REVIEWER I

The manuscript, “A model for the Artic mixed layer circulation under a summertime lead: Implications on the near-surface temperature maximum formation” by Alvarez develops a simplified 2D model of a summertime Arctic lead using SHEBA data to examine the sensitivity of the near surface temperature maximum to changes in solar radiation, winds, and ice motion.

Global climate models have biased salinity and temperature distributions in the upper Arctic Ocean. It has been suggested this could be associated with resolution or parameterizations of vertical mixing (Rosenblum et al. 2020). Future changes in the upper ocean are also very uncertain as the changing sea ice state may modulate ocean circulation. The manuscript touches on an important issue of simulating processes controlling the structure of the upper Arctic Ocean but requires a clearer discussion of the novel conclusions that separate this study from previous studies of the summertime NSTM and to be put in a broader context in terms of the Arctic as a whole and other more complex models. I have listed these concerns below. My recommendation is major revisions.

I thank the reviewer for his/her comments and suggestions. I detail below the actions taken to answer or clarify them.

1. Previous studies, such as Richter-Menge et al. (2001), Steele et al. (2011), and Gallaher et al. (2017) have recognized the importance of solar radiation, winds, and sea ice motion in the formation and persistence of the NSTM layer beyond summer. This is mentioned in the discussion, but the results seem to confirm previous findings, not add very much new. Could you expand on the novel results and the benefits of this model within the hierarchy of the models from the other studies?

   The following paragraphs (in bold) are suggested for inclusion in the Discussion Section to address this comment:

L 415 ….A net stretching and deepening of warm waters result from the daily cycle process**. This finding of the current work dynamically explains the deepening and lateral spreading under the adjacent ice of warm water masses, observed by Richter-Menge et al., (2001) in summertime leads under persistent calm conditions. Furthermore, model results extend the dynamical analysis to subsurface layers not considered in Richter-Menge et al., (2001). The background conditions of these subsurface layers is a fundamental component in the mechanism for the formation of the NSTM layer. Specifically, there is a scientific consensus in attributing the development of the NSTM layer to the solar radiation penetrating in the upper ocean (Maykut and McPhee, 1995; Jackson et al., 2010, Steele et al., 2011, Gallaher et al., 2017). In this study, we find that subsurface heating in summertime leads is also mediated by the sink of warm surface waters to the lower layers by convection cells. The mechanism develops by the buoyancy forcing and lateral boundary conditions of the lead, so it goes unnoticed in one-dimensional study domains (Gallaher et al., 2017) or in open ocean environments (Steele et al., 2011).**

L 433 ….from the sea surface by a layer of cooler, fresher water. **Despite the different model complexity and resolution, Steele et al., (2011, Figure 2a and corresponding text) found the same mechanism deepening the temperature maximum layer in their simulations with the Pan-Arctic Ice–Ocean Modeling and Assimilation System (PIOMAS). On the other hand, the hypothesis attributing the resilience of the NSTM layer to the protective action of the upper layer on the underneath ones (Maykut and McPhee, 1995; Jackson et al., 2010; Gallaher et al., 2017) is not supported here.**

L438 ….and being absent during the wind event
The two-dimensional physical description of this study highlights other novel aspects related to the formation of the NSTM layer in summer leads. The superficial shear stress generated by the movement of the ice dominates that generated by the wind in the horizontal dispersal of subsurface heat. This is due to the limited wind fetch within the leads. In contrast, in a one-dimensional description of a summer lead physics (Callaher et al., 2017), both sources of surface stress are indistinguishable. The layered structure of the resulting NSTM also emerges from the two-dimensional description used here. Periodic lateral boundary conditions idealize an ice landscape made up of large plates separated by long, narrow open leads as observed during the early melting period (Perovich et al. 2001). The surface stress generated by the repetitive passage of ice plates spreads laterally the warm waters accumulated under the leads, connecting the warm waters accumulated on unconnected leads. Another finding of this study, relates the preferential formation of the NSTM layer in environments with thermal profiles where the temperature decreases with depth. In the opposite case, eroding the top part of the thermal profile after the calm period may only result on a monotonic increase of temperature with depth. This would occur when the temperature just beneath the cold and fresh mixed layer does not exceed the temperature of the lower warm layers. This could be the case in regions of the Eurasian Arctic if warm Atlantic waters flow near the surface.

In addition, the revised manuscript will incorporate new and novel parametric analyses of different aspects of the NSTM formation as a result of this reviewing process. These include new initial stratification (see below), the role of the calm period and the effect of the lead separation.

2. While there was good discussion about the caveats and limitations of this modeling study, I had a question about a couple more. For example, the model developed here does not include important aspects such as large-scale ocean circulations and only has a very simple representation of freshwater input, which have both been highlighted in the previous studies as important for the NSTM. The model was also developed based on a very short time period from SHEBA and the Arctic has changed considerably since then (Dewey et al., 2018). Does the author expect the conclusions would change with a more recent case? Although it was located in different region of the Arctic, what about with MOSAIC?

A new sensitivity study using a different and more recent initial profile, would be included to answer this question. In particular, the following section would be incorporated to the study:

L 361 ***3.3.4 Stratification***

A different initial stratification of the water column was considered in the numerical study to assess the sensitivity of the reported formation mechanism to this variable. Specifically, Figure 12a displays stratification conditions considered for this assessment. The profiles of temperature and salinity were collected in late April of 2015 at 89.20º N, 55º W in the framework of the project North Pole Station: A Distributed Long-Term Environmental Observatory (Kelly and Morison, 2009). Unlike

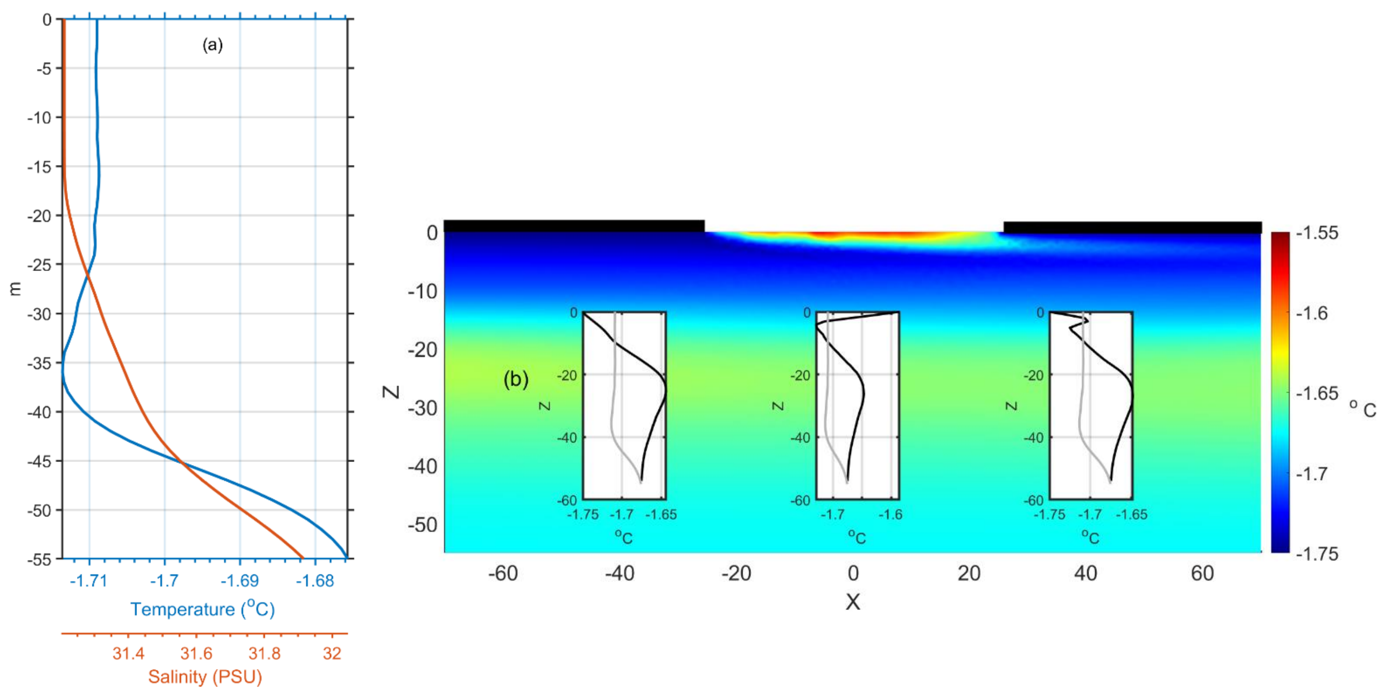

Figure 12: (a) Initial temperature and salinity profiles and (b) thermal distribution at the end of the simulated wind period with wind intensity 6 ms^{-1} and wind factor of 2%. The inserted plots in panels (a) and (b) compares the salinity and temperature profile (black lines) with their reference profiles at the lead center (x=0 m) and in the control stations located at x=-40 m and x=40 m, respectively.

the previous case (Figure 1), almost homogeneous profiles in temperature and salinity characterize the stratification conditions in a large part of the range of depths considered. In addition to homogeneity, the water column is fresher and colder than the previous conditions up to 45 m depth. Below that depth, the temperature profile is warmer than the one observed at SHEBA location (Figure 1). The numerical simulation followed the

same procedure and forcing reported in Subsections 3.1 and 3.2, except for the new initial conditions of stratification.

A local temperature maximum also develops between 20 and 30 m depth for the selected initial profiles (Figure 12b). The resulting temperature maximum is slightly cooler than that found with the previous stratification (Figure 7b). The NSTM layer clearly differs from the colder upper layer, but the temperature difference between the NSTM and lower layers is less marked. This is a consequence of the fact that the initial temperature profile is warmer at depth than at the surface (contrary to the previously examined thermal profile). The implications of this finding will be discussed below. The spatial variability of the temperature field is smoother than that observed in Figure 7b. This is presumed to be a result of the limited potential energy initially available in the nearly homogeneous density profile (salinity dependent only) down to 20 m depth, to trigger instabilities when surface mixing is active.

These results would be commented in the Discussion Section:

Another finding of this study, relates the preferential formation of the NSTM layer in environments with thermal profiles where the temperature decreases with depth. In the opposite case, eroding the top part of the thermal profile after the calm period, may only result on a monotonic increase of temperature with depth. This would occur when the temperature just beneath the cold and fresh mixed layer does not exceed the temperature of the lower warm layers. This could be the case in regions of the Eurasian Arctic if warm Atlantic waters flow near the surface.

The Section will also discuss aspects related to the role of the calm period and the effect of the lead separation.

3. There are instances throughout the manuscript that require some proofreading. For example, in the paragraph beginning on Line 194, the first and second sentences are missing “are” and “is”, respectively and in the last sentence computing should be changed to computing. Another example is in the use of minimum and maximum throughout the manuscript. However, I felt it was well constructed, as I appreciated that the methods section describing the model was easy to follow and the approaches taken are appropriate.

Dewey, S., Morison, J., Kwok, R., Dickinson, S., Morison, D., & Andersen, R. (2018). Arctic ice-ocean coupling and gyre equilibration observed with remote sensing. Geophysical Research Letters, 45(3), 1499-1508.

Rosenblum, E., Fajber, R., Stroeve, J. C., Gille, S. T., Tremblay, L. B., & Carmack, E. C. (2021). Surface salinity under transitioning ice cover in the Canada Basin: Climate model biases linked to vertical distribution of fresh water. Geophysical Research Letters, 48(21), e2021GL094739.

The revised manuscript will be submitted for professional English editing and proofreading. References will be included in the revised text.