

RE: acpd-13-C4844-2013-supplement.pdf “Referee report”

Introduction

Title: Asymmetric and axisymmetric dynamics of tropical cyclones

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General comments: This paper presents a thorough comparison between the three-dimensional version (3D) of the tropical cyclone model CM1 and its axisymmetric version (AX) by simulating idealized hurricane-like vortices. Comprehensive reviews on the dynamics and physical processes contributing to the intensification of tropical cyclones are provided in the introduction as well as in the relevant parts throughout the paper.

In general, the results of the simulations with CM1 presented here are consistent with previous studies in which the AX version produces a stronger vortex than the 3D version. Furthermore, this study performs in-depth analyses to reveal and explain the differences between the 3D and AX versions. The paper offers several new insights into the dynamics of tropical cyclone in the 3D and AX frameworks.

- a) The 3D simulation shows that, in contrast with previous studies, eddy processes associated with the vortical plume structures may help the intensification.*
 - b) The average heating rates in the AX model are much greater than that in the 3D model and, hence, consistent with the higher intensity achieved by the AX vortex. In turn, the higher mean heating rates in the AX version are explained in terms of a less hostile environment and an inherent ring-like structure of convection in the AX version compared with the 3D version.*
 - c) As the 3D vortex takes longer time to organize convection into the annual ring-like structure, its intensification rate is lower than the AX counterpart and ultimately a weaker mature vortex is resulted after 12 days.*
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- d) *The parameterizations of subgrid-scale turbulence above the boundary layer in both versions are shown to be inconsistent with the resolved eddy momentum fluxes.*
 - e) *The analyses from the 3D simulation do not support the role of small-scale vertical mixing processes in the outflow layer in the upper-troposphere in controlling the intensification.*
 - f) *The 3D and AX versions respond significantly differently to the changes in the surface drag. This difference is explained partially by the role of surface drag in organizing convection in the azimuth for the 3D version. This process is not present in the AX version.*
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Overall, the paper contributes significantly to our understanding of the intensification processes in the frameworks of three-dimensional and axisymmetric models. Intrinsic limitations of the strictly axisymmetric assumption are pointed out and explained by comparing with the three-dimensional counterpart. This knowledge is useful for the interpretation of axisymmetric model outputs for studying intensification processes in tropical cyclones.

Recommendation: Accept for publication with minor revisions.

Specific comments:

1.

Abstract, line 17: "... not represented properly by the subgrid-scale parameterizations in the AX configuration". This sentence is not fully consistent with the conclusions (page 13387, line 19), where the subgrid-scale parameterization in the 3D configuration also differs from the resolved horizontal eddy momentum flux.

Original Abstract, full sentence:

The comparisons show that the resolved 3-D eddy momentum fluxes above the boundary layer exhibit counter-gradient characteristics and are generally not represented properly by the subgrid-scale parameterizations in the AX configuration.

Original Conclusions, page 13387:

Comparisons between the two model configurations indicate that the structure of the resolved eddy momentum fluxes above the boundary layer differs from that prescribed by the subgrid-scale parameterizations in either the three-dimensional or axisymmetric configurations, with the exception perhaps of the resolved horizontal eddy momentum flux during the mature stages.

Response:

We agree that the abstract is not as precise as what we wrote in the conclusions.

Implemented edit to abstract:

The comparisons show that the resolved 3-D eddy momentum fluxes above the boundary layer exhibit counter-gradient characteristics during a key spin-up period, and more generally are not solely diffusive. The effects of these eddies are thus not properly represented by the subgrid-scale parameterizations in the AX configuration.

2.

Figures 11 and 13: Missing the plots for the sum of all tendency terms. I can imagine that these plots could be very noisy. Since the averaging periods are long (12-24 hours), the tendencies may cancel each other, resulting in near-zero noisy fields. However, it is worth to show here for completeness.

Response:

The reviewer's question has prompted us to reexamine this issue. On review, we have identified three significant causes for error in the calculation. 1) Time sampling introduces a random error. 2) Recreating the modeled parameterization of subgrid scale mixing and of surface fluxes. 3) Use of centered spatial differences to compute advection tendencies rather than the 5th-order upstream advection scheme used in the CM1 model. Estimates of the error –type 3- in areas of large second derivative of the tangential wind or of large change in the advecting wind in the direction of motion indicate that the error can be of order 50%. The nature of the errors of types 2 and 3 is such that they tend to overestimate the tendency, but not to reverse the overall spatial gradients of the tendency or change the overall sign of the tendency. We now note these errors of the calculation in the text.

Implemented edit (p13361):

Figure 10h shows the azimuthal-mean tangential wind tendency from model output (the left hand side of Eq. (12)), while Fig. 10i shows the corresponding tendency diagnosed from the sum of mean and eddy terms plus the subgrid scale (boundary layer and diffusion) processes (the right hand side of Eq.(12)). The two panels agree reasonably well quantitatively, although three sources of error in our calculation must be acknowledged. These are the sampling of the output data, the evaluation of parameterized internal diffusion and surface fluxes, and the use here of centred spatial differences to calculate advection, whereas the CM1 model uses a 5th-order upstream advective scheme. The nature of these errors is not to change the overall sign or reverse the overall direction of the gradient of these computed tendency fields, but the errors become most apparent in the boundary layer when the storm approaches a mature intensity and where both the second and third sources of error are especially prevalent. For the time interval shown in Fig. 10, the maximum tangential winds are found to reside in the eyewall region near the top of the boundary layer, where the radial spin-up mechanism associated with the sum of the vorticity influx and vertical diffusion terms is a maximum.

3.

Page 13366, Equation 17: I have some troubles understanding this expression of D_v for the 3D version of the model. This expression is certainly true for the axisymmetric version. But for the 3D version, perhaps there is another term representing the gradient of the subgrid-scale stresses in the azimuthal direction. Please clarify.

Response:

Our equation 17:

$$\langle D_v \rangle = \frac{1}{r^2} \frac{\partial r^2 \langle \tau_{r\lambda} \rangle}{\partial r} + \frac{\partial \langle \tau_{\lambda z} \rangle}{\partial z}$$

The only remaining term would be a $\tau_{\lambda\lambda}$ -term, which vanishes upon azimuthal averaging.

Implemented edit: None.

4.

Page 13366: The definition of τ_{rz} could be added after equations 18 and 19. Although this term is not present in the expression for sub-grid scale tendency (Eq. 17), it is calculated and presented in Figures 14-18.

Response:

We have added the equation at the end of the paragraph of equations 18 and 19.

Implemented edit:

...with parameterization formulae for horizontal and vertical eddy diffusivities, $K_{m,h}$ and $K_{m,v}$.
The analogous specification for τ_{rz}

$$\langle \tau_{rz} \rangle = \langle K_{m,v} \left(\frac{\partial u}{\partial z} + r \frac{\partial w/r}{\partial r} \right) \rangle$$

is also shown in the figures below.

5.

Page 13369, line 27-13370, line 1: "In the AX simulation, the sub-grid flux (Fig. 16d) becomes comparable with... (Fig. 15g), but its dipole pattern in the low to mid-troposphere updraught region is essentially the reverse of the 3-D resolved eddy pattern." The 3-D resolved eddy-flux is shown in Fig. 15d. Comparing Figs. 16d and 15d, I am not quite convinced with your interpretation that they are reverse patterns of each other.

Response:

The panel references in that sentence are as we intended, but we will add a reference to Fig. 15d at the end of the sentence, which should help interpretation.

Implemented edit:

In the AX simulation, the subgrid flux (Fig. 16d) becomes comparable with that found in the 3D simulation during the second intensification phase (Fig. 15g), but its radial dipole pattern in the lower troposphere updraught region is essentially the reverse of the 3D resolved-eddy pattern and bear little resemblance to one another (Fig. 15d).

6.

Page 13372, line 1: “there is some pattern similarity in the negative $-\langle v'w' \rangle$ and $\langle \tau_{rz} \rangle$...” Did you mean “ $\langle \tau_{\lambda z} \rangle$ ”? (e.g., Figs. 15f and 15i have similar patterns but different magnitudes.)

Response:

The reviewer is correct. We have changed $\langle \tau_{rz} \rangle$ to $\langle \tau_{\lambda z} \rangle$.

Implemented edit:

There is some pattern similarity in the negative $-\langle v'w' \rangle$ and $\langle \tau_{\lambda z} \rangle$ in the upper-troposphere updraught region in the 3-D simulation, but the latter is much smaller, and in the AX simulation this feature is entirely absent.

Typing errors

Page 13335, line 21

Remove ‘should’

Response:

Agreed.

Page 13372, line 7

Change ‘not’ to ‘no’

Response:

It would appear that “no” is favoured by grammar checkers. The suggested edit has been performed.