Ocean Sci. Discuss.,
https://doi.org/10.5194/os-2017-23-AC3, 2017

Interactive comment on "Mesoscale cascades and the "conundrum" of energy transfer from large to dissipation scales in an adiabatic ocean" *by* Mikhail S. Dubovikov

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Received and published: 14 September 2017

Reply to the comments of the Referee#2 (R2)

First of all, I would like to thank R2 for his extensive work in examining and critically reviewing the manuscript. R2 clearly and concisely interpreted the basic features of the presented mesoscale energy cycle: "it is demonstrated that from the turbulence closure approach by Canuto, Dubovikov et al it follows that there is indeed conversion from EKE to EPE at scales like the Rossby radius" and that "the directions of the energy cascades are apparently assumed but in agreement with common believe." R2 recognizes some progress by the presented scheme: "This is a nice idea of the meso-scale energy

cycle. The inverse energy cascade would just be a closed loop within a larger scope with a cascade of total energy towards small scale." The only objection of R2 is as follows: "However, it must be wrong since it is against all believes that energy conversion by baroclinic instability is directed from EPE to EKE at the scale of the Rossby radius. In fact in all studies I know of, it is directed from EPE to EKE at all scales." Indeed, in the chapter 6.8 titled "The energetics of linear baroclinic instability" of the well-known book by Vallis "Atmospheric and Ocean Fluid Dynamics" the author studies the problem of the baroclinic instability and concluded in the end of the chapter that "baroclinic instability converts potential energy into kinetic energy." However, this conclusion was drawn on the basis of the linear analysis within which the energy exchange between different Fourier modes is absent altogether, as well as the energy cascades. As for numerical models, in all of them the energy transformation was studied for one-point quadratic functions like EKE and EPE rather than for two-points correlation functions and their spectra. The production of EKE spectrum is contributed by the work of both the linear force and that of the non-linear (NL) one, which is referred to in turbulence studies as "transfer". Since the integral over the spectrum of the transfer exactly vanishes, the full (spectrum integrated) EKE production is determined by the linear force only. Therefore, the energy transition "is directed from EPE to EKE", as R2 correctly states. Nevertheless, in the case of strong turbulence in certain wavenumber ranges the modulus of the transfer considerably exceeds that of the work of the linear force and, thus, the production of the EKE spectrum in those ranges is determined mostly by the transfer. This means that in the most part of the range where the works of the linear and NL forces have opposite signs, EKE transforms to EPE. This conclusion does not depend on a concrete closure and refutes R2's statement that the energy conversion "is directed from EPE to EKE at all scales".

In the real Ocean, as Dubovikov (2003, D3) and Canuto and Dubovikov (2005, CD5) showed theoretically, the mesoscale turbulence is strong and the NL interactions determine the mesoscale dynamics. The analogous conclusion was drawn by Chelton et al. (2011) from the analysis of observational data: "essentially all of the observed mesoscales features are non-linear". Thus, we expect that the NL mesoscale dynamics radically modifies the transformation of EPE and EKE in comparison with the linear analysis and there is a scale range in the mesoscale spectrum where EKE transforms to EPE against the common preconception. In the supplement we show that within the closure developed in D3 and CD5, EKE transforms to EPE namely at the scales of the deformation radius. Even though R2 criticizes this result, I thank him for the remark that his criticism "does not mean that all predictions and the whole closure is wrong". To confirm this statement, in the supplement I show also some other appreciable results of the closure which are compared favorably with observations. The closure is notting more than the old-time mixing length model reformulated in wave-number terms. The basis of it is the generation of the inverse energy cascade in mesoscale turbulence whose existence is now commonly recognized (Muller et al., 2005; Ferrari and Wunsch, 2009; Bruggemann and Eden, 2015; Jansen et al., 2015) and confirmed by sea surface height data (Scott and Wang, 2005; Scott and Arbic, 2007). As Kraichnan (1975) showed and as it was confirmed in numerous direct numerical simulations (DNS) and large eddy simulations (LES), such cascades yield the negative turbulent viscosity which drastically changes outputs of the mesoscale dynamics which can be tested against data of observations and OGCMs numerical computations.

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Please also note the supplement to this comment:
https://www.ocean-sci-discuss.net/os-2017-23/os-2017-23-AC3-supplement.pdf

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