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Nonlinear Processes in Geophysics
Discussions
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Interactive comment on "Theoretical comparison of subgrid turbulence in the atmosphere and ocean" *by* V. Kitsios et al.

V. Kitsios et al.

vassili.kitsios@csiro.au

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GENERAL COMMENTS:

We are pleased that the reviewer found the work mathematically rigorous. As mentioned in the response to the other reviewers, we further emphasise the new and novel aspects at the end of the introduction in the revised manuscript, by including the following points

1. We believe that this is the first ever study to systematically compare subgrid models of quasigeostrophic (QG) turbulence in the atmosphere and ocean. In particular it is the first study were simple unified scaling laws have been presented that

apply to both media.

2. The study uses a much larger set of simulations covering a much broader range of flow parameters, including an order of magnitude change in the Rossby radius of deformation and the energy containing scale, compared with previous studies.

3. By focussing on the enstrophy cascading inertial range in both media, the large number of simulations and wide parameter range has enabled the establishment of robust scaling laws.

4. The scaling laws presented here are particularly simple with eddy viscosity magnitudes that are proportional to T_R^{-1} and power exponents that are approximately proportional to T_R. These results, and the fact that $\nu_\mathrm{d} \approx 2\nu_\mathrm{b}$, are suggestive of robust fundamental properties of QG turbulence.

We now address the reviewer's general comments and minor points. Associated changes to the manuscript are marked in blue text.

With regard to the reviewer's comments concerning the possible effects of topography, we are currently working on the subgrid modelling studies of atmospheric simulations with topography. We find that the scaling laws governing the eddy-eddy interactions, as presented in the present manuscript, are largely independent of the the topography. In recently published work, Frederiksen et al. (2015) have recovered analogous subgrid coefficients for more complex primitive equation models. These results suggests that the findings from the QG simulations adopted in the present study apply more broadly.

Frederiksen and Kepert (2006) looked at predictability in 10 day simulations with LES, and it was found that model errors and initial conditions error are in fact much larger than any errors associated with the type of subgrid model adopted in both in Frederiksen and Kepert (2006) and also in our present study. It has been found that correct representation of the kinetic energy spectrum, and the addition of stochastic backscatter in the subgrid models improves the ensemble spread and hence predictability of the system (O'Kane and Frederiksen, 2004; Shutts, 2005; Tennant et al., 2011).

The updated manuscript can be found in the supplementary material.

MINOR POINTS:

- *The choice of atmospheric Rossby deformation radius is rather small at 447 km. This may not be very important but I would prefer to see the value at 1000 km.*

The study covers the sensitivity of the subgrid model coefficients to k_R and hence the Rossby radius across an order of magnitude. As you we suggest that the specific value of the atmospheric Rossby radius is not necessarily important.

- *page 1682 line 17 - perhaps a comment could be made on the origin of the Error function dependence ?*

The error function dependence for the drag in the oceanic simulations is used to control the wavenumber location of k_E. Using this approach we are able to study the influence of k_E on the subgrid coefficients, and in the manuscript we develop scaling laws to represent the variability in both k_R and k_E. The updated version now includes the following sentence in the above referenced place:

This functional form allows us to control the location of the energy containing wavenumber

- *In the conclusions, the authors should discuss how their ideas could be modified to take account of the differing dynamical cores used in real NWP and climate models. Their advection schemes are typically quite dissipative and it's difficult*

to see how the turbulence theory could be amended to account for each specific scheme (e.g. semi-Lagrangian/semi-implicit or finite element).

We would first like to reiterate that the focus of this manuscript is to accentuate the similarities between the properties of subgrid turbulence in the atmosphere and ocean, and not on addressing issues associated with specific numerical implementations of various dynamical cores. Having said that, as you request, we have addressed the issues associated with semi-Lagrangian and semi-implicit time stepping schemes below.

We are actually currently implementing these scaling laws into a complex GCM, which is used for national weather prediction and climate studies. This grid point based GCM is called ACCESS, which is a version of the Hadley Centre model. The subgrid models are being implemented in the ACCESS GCM via grid to spectral transforms, with the specifics discussed in response to the comments of reviewer 3. This GCM has a Lagrangian time stepping scheme, which as the reviewer correctly points out has its own resolution dependent dissipation, and deformation of the kinetic energy spectra. We have run this GCM at various resolutions and do indeed observe resolution dependence associated with the Lagrangian time stepping. Whilst the Lagrangian time stepping allows an order N increase in time step size, it does introduce an significant artificial dissipation range, which to cure requires an order N increase grid resolution, conservatively resulting in an order N^3 increase in computational effort. We can (and have) used the stochastic modelling framework outlined in the current paper to modify the dissipation associated with the Lagrangian time stepping, and avoid such required increases in grid resolution. This, however, is not ideal and a semi-implicit time stepping scheme with known dissipation characteristics would be preferred. The issue of deformation of the kinetic energy spectra may not be a significant one in weather prediction since over the course of 7 days the spectra remains relatively constant. However, for climate simulations undertaken over a period of many years, spectral deformation and resolution dependence is a significant problem.

The following trimmed down version of the above discussion pertaining mainly to implementation of the scaling laws into grid point/finite element codes has been added to the conclusions in the updated version of the manuscript.

The scaling laws developed here can be implemented directly into spectral simulations, and are expected to improve the efficiency and accuracy of numerical weather and climate simulations (Frederiksen et al., 2003, 2015). There are also two possible approaches to implement these scaling laws into grid point codes. The simplest approach is to apply the subgrid model directly in grid-point space via a Laplacian operator of the appropriate power, as outlined in Table 1. More generally it is also possible to employ grid to spectral transforms, where the subgrid model is calculated in spectral space, and then applied in physical space.

References

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Please also note the supplement to this comment:

http://www.nonlin-processes-geophys-discuss.net/2/C709/2016/npgd-2-C709-2016-supplement.pdf

Interactive comment on Nonlin. Processes Geophys. Discuss., 2, 1675, 2015.