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Biogeosciences Discussions

Interactive comment on "Modelling the effect of boundary scavenging on Thorium and Protactinium profiles in the ocean" *by* M. Roy-Barman

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Dear Dr. Heinze,

First, I would like to thank M. Rutgers van der Loeff and R. Anderson for their positive and constructive comments. All the small changes (typos, grammar, wording, missing references…) requested by the reviewers have been done. The revised ms is provided as supplement to this letters (all the changes are in red caracters). Here I detail the answer to their main comments: mostly the implicit assumptions of the model that are now stated explicitly in the revised ms.

Answer to the comments of M. Rutgers van der Loeff

** Comment: Discrepency between the bathymetry of the real ocean and the bathymetry of the model at the ocean margin: ** Answer: I agree that the model implicitly assumes that the coastal ocean has opposed with a shelf and a slope. This point is explicitly mentioned in the section 2.1. and figure 1 has been changed accordingly.

Answer to the comments of R. Anderson

** Comment: R. Anderson points out simple 2-box model neglects ventilation of deep layers by lateral exchange with polar regions. ** Answer: This assumption is stated explicitly in section 2.1. (model description) and specific discussions are provided in the Pacific (3.1.1.) and Arctic (sections 3.2.1, already present in the original ms). In particular CFC-derived ventilation ages are compared with the scavenging residence time of Th and it is concluded that the impact of ventilation is low. The effect of ventilation is certainly stronger for 231Pa that has a longer scavenging residence time although it is not possible to clearly quantify this effect. In most studies the effect of the thermocline ventilation on the 230Th and 231Pa are neglected. .

** Comment: R. Anderson points out that it is assumed in Eqn 3 that K (dissolved-particulate partition coefficient) is not a function of depth. This is almost certainly not true, as degradation and dissolution of biogenic particles causes the abundance and composition of particles to vary with depth. ** Answer: In this paper, KTh and KPa are assumed to be constant with depth, as also assumed in the 1D model and the scavenging–mixing model. This may be questionable as, for example, degradation and dissolution of biogenic particles causes the abundance and composition of particles to vary with depth. A significant dissolution Th bearing phases would produce a non-linear profile that is not consistent with observations (Roy-Barman et al., 1996). Pa is preferentially scavenged by biogenic silica that is known to experience dissolution through the water column (Scholten et al., 2008). However, the accelerated increase of dissolved 231Pa with depth that could be expected (based on the analysis of 230Th distribution by Roy-Barman et al., 1996) is not obvious in the data (Nozaki and Nakanishi, 1985, Bacon et al., 1989).

* Comment: R. Anderson points out that is assumed that the concentrations of dissolved Th are zero at the sea surface (C=0 at z=0). Observations show that this is not strictly true, due in part to vertical mixing, which is particularly rapid in the mixed layer. It is reasonable to make this assumption in order to keep the analytical solutions manageable, but the assumption should be stated and the magnitude of offset from measured profiles induced by this assumption should be discussed. ** Answer: The effect of the mixed layer on the Th profile was studied by Roy-Barman et al., 1996. The 230Th concentration over the mixed layer of depth h is constant and equal to the concentration expected at the depth h with the linear profile if there was no vertical mixing. Hence the effect of the mixed layer on the real profile will be limited to the very surface sample(s) and it can be neglected for the purpose of this article where the discussion concerns mostly the deep profile. This assumption is now mentioned in section 2.3. and 3.1.1..

* Comment: R. Anderson points out that it is assumed that vertical mixing has a negligible impact on vertical concentration profiles. If upward diffusion of radionuclides served as a significant source at any depth, then one would expect vertical mixing to create curvature in the vertical concentration profiles. The assumed negligibility of vertical diffusion should be stated. If possible, place limits on the significance of vertical mixing, although I am not certain if meaningful limits can be established. ** Answer: Vertical (crosspicnal) eddy diffusion in the deep ocean cannot account for the curvature of the profile. Using a typical vertical eddy diffusion coefficient in the deep ocean Kz = 1 cm2/s (Munk, 1966, Thorpe, 2004) for the whole water column and assuming no diffusion of 230Th from the sediment, it appears that the curvature of the profile due to the vertical eddy diffusivity is restricted within ∼100 m above the seafloor (Roy-Barman et al., 1996). For 231Pa that will be presented in the next section and that is 10 times les particle reactive than 230Th, using the same for 231Pa that will be presented in the next section, the curvature of the profile due to the vertical eddy diffusivity is restricted within ∼500 m above the seafloor. Higher, Kz value (> 1cm2/s) occurs in the deep ocean but they are restricted very close to the bottom topography (Ledwell et al.

2000), limiting its effect on the Th or Pa profile to the seafloor vicinity. In addition, it must be noted that isopycnal diffusion along slopping isopycnal surfaces probably accounts for most of the vertical eddy diffusivity in the deep ocean (Sarmiento and Rooth, 1980).

* Comment: The deep box of the interior ocean is not well mixed (i.e., concentrations are not homogeneous throughout the box in the real ocean). Roy-Barman mentions this point later in the paper. I suggest that it be included here, along with a list of other significant assumptions that are implicit in the model. In each case, I believe that the assumptions are legitimate. However, I believe that they should be stated in the paper and discussed briefly. ** Answer: This point is now mentioned in section 2.1. and developed in the discussion in section 3.1.3. for the Pacific Ocean. The very low 232Th content observed at the HOT station may be due to the reduced inflow of margin water to the centre of the gyre compared to the average open ocean (modelled reservoir). This would be consistent with the perfectly linear 230Th profile that is not perfectly reproduced by the slightly curved 230Th modelled profile of the Pacific 2 data set (Tab.1, Fig. (2d)).

* Comment: p. 7864, line 4 and Table 1: the text refers to literature data in Table 1, but Table 1 contains no literature citations. ** Answer: Footnotes are added to table 1. They indicate for each parameter of the model the references used to determine its value and which parameters are derived in this paper by fitting the models to data.

* Comment: p. 7864, lines 6-7: The relative magnitude of K(Pa) compared to K(Th) was described by Anderson et al., 1983, cited in this paper, before any of the papers by Nozaki. ** Answer: A reference to Anderson et al. 1983 is added

* Comment: p. 7874, line 28: Broecker, 2008, does not discuss the ballast effect. ** Answer: Broecker, 2008, did not discuss the ballast effect indeed. The reference to this article has been removed for this point.

References Cited:

Ledwell JR, Montgomery ET, Polzin KL, St Laurant LC, Schmitt RW, and Toole JM.: Evidence for enhanced mixing over rough topography in the abyssal ocean. Nature 403, 179–82, 2000.

Munk W.: Abyssal recipes. Deep Sea Res.13, 207–30, 1966.

Roy-Barman, M., Chen, J. H., and Wasserburg, G. J.: 230Th-232Th systematics in the Central Pacific Ocean: the sources and the fates of thorium, Earth Planet. Sci. Lett., 139, 351-363, 1996.

Sarmiento, J. L., and Rooth C. G. H.: A comparison of vertical and isopycnal mixing models in the deep sea based on radon 222 measurements, J. Geophys. Res., 85, 1515-1518, 1980.

Thorpe S.A.: Recent developments in the study of ocean turbulence. Annu. Rev. Earth Planet. Sci., 32, 91–109, 2004.

Please also note the Supplement to this comment.

Interactive comment on Biogeosciences Discuss., 6, 7853, 2009.