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Interactive comment on "Spiciness theory revisited, with new views on neutral density, orthogonality and passiveness" *by* Rémi Tailleux

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Response to Referee 1

This manuscript aims at clarifying the long-debated definition of a passive variable along neutral/isopycnal layers, commonly referred as "spiciness". The paper clarifies and demonstrates that the use of thermohaline anomalies (in particular absolute salinity) along neutral surfaces is sufficient to provide orthogonality in physical space. The long sought orthogonality in thermohaline space is showed to be flawed and not necessary to construct an inert variable along neutral surfaces. Moreover, the author discusses and resolves several issues raised by the definition of a physical variable satisfying the properties of spiciness. The existence of neutral surfaces is revealed to

be key to the construction of a spiciness-like variable. By using theoretical arguments and a quasi-linear transformation of T/S space, the author also compares published definitions based on different assumptions and unifies them under basic principles.

I found the manuscript very interesting and well written. It surely provides an important step forward to the study of water mass. I therefore only have a few minor comments and recommend this paper to be published.

Response and suggested changes I thank the referee for his/her supportive comments. In addition to implementing the corrections suggested, I plan on making the following changes in response.

- I will be more specific about what I mean by orthogonality in physical space in the introduction;
- I will add a quantification of the orthogonality of Θ, and will also quantify the improvement in orthogonality between ξ and $\xi - \xi_r(\gamma)$
- I'll try to see whether it is possible to reach definitive conclusions about whether S'_A can be expected to be more dynamically inert where β is the smallest.

Response to specific comments

- l60 and Fig 1 : What is the source of the data shown?
  Good point. I used the WOCE dataset, available at:
  `http://icdc.cen.uni-hamburg.de/1/daten/index.php?id=woce&L=1`
- Fig2 : In caption : $\sin(\nabla\sigma_1, \nabla\xi)$? Why is the yellow histogram closer to 0 (ie sine closer to 1, angle closer to $\pi/2$), but described as the less orthogonal? Have the

blue and yellow histograms been swapped? How does Θ variable compare to S_A in terms of orthogonality?
The caption is as suggested by the referee. It is our impression that we correctly describe salinity as the variable the most orthogonal to σ_1 and can't quite reconcile what the referee says and what we say. Θ is sizeably much less orthogonal than S_A, I will add Θ to the histogram in the revised version.

- l149 : What would be the proportion of the world ocean covered in that range? To identify regions where a spiciness definition would be challenged could be an interesting add to the paper.
I have not attempted to quantify the accuracy of the quasi-linear approximation of density for the ocean's water masses, as it does not really matter for the arguments developed in the paper. My main aim was to construct a variable that can be used as a proxy for the spiciness variables of Jackett and McDougall (1995) and McDougall and Krzysik (2015) extending such variables to a wider range of reference pressures, allowing among other things to use a reference pressure $p_r(S,\theta)$ or $p_r(S_A,\Theta)$.

- Along the manuscript, it is commonly referred to "orthogonality in physical space" and I think it would be nice to have a clear definition of what it means in introduction. I agree as I can see from the other comments that not doing so has created some confusion. This will be fixed in the revised version of the paper.

- I have the feeling that in regions of the ocean with temperature-driven density, salinity anomalies will have be a better choice to construct an inert variable. Am I speculating too much? Would Θ' be any better than S_A' where density is salinity-driven (eg, coastal ocean, near sea-ice, Mediterranean, Red, Black Seas, . . .)?
This is an interesting question, which I find difficult to answer. Indeed, as first showed by Jackett and McDougall (1995), all thermodynamic variables are approximately dynamically inert on a material approximately neutral $\gamma = constant$

density surface. Whether the approximation is better for S_A' than Θ', and whether this can be proven, is an interesting suggestion that I need to think more about.

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