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Discussions

Interactive comment on "Volume and temperature transports through the main Arctic Gateways: A comparative study between an ocean reanalysis and mooring-derived data" *by* Marianne Pietschnig et al.

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Our response to Prof. Schauer's comment from February 3rd, 2018 on the reference temperature issue has three parts. First, we clarify the consequence of the chosen reference values on oceanic transport estimates. Second, we note that the issue is well recognised and it has been treated carefully in the oceanographic community. Finally, we defend our standing point on the topic.

We first clarify the consequence of the chosen reference values on oceanic transport estimates. Most oceanic transports across sections are fundamentally dependent on a reference value, because mass conservation cannot be achieved in most cases. Oceanic transport of any type of property across a section (F) is quantified as

$$F = \int\int b(C - C^{ref}) v dx dz \tag{1}$$

where b is a coefficient, C is concentration or temperature, C^{ref} is a reference value of the property, v is cross-sectional velocity, x is along-section coordinate and z is the depth coordinate. In the case of heat transport, b is ρc_p, where ρ is the density of sea water, c_p is the heat capacity of sea water, and C is potential temperature. For the case of salt transport, b is 1 and C is salinity. For the case of nutrient transports, b is 1 and C is nutrient concentration.

Oceanic transports with different reference values are described as

$$F_j = \int\int b(C - C_j^{ref}) v dx dz \tag{2}$$

where j represents different reference values. When b is constant, the difference of oceanic transports is described as

$$F_1 - F_2 = \int\int b(C - C_1^{ref}) v dx dz - \int\int b(C - C_2^{ref}) v dx dz = b(C_1^{ref} - C_2^{ref}) \int\int v dx dz \tag{3}$$

From Equation 3, three conclusions can be drawn. First, the difference becomes zero only when ocean circulation is closed (i.e. $\int\int v dx dz = 0$). Second, the transport difference due to the different reference values is proportional to the volume transport through the considered section. Third, the transport difference is not constant in time because the velocity varies in time.

We note that similar discussions can be found in Tsubouchi et al. [2012] in section 4.1 and Bacon et al. [2015] in section 5, with focus on freshwater transport. Although freshwater transport is slightly different from heat transport (see discussion in the referred papers), the fundamental caveats on the freshwater transport estimates in the mass-closed system are similar to heat transport estimates. Tsubouchi et al [2012] state that 'This clearly demonstrates both points: (1) net fluxes for an enclosed region are barely affected by use of reference values but (2) the component transports are substantially affected.'

In this context we would like to note that, although people pay little attention, volume transport is also dependent on the 'reference velocity', which is set to zero as a hidden assumption. If a different reference velocity were used, volume transport numbers in the Arctic main gateways would look different. This is not trivial because we choose the rotating system (i.e. sitting on the rotating Earth) to quantify the volume transports. If we chose the non-rotating system (i.e. sitting in space), quantified volume transports would be different. This is somehow comparable to using different temperature scales: the Celsius scale (°C) vs. the Kelvin scale (K). However, nobody questions the value of volume flux estimates through non-closed sections.

Next, we disagree with Prof. Schauer's statement that the reference temperature issue is mostly ignored by the scientific community. In fact, it is widely recognised that heat transport estimates depend on the choice of reference temperature. Therefore, the transport estimates are presented carefully. For example, Talley [2003] distinguishes them by using different units (PWT and PW, see their table 1 for example). Johns et al [2011] distinguish them by using different terminology (temperature transport and heat transport, see their figure 8 and table 1 for example). Schauer and Beszczynska-Möller [2009] also distinguish them by using the different terminology.

In the Arctic Ocean, people have chosen different reference temperatures depending on the question they want to address. Woodgate et al. [2010] choose the freezing temperature to study the contribution of Pacific water inflow to the 2007 sea ice loss in the Pacific sector. Lique and Steele [2013] choose the mean temperature of the Arctic Ocean to address heat content variability in the Arctic Ocean. Tsubouchi et al. (2012) choose the mean temperature across the boundary to infer surface heat flux. The choice of 0°C may not address a specific question, as we already noted in our first response.

We think Prof. Schauer's suggestion is too strict and would prevent the scientific community from gaining an understanding on the driving factors of heat transport and its impact on the local Arctic climate system (e.g. sea ice melt in the Pacific sector or Barents Sea). If we were to follow her suggestion, we would only be allowed to quantify the heat transport divergence (or, in the area integral, the net heat transport) into the Arctic. We think that it would be almost impossible to gain an understanding on its driving factors and its impact on the Arctic climate system from only considering the net heat transport time series. To understand the main contributors to the transport, we have to look at quantities depending on reference frames and reference temperatures / concentrations. Ambiguities can be avoided in this case by agreeing on reference values within the scientific community. This is not much different than agreeing on SI units. We think that choosing a reference temperature is comparable to choosing a reference frame for velocity.

We think the most constructive way to go forward on the reference temperature issue is (1) to allow people to choose any reference temperature depending on the question they want to address, and (2) to remind them about the consequence of their choice of reference values.

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