Mesoscale optical turbulence simulations at Dome C

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ABSTRACT

In recent years, ground-based astronomy has been looking towards Antarctica, especially its summits and the internal continental plateau, where the optical turbulence appears to be confined in a shallow layer close to the icy surface. Preliminary measurements have so far indicated rather good values for the seeing above 30–35 m: around 0.3 arcsec at Dome C. Site-testing campaigns are however extremely expensive; instruments provide only local measurements and atmospheric modelling might represent a step ahead in the search and selection of astronomical sites, thanks to the possibility of reconstructing three-dimensional (3D) $C_n^2$ maps over a surface of several km. The Antarctic Plateau therefore represents an important benchmark test to evaluate the possibility of discriminating between sites on the same plateau. Our group has proven that the analyses from the European Centre for Medium-Range Weather Forecasts (ECMWF) global model do not describe the Antarctic boundary and surface layers in the plateau with the required accuracy. A better description could be obtained with a mesoscale meteorological model. The mesoscale model Meso-NH has proven to be reliable in reproducing 3D maps of optical turbulence above mid-latitude astronomical sites. In this paper we study the ability of the Meso-NH model to reconstruct the meteorological parameters as well as the optical turbulence above Dome C with different model configurations (monomodel and grid-nesting). We concentrate our attention on the abilities of the model in reproducing the optical turbulence surface-layer thickness ($h_{sl}$) and the integral of $C_n^2$ in the free atmosphere and in the surface layer. It is worth highlighting that these are the first estimates ever made with a mesoscale model of the optical turbulence above the internal Antarctic Plateau.

Key words: turbulence – atmospheric effects – site testing.

1 INTRODUCTION

The internal Antarctic Plateau is, at present, a site of potential great interest for astronomical applications. The extreme low temperatures, dryness and typical high altitude of the internal Antarctic Plateau (more than 2500 m), together with the fact that the optical turbulence seems to be concentrated in a thin surface layer, the thickness of which is of the order of a few tens of metres, make this site a place in which, potentially, we could achieve astronomical observations otherwise possible only from space. In spite of some exciting first results (Lawrence et al. 2004; Aristidi et al. 2005; Trinquet et al. 2008), the effective gain that astronomers might achieve from ground-based astronomical observation from this location still suffers from serious uncertainties, and doubts have been raised in previous work (Geissler & Masciadri 2006; Masciadri & Egner 2006; Hagelin et al. 2008; Stoesz et al. 2008). A better estimate of the properties of the optical turbulence above the internal Antarctic Plateau can be achieved with both dedicated measurements performed simultaneously with different instruments and simulations provided by atmospheric models. Simulations offer the advantage of providing volumetric maps of the optical turbulence ($C_n^2$) extended over the whole internal plateau and, ideally, retrieving comparative estimates in a relatively short time and homogeneous way for different parts of the plateau. In a previous paper (Hagelin et al. 2008), our group performed a detailed analysis of the meteorological parameters on which the optical turbulence depends, provided by the General Circulation Model (GCM) of the European Centre for Medium-Range Weather Forecasts (ECMWF). In that work we quantified the accuracy of the ECMWF estimates of all the major meteorological parameters and, at the same time, we pointed out the limitations of GCMs. In contexts in which GCMs fail, mesoscale models can supply more accurate information because they are conceived to reconstruct phenomena that develop at spatial and temporal scales too small to be described by a GCM. In spite of the fact that mesoscale models can attain higher resolution than GCMs, some parameters, such as the optical turbulence, are not explicitly resolved but are parametrized, i.e. the fluctuations of the microscopic physical quantities are expressed as a function of the corresponding macroscopic quantities averaged on a larger spatial domain.
scale (a cell of the model). For classical meteorological parameters, a mesoscale model should be useless if GCMs such as the ECMWF one can provide estimates with an equivalent level of accuracy. For this reason the Hagelin et al. (2008) paper has been a first step towards the exploitation of the mesoscale Meso-NH model above the internal Antarctic Plateau. In that study we retrieved an exhaustive characterization of all the meteorological parameters from the ECMWF analyses (wind field, potential temperature, absolute temperature, etc.) and, at the same time, defined the limitations of the ECMWF analyses: we concluded that, in the first 10–20 m, the ECMWF analyses show a discrepancy with respect to measurements of the order of 2–3 m s$^{-1}$ for the wind speed and 4–5 K for the temperature.

The Meso-NH model has been proven to be reliable in reproducing 3D maps of optical turbulence (Masciadri et al. 1999a, b; Masciadri, Vernin & Bougeault 2001) and has been statistically validated (Masciadri & Jabouille 2001; Masciadri et al. 2004; Masciadri & Egner 2006) above mid-latitude astronomical sites (see details in the next section). Preliminary tests concerning the optimization of the model configuration and sensitivity to the horizontal and vertical resolution have already been conducted by our team (Lascaux et al. 2007) for the internal Antarctic Plateau. In this paper we intend to quantify the performance of the model above this peculiar environment. More precisely, our goals are as follows.

(i) To compare the performance of the mesoscale Meso-NH model and the ECMWF GCM in reconstructing wind speed and absolute temperature (the main meteorological parameters on which the optical turbulence depends) with respect to the measurements. This analysis will quantify the performance of the Meso-NH model with respect to the GCM from the ECMWF.

(ii) To perform simulations of the optical turbulence above Dome C (75°06′04″S, 123°20′48″E), employing different model configurations, and to compare the typical simulated thickness of the surface layers as well as the seeing in the free atmosphere with the values measured by Trinquet et al. (2008, hereafter TR2008). In this way we aim to establish which configuration is necessary to reconstruct the $C_\lambda^5$ correctly. In summary, we aim to validate the Meso-NH model on the Antarctic site.

There are two factors that might make this Earthbound location very appealing to astronomers: (1) the surface-layer thickness $h_d$ and (2) the typical seeing in the free atmosphere. It might be extremely useful to have an independent confirmation from models of the typical values measured on the site. This study is focused on the winter season. In Section 2 we present the Meso-NH model and the different configurations that were used to perform numerical weather simulations above the internal Antarctic Plateau. Section 3 is devoted to a statistical comparison of standard meteorological parameters (wind speed and temperature) deduced from Meso-NH simulations, ECMWF analyses and radiosoundings. In Section 4 we present the results of the computation with Meso-NH of the surface-layer thickness for 15 nights in winter and a comparison with the observed surface-layer thickness from TR2008. Finally, conclusions are drawn in Section 5.

2 MODEL NUMERICAL SET-UP

Meso-NH (Lafore et al. 1998) is the non-hydrostatic mesoscale research model developed jointly by Météo-France and Laboratoire d’Aérologie.

It can simulate the temporal evolution of three-dimensional atmospheric flow over any part the globe. The prognostic variables forecast by this model are the three Cartesian components of the wind $u, v, w$, the dry potential temperature $\Theta$, the pressure $P$ and the turbulent kinetic energy $\kappa$.

The system of equations is based upon an anelastic formulation allowing for an effective filtering of acoustic waves. A Gal-Chen & Sommerville (1975) coordinate on the vertical and a C-grid in the formulation of Arakawa & Messinger (1976) for the spatial digitization is used. The temporal scheme is an explicit three-time-level leap-frog scheme with a time filter (Asselin 1972). The turbulent scheme is a one-dimensional 1.5 closure scheme (Cuxart, Bourguet & Redelsperger 2000) with the Bourguet & Lacarrère (1989) mixing length. The surface exchanges are computed in an externalized surface scheme (SURFEX) including different physical packages, among them Interaction Soil Biosphere Atmosphere (ISBA: Noilhan & Planton 1989) for vegetation.

Masciadri et al. (1999a, b) implemented the optical turbulence package to be able to forecast the optical turbulence ($C_\lambda^5$ 3D maps) and all the astroclimatic parameters deduced from the $C_\lambda^5$. We will refer to the ‘Astro-Meso-NH code’ to indicate this package. To compare our simulations with measurements, the integrated astroclimatic parameters are calculated integrating the $C_\lambda^5$ with respect to the zenith in the Astro-Meso-NH code. The parametrization of the optical turbulence and the reliability of the Astro-Meso-NH model have been proven in successive studies in which simulations have been compared with measurements provided by different instruments (Masciadri et al. 2001, 2004; Masciadri & Egner 2006). This has been achieved thanks to a dedicated calibration procedure that was proposed and validated by the same authors (Masciadri & Jabouille 2001).

The atmospheric Meso-NH model is conceived for research development and for this reason it is in constant evolution. One of the major advantages of Meso-NH that was not available at the time of Masciadri’s studies is that it now allows use of the interactive grid-nesting technique (Stein et al. 2000). This technique consists of using different imbricated domains with increasing horizontal resolution, with mesh sizes that can reach 10 m.

In this study we use the Astro-Meso-NH package, implemented in the most recent version of the atmospheric Meso-NH model. To place this in the context of this work, the differences that have been implemented in the model configuration with respect to Masciadri’s previous studies are listed here.

(i) A higher vertical resolution near the ground has been selected. We still work with a logarithmic stretching near the ground up to 3.5 km, but we start with a first grid point of 2 m (instead of 50 m) with 12 points in the first hundred metres. This configuration is allowed thanks to the extremely smooth orography of this region of the Earth. It is clearly preferred, because it permits us to quantify better the turbulence contribution that typically develops in the thin vertical slabs within the first hundred metres above the internal Antarctic Plateau. Above 3.5 km the vertical resolution is constant and equal to $\Delta H = 600$ m as in Masciadri’s previous work. The maximum altitude is 22 km.

(ii) The grid nesting (see Table 1) is implemented with three imbricated domains, allowing a maximum horizontal resolution of 1 km in a region around Concordia Station (80 km $\times$ 80 km).

(iii) The simulations are forced at synoptic times (every 6 h) by analyses from the ECMWF. This permits us to perform a real forecast of the optical turbulence. To avoid misunderstandings, we highlight the fact that, as has been extensively explained in
Table 1. Meso-NH model configuration. The second column gives the horizontal resolution $\Delta X$, the third column the number of grid points and the fourth column the horizontal surface covered by the model domain.

|        | $\Delta X$ (km) | Grid points | Surface (km) |
|--------|-----------------|-------------|--------------|
| Monomodel | 100             | $60 \times 60$ | $6000 \times 6000$ |
|         | 25              | $120 \times 120$ | $3000 \times 3000$ |
| Grid-nesting | 5               | $80 \times 80$ | $400 \times 400$ |
|         | 1               | $80 \times 80$ | $80 \times 80$ |

previous studies (Masciadri et al. 2004; Masciadri & Egner 2006), the Meso-NH model has so far been used for simulations of the optical turbulence in a configuration permitting a quantification of the mean optical turbulence over a night and not a forecast of the optical turbulence. We therefore take a step ahead with respect to the results obtained so far with the Astro-Meso-NH code.

In spite of the fact that the orographic morphology is almost flat above Antarctica, it is known that even a weak slope can be an important factor in inducing a change in the wind speed at the surface in these regions. The physics of the optical turbulence strongly depends on a delicate balance between the wind speed and temperature gradients. In order to study the sensitivity of the model to the horizontal resolution and to identify which configuration provides more reliable estimates, we performed two sets of simulations with different model configurations.

In the first configuration (which we will call monomodel) we used a horizontal resolution $\Delta X = 100$ km covering the whole Antarctic continent (Figs 1(a) and (b) and Table 1). We selected this configuration because it permits us to discuss, where possible, our results with respect to those obtained by Swain & Gallée (2006, hereafter SG2006) with the regional atmospheric model MAR above the Antarctic Plateau. In that case, indeed, the authors used an extremely low horizontal resolution that has the advantage of being cheap from a computational point of view. This model configuration permits fast simulations but it is certainly necessary to verify that its resolution is high enough to resolve correctly the most important features of the optical turbulence near the ground and in the high part of the atmosphere.

In the second configuration (Table 1) we used the grid-nesting technique, more expensive from a computational point of view but potentially more accurate in the reconstruction of the spatial distribution of the optical turbulence. The grid-nested simulations involved three domains. The largest domain covers all the Antarctic Plateau with $120 \times 120$ points and it has a 25 km mesh size (Fig. 1c). The second domain has a 5 km mesh size, $80 \times 80$ points and is centred above Dome C (Fig. 1d). The innermost domain has a 1 km mesh size, $80 \times 80$ points and is centred above the Concordia Station area near Dome C (Fig. 1e). Owing to the fact that the typical topography of the internal Antarctic Plateau is much smoother than typically observed at mid-latitude sites, it was decided to use a maximum resolution of 1 km instead of 500 m as was done in all Masciadri’s previously cited studies.

The use of high resolution has one major impact: as can be seen in Fig. 1, the Dome C area is more fairly reproduced in the grid-nested simulation than in the low-horizontal-resolution simulation (Figs 1b and e). The altitude above mean sea level of Concordia Station with high resolution is around 3230 m, whereas it is around 3200 m with the low-resolution grid.
3 Meso-NH simulations: Absolute temperature and wind speed

The purpose of this section is to verify the performance of the mesoscale Meso-NH model above the internal Antarctic Plateau and to verify whether such a mesoscale model can provide a better estimate of the atmospheric flow than the GCM from the ECMWF.

A significant number of winter nights (47) were simulated with the Meso-NH mesoscale model. We analyse here the key meteorological parameters on which the optical turbulence depends: the temperature and the wind speed. Both configurations (low-horizontal-resolution monomodel and high-horizontal-resolution grid nesting) are tested and evaluated. The model is initialized with ECMWF analyses extracted at the nearest grid point with respect to Dome C. All the simulations started at 0000 UTC and were integrated for 12 h. Simulation outputs at 1200 UTC are compared with measurements we retrieved from the site (http://www.climantarctide.it) as well as with the analyses from the ECMWF GCM. Every 6 h we forced the simulations with the ECMWF analyses in order to avoid the model diverging and/or correcting the atmospheric flow as a function of the predictions at larger spatial scales.

In this section a statistical study of the wind and temperature profiles at Concordia Station, Dome C, is performed. The 47 nights have been selected in 2005 June, July and August and 2006 July. For all the 47 nights selected, we respected the following criteria.

(i) A radiosounding is available at the end of the simulation (at 1200 UTC on the selected night) to perform comparisons between Meso-NH outputs, ECMWF analyses and observations.

(ii) We selected nights in which the corresponding radiosoundings, launched at time \( t = t_0 + 12 \) h (with \( t_0 \) the initial time of the simulation), cover the longest path along the \( z \)-axis (perpendicular to the ground) before explosion. It was impossible in winter time to collect 47 nights in which all the balloons reached 20 km. The mean altitude reached by the selected balloons was about 10 km above ground level.

3.1 Model validation: vertical profiles of temperature and wind speed

Figs 2 and 3 show the mean vertical profiles of temperature and wind speed, respectively, computed for 47 winter nights from the two model configurations (low- and high-horizontal resolution), the ECMWF analyses and the radiosoundings. The location of the profiles is Concordia Station, in the Dome C area. All profiles have been interpolated on a regular 5-m vertical grid, in order to ease the comparison.

3.1.1 Temperature

The mean temperature profiles are very similar over the entire free atmosphere (Fig. 2a). In the first kilometre the temperature gradients reconstructed by the Meso-NH simulations (with high and low resolution) and the ECMWF analyses are not as pronounced
as the ones obtained with the radiosoundings. This means that the mesoscale model, as well as the GCM (ECMWF), reconstructs a slightly less stable atmosphere in this region, even if the mesoscale model better approaches the observational trend. However, as will be shown in the next section, the mesoscale model (Meso-NH) provides a more accurate estimate of the surface temperature than the ECMWF model can.

3.1.2 Wind speed

Fig. 3 shows the mean wind speed during the 47 days, with the corresponding standard deviation. From the ground up to 10 km, analysis and radiosounding mean wind speeds are well correlated. Above 10 km the wind speed reconstructed by the ECMWF analyses is slightly larger than the one reproduced by Meso-NH (monomodel and grid nesting: Fig. 3a). It is hard to say whether the ECMWF analysis or the Meso-NH simulation is the best, since no mean value from the observations is available at this altitude. Between 1 and 10 km there are no major differences between the mesoscale model and the ECMWF one. Below 1 km it is clearly visible that Meso-NH reconstructs the strong wind shear better than the ECMWF analyses, to achieve a more correlated wind speed value near the surface. At 150 m this difference is maximized: the wind speed provided by the ECMWF analyses is a bit too weak (12 m s\(^{-1}\) instead of 14 m s\(^{-1}\) in the observations). At the same altitude the Meso-NH simulations give better results, with a mean wind profile perfectly correlated to the one measured by the radiosoundings. The improvement is even better in the case of the high-resolution model. The difference between low-horizontal-resolution and high-horizontal-resolution simulations is more important above 12 km, with an increase in intensity of the wind being more important in the high-resolution simulation. These results match perfectly with a dedicated analysis that our group (Hagelin et al. 2008) carried out on a comparison between the wind speed provided by ECMWF analyses and radiosoundings near the surface.

3.2 Model validation: the surface

The mean values of the surface wind speed and absolute temperature at Dome C were computed for the 47 nights. The results are reported in Tables 2 and 3 (mean values for ECMWF analyses, radiosoundings and Meso-NH low- and high-horizontal-resolution simulations, respectively). In another paper (Hagelin et al. 2008) our group showed that the radiosoundings at the first grid point perfectly match the measurements provided by automatic weather stations (AWS).

3.2.1 Temperature

One can see that the ECMWF analyses, as already reported in a previous paper of our team (Hagelin et al. 2008) for a different data sample, are too warm at the surface (with a difference of almost 4 K, Table 2) in winter with respect to the observations.

The mean surface temperature simulated by Meso-NH after 12 h is closer to the observations than the ECMWF analyses. The difference between the ECMWF analyses and observed mean temperature is \(\Delta T_{\text{ecmwf}, \text{obs}} = 3.74 \text{ K}\). The mean surface temperature in the low-resolution simulation is \(\Delta T_{\text{mnh}, \text{low}, \text{obs}} = 2.02 \text{ K}\) higher than in the observations. It is only \(\Delta T_{\text{mnh}, \text{high}, \text{obs}} = 1.60 \text{ K}\) higher for the grid-nested simulation. This means that the mesoscale model reconstructs a surface temperature that is typically a factor \(\sim 2-2.5\) (that is \(\Delta T_{\text{ecmwf}, \text{obs}} / \Delta T_{\text{mnh}, \text{high}, \text{obs}}\) more accurate than the ECMWF analyses. Moreover it can be seen that the surface temperature is better retrieved with the use of high horizontal resolution (\(\Delta X = 1 \text{ km}\) in the innermost domain) than low horizontal resolution (\(\Delta X = 100 \text{ km}\)).

3.2.2 Wind speed

Tables 2 and 3 show the mean values of the wind speed at the first interpolated point of the profiles. The mean wind speed in the ECMWF analyses (6.51 m s\(^{-1}\)) is higher than the observed wind speed (4.02 m s\(^{-1}\)) at 12 km, thus there is a difference of \(\Delta V_{\text{ecmwf}, \text{obs}} = 2.49 \text{ m s}^{-1}\). Both mesoscale low- and high-horizontal-resolution simulations reproduce the surface wind speed more accurately than the ECMWF analyses. With a mesh size of 100 km in Meso-NH, the difference between the simulated and measured mean wind speeds is \(\Delta V_{\text{mnh}, \text{low}, \text{obs}} = 0.21 \text{ m s}^{-1}\). The grid-nested simulations (\(\Delta X = 1 \text{ km}\) in the innermost domain) give even better results, with a difference of \(\Delta V_{\text{mnh-high}, \text{obs}} = 0.04 \text{ m s}^{-1}\) only. This means that the mesoscale model reconstructs a surface wind speed that is typically a factor \(\sim 60\) (that is \(\Delta V_{\text{ecmwf}, \text{obs}} / \Delta V_{\text{mnh-high}, \text{obs}}\) more accurate than the ECMWF analyses.

The median value obtained with the mesoscale model MAR (SG2006) differs from the measurements done on the same statistical sample, \(\Delta V_{\text{MAR}, \text{obs}} = 0.9 \text{ m s}^{-1}\). We conclude therefore that our simulations performed with Meso-NH are a factor \(\sim 4\) \(\Delta V_{\text{MAR}, \text{obs}} / \Delta V_{\text{mnh-low}, \text{obs}}\) more accurate than those performed with MAR by SG2006 if we use the same horizontal resolution. They are a factor \(\sim 22\) \(\Delta V_{\text{MAR}, \text{obs}} / \Delta V_{\text{mnh-high}, \text{obs}}\) more accurate if we use the high horizontal resolution with Meso-NH. We also note that in that paper just the standard deviation (\(\sigma\)) is reported and not the statistical error (\(\sigma / \sqrt{N}\), where \(N\) is the number of independent estimates). The former is appropriate to describe the dispersion of the data set and the latter is useful to describe the precision of

| Table 3. Mean values over 47 days at Concordia Station near Dome C of wind speed and temperature at the surface level, for the Meso-NH simulations: 1-MOD is for the low-horizontal-resolution simulation with \(\Delta X = 100 \text{ km}\) and Grid-N is for the high-horizontal-resolution grid-nested simulation with \(\Delta X = 1 \text{ km}\), for the innermost model centred above the Dome C area. Bracketed numbers denote the corresponding statistical error (\(\sigma / \sqrt{N}\)). |
| Wind speed (m s\(^{-1}\)) | Temperature (K) |
|-----------------|-----------------|
| 1-MOD | Grid-N |
| 4.23 (±0.26) | 3.98 (±0.28) |
| 214.92 (±0.68) | 214.50 (±0.72) |

\(^2\) Differences from the Hagelin et al. (2008) paper values are just due to the fact that in that paper all the nights during the three months (June, July and August) were used, while in this paper we simulated just 47 nights selected in two different years (2005 and 2006). The statistical sample is therefore not the same.
the estimate of the mean values; it is therefore more appropriate to quantify the performance of the simulations with respect to observations. This means that each standard deviation in Table 1 (SG2006) should be multiplied by $1/\sqrt{N}$, where $N = 90$ is the number of nights in three months.

### 4 MESO-NH SIMULATIONS: OPTICAL TURBULENCE

We have seen in the previous section that the Meso-NH model allows for better forecasting of meteorological parameters such as wind speed and temperature than the analyses from the ECMWF GCM. These thermodynamic parameters are very important for the forecasting of optical turbulence, because the computation of the astroclimatological parameters (seeing $\varepsilon$, isoplanatic angle $\theta_0$, and wavefront coherence time $\tau_0$) depends directly on them. As it has been highlighted in the Introduction, the model has been run with the Astro-Meso-NH package, which allows the prediction of 3D $C_N^2$ maps. The most important features that characterize the optical turbulence above the internal Antarctic Plateau are as follows:

(i) the typical surface-layer thickness;
(ii) the median seeing in the free atmosphere;
(iii) the median seeing in the whole atmosphere.

These three elements permit us to perform a complete analysis of the optical turbulence developed above Dome C. Our tests are made on all 15 nights in winter time for which measurements of the optical turbulence surface thickness and partial seeing in different vertical slabs (free atmosphere seeing and total seeing) are available (see TR2008). Owing to the fact that in the Trinquet et al. (2008) paper only the median $C_N^2$ profile for the four seasons is available, and not the $C_N^2$ profile for each individual night, we selected our sample taking only (and all) the nights belonging to winter as defined by TR2008 i.e. between June 21 and September 21. This is the most interesting period for stellar astronomical applications.

#### 4.1 Surface layer thickness ($h_d$)

In order to verify how well the simulated surface thickness ($h_d$) matches the measured one, we are forced to compute the typical height of the surface layer using the same criterion as in TR2008. The authors defined the thickness $h_d$ of the surface layer as the part containing 90 per cent of the first-kilometre boundary-layer optical turbulence:

$$\frac{\int_{1/2}^{h_d} C_N^2(h) \, dh}{\int_{1/2}^{1} C_N^2(h) \, dh} < 0.90,$$

where $C_N^2$ is the refractive index structure parameter.

The observed $h_d$ for 15 winter nights from TR2008 are reported in Table 4. The simulated $h_d$ for the same 15 nights, calculated for the two configurations (monomodel, i.e. low horizontal resolution, and grid nesting, i.e. high horizontal resolution), are reported in Table 5.

Two different time intervals were chosen for the computation of the mean values (1100–1700 UTC and 1200–1600 UTC), both temporally centred around 1400 UTC, i.e. the time at which the balloons were launched. We show in Fig. 4 a correlation plot where the measured and the simulated (mean values between 1200 and 1600 UTC only) $h_d$s are compared.

It is worth noting how the comparison between measurements and simulations is done. At the present time, it is meaningless to predict $C_N^2$ at a time $t = t_0$. The optical turbulence is indeed a parameter fluctuating in space and time at much smaller scales than either classical meteorological parameters or the model mesh sizes. The optical turbulence is parametrized in the model and not resolved explicitly, and has to be quantified statistically. For this reason it is not realistic at the present time to forecast the $C_N^2$ profiles with a better precision in time than a $\Delta t$ value of a few hours.\(^3\) Our objective is therefore to find a correlation between the measurements obtained during one balloon launch ($C_N^2$ profile) and the mean of the temporal evolution of the simulations ($C_N^2$ profiles) extended

\(^3\) We refer the reader to Masciadri & Egner (2006), Session 2 for an extended explanation of this concept. The perspective of this type of study is to attain smaller and smaller $\Delta t$. 

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**Table 4.** Surface-layer thickness $h_d$ for 15 winter nights (TR2008). Units are metres ($m$). The criterion used is the one from equation (1). The mean value is also reported, with the associated statistical error $\sigma/\sqrt{N}$, where $N$ is the number of independent estimates.

| Date (d/m/y) | Observed surface-layer thickness | Date (d/m/y) | Observed surface-layer thickness |
|--------------|---------------------------------|--------------|---------------------------------|
| 04/07/05     | 30                              | 12/08/05     | 22                              |
| 07/07/05     | 21                              | 29/08/05     | 47                              |
| 11/07/05     | 98                              | 02/09/05     | 41                              |
| 18/07/05     | 26                              | 05/09/05     | 20                              |
| 21/07/05     | 47                              | 07/09/05     | 39                              |
| 25/07/05     | 22                              | 16/09/05     | 24                              |
| 01/08/05     | 40                              | 21/09/05     | 22                              |
| 08/08/05     | 30                              |               |                                |

| Mean         | 35.3                            | $\sigma$     | 19.9                            |
| $\sigma/\sqrt{N}$ | 5.1                             |               |                                |

**Table 5.** Mean surface-layer thickness $h_d$ for the same 15 winter nights as in Table 4, deduced from Meso-NH computations using the criterion in equation (1). Two different time intervals were chosen: 1100–1800 UTC and 1200–1600 UTC. Units are metres ($m$). The mean value is also reported, with the associated statistical error $\sigma/\sqrt{N}$.

| Date (d/m/y) | Surface-layer thickness | Surface-layer thickness |
|--------------|------------------------|------------------------|
|              | Interval (UTC)         | Meso-NH grid-nesting   | Meso-NH monomodel             |
|              |                       | 1100–1700              | 1200–1600                     |
| 04/07/05     | 24.5                   | 25.3                   | 43.9                           |
| 07/07/05     | 37                     | 36.9                   | 33                             |
| 11/07/05     | 65.1                   | 63.9                   | 91.7                           |
| 18/07/05     | 38.9                   | 38.2                   | 72.4                           |
| 21/07/05     | 46.4                   | 46.2                   | 56.9                           |
| 25/07/05     | 83.4                   | 82.1                   | 31.6                           |
| 01/08/05     | 27.9                   | 27.9                   | 41.1                           |
| 08/08/05     | 33.3                   | 29.7                   | 145.7                          |
| 12/08/05     | 23.1                   | 18.2                   | 44.3                           |
| 29/08/05     | 92                     | 84.6                   | 77.3                           |
| 02/09/05     | 52.8                   | 54.5                   | 66.5                           |
| 05/09/05     | 120                    | 122                    | 37.2                           |
| 07/09/05     | 58.1                   | 56.9                   | 89                             |
| 16/09/05     | 27.6                   | 29.4                   | 40                             |
| 21/09/05     | 17                     | 17.3                   | 105                            |

| Mean         | 49.8                   | 48.9                   | 65.9                           |
| $\sigma$     | 29.4                   | 29.3                   | 32.7                           |
| $\sigma/\sqrt{N}$ | 7.6                   | 7.6                   | 8.2                             |
|               | 8.7                   | 8.7                   |                                |
over Δt of a few hours. Looking at Table 5, we observe that the values of the simulated surface-layer thickness are weakly dependent on the selection of the temporal interval of integration (Δt: 1100–1700 UTC and 1200–1600 UTC). We chose the second one because the associated simulations give a slightly better correlation with the measurements (Table 4). Using the criterion expressed by equation (1), the grid-nested simulations give a mean surface thickness $h_{sl,mbh-high} = 48.9 \pm 7.6$ m (where $\sigma/\sqrt{N} = 7.6$ m) and the monomodel a mean thickness $h_{sl,mbh-low} = 65.9 \pm 8.7$ m (Table 5). The low-resolution configuration leads to a higher mean forecast thickness with respect to the observed one ($h_{sl,obs} = 35.3 \pm 5.1$ m), while the grid-nested technique is closer to the observations ($h_{sl,obs,mbh-high} = 13.6$ m) and within the typical $\sigma$. If we take into account the statistical error ($\sigma/\sqrt{N} = 7.6$ m) we conclude that the mesoscale model provides, for this statistical sample of 15 nights, a typical surface-layer thickness just $\sim 6$ m higher than the observed one. The dispersion $\sigma$ of the surface-layer thickness for the simulated nights ($\sigma = 29.3$ m) is just slightly larger than the observed one ($\sigma = 19.9$ m). This indicates that the intrinsic dispersion of $h_{sl}$ is well reconstructed by the model. Fig. 4 shows the correlation between simulated and observed $h_{sl}$ with the corresponding $\sigma$ values. We observe, moreover, that in spite of the more expensive simulations in terms of computational resources (in terms of time and memory) the high-horizontal-resolution grid-nested configuration seems to be necessary to reconstruct more closely the concentration of the turbulence in a thin layer near the surface. More precisely, a horizontal resolution of 100 km provides a bias in the typical $h_{sl}$ of the order of $\sim 30$ m. This result is significant with respect to the study done by SG2006, who used a resolution of 100 km and found a mean of 39 m for a sample of 90 nights. Unfortunately, the authors define $h_{sl}$ as the elevation (starting from the lowest model layer) at which the turbulent kinetic energy contains 1 per cent of the turbulent kinetic energy of the lowest model layer. This definition is completely different from that used by TR2008 (and by us), i.e. the elevation in which 90 per cent of the optical turbulence developed in the first kilometre is included. It is therefore in no sense whatever a comparison of measured $h_{sl}$ with that of SG2006. To have an idea of the impact of the selected criteria on the mean $h_{sl}$ estimate, we repeated the statistical calculation using the same criteria employed by SG2006. The mean $h_{sl}$ obtained with high resolution is 32.3 m, i.e. $\sim 17$ m lower than the 48.9 m estimated with the criteria used by TR2008. We therefore deduce that the typical thickness estimated by SG2006 using the same criteria employed by TR2008 should certainly be much larger than 39 m. This confirms the fact that mesoscale models provide an overestimation of $h_{sl}$ if they are run with $\Delta X = 100$ km.

What about the morphology of the surface layer? Looking at Table 4 it is clearly visible that the dispersion ($\sigma$) of the measurements is relatively large and sometimes the surface-layer thickness can be of the order of many tens of metres. Is the mesoscale model Meso-NH able to reconstruct such large variability in the morphology of the surface layer? Table 5 shows that basically for all the nights the model reconstructs the corresponding observed value within the $\sigma$ value. In only one case (2005 September 5) is the simulated thickness much larger ($\sim 120$ m instead of the observed 20 m). We highlight that a larger surface thickness does not necessarily mean a thicker and more developed turbulence near the ground, but simply that in the first kilometre 90 per cent of the turbulence develops in the $(0, h_{sl})$ range.

To highlight the potential of Meso-NH in discriminating between different turbulent nights, and to better visualize the impact of the model configuration (low and high resolution) on the forecast optical turbulence, the temporal evolution of the $C_{\chi}^2$ profiles near the surface and the corresponding surface-layer heights are displayed for three nights (Fig. 5). The first hours of the simulation should not be taken into account because they correspond to the spin-up of the model, and do not describe realistic $C_{\chi}^2$ profiles. The left-hand side of Fig. 5 shows the simulations with low resolution, while the right-hand side shows the simulations with high resolution. The three selected nights are, from top to bottom: 2005 July 4, 2005 July 18 and 2005 August 12. In all the three cases the developed turbulence layer is thinner for the high-horizontal-resolution case than for the low-resolution one. The high-resolution case also provides better correlation with observations.

(i) During the night 2005 July 4 (Figs 5a and b for monomodel and grid-nested configurations, respectively), the predicted surface layer remains constant in time, with a mean forecast thickness well correlated with the observed one ($h_{sl,mbh-high} = 25.3$ m, $h_{sl,mbh-low} \approx 44.9$ m and $h_{sl,obs} = 30$ m). The high-resolution simulation matches the observations within $\sigma/\sqrt{N}$.

(ii) During the night 2005 July 18 (Figs 5c and d for monomodel and grid-nested configurations, respectively), the predicted surface layer remains constant in time. The simulation at low horizontal resolution ($h_{sl,mbh-low} \approx 72.3$ m) overestimates the observation ($h_{sl,obs} = 26$ m) while the simulation with high resolution ($h_{sl,mbh-high} \approx 38.2$ m) is better correlated.

(iii) During the night 2005 August 12 (Figs 5e and f for monomodel and grid-nested configurations, respectively), it can be seen that the morphology of the reconstructed surface layer is thin, as in the previous cases. For this night, the high horizontal resolution provides evidence of better sensitivity of the model to the temporal variability of $C_{\chi}^2$ that was also observed for other nights. Indeed we observe, just above the surface layer in the last part of the simulation, short bumps of optical turbulence, i.e. fluctuations of the $C_{\chi}^2$ profile forecast by the model near the surface. This $C_{\chi}^2$ variability is the signature of obvious temporal evolution of the turbulent
energy distribution, even in conditions of a strongly stratified atmosphere. Also, in this last case, even if both simulated heights \((h_{\text{sl,mbh}}^{\text{high}} \simeq 18.2 \text{ m} \text{ and } h_{\text{sl,mbh}}^{\text{low}} \simeq 44.8 \text{ m})\) are well below 100 m, the high resolution clearly provides a better correlation (within \(\sigma/\sqrt{N}\)) to the observations \((h_{\text{sl,obs}} = 22 \text{ m})\).

4.2 Optical turbulence vertical distribution: seeing in the free atmosphere and in the whole atmosphere

Fig. 6 shows the median of the \(C_n^2\) profile measured by microthermal sensors mounted on the balloons (15) launched at Dome C during the winter of 2005 and simulated by the Meso-NH model with low and high horizontal resolutions. We observe that the shape of the \(C_n^2\) profile is well reconstructed all along the 13-km height by the model. Also, the model can reconstruct \(C_n^2\) above 13 km. In this region a comparison with measurements is not possible because the balloons usually explode at these heights (see discussion in Hagelin et al. 2008). In the first kilometre, the simulated \(C_n^2\) profile decreases (from the ground to higher altitudes) in a less sharp way than that monitored by observations (at \(\sim 30\) m from the ground). This is not surprising, and derives from the fact that simulations are slightly less thermally stable than observations near the surface. However, in the zoom of the first 100 m (Fig. 6, right-hand side) it is clearly visible that the shape of the median simulated \(C_n^2\) profile achieved with the high-horizontal-resolution configuration is much better correlated with the shape of the observed median \(C_n^2\) profile than the one obtained with a low horizontal resolution.

The seeing in the free atmosphere and in the whole atmosphere for \(\lambda = 0.5 \times 10^{-6}\) m is given by

\[
\varepsilon_{FA} = 5.41 \times \lambda^{-1/5} \left( \int_{h_{\text{sl}}}^{h_{\text{top}}} C_n^2(h) \, dh \right)^{3/5},
\]
Figure 6. Left: median $C_n^2$ profile measured (black line) with microthermal sensors mounted on balloons (from Trinquet et al. 2008) and simulated with the Meso-NH mesoscale model with low (blue line) and high (red line) horizontal resolution. Right: zoom of the first 100 m. Units are m$^{-2/3}$.

Table 6. Total seeing $\epsilon_{\text{TOT}} = \epsilon_{\text{obs}} + \epsilon_{\text{TOT, mnh}}$ and seeing in the free atmosphere $\epsilon_{\text{FA}} = \epsilon_{\text{FA, low}}$ calculated for 15 nights and averaged over the temporal range 1200–1600 UTC. See the text for the definition of $h_{\text{sl}}$ and $h_{\text{top}}$. In the second column the observed values are reported, in the third and fourth columns the simulated values obtained with high and low horizontal resolution respectively. Units are arcsec.

| Date (d/m/y) | Obs. $\epsilon_{\text{FA, low}}$ ($h_{\text{sl}} = 33$ m) | Meso-NH high $\epsilon_{\text{FA, high}}$ ($h_{\text{sl}} = 48.9$ m) | Meso-NH low $\epsilon_{\text{FA, low}}$ ($h_{\text{sl}} = 65.9$ m) |
|--------------|---------------------------------|-------------------------------------------------|-------------------------------------------------|
| 04/07/05     | 0.3/1.6                          | 0.20/3.40                                       | 0.45/4.61                                       |
| 07/07/05     | 0.2/1.5                          | 0.35/3.03                                       | 0.31/2.64                                       |
| 11/07/05     | 1.4/1.7                          | 2.42/3.55                                       | 3.27/3.32                                       |
| 18/07/05     | 0.3/2.0                          | 0.35/3.67                                       | 1.57/4.68                                       |
| 21/07/05     | 0.7/1.1                          | 0.51/2.12                                       | 0.52/2.17                                       |
| 25/07/05     | 0.3/1.0                          | 0.29/0.84                                       | 0.35/5.58                                       |
| 01/08/05     | 0.8/1.6                          | 0.26/3.91                                       | 0.28/4.17                                       |
| 08/08/05     | 0.3/2.3                          | 0.46/2.21                                       | 0.46/1.12                                       |
| 12/08/05     | 0.2/1.5                          | 0.32/1.96                                       | 0.42/5.16                                       |
| 29/08/05     | 2.5/3.6                          | 2.67/3.35                                       | 1.97/4.52                                       |
| 02/09/05     | 0.9/1.9                          | 0.66/2.26                                       | 0.73/2.82                                       |
| 05/09/05     | 0.3/1.0                          | 0.38/1.05                                       | 0.37/2.81                                       |
| 07/09/05     | 1.4/2.8                          | 2.58/6.77                                       | 3.33/7.02                                       |
| 16/09/05     | 0.2/1.5                          | 0.28/1.44                                       | 0.27/1.19                                       |
| 21/09/05     | 0.2/1.7                          | 0.32/2.29                                       | 0.27/0.87                                       |
| Median       | 0.3/1.6                          | 0.35/2.29                                       | 0.42/3.58                                       |
| $\sigma$     | 0.7/0.7                          | 0.92/1.46                                       | 1.07/1.64                                       |
| $\sigma/\sqrt{N}$ | 0.2/0.2                             | 0.24/0.38                                       | 0.28/0.42                                       |

where $h_{\text{sl}}$ is calculated for all the nights in the [February–November] range. For the simulations we considered $h_{\text{sl}}$ as retrieved from Table 5.

Again we observed that results are weakly dependent on the temporal range over which the mean values are calculated, and for this reason we report only the 1200–1600 UTC case. Fig. 7 shows the correlation between the observed and simulated values for the seeing in the free atmosphere and the whole atmosphere. The median of the observed seeing in the free atmosphere for the 15 nights is $\epsilon_{\text{FA, obs}} = 0.3 \pm 0.2$ arcsec; the median seeing in the free atmosphere simulated by Meso-NH with high horizontal resolution is $\epsilon_{\text{FA, mnh-high}} = 0.35 \pm 0.24$ arcsec and with low horizontal resolution is $\epsilon_{\text{FA, mnh-low}} = 0.42 \pm 0.28$ arcsec. Both median simulated values (with low and high resolution) match the median value obtained by observation within the statistical error, even if the high-resolution one is much better correlated (relative error of 16 per cent, $\Delta \epsilon_{\text{obs, sim}} = 0.05$ arcsec). If we look at the total seeing developed over the whole atmosphere, it is clearly visible (Table 6 and Fig. 7) that the model overestimates the measurements at both resolutions. We have a simulated median $\epsilon_{\text{TOT, mnh-low}} = 3.58 \pm 0.42$ arcsec and $\epsilon_{\text{TOT, mnh-high}} = 2.29 \pm 0.38$ arcsec versus an observed median $\epsilon_{\text{TOT, obs}} = 1.6 \pm 0.2$ arcsec. Even if we take into account the more accurate estimates (high resolution) we obtain a dispersion simulation/observation $\Delta \epsilon \sim 0.7$ arcsec. The excess of optical turbulence reconstructed by the Meso-NH model is clearly concentrated in the surface layer. We cannot exclude an underestimate from measurements but there are, at the present time, no major elements that lead to this assumption. On the contrary, we are working on a paper to explain this discrepancy and overcome this limitation. Considering that we proved that the meteorological parameters are well reconstructed by the Meso-NH model near the surface (Section 3) and that the surface numerical scheme (ISBA) responsible for control of the budget of turbulent ground/air fluxes has been recently optimized for Antarctic applications (Le Moigne et al. 2008) in the context of our project, we concentrated our attention on the dynamical and optical numerical turbulence schemes.

In terms of comparison with the SG2006 study, we note that the latter study indicates a typical underestimated total seeing of 1.16 arcsec with respect to the observed one (1.6 arcsec). The discrepancy is smaller from a quantitative point of view ($\Delta \epsilon_{\text{TOT}} = 0.45$ arcsec) with respect to what we find, and it is in the opposite

$$\epsilon_{\text{TOT}} = 5.41 \times \lambda^{-1/5} \left( \int_{8 \text{m}}^{h_{\text{top}}} C_n^2 \, dh \right)^{3/5},$$

with $h_{\text{top}} \sim 13$ km from sea level, i.e. where the balloons explode and we lose their signal.

Table 6 reports, for the 15 nights, the seeing in the free atmosphere ($\epsilon_{\text{FA}} = \epsilon_{\text{FA, low}}$) and in the whole atmosphere ($\epsilon_{\text{TOT}} = \epsilon_{\text{FA, low}}$) calculated for the simulations and the observations. Values of observed $\epsilon_{\text{TOT}}$ are taken from TR2008. We considered $h_{\text{sl}} = 33$ m instead of 35.3 m (Table 4) for the observations because, in the Trinquet et al. (2008) paper, the authors provide the seeing integrated above $h_{\text{sl}}$, with $h_{\text{top}} \sim 13$ km from sea level, i.e. where the balloons explode and we lose their signal.
direction. The questionable issue in the SG2006 study is that the turbulence kinetic energy provided by SG2006 in the first levels of the MAR model is often of the order of $10^{-4}$ m$^2$s$^{-2}$ (Gallée 2007). This value is extremely low, and it basically indicates no turbulent kinetic energy at the first level of the model; such a condition is contrary to what is observed with measurements. This is consistent with the fact that the MAR model underestimates the seeing in the surface layer.

We conclude that the Meso-NH model, in the present configuration, reconstructs $h_d$ and seeing in the free atmosphere with good statistical reliability, while showing a tendency to overestimate the strength of the seeing in the surface layer. An interesting result of this paper is therefore the fact that the most important features for astronomical interest (the surface-layer thickness and typical seeing in the free atmosphere) observed with measurements are confirmed with the mesoscale atmospheric model. We note that the this is the first confirmation made by a mesoscale model of the typical seeing in the free atmosphere. Besides this, it is worth highlighting that these are the first $C_N^2$ simulations ever made above the internal Antarctic Plateau and extended along the whole atmosphere. Fig. 8 shows the temporal evolution of the $C_N^2$ profile in the free atmosphere (more precisely in the (1, 12) km vertical slab) related to three selected nights in the sample of 15 simulated nights. In all three nights it is clearly visible that, even at such high altitudes, the model is active and the vertical distribution of the optical turbulence changes in time with a non-negligible dynamic from a quantitative point of view. The $C_N^2$ values extend, indeed, on the logarithmic scale ($-18$,$-16.5$). In all three cases it can be clearly seen that high horizontal resolution provides better temporal variability, as expected. These results are therefore very promising in terms of predictions of the $C_N^2$ 3D maps over long time-scales.

5 CONCLUSIONS

In this paper we study the performance of the Meso-NH mesoscale meteorological model in reconstructing meteorological parameters (wind speed and temperature) as well as the optical turbulence above Concordia Station in the Dome C area, a site in the internal Antarctic Plateau. This is, to our knowledge, the first study concerning the optical turbulence reconstructed with an atmospheric mesoscale model above Antarctica for the whole atmosphere. This study concentrates on the winter season, i.e. the most interesting season for stellar astronomical applications. The validation of the model for the meteorological parameters has been done by comparing measurements (radiosoundings) and simulations for a sample of 47 nights. The validation of the model for the optical turbulence has been done by comparing simulations with measurements for a sample of 15 nights. Two different model configurations were tested: monomodel simulations using low horizontal resolution ($\Delta X = 100$ km) and grid-nesting simulations with high horizontal resolution ($\Delta X = 1$ km for the innermost domain). The low-resolution model permitted us to discuss the results obtained previously in the literature. The observations used for the validation are, for the meteorological parameters, the analyses from the ECMWF GCM and radiosoundings (47 nights) and, for the optical turbulence, the $C_N^2$ and seeing values (15 nights) measured in situ (Trinquet et al. 2008).

The main conclusions of this study are as follows.

(1) We showed that, near the surface, Meso-NH retrieved better wind-speed vertical gradient (wind shear) than the ECMWF analyses from a qualitative as well as quantitative point of view, thanks to the use of the highest vertical resolution. We expect, therefore, a better reconstruction of the katabatic winds typical of these regions from the Meso-NH model than from GCM models. Also, Meso-NH better reconstructs the thermal stability near the surface than do GCMs. The analysis of the first vertical grid point permits us to conclude that the Meso-NH model surface temperature is closer to the observations ($\Delta T_{\text{mnh-high,obs}} = 1.60$ K) than the ECMWF GCM ($\Delta T_{\text{ecmwf,obs}} = 3.74$ K), which is too warm. The improvement in the estimate of wind speed is even more evident ($\Delta V_{\text{mnh-high,obs}} = 0.04$ m s$^{-1}$ versus $\Delta V_{\text{ecmwf,obs}} = 2.49$ m s$^{-1}$).

(2) Regarding the parameters concerning the optical turbulence, again the results are resolution-dependent. The simulations with low resolution provide too thick a surface layer (almost double the observed one) while those with high resolution provide a mean $h_{d,\text{mnh-high}} = 48.9 \pm 7.6$ m versus an equivalent observed
Figure 8. Temporal evolution at 1800h of the $C_N^2$ profiles in the vertical slab 1–12 km, in relation to three nights chosen from the selected sample of 15 nights. The dynamic of $C_N^2$ (colour palette) has been tuned to show evidence of the variation of the $C_N^2$ values (logarithmic scale) during times in the range $(-18, -16.5)$. h_{d, obs} = 35.3 ± 5.1 m. Taking into account the statistical error, we observe that the high horizontal mode provides a surface-layer thickness that is statistically just 6 m higher than the observed one but within the dispersion $\sigma$ of the observations.

(3) The integral of $C_N^2$ above $h_d$, i.e. the seeing in the free atmosphere $\varepsilon_{FA, obs} = 0.3 \pm 0.20$ arcsec, is reconstructed with an excellent level of reliability ($\Delta \varepsilon = 0.05$ arcsec) by the model used with the high-resolution configuration, $\varepsilon_{FA, mnh\text{-}high} = 0.35 \pm 0.24$ arcsec. Low resolution provides a worse estimate although within the $\sigma$ of the observations.

(4) The model still shows a tendency to overestimate the turbulence in the surface layer. For an observed $\varepsilon_{TOT, obs} = 1.6$ arcsec we have a simulated $\varepsilon_{TOT, mnh} = 2.29$ arcsec with the model in high-horizontal-resolution mode. This is the subject of an ongoing study conceived to resolve this open issue.

(5) The results concerning the computation of the mean thickness of the surface layer as well as the seeing in different vertical slabs are not very dependent on the time interval used to average it. This widely simplifies the analysis of simulations.

(6) Estimates obtained with the grid-nested simulations are closer to the observations than those obtained with monomodel simulations. This study highlighted the necessity of using high horizontal resolution to reconstruct a good meteorological field as well as the parameters characterizing the optical turbulence in Antarctica, even if the orography is almost flat over the internal Antarctic Plateau. The employment of low resolution (100 km) alone can scarcely be used to identify the best site on the Antarctic Plateau. However, it can be used to identify rapidly, over the whole Antarctic Plateau, the most interesting regions in which to focus, successively, simulations with high horizontal resolution for smaller surface domains. By ‘the most interesting regions’ we mean those with the lowest surface-layer thickness, for example.

(7) The Meso-NH model is able to reconstruct a mean $C_N^2$ profile that fits well the vertical optical turbulence distribution.
measured for the first 20 km from the ground. The model also shows a non-negligible temporal variability over the whole 20 km from the ground in a very small dynamic range. The latter is to be considered a very interesting feature, because it is known that this is a region of the atmosphere in which in general mesoscale models are less sensitive than near the ground. It is therefore a further indication that the Meso-NH model is well placed to forecast turbulence evolution at these time-scales.

Once the tendency to overestimate the strength of the turbulence in the surface layer is solved (in a forthcoming paper) we plan to run the Meso-NH model in other regions of the internal Antarctic Plateau to identify the best locations for astronomical observations, i.e. the places with the best turbulence characteristics from an astronomical point of view.

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