First, we wish to thank the reviewer for his/her careful review. Below is our response to the comments (in blue) on a point-by-point basis. The text referring to the article is indicated in italic.

Answers to major comments

1 The motivation for using Lagrangian particle model is not clearly state.

To model wind fields at high temporal and spatial resolutions from a grid point simulation, there are two main methods. First, a method of adaptive grid refinement may be used. The method aims at refining the grid only where studied processes take place to be sure to have high resolution enough to resolve these processes. It is a costly method which requires the implementation of finite volume or finite element models. The alternative method is to use mesh-free particle models inside the grid cells. Starting from an Eulerian grid point model, the sub-grid fields are modeled using a Lagrangian approach. One of the main advantages of Lagrangian particle models is the ability to model nonlinear evolutions. This method is easier to implement than the adaptive grid refinement method, but it has its own drawbacks depending on the mesh-free model (interpolation issues for instance [4]). In this work, the mesh-free method has been chosen for a practical reason. The work on the Lagrangian model presented in the article has started from instrumental issue – signal filtering and turbulence estimation. In this framework, the Lagrangian particle model has given very good results [2, 12, 9, 10, 11]. For instance, using particle method, real time turbulence estimations are now available from wind observations. Thus using the same model for turbulence modeling was a natural approach. It has led us to a new downscaling method which opens new perspectives such as sub-grid TKE estimation in aeronautical areas or in data assimilation.We have modified the text in order to better state the motivation for using Lagrangian particle model.

Lines 62-81 *Instead of a larger decrease of the grid size, we suggest here another way to model sub-grid turbulence. In this paper, we present a stochastic downscaling approach. Our method is based on particle systems that are driven by a local turbulence model. Those particles are embedded in grid cells (illustration 1). [...] The pdf time evolution is thus given by the particle evolution. The suggested particle approach enables to model physical phenomena with nonlinear temporal evolutions. However, depending on the particle model, particle methods may have drawbacks such as interpolation issues for instance [4]. In the present work, the only delicate point is to ensure that the particle density is high enough in each grid cell.*

2 The focus is on the assessment of the subgrid turbulent kinetic energy (and spectra), however, for a model to be a viable turbulence model it needs to represent (subgrid) turbulent stresses and fluxes, but these were not evaluated.

The focus is on the assessment of the subgrid turbulent kinetic energy because this variable is used in the Lagrangian particle model. Reynolds stresses $\overline{u_i'u_j'}$ may also be computed. It would be interesting to look at turbulent stresses and fluxes. However, turbulent fluxes cannot be computed for the particle fields since we have only wind simulations, and turbulent stresses are not usual studied variables to work on convective boundary layer. Thus they have not been presented in the manuscript because it was a first work to test the downscaling method.

3 The analysis is limited to a relatively small part of the Meso-NH computational domain (2x2x2 coarse grid cells, or 8x8x4 grid cells) and a short time period (15 minutes) and therefore the results may not be robust.

The small computational domain and the short time period are due to memory allocation problems of our programming software. From the presented study, we can not conclude about the result robustness. However, we have looked at the grid-point fields in areas of subsidence and of updraft. The fields were similar to the fields used in the present work, so the studied case may be considered as representative of the simulation. In addition, before using the BLLAST experiment simulations, simulations performed for the IHOP_2002 experiment have been used. These simulations have a larger grid size (100m for the horizontal resolution for instance [5]), this is why we have then worked on the BLLAST simulations. The very first results obtained with the IHOP_2002 simulations were very similar to the presented results indicating some universality of the results for convective boundary layer. Thus, even if the robustness has still to be proved, we are rather confident about it.

Lines 765-774 *This experience has been realized on a small domain, with a reduced number of particles in each cell. These two constraints were related to the long computational time. Extending the domain and the duration of the simulation should be one of the next steps. It would improve the PSD quality, and limit the influence of the edges. Then, a supplementary work on the spatial resolution of the particle simulations might be done and the result robustness may be tested. To give a very first answer to the robustness issue, we remind that we have compared the studied fields to fields on different areas on the same vertical level. The comparison has shown that Meso-NH fields are similar in the different areas. Thus, the downscaling method should provide similar results when being applied in these areas. Extending the duration of the simulation would also enable us to compare the particle wind and the particle TKE to the in-situ observations.*

4 The limitations of Lagrangian particle models have not been clearly stated and computational cost compared to more common turbulence closures has not been addresses.

We underline that the aim of this work is not to provide cheap turbulence closures. The idea is instead to work on a new way to model sub-grid turbulence for research purposes. On one hand, particle methods are costly, and require a particle management method to ensure that there are enough particles in each grid cell to compute sub-grid fields. On the other hand, particle methods are adapted to model nonlinear physical processes, such as atmospheric turbulence. Besides, horizontal and vertical velocities are treated differently because the Lagrangian model does not assume homogeneous or isotropic turbulence. Thus the new downscaling method should be seen as an alternative solution to common turbulence closures which often assume isotropic and homogeneous turbulence. In the long term, it could also be seen as a tool to improve or to evaluate the quality of common turbulence closures used in operational models.

Lines 765-774 *Among the future works, there is first the application of the downscaling method to a larger domain, and the comparison of the sub-grid fields to observations. Then, there is the study of the TKE parametrization used in Meso-NH by comparison with the TKE modeled by the particles. Despite the computational time, in a long-term perspective we may also think to experiences where the sub-grid parametrization used in Meso-NH will be replaced by sub-grid particle modeling. Indeed, for research purposes, the downscaling method may be an alternative solution to common turbulence closures which often assume isotropic and homogeneous turbulence.*

5 Fundamental question that is not addressed in the manuscript is what scales of turbulence is Lagrangian particle model representing, this essential question needs to be addressed in the manuscript.

The question of the scales represented by the Lagrangian particle model is actually a fundamental question. So far we have few answers to this question. To know the spatial scale associated to each particle, a Voronoï diagram could be plotted using particles as seeds. However it is a costly solution to know the particle scale, and we are not sure that the physical interpretation of this scale is relevant. A cheaper solution is to divide the grid cell surface by the mean number of particles. There are 75 particles in each 40mx40m cell, that is to say that each particle represents a 21m^2 surface. Thus a particle has approximatively a length of 4.6m. An other solution to know the scales represented by the particle system is to use the power spectrum densities and the mean velocities to evaluate Lagrangian lengths. Looking at the spectrum of the first component of the wind, we can see that the spectrum is flat for frequencies higher than 5.10^{-2}s^{-1} (figure 1). In average over the domain, the first component of the particle wind is about 1.3m/s. Thus a Lagrangian length associated to the particles for the first wind component is about 26m. The second and the third mean wind components are 0.3m/s and -0.22m/s. Thus, using the same cut-off frequency, we obtain Lagrangian lengths about 6m and 4m for the second and the third wind component respectively.
So far these lengths are the only estimations of the scales represented by the Lagrangian particle model. However a specific work has still to be done to figure out the scales represented by the Lagrangian particle model. To underline this issue, paragraphs will be added in the section which presents the power spectrum densities and in the discussion section.

Before line 622 *The spatial resolution of the particle simulations is tricky to estimate. A first estimation may be given by the Lagrangian lengths associated to the wind components. The lengths can be evaluated using the power spectrum densities and the mean velocities. Looking at the spectrum of the first component of the wind, we can see that the spectrum is flat for frequencies higher than $5.10^{-2}s^{-1}$ (figure 8). In average over the domain, the first component of the particle wind is about 1.3m/s. Thus a Lagrangian length associated to the particles for the first wind component is about 26m. Using the same cut-off frequency, we obtain Lagrangian lengths about 6m and 4m for the second and the third wind component respectively. The differences*

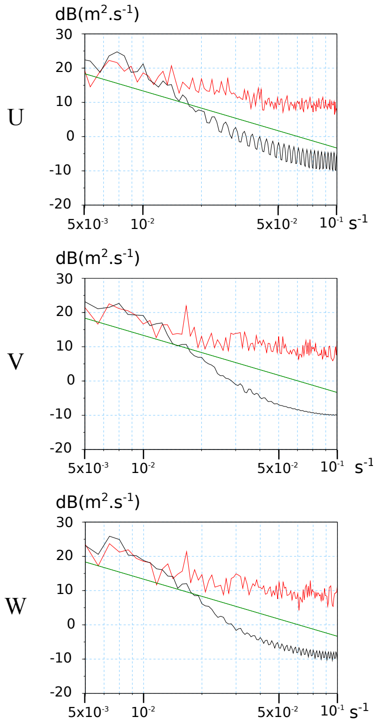

Fig. 1: Power spectrum densities of the components of the fine Meso-NH wind in black and of the components of the particle wind in red, calculated on a 4x4 grid cells domain, for the second level of the fine grid. In green we have the -5/3 slope according to the K41 laws.

between the lengths computed for the three components clearly show the difficulty to use this method to evaluate the spatial resolution of the particle simulations.

Following line 774 *Related to the question of the spatial resolution of particle simulations, there is also the fundamental question of the scale of the turbulence represented in the particle fields. So far, only a first estimation of the scale has been given, and a specific work has still to be done to figure out the scales represented by the particle model.*

6 The conclusions that Lagrangian particle model follows Kolmogorov law is not supported by the results (i.e., the spectrum does not follow -5/3 scaling).

As explained in the article, the Stochastic Lagrangian Model comes from the work of S.B. Pope [8]. The original model presented by Pope has been designed to follow the Kolmogorov law. Then it has been adapted for atmospheric turbulence estimation by Baehr [1, 2]. In the turbulence estimation framework, results have shown that the model follows the Kolmogorov law. The present downscaling method uses the model from Baehr work with a small simplification due to the vertical size of the domain – we assume that vertical gradients of horizontal wind are null. The main difference with the works of Pope and Baehr is not about the model formulation. It is due to the different ways to compute the control parameters. Our work is a first attempt to use control parameters given by an Eulerian grid point simulation. In this framework, the model behaviour has not been completely assessed yet. As presented in the article, the spectra do not perfectly follow the -5/3 scaling. However, they have regular slopes. One can see that it is not the case for the Meso-NH spectra. Longer simulations are needed to continue working on the model behaviour. Spectrum calculated from longer time series will be more representative of the model behaviour, and the spectrum shape will be easier to interpret. It has not been done yet because of computational costs. Another interesting point is to work on one of the control parameters, the eddy dissipation rate (EDR). As it is a preliminary work, the EDR variable of Meso-NH has been used. This variable is computed using a closure scheme which can introduce errors on the EDR modeling. An alternative solution could be to compute the EDR directly from the grid point wind fields. Improving the EDR modeling should directly improve the sub-grid turbulence modeling and thus the model behaviour.

Lines 593-604 *Figure 9 presents the PSDs of the three components of the fine Meso-NH wind and of the particle wind. It appears that neither the particle wind or the fine Meso-NH wind follows perfectly the energy cascade given by the Kolmogorov's theory and represented by the -5/3 slope. But we may notice that the particle wind spectra present a regular slope. The regularity of the slope is a good point to assess the particle wind and its fast fluctuations. It shows that the energy cascades are the same whatever the considered scales. However the slope is slightly more gentle than the energy cascade. There may be too much energy associated to the turbulence modeled by the particles at high frequencies. As presented in section 3.4, the SLM has been designed to follow Kolmogorov laws, but the spectra on figure 9 have been obtained by applying the model in a new framework. Our work is a first attempt to use control parameters given by an Eulerian grid point simulation. In this framework, the model behaviour has not been completely assessed yet. Longer simulations are needed to continue working on it.*

Manuscript organization

Considering that there may not be any previous examples of use of Lagrangian particle model as a closure for subgrid turbulence in LES (none are cited in the manuscript) the authors should have provided better background and motivation for their approach.

The motivation for our approach has been detailed in the first point of the "Answers to major comments" section. Modifications in the article have also been suggested in this section.

Also, the Lagrangian particle model output is compared to higher-resolution LES, however, this is likely not a fair comparison considering that spatial and temporal resolution with Lagrangian particle model may be significantly higher than high-resolution LES.

We agree that spatial and temporal resolution with Lagrangian particle model may be significantly higher than high-resolution LES. However we have done the comparison because it was the only way to study the sub-grid fields modeled using a the particle system. In the present application, a high resolution LES has been used as a reference. This LES has been chosen because the simulated case was documented by turbulence observations in an other study [7]. In order to force the particle system we have built a lower resolution simulation using the reference LES. One of the limitations for the validation has been that the difference of resolution was not large enough. Thus the resolution of the reference was not high enough to be compared to the particle simulation. To tackle it, the ideal solution would be to use direct numerical simulations (DNS) of turbulent atmosphere to validate the sub-grid modeling. Such simulations are very costly and could not be done for the present case.

Lines 761-764 : *This article presents a preliminary work on a new way to model sub-grid processes using particle systems. One of the major improvement is the use of a simple turbulence model instead of complex model such as LES or DNS. However, to fully validate the method, one of the first steps should be to use a DNS or to apply the downscaling method to a toy model to know exactly the sub-grid fields. Unfortunately, such a validation could not have been done yet.*

The authors do not address the issue of scales.

Concerning the interesting issue of scales represented by the Lagrangian particle model, two paragraphs will be added in the article (see point 5).

Furthermore, the manuscript is not organized well: as indicated earlier, the motivation is not clearly stated, the model development is not concisely outlined, e.g, use of Meso-NH simulations to force the model is discussed before the model is presented, and the analysis does not follow logical order, e.g. turbulence spectra are analyzed before TKE is analyzed.

Motivations will be clearly indicated and models will be presented before discussing the use of Meso-NH simulations to force the particle system. Concerning the TKE analysis, we have chosen to present it after the analysis of the wind and the power spectrum densities because the subgrid TKE is computed from the particle TKE and not directly from the wind (see section 5.2 of the article). Thus we have chosen to analyse all results about the sub-grid wind (including spectra) before analysing results about the sub-grid TKE. An explanation of this choice will be added at the beginning of the results section.

Lines 482-488 *In the previous sections, the downscaling algorithm has been described in details. The obtained results are now presented. To assess the behavior of the particle system, we compare the 3D wind given by the particle and by Meso-NH. First results on the coarse grid are shown. Then we present the comparison between the particle fields and the fine Meso-NH fields. Wind power spectrum densities are then presented. Finally, results for subgrid TKE are presented. This results are presented separately because the subgrid TKE is computed from the particle TKE and not directly from the wind.*

Specific remarks

- Corrections about the vocabulary will be taken into account. The authors thank the referee for the suggestions.

- Line 243, since the eddy dissipation rate is used in the model it should be stated how is it computed in Meso-NH.

The eddy dissipation rate is computed from the subgrid turbulent kinetic energy which is a prognostic variable of Meso-NH. More precisely, a closure scheme based on the mixing length is used [6].

Lines 201-210 *For our simulations, the 3D turbulence scheme is a one and a half order closure scheme (Cuxart et al., 2000). Thus the sub-grid TKE is a prognostic variable whereas the mixing length is a diagnostic variable. The mixing length and the dissipative length are computed separately according to Redelsperger et al. (2001). The mixing length is given by the mesh size depending on the model dimensionality. This length is limited to the ground distance and also by the Sommeria and Deardorff (1977) mixing length, which is pertinent in the stable cases. The eddy dissipation rate is computed from the subgrid turbulent kinetic energy using a closure scheme based on the mixing length.*

- Line 323, number of particles used (75 per grid cell) is quite large, increasing grid resolution for the same number of grid cells per coarse grid cell would result in almost an order of magnitude higher resolution.

The number of particles which has been used may seem large, but it may be compared to the number of particles (800 per grid cell) used by Bernardin et al for the same kind of application [3]. As there is a link between the number of grid cells and the resolution of the grid point model, there is a link between the number of particles and the Lagrangian particle model resolution. However we think that the number of particles may not be directly compared to the number of grid cells. As explained previously, the work on the Lagrangian particle model resolution has not been done yet.

Lines 321-323 *The results of the sub-grid modeling are presented in section 6. They are obtained with 75 particles in each fine grid cell. Thus the whole system contains 19200 particles. This number may be compared to the 800 particles per grid cell used by [3] for the same kind of application.*

- Line 388, instead of a reference to Shannon (1949) original work by Nyquist should be referenced (This is actually Nyquist frequency, c.f. Certain factors affecting telegraph speed (1924) and Certain topics in Telegraph Transmission Theory (1928)).

The reference to Shannon work will be replaced by a reference to Nyquist paper.

- Line 427, the rationale for different treatment of horizontal and vertical velocities should be provided.

The rationale for different treatment of horizontal and vertical velocities is that the velocities are not driven by the same physical processes. Large scale horizontal velocities are driven by pressure gradients, whereas large scale vertical velocities are driven by buoyancy. To improve our study, temperature gradients computed from Meso-NH simulations could be taken into account.

Lines 427-432 *The horizontal velocities are forced with the pressure gradient and the dissipation rate. For the vertical velocities, the forcing is slightly different : it uses the vertical velocity coarse fields instead of the pressure fields. This choice has been done because horizontal velocities are driven by pressure gradients, whereas vertical velocities are driven by temperature gradients. To improve the downscaling method, temperature gradients computed from Meso-NH simulations could be taken into account. We may notice that in this work, the EDR used to force the particles is considered isotropic.*

- Figure 5, it is not clear what is the purpose and value of the comparison shown in this figure.

Figures 5 compares the wind modeled by the coarse grid point simulation to the particle wind averaged coarse cell by coarse cell. The aim is to assess the particle behaviour at the forcing scale. This step is necessary because, for the horizontal velocity, the average particle behaviour is given by the pressure gradient and not by an average velocity.

Lines 497-504 *To assess the downscaling method, the first thing to look at is the agreement between the coarse wind and the average of the sub-grid wind modeled by the particle system. The aim is to assess the particle behaviour at the forcing scale. This verification is important, especially for the horizontal velocity which is not directly forced by the coarse horizontal velocity fields. We remind that to compare the particle wind to the coarse wind fields, the particle values are averaged coarse cell by coarse cell.*

- Lines 509-514, the statements are based solely on a limited qualitative analysis (comparison of plots) and as such they are of little value.

The qualitative analysis may be completed with a more quantitative analysis. For instance root mean square errors (RMSE) can be added. For the first component, the RMSE of the particle wind averaged at the large scale is 0.045 m/s. For the second and the third components, the RMSE are respectively 0.062 m/s and 0.135 m/s.

Lines 507-514 *The averaged particle wind is consistent with the coarse wind, especially for the horizontal wind. The root mean square errors associated to the first and the second particle wind components are respectively* $0.045 m.s^{-1}$ *and* $0.062 m.s^{-1}$. *For the vertical wind, there is more discrepancy between the particle wind and the Meso-NH wind, but they present the same variations. The associated error is* $0.135 m.s^{-1}$. *Similar results have been obtained for the other coarse cells (not shown). Thus, as expected, the 3D wind modeled by the particles is in good agreement with the wind modeled by the coarse Meso-NH model.*

- Line 523, the statement "more turbulent" is qualitative, that needs to be qualified. The question is what should be the level of turbulence at the scales that are resolved. Another question is what scales are particles representing.

  The statement "more turbulent" is implicitly qualified by the shape of the power spectrum densities represented figure 1 –figure 9 in the manuscript. Looking at the spectra, one can see that the energy associated to high frequencies is higher in the particle wind than in the reference Meso-NH wind. An explanation of the statement will be added to the manuscript. The complementary issue of the scales represented by the particles has not been addressed in the manuscript. As explained previously, it is still an open question. This preliminary work has raised questions about the effective resolution of the particle Lagrangian model. A more advanced work is necessary to answer it. We will add paragraphs about this issue in the article (see point 5).

  Lines 523-527 *First, we notice the more turbulent profile of the 3D wind represented by the particles than the fine Meso-NH wind profile. Indeed, the Meso-NH wind appears smoother while the particle wind presents more temporal fluctuations. The interpretation of the power spectrum densities presented section 6.1.3 will confirm that the energy associated to high frequencies is higher in the particle wind than in the reference Meso-Nh wind.*

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