

MESO-NH SIMULATIONS OF THE ATMOSPHERIC FLOW ABOVE THE INTERNAL ANTARCTIC PLATEAU

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ABSTRACT

Mesoscale model such as Meso-Nh have proven to be highly reliable in reproducing 3D maps of optical turbulence (see Refs. 1, 2, 3, 4) above mid-latitude astronomical sites. These last 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 pretty good value for the seeing above 30-35 m: 0.36" (see Ref. 5) and 0.27" (see Refs. 6, 7) at Dome C. Site testing campaigns are however extremely expensive, instruments provide only local measurements and atmospheric modelling might represent a step ahead towards the search and selection of astronomical sites thanks to the possibility to reconstruct 3D C_N^2 maps over a surface of several kilometers. The Antarctic Plateau represents therefore an important benchmark test to evaluate the possibility to discriminate sites on the same plateau. Our group⁸ has proven that the analyses from the ECMWF global model do not describe with the required accuracy the antarctic boundary and surface layer in the plateau. A better description could be obtained with a mesoscale meteorological model. In this contribution we present the progress status report of numerical simulations (including the optical turbulence - C_N^2) obtained with Meso-Nh above the internal Antarctic Plateau. Among the topic attacked: the influence of different configurations of the model (low and high horizontal resolution), use of the grid-nesting interactive technique, forecasting of the optical turbulence during some winter nights.

Keywords: Atmospheric effects, optical turbulence, mesoscale model, site testing

1. INTRODUCTION

The Internal Antarctic Plateau is, at present, a site of potential great interest for astronomical applications. The extreme low temperatures, the dryness, the typical high altitude of the Internal Antarctic Plateau (more than 2500 m), joint to the fact that the optical turbulence seems to be concentrated in a thin surface layer whose thickness is of the order of a few tens of meters do of this site a place in which, potentially, we could achieve astronomical observations otherwise possible only by space.

In spite of the exciting first results (see Refs. 6, 9, 7) the uncertainties on the effective gain that astronomers might achieve from ground-based astronomical observation from this location still suffers from serious uncertainties and doubts that have been pointed out in previous work (see Refs. 10, 11, 8). A better estimate of the properties of the optical turbulence above the Internal Antarctic Plateau can be achieved with both dedicated measurements done in simultaneous ways with different instruments and simulations provided by atmospheric models. Simulations offer the advantage to provide volumetric maps of the optical turbulence (C_N^2) extended on the whole Internal Plateau and, ideally, to retrieve comparative estimates in a relative short time and homogeneous way on different places of the Plateau. In a previous paper⁸ our group performed a detailed analysis of the meteorological parameters from which the optical turbulence depends on, provided by the General Circulation Model (GCM) of the European Center 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 which are the limitations of the General Circulation Models. In contexts in which the GCMs fail, mesoscale models can supply more information. The latter are indeed conceived to reconstruct phenomena (such

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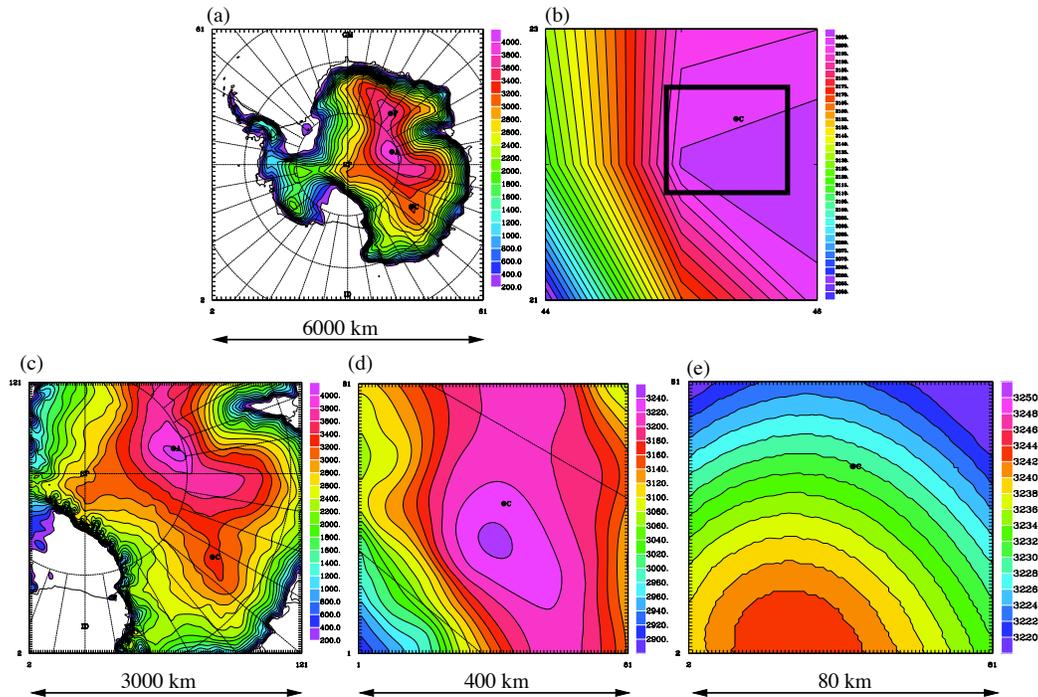


Figure 1. Orography of Antarctica as seen by the Meson-Nh model (polar stereographic projection) in (a) the monomodel simulation, with $\Delta X = 100km$; (b) zoom of (a) above the Dome C area (the black square represents the same area as in (e)); (c) the dad model of the grid-nested simulation with $\Delta X = 25km$; (d) the second domain of the grid-nested simulation with $\Delta X = 5km$; (e) the innermost domain of the grid-nested simulation with $\Delta X = 1km$. The dot labelled 'C' is located at the Concordia Station. The dot labelled 'A' is the Dome A.

as the optical turbulence) that develop at a too small spatial and temporal scale to be described by a GCM. In spite of the fact that mesoscale models can attain higher resolution than the GCM, these parameters such as the optical turbulence are not explicitly resolved but are parameterized, i.e. the fluctuations of the microscopic physical quantities are expressed as a function of the corresponding macroscopic quantities averaged on a larger spatial scale (cell of the model). For classical meteorological parameters the use of a mesoscale model should be useless if GCMs such as the one of the ECMWF could provide estimate with equivalent level of accuracy. For this reason the Hagelin et al paper⁸ has been a first step towards the exploitation of the mesoscale Meso-Nh model. We retrieved all what it was possible from the ECMWF analyses and we defined their limitations at the same time. 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 of 4-5 K for the temperature.

Preliminary tests concerning the optimization of the model configuration and sensitivity to the horizontal and the vertical resolution with the Meso-Nh model have already been conducted by our team¹² for the Internal Antarctic Plateau. In this paper we present further progress of that work. More precisely, we intend:

- To compare the performances of the mesoscale Meso-Nh model and the ECMWF General Circulation Model in reconstructing wind speed and absolute temperature (main meteorological parameters from which the optical turbulence depends on) with respect to the measurements. This analysis will quantify the performances of the Meso-Nh model with respect to the GCM from the ECMWF.
- To perform simulations of the optical turbulence above Dome C employing different model configurations and compare the typical simulated thickness of the surface layer with the one measured by Trinquet et al⁷. In this way we aim to establish which configuration is necessary to reconstruct correctly the C_N^2 .

2. MESO-NH MESOSCALE MODEL: NUMERICAL SET-UP

Meso-Nh¹³ is the french non-hydrostatic mesoscale research model developed jointly by Météo-France and Laboratoire d'Aérodynamique.

It can simulate the temporal evolution of the three-dimensional atmospheric flow over any part of the globe. The prognostic variables forecasted by this model are the three cartesian components of the wind u , v , w , the dry potential temperature Θ , the pressure P , the turbulent kinetic energy TKE .

The system of equation used is based upon the Lipps and Hemler¹⁴ anelastic formulation allowing for an effective filtering of acoustic waves. A Gal-Chen and Somerville¹⁵ coordinate on the vertical and a C-grid in the formulation of Arakawa and Messinger¹⁶ for the spatial digitalization is used. The temporal scheme is an explicit three-time-level leap-frog scheme with a time filter.¹⁷ The turbulent scheme is a one-dimensional 1.5 closure scheme¹⁸ with the Bougeault and Lacarrère¹⁹ mixing length. The surface exchanges are computed in an externalized surface scheme (SURFEX) including different physical packages, among which ISBA²⁰ for vegetation.

Masciadri et al (see Refs. 1, 2) implemented the optical turbulence package in order to be able to forecast not only the standard meteorological parameters with Meso-Nh, but also the optical turbulence (C_N^2 3D maps) and all the astroclimatic parameters deduced from the C_N^2 . We will refer to the Astro-Meso-Nh code to indicate this package. To compare simulations with measurements the integrated astroclimatic parameters are calculated integrating the C_N^2 with respect to the zenith in the Astro-Meso-Nh-code. The parameterization of the optical turbulence and the reliability of the Astro-Meso-Nh model have been proved in successive studies in which simulations have been compared to measurements provided by different instruments (See Refs. 4,21). A dedicated calibration has been proposed and validated³.

The atmospheric Meso-Nh model is conceived for research development and for this reason is in constant evolution. One of the major advantages of Meso-Nh that was not available at the time of the Masciadri's studies is that it allows now the use of the interactive grid-nesting technique²². This technique consists in using different imbricated domains with increasing horizontal resolutions with mesh-sizes that can reach 10 meters.

We use in this study of the atmosphere above the Antarctica Plateau the same optical turbulence package, implemented in the most recent version of the atmospheric Meso-Nh model. We list here down the differences in the model configuration that we implemented to do a step ahead in the research:

- We use a higher vertical resolution near the ground with respect to previous studies. 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 meters. This configuration has been allowed now thanks to a better description of the model pressure solver (available in the new atmospheric Meso-Nh version) and it is obviously preferable because it permits to better quantify the turbulence contribution in the thin vertical slabs in the first hundred of meters. Above 3.5 km the vertical resolution is constant and equal to $\Delta H = 600$ m as well as in Masciadri's previous work. The maximum altitude is 22 kilometers.
- The grid-nesting is implemented with 3 imbricated domains allowing a maximum horizontal resolution of 1 km in a region around the telescope (~ 80 km \times 80 km).
- The simulation are forced at synoptic times by analyses from the European Center for Medium-range Weather Forecasts (ECMWF). This permits to perform a real forecast of the optical turbulence and it represents a step ahead with respect to the Masciadri et al.'s previous work. We highlight indeed, that in all the Masciadri's work the model has been used in a simple domain configuration permitting a quantification of the mean optical turbulence during a night and not really a forecast of the optical turbulence.

In spite of the fact that the orographic morphology is almost flat above Antarctica, we know that even a weak slope on the ground can be an important factor to induce a change in the wind speed at the surface in these regions. The physics of the optical turbulence strongly depend on a delicate balance between the wind speed and temperature gradients. In order to study the sensitivity of the model to the horizontal resolution we performed two sets of simulations with different model configurations.

In the first configuration (that we will call *monomodel*) we use a horizontal resolution $\Delta X = 100$ km covering the whole Antarctic continent (Figure 1a,b). This permits to perform low time consuming simulations. Such a horizontal resolution has been also employed by Swain & Gallée²³ in a study on the boundary layer seeing done with regional atmospheric model MAR.

In the second configuration we used the grid-nesting technique to test the impact of the high-resolution on the optical forecasting. The grid-nested simulations involved three domains. The biggest one has a 25 km mesh-size and covers all the Antarctic Plateau with 120x120 points (Figure 1c). The second one has a horizontal resolution of 5 km, 80x80 points and is centered above the Dome C (Figure 1d). The innermost domain has a 1 km mesh-size, 80x80 points and is centered above the Concordia Station area near the Dome C (1e).

The use of high-resolution has one first major impact: the Dome C area is more fairly reproduced in the grid-nested simulation than in the low horizontal resolution simulation (Figure 1b,e). The altitude above mean sea level of the Concordia Station with high resolution is around 3230 m, whereas it is around 3200 m with the low resolution grid. More over in Fig. 1e we can observe that the Concordia Station is not located exactly in correspondence of the summit of Dome C but at ~ 60 km far away with a slightly lower altitude ($\Delta h \sim 15$ m). Such a morphology can not be distinguished with the mono-model configuration.

In section 4 we will compare the typical thickness of the optical turbulence surface layer reconstructed by the model with the two different configurations with the measurements performed recently⁷ to identify if the model is sensitive to this parameter (horizontal resolution) and in case this answer is positive, which configuration better matches with observations.

In the next section we first start to compare results from a General Circulation model (ECMWF) and the two configurations from the mesoscale model Meso-Nh.

All the simulations are initialized and forced every 6 hours with the analyses of the European Center of Medium-range Weather Forecast (ECMWF).

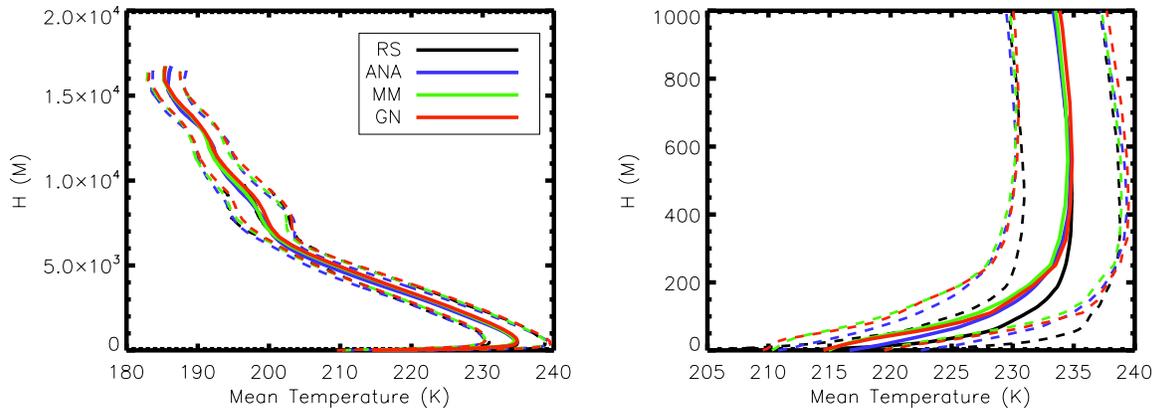


Figure 2. Mean temperature profiles at the Concordia Station in the Dome C area over 47 winter nights (bold lines) and the corresponding standard deviation (dashed lines). In black, from radiosoundings; in blue, from the ECMWF analyses; in green, from the Meso-Nh low horizontal resolution simulation; in red, from the Meso-Nh grid-nested simulation. On the left, profiles are plotted over 20 km. On the right, over the first kilometer.

3. MESO-NH SIMULATIONS IN WINTER ABOVE DOME C - METEOROLOGIC PARAMETERS

The purpose of this section is to verify the performances of the mesoscale Meso-Nh model above the Internal Antarctic Plateau and to verify if such a mesoscale model can provide a better estimate of the atmospheric flow than a General Circulation model.

	Radiosondes	ECMWF
Windspeed (m.s ⁻¹)	4.02 (± 2.55)	6.51 (± 2.51)
Temperature (K)	212.90 (± 7.64)	216.64 (± 5.83)

Table 1. Mean values on 47 winter days at Concordia Station near Dome C of wind speed and temperature at the surface level, for radiosoundings, ECMWF analyses. Into brackets, the corresponding sigma.

	Meso-Nh	
	1-MOD	Grid-N
Windspeed (m.s ⁻¹)	4.23 (± 1.77)	3.98 (± 1.95)
Temperature (K)	214.92 (± 4.64)	214.50 (± 4.97)
TKE (m ² .s ⁻²)	0.39 (± 0.30)	0.35 (± 0.33)

Table 2. Mean values on 47 days at Concordia Station near Dome C of wind speed and temperature at the surface level, for Meso-Nh simulations: 1-MOD is for the low horizontal simulation with $\Delta X=100$ km and Grid-N is for the high horizontal grid-nested simulation with $\Delta X=1$ km for the innermost model centered above the Dome C area. Into brackets, the corresponding sigma.

An important number of winter nights (47) were simulated with the Meso-Nh mesoscale model. We analyze here the key meteorologic parameters from which the optical turbulence depends on: the temperature and the wind speed. Both configurations (low horizontal resolution monomodel, and high horizontal resolution grid-nesting) are tested and evaluated. All the simulations start at 00 UTC and are integrated for 12 hours. Simulations outputs at 12 UTC can be compared with measurements (<http://www.climantartide.it>) as well as to the analysis from the General Circulation model from the ECMWF. Every 6 hours we force the simulations with the ECMWF analyses in order to avoid that the model diverge and/or correct 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 June, July and August 2005 and July 2006. For all the 47 nights selected, we respected the following criterion:

- A radiosounding is available at the end of the simulation (at 12 UTC of the selected night) to perform comparisons between Meson-Nh outputs, ECMWF analysis and observations.
- For the selected nights, the radiosoundings cover the longest path along the z-axis (perpendicular to the ground) before to explode. It was impossible to collect in winter time 47 nights in which all the balloons reached the 20 km.

3.1 Temperature profiles at Dome C

3.1.1 General behaviour of Meso-Nh

The figure 2 shows the mean temperature profiles at the Concordia Station computed over 47 winter nights from the two model configurations (low and high horizontal resolution), the ECMWF analyses and the radiosoundings. All profiles have been interpolated on a regular 5 m vertical grid, in order to ease the comparison. The mean temperature profiles are very similar over the entire free atmosphere (Figure 2, left). Some light discrepancies appear on the first kilometer above the ground, where both the ECMWF analyses and the Meso-Nh model present a negative bias of 4-5 K up to 200 m. At this altitude, the grid-nested simulation and the low resolution simulation give similar results and are not necessarily better than the ECMWF. The temperature gradients provided by the two Meso-Nh configurations and the ECMWF analyses are not as pronounced as the one obtained with the radiosoundings. In the next section we will analyse the performances of ECMWF analyses and Meso-Nh model at the very surface level. i.e. the region in which the energetic fluxes budget between the ground and the atmosphere takes place. For this reason most of the ability for a model in reconstructing the correct atmospheric evolution near the ground relies on its ability in reconstructing the temperature of the surface.

3.1.2 Surface temperature

Tables 1, 2, 3 and 4 report the mean and median temperature at the surface measured and simulated by the ECMWF analyses and the Meso-Nh model in the two configurations (mono-model and grid-nesting).

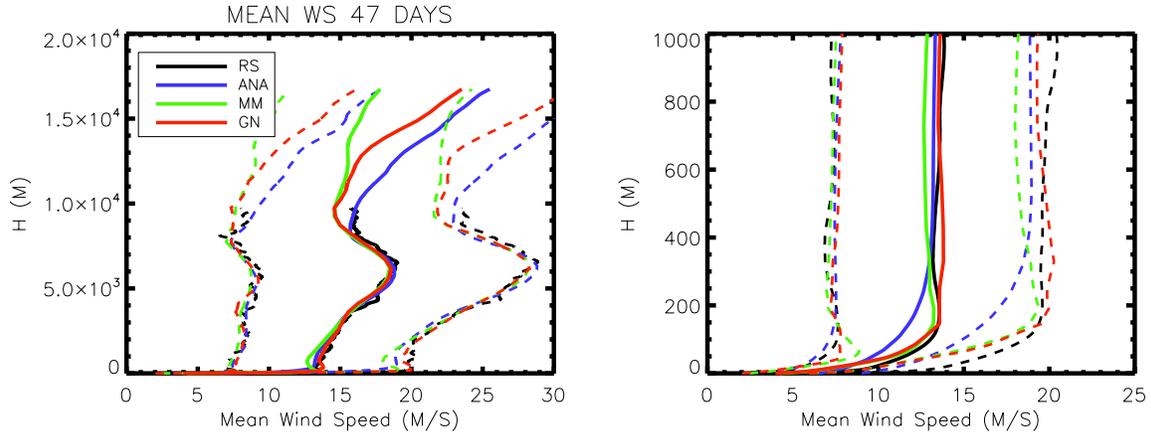


Figure 3. Mean wind profiles at the Concordia Station in the Dome C area over 47 winter nights (bold lines) and the corresponding standard deviation (dashed lines). In black, from radiosoundings; in blue, from the ECMWF analyses; in green, from the Meso-Nh low horizontal resolution simulation; in red, from the Meso-Nh grid-nested simulation. Units in m.s^{-1} . On the left, profiles are plotted over 20 km. On the right, over the first kilometer.

One can see that the ECMWF analyses, as already reported in a previous paper of our team⁸, are too warm at the surface (almost 4 K for the mean, and 3 K for the median) in winter with respect to the observations. However, the surface temperatures (both mean and median) simulated by Meso-Nh after 12 hours are closer to the observations than the ECMWF analyses.

The difference between ECMWF analyses and observed mean temperature is 3.74 K (2.97 K for the median). The mean surface temperature in the low-resolution simulation is 2.02 K higher (1.23 K for the median) than in the observations. It is only 1.60 K higher for the grid nested simulation (0.78 K for the median). One can see that the surface temperature are even better retrieved with the use of the high horizontal resolution ($\Delta X=1$ km in the innermost domain) than the low horizontal resolution ($\Delta X=100$ km).

3.2 Wind profiles at Concordia Station, Dome C area

3.2.1 General behaviour of Meso-Nh

Figure 3 shows the mean wind during the 47 days, with the corresponding standard deviation. The highest mean altitude reached by the balloons is 10 km. From the ground to 10 km, analyses and radiosoundings mean wind speed are well correlated. Above 10 km the wind speed reconstructed by the ECMWF analyses is larger

	Radiosondes			ECMWF		
	Median	75%	25%	Median	75%	25%
Windspeed (m.s^{-1})	3.10	4.80	2.30	6.08	8.64	4.60
Temperature (K)	213.10	219.15	205.85	216.03	221.81	211.07

Table 3. Median values on 47 days and the corresponding quartiles at Concordia Station of wind speed and temperature at the surface level, for radiosoundings and ECMWF analyses and relative percentiles.

	Meso-Nh					
	1-MOD			Grid-N		
	Median	75%	25%	Median	75%	25%
Windspeed (m.s^{-1})	4.08	5.64	2.80	3.42	4.99	2.42
Temperature (K)	214.33	218.44	210.56	213.88	217.13	210.57
TKE ($\text{m}^2.\text{s}^{-2}$)	0.32	0.49	0.14	0.20	0.44	0.10

Table 4. Median values on 47 days and the corresponding quartiles at Concordia Station of wind speed and temperature at the surface level, for Meso-Nh simulations: 1-MOD is for the low horizontal simulation with $\Delta X=100$ km and Grid-N is for the high horizontal grid-nested simulation with $\Delta X=1$ km for the innermost model centered at Concordia Station.

than that reproduced by Meso-Nh (monomodel and grid-nesting) (left of figure 3). It is hard to say whether the ECMWF analyses or the Meso-Nh simulation is the best since no mean value from the observations is available at this altitude. On the first kilometer above the ground, and especially around 150 m, it is well visible that Meso-Nh better reconstructs the strong wind shear than the ECMWF analyses. The wind speed provided by the ECMWF analyses is a bit too weak (11 m.s^{-1} instead of 13 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 differences between low horizontal and high horizontal simulations is more important above 12 km, with an increase in intensity of the wind more important in the high-resolution simulation.

3.2.2 Surface wind

Tables 1, 2, 3 and 4 show the mean and median values of the wind speed at the first interpolated point of the profiles. The mean wind speed in the ECMWF analyses is higher than the observed wind speed (6.51 m.s^{-1} against 4.02 m.s^{-1}), thus a difference of 2.49 m.s^{-1} (*). The difference in the median is of the same order of intensity: 3.02 m.s^{-1} . Both low and high horizontal simulations reproduce better the surface wind than the ECMWF analyses. With a mesh-size of 100 km in Meso-Nh, the difference in simulated mean wind speed and observations is of 0.21 m.s^{-1} (0.98 m.s^{-1} for the median). The grid nested simulations give even better results with a difference of 0.04 m.s^{-1} only for the mean and 0.32 m.s^{-1} for the median.

4. FORECAST OF OPTICAL TURBULENCE: FIRST NIGHTS

In this section the optical turbulence package developed by our team¹ and implemented in our Meso-Nh version of the model is used to perform the first simulations of some winter nights above the Antarctic Plateau.

All the 11 nights in the winter time (June, July and August) documented in Trinquet et al⁷ were simulated. We present here the first results obtained with Meso-Nh and concerning the height of the surface layer with the observations present in Trinquet et al⁷.

As an example, figure 4 displays the temporal evolution of the C_N^2 profiles for three nights. The temporal window starts at 11 UTC and ends at 17 UTC for each night. All balloons have been launched between 14 and 15 UTC. For each simulation, the average height of the surface layer is computed for the time period extended from 11 UTC to 17 UTC. The optical turbulence is indeed a parameterized parameter therefore it is a little hazardous to consider a precise time *forecasted time* as in the case of an explicitly resolved parameter such as the wind speed or the absolute temperature.

In order to verify how much simulations match with measurements we compute the typical height of the surface layer using the same criterion as in Trinquet et al⁷. They defined the thickness h_{sl} of the surface layer as the part containing 90% of the first kilometer boundary layer optical turbulence:

$$\frac{\int_{8m}^{h_{sl}} C_N^2(z) dz}{\int_{8m}^{1km} C_N^2(z) dz} < 0.90 \quad (1)$$

This criterion is misleading, because it does not take into account the turbulence in the entire free atmosphere. We propose to use a different criterion based on the computation of the total integrated C_N^2 over the whole 20 kilometers:

$$\frac{\int_{8m}^{h_{sl}} C_N^2(z) dz}{\int_{8m}^{20km} C_N^2(z) dz} < 0.90 \quad (2)$$

The observed surface layer thickness for 11 winter nights from Trinquet et al⁷ are reported on table 5. All mean values computed by Meso-Nh are reported in tables 6 (criterion described by Eq.1) and 7 (criterion described by Eq.2). Different time intervals were chosen (between 12 UTC and 16 UTC, 11 UTC and 17 UTC, and 12 UTC

*Difference from the Hagelin et al paper⁸ values are just due to the fact that in that paper, all the nights of the three months (June, July and August) are used while in this paper we simulated just 47 nights selected in two years. The statistical sample is not therefore the same.

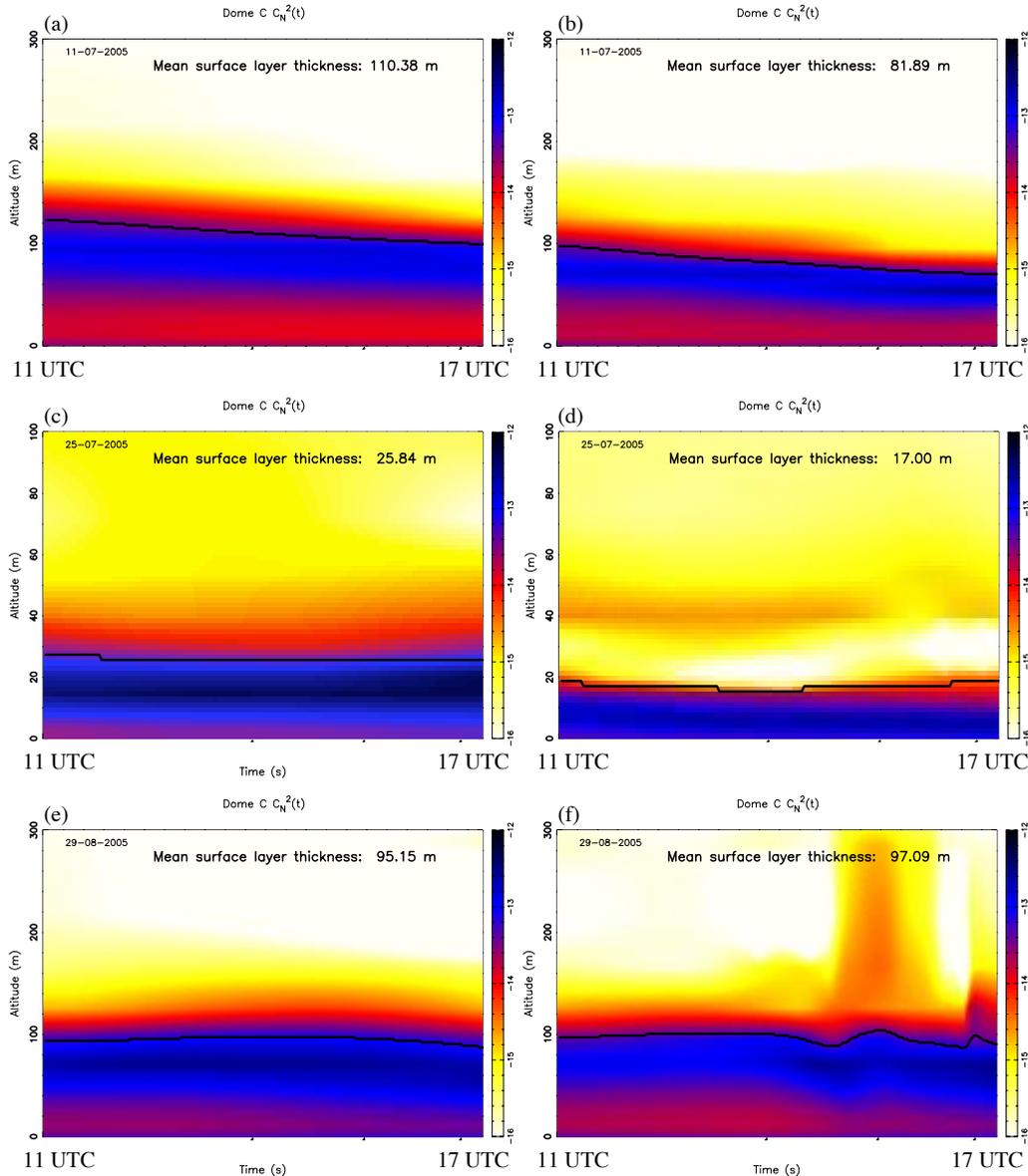


Figure 4. Temporal evolution of the C_N^2 profile at Concordia Station obtained with Meso-Nh between 11 UTC and 17 UTC for (a) 2005 July 11, low horizontal resolution simulation, (b) 2005 July 11, grid-nested simulation, (c) 2005 July 25, low horizontal resolution simulation, (d) 2005 July 25, grid-nested simulation, (e) 2005 August 29, low horizontal resolution simulation and (f) 2005 August 29, grid-nested simulation. The mean value of the computed mean height of the surface layer is written on the top-right of each graph (see text for calculation details). The thick black line represent the evolution of the surface layer height.

and 18 UTC) for the mean calculation. Independently from the time interval chosen for computing the mean, using the criterion of Trinquet et al⁷ the grid-nested simulations give a mean surface thickness f around 48 m and the monomodel a thickness of 60 m. Both configurations provide some higher mean thickness with respect to the observed one (36.9 m) but the grid-nested configuration is closer to observations ($\Delta h \sim 10$ m). In spite of the more expensive simulations, the grid-nested configuration seems to be necessary to better reconstruct the concentration of the turbulence in a thin layer near the surface.

However, using our criterion (Eq.2), the mean thickness is now 64 m for the grid-nested simulation (75 m for the monomodel). This criterion provides, for both configurations (grid-nested and mono model) a surface layer ~ 15 m thicker than what obtained with the criterion given in Eq.1. This is far from being negligible for

Date	Observed surface layer thickness (m)
13/06/05	23
04/07/05	30
07/07/05	21
11/07/05	98
18/07/05	26
21/07/05	47
25/07/05	22
01/08/05	40
08/08/05	30
12/08/05	22
29/08/05	47
Mean	36.9

Table 5. Surface layer heights for 11 winter nights⁷. Units in m. The criterion used is the one from Eq.1.

Date	Surface thickness - Meso-Nh - Grid-N			Surface thickness - Meso-Nh - 1-MOD		
	11-17 UTC	12-16 UTC	12-18 UTC	11-17 UTC	12-16 UTC	12-18 UTC
13/06/05	23.12	22.37	22.02	27.10	25.99	27.28
04/07/05	26.18	25.43	25.77	42.14	42.55	41.01
07/07/05	58.91	58.69	58.55	54.26	54.28	53.42
11/07/05	81.89	81.36	77.62	110.38	110.01	106.68
18/07/05	54.15	53.54	51.80	84.87	84.88	81.73
21/07/05	66.05	67.42	67.19	76.80	75.15	79.26
25/07/05	17.00	16.56	17.16	25.84	25.62	25.86
01/08/05	34.62	34.39	32.60	44.51	44.36	42.39
08/08/05	40.66	41.75	38.52	64.09	69.42	60.36
12/08/05	28.50	29.76	33.50	37.74	37.82	40.90
29/08/05	97.09	98.26	95.04	95.15	96.51	93.47
Mean	48.02	48.14	47.25	60.26	60.60	59.31

Table 6. Surface layer heights for 11 winter nights deduced from Meso-Nh computations using the criterion in Eq.1. The mean value is also reported. Units in m.

astronomical applications. The solution to overcome the turbulence surface layer with a tower might be put in serious discussion as a consequence of this result.

The three nights presented here exhibit different turbulent conditions. They show the ability of the model to react and predict the evolution of different surface layers. During the first night (2005 July 11) the surface layer is constant in time, with a mean forecasted thickness of 82 m (with the grid-nested simulation, fig. 4b). The observation for this night⁷ gave a value of 98 m at 14:10 UTC. The second night (2005 July 25) has a forecasted mean surface layer height lower (with the grid-nested simulation, fig. 4d): 17 m. The observed value was 22 m at 13:53 UTC. The third and last night displayed (2005 August 29) has a forecasted mean surface layer height of 97 m (always with the grid-nested simulation, 4f). The observed value for this night was 47 m at 14:47 UTC.

In two of these three nights, the thickness of the surface layer retrieved by the model is well correlated with the observed one. One can notice that for these two nights, the monomodel simulations give higher values than the grid-nested simulations. The third night shows some interesting variability of the surface layer height, which are not present in the other nights and that is a signature of an evident temporal evolution of the turbulent energy distribution even in conditions of a pretty stratified atmosphere. For this night Meso-Nh gives a thickness for the surface layer of around 97 m instead of the observed one (47 m).

Date	Grid-N			1-MOD		
	11-17 UTC	12-16 UTC	12-18 UTC	11-17 UTC	12-16 UTC	12-18 UTC
13/06/05	23.70	23.07	22.57	27.82	26.54	27.72
04/07/05	26.83	26.25	26.38	42.73	43.16	41.88
07/07/05	59.93	59.47	59.54	55.88	56.13	55.32
11/07/05	83.48	82.92	79.06	112.07	111.76	108.33
18/07/05	55.16	54.52	52.70	86.01	85.98	82.82
21/07/05	173.91	194.67	168.58	156.87	150.07	170.65
25/07/05	59.30	52.32	74.59	26.16	25.85	26.15
01/08/05	35.08	34.87	33.03	45.45	45.33	43.31
08/08/05	55.42	55.66	55.50	142.80	173.55	135.57
12/08/05	29.40	30.86	34.52	38.69	38.61	41.85
29/08/05	98.39	99.53	96.20	95.86	97.31	94.26
Mean	63.70	64.92	63.88	75.49	77.66	75.26

Table 7. Surface layer heights for 11 winter nights deduced from Meso-Nh computations using the criterion in Eq.2. The mean value is also reported. Units in m.

5. CONCLUSIONS

In this paper we studied the performances of a mesoscale meteorological model, Meso-Nh, in reconstructing wind and temperature vertical profiles above Concordia Station, a site in the Internal Antarctic Plateau. Two different configurations were tested: monomodel low horizontal resolution, and grid-nesting high horizontal resolution. The results were compared to the ECMWF General Circulation Model and radiosoundings.

Several conclusions can be drawn:

- (1) We showed that near the surface, Meso-Nh retrieved better the wind vertical gradient than the ECMWF analyses, thanks to the use of a highest vertical resolution. More over, the analysis of the first vertical grid point permits us to conclude that, as is, the Meso-Nh model surface temperature is closest to the observations than the ECMWF General Circulation Model which is too warm.
- (2) The outputs from the grid-nested simulations are closer to the observations than the monomodel simulations. This study highlighted the necessity of the use of high horizontal resolution to reconstruct a good meteorological field in Antarctica, even if the orography is almost flat over the Internal Antarctica Plateau. The computations estimates from a previous study²³ are probably affected by the low horizontal resolution they used in their simulations.
- (3) For what concerns the optical turbulence, both configurations predict a mean surface layer height higher than in the observations. However, it is always inferior at 100 m (when we used the criterion 1 of Trinquet et al⁷). The configuration of Meso-Nh giving better estimate (closer to observations) is in grid-nesting mode.
- (4) The results of Meso-Nh concerning the computation of the mean thickness of the surface layer are not very dependent of the time interval used to average it. This widely simplifies the analysis of simulations.
- (5) The criterion used in Trinquet et al⁷ appears to be misleading. Indeed, it underestimates the typical thickness of the turbulent surface layer. We propose the use of another criteria (presented in the last section of the paper) instead. It gives a mean value higher of around 15 m for the eleven nights. This result has an important implication for astronomical application. It is indeed not so realistic to envisage a telescope placed above a tower of more than 50 m and the use of the Adaptive Optics remains the unique path to follow to envisage astronomical facilities at Dome C.

This optical turbulence study is based upon a little number of nights (11). We need to extend it to a higher number of nights in order to have a more reliable statistical analysis of the results.

In this paper we did not present results concerning the seeing. We will focus our work ahead on this parameter, discriminating between two different partial contributions: the seeing in the free atmosphere, and the seeing of the surface layer. We plan to make comparisons between Meso-Nh output and observations.

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REFERENCES

- [1] E. Masciadri, J. Vernin and P. Bougeault, "3D mapping of optical turbulence using an atmospheric numerical model. I: A useful tool for the ground-based astronomy.", *A&ASS*, **137**, pp. 185-202, 1999.
- [2] E. Masciadri, J. Vernin and P. Bougeault, "3D mapping of optical turbulence using an atmospheric numerical model. II: First results at Cerro Paranal.", *A&ASS*, **137**, pp. 203-216, 1999.
- [3] E. Masciadri and P. Jabouille, "Improvements in the Optical Turbulence Parameterization for 3D simulations in a region around a telescope", *A&A*, **376**, pp. 727-734, 2001.
- [4] E. Masciadri, R. Avila and L.J. Sanchez, "Statistic reliability of the Meso-Nh atmospheric model for 3D C_N^2 simulations", *RMxAA*, **40**, pp. 3-14, 2004.
- [5] A. Agabi, E. Aristidi, M. Azaouit, E. Fossat, F. Martin, T. Sadibekova, J. Vernin and A. Ziad, "First whole atmosphere nighttime seeing measurements at Dome C, Antarctica", *PASP*, **118**, pp. 344-348, 2006.
- [6] J. Lawrence, M. Ashley, A. Tokovinin, T. Travouillon, "Exceptional astronomical seeing conditions above Dome C in Antarctica", *Nature*, **431**, pp. 278-281, 2004.
- [7] H. Trinquet, A. Agabi, J. Vernin, M. Azout, E. Aristidi and E. Fossat, "Nighttime optical turbulence vertical structure above Dome C in Antarctica", *PASP*, **120**, pp. 203-211, 2008.
- [8] S. Hagelin, E. Masciadri, F. Lascaux and J. Stoesz, "Comparison of the atmosphere above the South Pole, Dome C and Dome A: first attempt", *MNRAS*, accepted.
- [9] E. Aristidi, K. Agabi, M. Azouit, E. Fossat, J. Vernin, T. Travouillon, J.S. Lawrence, C. Meyer, J.W.V. Storey, B. Halter, W.L. Roth and V. Walden, "An analysis of temperatures and wind speeds above Dome C, Antarctica", *A&A*, **430**, pp. 739-746, 2005.
- [10] E. Masciadri, F. Lascaux, J. Stoesz, S. Hagelin and K. Geissler, "A different "glance" to the site testing above Dome C", Roscoff Arena Workshop 13-20 October 2006.
- [11] K. Geissler and E. Masciadri, "Meteorological parameter analysis above Dome C using data from the European Centre for Medium-Range Weather Forecasts", *PASP*, **118**, 845, pp. 1048-1065, 2006.
- [12] F. Lascaux, E. Masciadri, J. Stoesz and S. Hagelin, "Mesoscale simulations above Antarctica for astronomical applications: first approaches", Symposium on Seeing, Kona-Hawaii, 20-22 March 2007. Proceeding available at <http://weather.hawaii.edu/symposium/publications>.
- [13] J. P. Lafore, J. Stein, N. Asencio, P. Bougeault, V. Ducrocq, J. Duron, C. Fischer, P. Hereil, P. Mascart, V. Masson, J.-P. Pinty, J.-L. Redelsperger, E. Richard and J. Vilà-Guerau de Arellano, "The Meso-Nh atmospheric simulation system. Part I: Adiabatic formulation and control simulations", *Annales Geophysicae*, **16**, pp. 90-109, 1998.
- [14] F. Lipps and R. S. Hemler, "A scale analysis of deep moist convection and some related numerical calculations", *J. Atmos. Sci.*, **39**, pp. 2192-2210, 1982.
- [15] T. Gal-Chen and C.J. Sommerville, "On the use of a coordinate transformation for the solution of the Navier-Stokes equations", *J. Comput. Phys.*, **17**, pp. 209-228, 1975.
- [16] A. Arakawa and F. Messinger, "Numerical methods used in atmospheric models", *GARP Tech. Rep.*, **17**, WMO/ICSU, Geneva, Switzerland, 1976.
- [17] R. Asselin, "Frequency filter for time integration", *Mon. Weather. Rev.*, **100**, pp. 487-490, 1972.
- [18] J. Cuxart, P. Bougeault and J.-L. Redelsperger, "A turbulence scheme allowing for mesoscale and large-eddy simulations", *Q. J. R. Meteorol. Soc.*, **126**, pp. 1-30, 2000.

- [19] P. Bougeault and P. Lacarrère, "Parameterization of orographic induced turbulence in a mesobeta scale model", *Mon. Weather. Rev.*, **117**, pp. 1972-1890, 1989.
- [20] J. Noilhan and S. Planton, "A simple parameterization of land surface processes for meteorological models", *Mon. Weather. Rev.*, **117**, pp. 536-549, 1989.
- [21] E. Masciadri and S. Egner, "First Seasonal Study of Optical Turbulence with an Atmospheric Model", *PASP*, **118**, 849, pp. 1604-1619, 2006.
- [22] J. Stein, E. Richard, J. P. Lafore, J.-P. Pinty, N. Asencio and S. Cosma, " High-resolution non-hydrostatic simulations of flashflood episodes with grid nesting and ice phase parameterization", *Meteorol. Atmos. Phys.*, **72**, pp. 203-221, 2000.
- [23] M. Swain and H. Gallée, "Antarctic boundary layer seeing", *PASP*, **118**, pp. 1190-1197, 2006.