Reviewer #2 (Comments to Author):

This paper is concerned with understanding why the Atlantic Ocean appears to have gained more heat than other ocean basins over the 20th Century. The authors use an ocean and sea ice model forced with the 20th Century Reanalysis to simulate the ocean state from 1871 to 2008. They also perform two additional experiments, in which the surface forcings are held "constant" at 1871-1900 conditions either north of 30S or south of 30S in order to better understand the role of remote wind stress forcing on Atlantic ocean heat content (OHC). The authors conclude that the primary reason for the large rise in Atlantic OHC is increased wind stress curl south of 30S and a commensurate increase in heat transport into the Atlantic basin.

This is an interesting piece of work, which will make an important contribution to the literature in an important area of research. However, I think the authors need to make a number of changes to the manuscript before it is suitable for publication.

Scientifically speaking, I think the work is sound, but there are numerous instances of imprecise use of language, insufficient references and areas that need clarification. The authors should iterate future submissions to a higher standard, so that reviewers can concentrate on evaluating the science content.

We would like to thank the reviewer for the thoughtful comments and suggestions. The manuscript is now revised substantially based on these comments. Pleas find below our reply to each comment from the reviewer.

Specific comments:

(0) *Paper structure. It would seem more logical to present the heat budget from EXP_CTR as the starting point, which gives us the answer to the relative importance of heat transport vs air-sea heat fluxes. Then discuss EXP_ATL and EXP_REM to show that is it the windstress changes south of 30S that affect heat transport, and not the buoynacy fluxes in the North Atlantic (as one might think, with deep convection in mind).*

We agree with the reviewer that the suggested structure is logical. However, we feel that the current structure of the manuscript also serves well the overall goal of this article. In the current structure, the result section (section 4) starts by showing the simulated Atlantic Ocean heat content changes from the three model experiments. This serves two objectives; (1) to validate the model experiment with observations (EXP_CTR versus OBS) and (2) to show that remote processes (EXP_REM) can largely explain (or local processes alone (EXP_ATL) cannot explain) the observed Atlantic heat content increase. At this point, our main question is pretty much answered. The heat budget plot (Figure 1b) is then used to confirm and strengthen the main conclusion that the simulated Atlantic Ocean heat content increase since the 1950s in EXP_CTR is mainly caused by remote processes (i.e., heat transport at 30^{o}S).

(1) *The abstract should be improved with more explanation about the proposed "hypothesis". I think the author's hypothesis assumes that if the ocean circulation is NOT affected by upper ocean warming, the heat transport into the Atlantic will increase purely due to higher near-surface temperatures (assuming that heat transport associated with the deep return flow remains essentially unchanged).*

My interpretation of the manuscript is that the authors find that changes in the MOC are actually the dominant contribution to Atlantic warming. The relative importance of warming/surface fluxes vs heat transport needs to be made clear and quantified in the absract - e.g. heat transport changes contribute 80% of the change in the model simulations (?).

The abstract is now revised (1) to clarify the proposed hypothesis by revising the first sentence to "… and the Atlantic Ocean should therefore gain extra heat thanks to the increased upper ocean temperature of the inflow via the Agulhas leakage.", and to emphasize that (2) "the observed warming trend of the Atlantic Ocean since the 1950s is largely due to the concurrent increase of the inter-ocean heat transport from the Indian Ocean"; and (3) "the increased heat transport into the Atlantic Ocean is not only caused by the increased upper ocean temperature of the inflow but also and more strongly by the increased Agulhas Current leakage".

(2) *Introduction. I don't think this paper can contribute much to the question of whether the observed Atlantic changes originate from internal variability or anthropogenic forcing of the climate system. I suggest that the authors concentrate on framing the question around the relative roles of heat transport or air-sea heat fluxes in the Atlantic basin.*

The following recent papers that directly address the relative role of heat transport and surface heat fluxes in the Atlantic should be included in the introduction and used to provide context when summarising the results:

Grist, Jeremy P., Josey, Simon A., Marsh, Robert, Good, Simon A., Coward, Andrew C., deCuevas, Beverly A., Alderson, Steven G., New, Adrian L. and Madec, Gurvan (2010) The roles of surface heat flux and ocean heat transport convergence in determining Atlantic Ocean temperature variability. Ocean Dynamics, 60, (4), 771-790. (doi:10.1007/s10236-010-0292-4)

Palmer M. D. and K. Haines (2009) "Estimating oceanic heat content change using isotherms", Journal of Climate, 22, 4953-4969.

If the authors decide to include work on the attribution of ocean warming, they should reference the following more recent papers, in addition to Levitus et al [2001]:

Barnett et al. (2005): Penetration of Human-Induced Warming into the World's Oceans Science 8 July 2005: 309 (5732), 284-287.Published online 2 June 2005 [DOI:10.1126/science.1112418]

Palmer, M. D., S. A. Good, K. Haines, N. A. Rayner, and P. A. Stott (2009), A new perspective on warming of the global oceans, Geophys. Res. Lett., 36, L20709, doi:10.1029/2009GL039491.

Grist et al. (2010), and Palmer and Haines (2009) are now cited and discussed in the introduction. Barnett et al. (2005) is also cited. We would like to retain some discussions of the anthropogenic greenhouse effect since it provides an important motivation to develop our hypothesis that uniform warming (cooling) of the world ocean will have a culminating effect in

the Atlantic basin thanks to the global overturning circulation that increases (decreases) inter-ocean heat transport into the Atlantic.

(3) *Page 3, line 4. The authors sate that radiative heating is "more or less uniform". This needs a supporting reference, I would suggest citing Palmer et al. (2007), who have demonstrated a fairly uniform heating of the upper ocean, once changes in ocean circulation have been filtered out.*

Palmer, M. D., K. Haines, S. F. B. Tett, and T. J. Ansell (2007), Isolating the signal of ocean global warming, Geophys. Res. Lett., 34, L23610, doi:10.1029/2007GL031712.

Palmer et al. (2007) is now cited.

(4) *Page 3, line 6. Replace "with" with "by".*

This is corrected.

(5) *Page 3, line 11. The authors need to cite the IPCC 4th Assessment or similar. What is the source of the increased buoyancy? Are the authors referring to increased atmospheric freshwater transport?*

This sentence is hypothetical one, which is a part of our hypothesis. We simply argue that if the upper ocean temperature of the inflow at 30^{o}S increases, the Atlantic Ocean should continue to warm until the warm water is flushed out from the Atlantic Ocean at depth. The source of increased buoyancy in this context is increased heat transport at 30^{o}S.

(6) *Page 3, lines 13-20. What are the trends in the N. and S. Atlantic cited in the Levitus papers? It is not obvious to the reader why a larger heat transport into the southern basin. The authors assume that ocean heat advection dominates - but this IS just an assumption. It would be better to just state what the observations show and then say that model simulations are a useful tool for understanding the mechanisms.*

These sentences are now removed.

(7) *Page 3, line 20. It needs to be clearer that we have an estimate of the atmospheric state and air-sea heat fluxes from a reanalysis. I think it is incorrect to say that we have a long time series of "observed surface flux fields".*

This sentence is revised to "….. because the relatively long time series of estimated surface flux fields, which constrain ocean-only (or ocean-ice coupled) models, are available from atmospheric reanalysis products."

(8) *I suggest that the authors re-structure sections 2 and 3, so that the current section 3 "Model Experiments" becomes section 2, and the current section 2, becomes section 2.1 "Model Initialization".*

We agree that the suggested change would improve the manuscript. However, we would like to keep the section 2 (20th century reanalysis) to stress that this is the first attempt to simulate the Atlantic Ocean for the entire 20th century using the 20CR.

(9) *Page 4, line 5. The authors should re-phrase this sentence, e.g. "The paucity of observational data makes is a challenge for proper initialization ocean models.."*

This sentence is rephrased as suggested.

(10) *Page 4, Line 8. Re-phrase to remove the word "abitrary".*

This phrase, "with an arbitrary set of initial conditions", is now changed to "This will finesse issues involving the model initialization".

(11) *Page 5, lines 10-13. Do the authors simply mean that they create a 200-year series of randomly selected years from the period 1871-1900? The text "forcing fields in each model year are alternated with" is confusing. Please clarify.*

This sentence is now revised to "…. during the spin-up the surface forcing fields in each model year are randomly selected from those during 1871 - 1900."

(12) *In the same section, it would be helpful to say something like "We choose this method rather than a climatology based on the period 1871-1900 because high frequency atmospheric variability is known to be important for deep convection". Please also provide a suitable reference.*

We believe that our sentence "To incorporate the impact of atmospheric noise, which plays a crucial role in the thermohaline convection and deep-water formation in the North Atlantic sinking regions" conveys the same meaning. We add "personal communication with Ping Chang" as the reference.

(13) *Page 4, lines 17 and 19. Be consistent with use of the term "spin up" OR "spin-up", throughout the manuscript.*

We revised the manuscript to use "spin-up" as a noun, and "spin up" as a verb. For instance, we use "To spin up the model…." and "The spin-up experiment …."

(14) *Page 6. line 3. Replace "spin-up experiment" with "EXP_REF". Also remove "real time".*

This is corrected as suggested.

(15) *Page 6, lines 5-6. Replace "the daily 20CR surface flux fields for the period of 1871-1900 as in the spin-up experiment" with "EXP_REF".*

This is corrected as suggested.

(16) *Page 6, line 6. Replace "real time as in" with "from".*

This is corrected as suggested.

(17) *Page 6. line 7. Replace "warming" with "heating".*

This is corrected as suggested.

(18) *Section 4 results, Figure 1a. The authors should show the time series from the Levitus et al. Observations. If there is a good reason not to do so, please make this clear in the text.*

We computed the upper 700m heat content of the Atlantic basin (30^{o}S – 75^{o}N) for 1955-2008 using the hydrographic database at NODC (the same dataset used in Levitus et al. [2009]) and plotted in Figure 1a.

(19) *Page 6. line 19. Replace "budget" with "content".*

This is corrected as suggested.

(20) *Page 6. lines 20-22. There are too many assumptions here. Figure S1 shows that the MOC appears to support the author's statements, but it is not referred to. This could be fixed by referring to MOC rather than heat transport, or offering more explanation about the relationship between the two quantities.*

The contribution of the AMOC on the heat transport at 30^{o}S is fully discussed in the next section (Section 5. AMOC variability at 30^{o}S).

(21) *Page 7, first paragraph. Please comment on the linearity of the changes - to what extent can we simply add EXP_REM and EXP_ATL and re-cover EXP_CTR?*

By plotting the heat content of the North and South Atlantic basins separately (Figure A1), we find that what appears to be a multidecadal oscillation of the Atlantic Ocean heat content in EXP_ATL, shown in Figure 1a, is restricted only to the North Atlantic basin. This leads to a conclusion that the simulated heat content changes in the North Atlantic Ocean in EXT_CTR is driven by both remote processes (i.e., heat transport at 30oS) and local processes (i.e., surface forcing), whereas those in the South Atlantic is purely by remote processes (i.e., heat transport at 30^{o}S). This issue is now discussed in the section 7 in more detail.

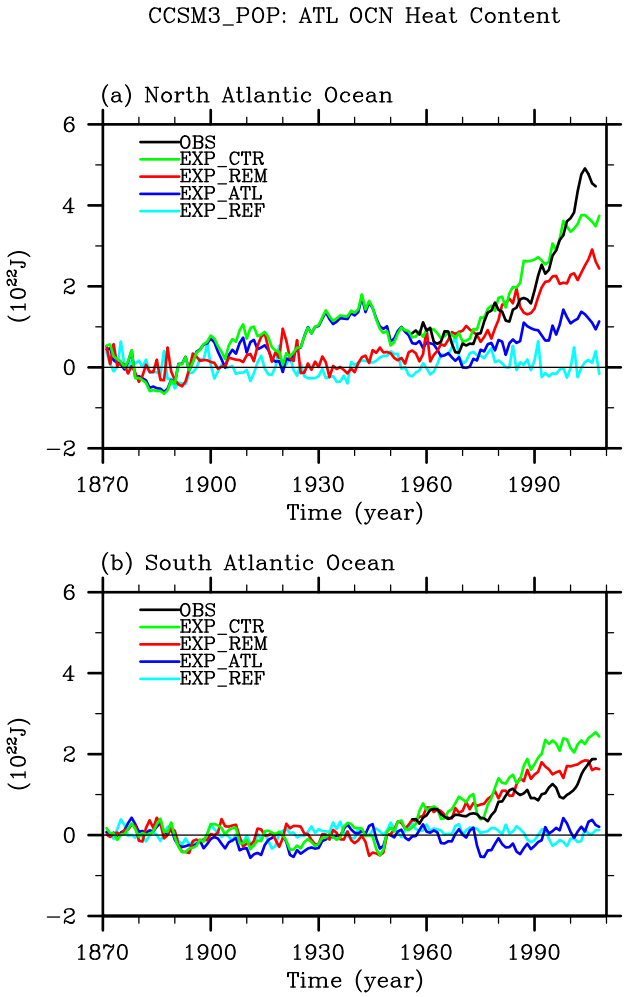

Figure A1. Simulated (a) North and (b) South Atlantic Ocean heat content changes in the upper 700m in reference to 1871-1900 obtained from the four model experiments. The thick black lines in (a) and (b) are the observed heat contents recomputed from Levitus et al. [2009] for the North (equator - 75^{o}N) and South Atlantic (30^{o}S - equator), respectively.

(22) *Page 7, line 10 (and Figure 1). The northward heat transport multiplied by -1 is the southward heat transport.*

This is now corrected.

(23) *Page 8, line 4. Please provide suitable reference(s) to support this statement.*

Mignot et al. [2006] is now cited.

(24) *Page 9. The manuscript needs to describe the observed shedding of Agulhas Rings, with suitable references. This will provide important context for the discussion of model limitations in section 7.*

Now, we add the following sentence: “In reality most Agulhas leakage is carried by Agulhas rings, mesoscale features that are not well represented at this model’s resolution [e.g. Beal et al., 2011 and references therein].”

(25) *Section 7. Discussion. The authors should re-name this section "Summary" and remove the final paragraph, which discusses "crucial questions".*

This section is now renamed as “Discussions” after removing the summary part (the first paragraph). This section now starts with the discussion of the ocean heat content changes in the North and South Atlantic, as suggested by reviewer #1.