0 = 10 m, and the third one has z_0 = 50 m. Figure 3 shows the NGW simulated above Maidanak for the night 2/1/2000. The bold line represents the simulation obtained with z_0 = 50 m, the dotted line with z_0 = 10 m, and the thin line with z_0 = 5 m. In the same figure the measurements of the NGW taken above Maidanak during the same night are shown with an asterisk. Figure 4 shows simulations and measurements for the Paranal site during the night 1/4/2000. In both cases the mean values corresponding to the simulations are calculated in the range [2000 – 10,800] s from the start of the simulation. The spurious first 2000 seconds are rejected because of the adaptation of the atmospheric flow to the ground. One can observe that, in both cases, z_0 = 10 m seems to be the best value for the first grid point. We chose this last configuration for our simulations. We underline that there is no one-to-one correlation between the simulation time and the real time at which the measurements were done, so we have to compare the simulation trend with the average estimate of the measurements. Table 1 reports the first 12 levels of the model (from the sea-level) above the Paranal site. We note that the model grid size needs to be small, or at least equal to the typical fluctuations scale of the wind. This last can be assumed to be of the order of a few ten meters near the ground. This means that our choice is reasonable. Moreover, we underline that Hanna & Yang (2001) compared NGW simulations obtained with meso-scale models (MM5 and RAMS) with measurements obtained with anemometers. The first vertical grid of their models is respectively, of 9 m and 10 m (similar to ours) and the altitude of the anemometer probe is 10 m.

TABLE 1

HEIGHT OF THE FIRST 12 MODEL LEVELS

N[a]	Alt.[b] (m)	N[a]	Alt.[b] (m)
0	2433	6	2564
1	2444	7	2614
2	2457	8	2678
3	2474	9	2762
4	2497	10	2871
5	2526	11	3012

[a]First and third columns: number of the first 12 vertical levels of the model above Paranal.

[b]Second and fourth columns: altitudes of the levels above the same site.

4. COMPARISON BETWEEN MEASUREMENTS AND SIMULATIONS. STATISTICAL ANALYSIS

We simulated the NGW above Maidanak (20 nights) and Paranal (25 nights) and we compared the measurements with the simulations obtained at the first grid point (10 m) above the ground. The nights considered belong to the years [1999 – 2000] and they are selected in an arbitrary way. The simulations are obtained using the same configuration described in the previous sections. We calculated the mean value as described in the previous section (rejecting the first 2000 s). Figure 5 shows the cumulative distribution of the relative errors ($CDRE$) obtained after 3 simulation hours (triangles) and at the time $t = 0$ s (circles) for the Maidanak case (left),

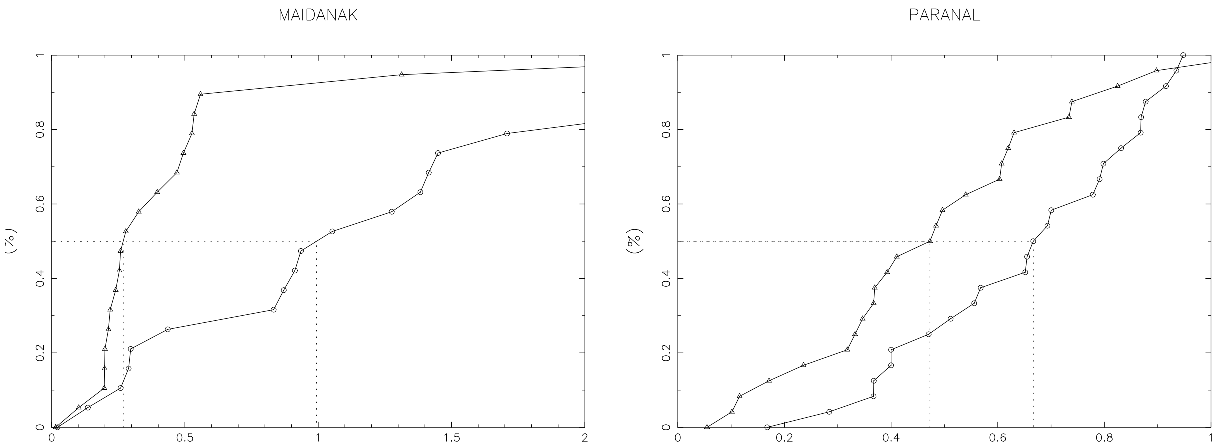

Fig. 5. Cumulative distribution obtained at Maidanak case (left side) and Paranal case (right case) after 3 simulations hours (triangles) and at the time $t = 0$ s (circles).

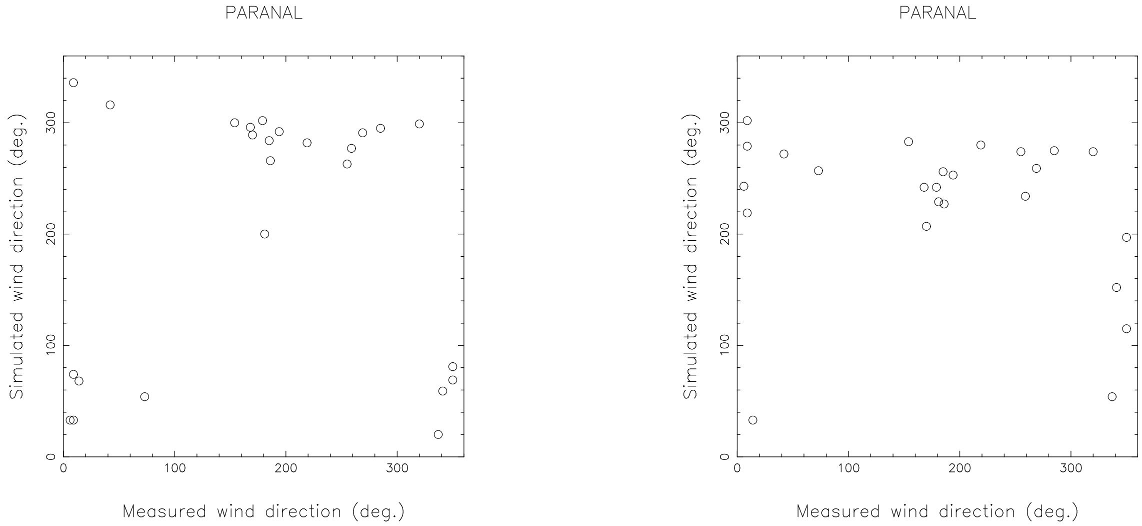

Fig. 6. Simulated versus measured wind direction averages over the range [2000 – 10,800] s (left) and at $t = 0$ s (right).

and the same for the Paranal case (right).

Table 2 summarizes the quantitative statistical results: the mean measured wind velocity above the two sites (v_{meas}), the median $CDRE$ value, and the mean simulated wind velocity (v_{sim}), at $t = 0$ s and after 3 hours. The statistical results obtained at $t = 0$ s (Table 2) tell us how reliable are the initialization data for the estimation of the NGW. Since the initialization data are provided by the GCMs, the NGW values at $t = 0$ are representative of the reliability of the GCMs. The comparison of the NGW values obtained after 3 hours of simulations (Fig. 5 - triangles) with those obtained at time $t = 0$ s (Fig. 5 - circles) permits us to know if a meso-scale model can provide a better estimation than the GCMs or not.

One can observe (Table 2) that the simulated mean value obtained after 3 hours (2.30 m/s) is well correlated with the measured one (2.33 m/s) in the Maidanak case. Moreover, the median of the $CDRE$ is extremely good (26.84%). A little bit worse ($CDRE \sim 47.30\%$) is the result obtained in the Paranal case. We underline that this rate of success is comparable to that obtained with more complex configurations including grid nesting (Hanna & Yang 2001). These results show that the Meso-Nh model can discriminate between the two sites in the correct way: the wind simulated at Maidanak is lower than that simulated at Paranal. The results obtained at $t = 0$ s (Fig. 5 - bottom) also show a generally worse reconstruction of the wind intensity at Maidanak ($CDRE = 99.40\%$) and Paranal ($CDRE = 66.67\%$). Moreover, we observe that, at $t = 0$ s, the wind intensity at Maidanak is larger than in Paranal. This means that the initialization data cannot discriminate between the two sites. In terms

TABLE 2

MEASURED AND SIMULATED WIND INTENSITY STATISTICAL ESTIMATION[a]

Parameter	Maidanak	Paranal
v_{meas} m/s	2.33	6.36
v_{sim} ($t = 3$ hours)	2.30	3.83
CDRE median (%)	26.84	47.30
v_{sim} m $/s$ ($t = 0$ hours)	4.52	1.67
CDRE median (%)	99.40	66.67

[a]Obtained above the Paranal and Maidanak sites. In the first line the measured wind intensity averaged over the all nights. In the following lines are shown the averaged simulated wind intensity and the CDRE after 3 hours of simulation and at the time $t = 0$.

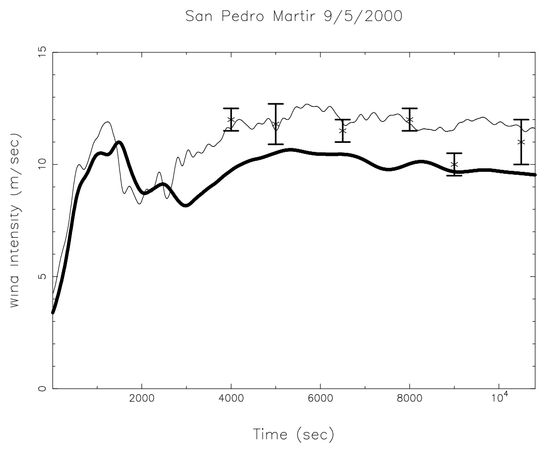

Fig. 7. Simulated NGW obtained with an horizontal resolution of 1000 m (bold line) and 500 m (thin line) above the San Pedro Mártir site the night 9/5/2000.

of the cumulative distribution of the relative error, the meso-scale model permits to pass, for the Maidanak case, from 99.40% to 26.84% (a gain of about 72.56%) and, for the Paranal case, from 66.67% to 47.30% (a gain of about 19.37%). It seems that meso-scale models (or at least Meso-Nh) improve on the results provided by the GCMs. Using this configuration, the model reconstructs a mean difference of the NGW between the two sites equal to 1.53 m/s when the corresponding observations give a difference of 4.02 m/s.

As a supplementary product of our analysis, we could estimate the wind direction at 10 m from the ground. We could not analyze the wind direction at Maidanak because the measurements of the direction are only qualitative, and are made only by quadrant (N/E, E/S, S/W, and W/N). The wind direction is a parameter less noteworthy for site testing discrimination, but it is interesting to estimate it because it is an index of the model capabilities for reproducing the correct orographic effects. Figure 6 reports the simulated versus measured wind direction obtained by averaging over the range [2000 − 10,800] s (left) and at $t = 0$ (right). One can observe that most of the initialization data are in the range $[200° - 300°]$ (ordinates in Fig. 6, right). After 3 hours, the model (Fig. 6, left) modifies the wind direction in the correct way in some of the cases (see for example the bottom-left hand side of Fig. 6) but it fails in most of the cases. Besides this, we estimate that the mean absolute error (AE) obtained with the Meso-Nh simulations is 62°, and at $t = 0$ it is 103°. The meso-scale model, therefore, gives a considerable gain with respect to the initialization data. We note that the value of 62° is similar to the typical value obtained by equivalent meso-scale models applied in rural regions with a lower horizontal resolution (Hanna & Yang 2001). As shown by ours and other results, it is more difficult to accurately simulate the wind direction than the wind intensity, especially when the wind intensity is low.

5. DISCUSSION

Our results show that Meso-Nh, at least in the chosen configuration, seems to be able to select the sites with the lowest wind intensity. Beside this, a detailed analysis showed a general tendency of the model to underestimate the wind when it has high values (≥ 10 m/s) and a strong gradient in the surface layer. In this particular case, the errors of the model can be high. Our results should be considered completely satisfactory if the criterion for the selection were simply the *'search of the lowest NGW'*. Beside this, in the context of the search of the best site for the ELTs, it would be useful to define a more general *function of merit* for each site depending on many parameters: the NGW, the cloud cover, the relative humidity, the sky brightness, the level of optical turbulence, and so on. This means that it would be useful to by-pass the limitations presented by the model and suggest some practical solutions in order to characterize, in the best possible way, the NGW of *all* the sites.

Just to give an example, the ability to detect sites characterized by a really strong wind is as important as the ability to detect sites characterized by a low wind. One would like *to select* the second ones and *to eliminate* the first ones. For this reason, we tried to look for some methods to by-pass the limitations shown by the model.

Here we analyze the possible reasons of the model underestimation of strong winds and then we propose a method for the estimation of such winds. A possible cause for the underestimation could be that the initialization data related to the region of the Paranal site (that is the Chilean region) are probably worse than those related to other regions in the world. Previous studies (Deidda et al. 1997) showed that the correlation between analyses and radiosoundings is not too high in the Chilean region. Another possible cause could be related to the configuration of the model. This means: horizontal resolution, vertical grid sample, using or not the grid-nesting configuration, and so on. It is difficult to quantify how much these different elements affect the results of our study. The ideal condition would be to apply the same study to a site characterized by a relatively strong wind and placed in a different region in the world. Here we show the result obtained with the simulation of the NGW above the San Pedro Mártir site for the night 9/5/2000, obtained using the same initialization procedure described previously. We chose this night because the anemometer of the Observatory measured a strong wind (11.38 m/s). We note that San Pedro Mártir is a site near the United States border and the quality of the initialization data is probably better than in the Chilean region. At present, the NGW is not systematically measured above this site so we could not do a systematic study. Figure 7 shows the results obtained by the simulations with a horizontal resolution of 1 km (bold line) and 500 m (thin line). The same figure shows the measured NGW ('crosses') during the same night. This result seems to indicate that Meso-Nh can simulate a relatively strong wind and that the horizontal resolution cannot be the cause of the underestimation of the NGW at Paranal. A difference of simply 1.74 m/s was estimated between the two resolutions, not enough to justify the underestimation detected in our statistical analysis of the Paranal site. The result obtained above San Pedro Mártir seems to indicate that the quality of the initialization data has a non negligible influence on the reliability of the model when the wind is particularly strong. It would be interesting to carry out a detailed study above the San Pedro Mártir site to better quantify this effect. However, this does not solve the problem of better identifying the sites with a strong wind. After a detailed analysis of the simulations we advance the hypothesis that, independently of the quality of the initialization data, the model probably shows some deficiencies in reconstructing the dynamical stresses that develop in coincidence with the shears of the wind profile in the cases in which the gradients are strong near the ground. We think that when the wind intensity is strong in the first tens of meters, it probably remains strong at about 200 m above the ground. At this altitude, the sensitivity of the meso-scale model should be better. Beside this, the general tendency is that the wind grows with altitude, independently of the site. We therefore studied the temporal evolution of the wind at 245 m above the ground (level 8 of the model vertical grid) in order to see if there is a clearer evidence of the difference of the wind intensity between Maidanak and Paranal. Figure 8 shows a vertical section in the east-west direction of the wind field simulated above Paranal on the night of 17/7/1999 (left) and on 8/5/1999 (right). One can observe that in the first 2 km above the ground the wind intensity is higher on 17/7 than on 8/5 over the extended region of 20 km square centered on the Paranal. Fig. 8, bottom, shows the vertical profile of the wind intensity simulated above the site on the night 17/7 (bold line) and on 8/5 (thin line). The strong gradient of the wind in the first 50 m is quite evident during the 17/7 night.

The model gives for the 17/7 night, at 10 m from the ground a mean value of about 8.56 m/s and at 245 m from the ground a value of about 14 m/s. During this same night a wind of 14.09 m/s was measured. As explained before, it seems that the model cannot reconstruct the correct gradient in the first tens of meters. On the 8/5 night, the wind simulated at 10 m is 2.28 m/s and at 245 m is about 3 m/s. During this same night, a wind of 2.07 m/s was measured. The vertical gradient of the wind profile is not as large as in the previous case, the wind values are more uniform in the first 245 m from the ground, and the measurements seem to be in better agreement with the simulations.

We therefore carried out a set of simulations studying the temporal evolution of the wind intensity at 245 m from the ground. Five nights were selected at Maidanak and five at Paranal. We chose all the nights in which the model had given a strong (but underestimated) wind for the Paranal and random nights for the Maidanak. Table 3 shows the obtained results. One can see that, at the Maidanak site, the model gives a wind intensity which is more or less uniform in the first 245 m, with weak gradients. In the Paranal site, on the contrary, the wind intensity is in general much larger at 245 m than at 10 m. We estimate an increment that can reach [50

TABLE 3

SIMULATED (AT 10 AND 245 M FROM THE GROUND) AND MEASURED WIND INTENSITY[a]

Maidanak Night	Sim.(10 m) m/s	Sim. (245 m) m/s	Meas. m/s
15/4/1999	1.92	1.89	4.12
25/4/1999	1.87	0.41	1.20
7/10/1999	0.99	0.90	1.47
2/1/1999	1.54	1.56	2.55
7/9/1999	1.52	0.62	1.38
Paranal Night	**Sim. (10 m) m/s**	**Sim. (245 m) m/s**	**Meas. m/s**
16/7/1999	7.75	12.97	12.25
17/7/1999	8.56	13.40	14.09
19/7/1999	4.48	8.09	12.13
5/10/1999	7.69	11.91	14.91
7/9/2000	3.70	7.13	13.88

[a]Wind intensity simulated at 10 m (second column) and 245 m (third column) from the ground and measured (fourth column) in Maidanak and Paranal sites during different nights.

– 90]%. This result seems to confirm the hypothesis that the model has some deficiencies in reconstructing the strong gradients near the ground. Although we cannot associate the measured wind with the wind simulated at 245 m, the simulations of the wind at this altitude can help to identify the sites with a strong wind near the ground.

6. CONCLUSIONS

The conclusions of this study are the following: **(a)** We find that Meso-Nh can discriminate between the Maidanak and Paranal sites. The initialization data (analyses and/or forecasts) cannot discriminate (or show a quite bad ability in discriminating) between the two sites.

(b) It seems that the Meso-Nh model can select sites characterized by an extremely low NGW (at the present time, Maidanak is known as the astronomical site having the lowest NGW). The selection can be obtained with a good sensitivity and a good statistical rate of success [26.84 – 47.30]%. It would be desirable to extend this same study to a richer statistical sample so as to confirm this preliminary result.

(c) The model shows a general underestimation in reconstructing strong winds ($\geq$ 10 m/s). At the present time, this has to be considered as a limitation of the methodology. Nevertheless, further simulations taken at a different altitudes from the ground proved that systematic simulations taken at about 250 m from the ground can help to detect the sites characterized by a strong wind. We conclude that systematic simulations taken at 10 m and about 250 m permit us to improve the estimation of the NGW above an astronomical site.

(d) As a supplementary result of our analysis we proved that the Meso-Nh model can reconstruct the NGW direction with a mean error of 62°, a great improvement with respect to the GCM, which provide wind direction with a mean dispersion of about 103°. Besides this, the model's ability to reconstruct the wind direction is to be considered unsatisfactory at least in this configuration.

(e) The results of this study were obtained running the Meso-Nh model on the Fujitsu VPP5000 supercomputer of the ECMWF centre. We used 3 hours of simulation time for each night corresponding to a CPU time equal to 3047 s. The whole characterization of the 45 nights corresponds to a CPU time of about 42 hours. The study applied to about 15 sites would have required about 630 hours of CPU equivalent to 2296 SBU units (SBU is the unit of the Fujitsu supercomputer resources depending on the CPU time, the allocated memory and the input/output memory). This is an absolutely realistic amount of resources that could be delivered by the ECMWF. We conclude that the application of Meso-Nh to about 15 sites is to be considered as a realistic possibility.

(f) The results of this study seem to indicate that the probabilities of retrieving useful information about the NGW from the NCEP global re-analysis (http://dss.ucar.edu/pub/reanalysis/) are poor. The NCEP re-analysis could in principle provide climatological information because they are analyses extended over large periods of time [1957 – 2000]. Beside this, the horizontal resolution is 1.875°, which is lower than the initialization data used in our study (0.5°).

This work has to be considered as a first step in the direction of the characterization of the NGW for the selection of the ELTs astronomical sites. Further studies have to be done in order to know if the meso-scale models can provide statistically reliable estimations to discriminate between sites. An interesting test would be to verify if using a grid-nesting

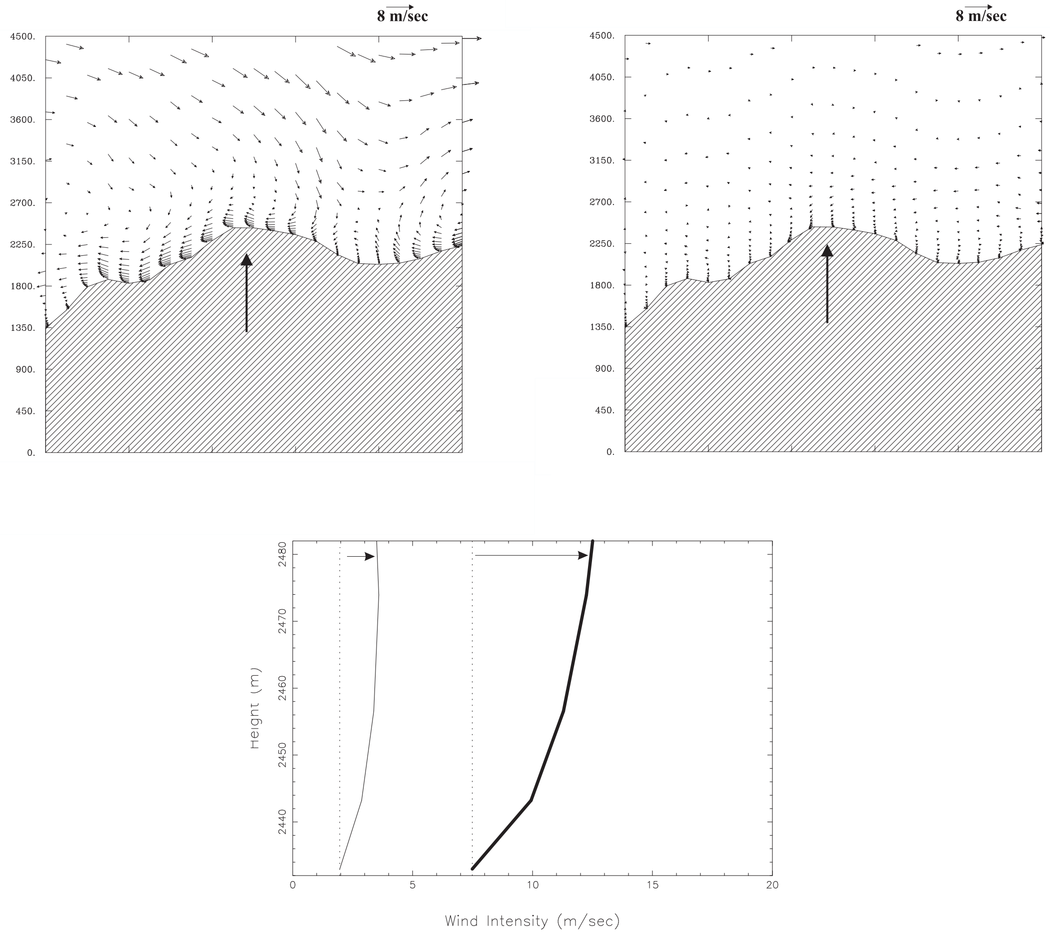

Fig. 8. Top: vertical east-west section of the wind field obtained after 3 hours of simulation centred above Paranal. The wind field is shown in the range [2433 – 4500] m (y-axis) and the section is along 20 km (x-axis). The intensity of the wind is marked by arrows having the same scale in both the nights: 17/7/1999 (left) and 8/5/1999 (right). The vertical arrows mark the position of the site. Bottom: vertical wind intensity profiles simulated above the site on the 17/7/1999 night (thin line) and on the 8/5/1999 night (bold line). The strong wind gradient in the first 50 m can be observed on the 17/7/1999 night.

configuration can improve the results that we obtained.

We note that the simulations shown in this paper could not have been done with a DNS (direct numerical simulations) method and a very high resolution (a few meters). It is possible to implement this model (even over a not too large surface), but the real drawback is different one. Unfortunately, with the DNS it is not possible to initialize the models with external 3D fields ($\tilde{\mathbf{V}}$, p, and T) sampled with such a high resolution.

Finally, we comment that it would be interesting to know the maximum wind intensity that the mechanical structure of very large telescopes can support. In this way, we could more easily study the ability of a meso-scale model to discriminate the sites having an average wind intensity higher or lower than the required threshold.

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