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Interactive comment on "A new method to assess mesoscale contributions to meridional heat transport in the North Atlantic Ocean" *by* Andrew Delman and Tong Lee

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Note: The original reviewer comments are indicated in italic font below, with the author responses and manuscript edits following in non-italic font.

This manuscript presents interesting results regarding the origin of meridional heat transport fluctuations in the North Atlantic. It is well written and to the point. I recommend publication with minor revisions.

Thanks to the reviewer for the very thoughtful and helpful comments on this manuscript. We have taken the suggestions into account as described below.

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1. The decomposition used by the authors, although mathematically correct, might not represent the effects of the "mesoscale" better than the other methods cited in the introduction. What I have in mind is not so much spatial vs temporal scales but the fact that "mesoscale" fluctuations drive mean circulations which themselves carry heat. These two effects tend to compensate each other so the real effect of the "mesoscale" remain unclear (see for example the Transformed Eulerian Mean framework and its use in discussing tracer transports in the atmosphere –usually some dissipation or diabatic effects are needed to make the compensation imperfect). The new decomposition, although clearly of interest, does not shed light on this and this should be mentioned somewhere in the text.

The reviewer is correct that there may be compensation between the large-scale and mesoscale circulations. To better refine our definition of the mesoscale circulation, we have made some improvements to the large-scale/mesoscale decomposition method in coastal/boundary regions (as described in Section 2.2.3, lines 174-198) in order to ensure that the volume transport of the mesoscale circulation is negligible over long distances (Figure 3 in the new manuscript). However, our method only assesses the "direct" effect of mesoscale velocity and temperature anomalies on the meridional heat transport, just as the time-varying "eddy" heat flux assesses only the direct effect of the temporal co-variability of velocity and temperature anomalies. Neither the spatial nor the temporal decomposition methods fully separate the effect of mesoscale variability on the large-scale mean circulation, though the spatial decomposition of v and T could be a helpful diagnostic to understand the relationship between large-scale and mesoscale variability.

To clarify this point, the text has been revised as follows: "The similarity in the ID standard deviations of large-scale and mesoscale MHT variability at 30-38°N may also indicate compensation between the large-scale and mesoscale due to mesoscale feedbacks on the large-scale circulation (e.g., Hoskins et al. 1983; Waterman and Jayne 2011) or large-scale preconditioning of flow variability and temperature gradients where

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mesoscale dynamics are active. Therefore our method does not entirely disentangle the effects of the large-scale and mesoscale flow on temperature fluxes and transport. However, it provides a more precise diagnostic for the flux directly associated with mesoscale velocity and temperature anomalies; the spatial and temporal variability of these anomalies may then be studied in the context of variability in the background (large-scale) state." (lines 237-244)

Another way to state this is that it is not clear if the heat transport captured by the author really is a heat transport: a warm blob could be advected poleward at depth (i.e., shielded from air-sea interactions and diabatic effects) for a while and then returned equatorward, still below the mixed layer, without creating a net heat transport in the mean although, in a timeseries, it would show up as an enhanced, then a decreased heat transport.

The reviewer seems to be referring to meridional heat transport (MHT) in a narrow sense, namely, the meridional movement of heat in the ocean that results in air-sea heat exchange (a diabatic process). However, MHT does not necessarily needs to be tied to air-sea heat exchange or other diabatic processes. We agree that the meridional movement of the subsurface warm blob shielded from the atmosphere as described by the reviewer only contributes to the temporal variability but not the time mean of MHT. Nevertheless, temporal variability of MHT is important to the study of the temporal change of regional oceanic heat content (e.g., to the north or south of the transect). However, it is true that the scenario described by the reviewer will not have a lasting impact on the temperature budget beyond the timescale of the original advection of the blob. Often in quantifying MHT we are interested in the effects of the time-mean circulation, as well as processes with spatial/temporal impacts that are rectified to larger/longer timescales than the original process. We highlight these rectified impacts by showing mostly mesoscale temperature fluxes that have been basin-integrated (Figures 4, 5, 9), or smoothed with a zonal filter (Figures 6c, 8a) to remove local, essentially rotational fluxes that have no rectified impact at larger scales.

This is described in Section 5.1: “Moreover, rather than being defined relative to a time mean over an arbitrary time period (e.g., the post-spinup time span of the model simulation), the mesoscale MHT is defined as the deviation from a regional background state at each time. Since the integrated volume flux associated with the mesoscale velocity is small across zonal scales » 10° longitude, the MTF smoothed over large zonal scales approximates a heat transport regionally and at each time.” (lines 385-389)

2. It might be more natural to analyse the heat transport along a mean streamline rather than across 40N, especially considering the model grid isn't latitude-longitude. This could remove some of the difficulties associated with steady meanders in the model Gulf Stream with scales comparable to those of the “mesoscale” and simplify the physical interpretation of the results (e.g., the cancellations between poleward and equatorward heat transport in Fig. 5a). I understand this isn't trivial to do but if the authors can do it within a reasonable amount of time it would add to the quality of the analysis.

The analysis suggested by the reviewer would be interesting and important, particularly in order to assess the impact of mesoscale fluxes on cross-stream gradients and the Gulf Stream circulation. It would require a substantial amount of time however to refine the method to assess mesoscale fluxes across a streamline and extract the needed output. It is beyond the scope of this paper, but we hope that this analysis is carried out and reported in another manuscript. The purpose of our paper is to investigate to what extent the “eddy” MHT presented in the literature based on temporal decomposition can represent mesoscale variability based on the spatial scales that are usually used to define mesoscales.

Minor comments:

1. The length of the integration should be mentioned in the text (I only had a hint of it by looking at the period covered by the timeseries displayed –I couldn't see this information in the model description).

This information has been added to the text in the beginning of Section 2.1: "The model integration was started from 15 years of spin-up using CORE normal-year forcing (Large and Yeager 2004), and run over 33 years (corresponding to forcing for the years 1977-2009); our analysis encompasses 32 years and begins in 1978 to focus on the period after the transition from spin-up." (lines 80-82)

2. line 290: "upgradient heat transport" needs to be stated with caution. You might need to remove the rotational component of the heat transport vector first.

We have added the caveat about the rotational component to the text in Section 4.2: "...the large-scale meridional temperature gradient has the same sign here as elsewhere (Fig. 11d). This would imply an upgradient flux of temperature at 60°-50°W, though it can not be determined solely from this zonal transect whether this apparent upgradient diffusivity is associated with a rotational component of the temperature flux (e.g., Marshall and Shutts, 1981)." (lines 342-345)

3. Abstract, line 5 "...that are more fundamental to the physics of ocean eddies". I am not sure the spatial scales are more fundamental than the temporal scales so maybe this could be removed.

The sentence has been revised as follows: "However, previous analyses of "eddy" MHT in the region have mostly focused on the contributions of time-variable velocity and temperature, rather than considering the association of MHT with distinct spatial scales within the basin." (lines 3-5)

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