Response to reviewer comments by Marylou Athanase

Thank you very much for your very insightful review and very constructive comments. We repeat your comments (using a dark blue font color) below.

Our responses are given in black font. Please excuse the delay of our reply. We realize that additional work will be required to prepare a revised manuscript.

Summary:

The present study proposes a new method for the detection of the cold halocline layer base depth in the Arctic Ocean. The authors define a new criterion based on vertical stability and compare the results to those obtained with two previously used methods: one based on the density ratio, and one based on temperature differences. Using the ITP and UDASH databases, they derive pan-Arctic maps of the cold halocline layer base depth using all three methods.

General assessment:

The topic is well within the scope of Ocean Science and is of particular importance given the complex and varying structure of the Arctic halocline throughout basins. However, several crucial points would need to be addressed, regarding the manuscript organization as well as the clarity of the method and completeness of the results. Below are listed my major and minor comments. For these reasons, I recommend that the manuscript undergo major revisions before being potentially suitable for publication.

Major comments:

- The manuscript lacks a clear, physical explanation of what the CHL and cold halostad are, and how the proposed method detects their boundaries. I would also suggest the authors emphasize the goal aimed to be achieved by defining a new criterion, e.g., enabling the robust detection of the CHL base depth across basins and seasons using only one criterion.

Thank you very much for this comment and the more detailed suggestions below. We have drafted a revised version of the introduction based on your comments and on the reviewer comments by I. Polyakov. Regarding the organization of the revised introduction, we followed your detailed suggestions, with five paragraphs introducing concepts, listing criteria, underlining importance, explaining our motivation, and introducing the organization of the manuscript.

In the revised version (see below), we first introduce layers and water masses. We start with the surface mixed layer and the halocline (HCL). Then, we introduce major components of the HCL: the CHL in the Eurasian Basin, the Pacific Halocline Water (PHW) in the Amerasian Basin, and the Lower Halocline Water (LHW), following the nomenclature of Polyakov et al. (2018). We then introduce Pacific Winter Water (PWW), which forms the cold halostad (CHS), and Pacific Summer Water (PSW).

The more detailed description of the HCL including the introduction of PSW and PWW in the first paragraph of the revised introduction owes to comments and suggestions by I. Polyakov. We strongly agree that introducing these water masses is useful for interpreting the results. For details on this point please refer to our response to the reviewer comments by I. Polyakov (unfortunately, we did not manage to revise the entire manuscript before the end of the discussion phase). We also provide additional detail on CHL formation mechanisms in the first paragraph because I. Polyakov suggested that the ST method may capture the beginning of new CHL formation. We now think that interpreting the results in the light of the Rudels et al. (1996) mechanism supports this idea. Again, for details on this point please refer to our response to the reviewer comments by I. Polyakov.

In the second paragraph of the revised introduction, we underline the importance of the HCL for the present and future of the Arctic Ocean. In the third paragraph, we combined the paragraphs describing the existing criteria to define HCL and CHL base. In the forth paragraph, we describe our original motivation for suggesting the stability (ST) method. Our original motivation was to use a threshold variable to define the HCL base which is more closely related to the role of the HCL as a stable layer which prevents warm Atlantic Water from reaching the SML and reducing sea ice than either the density ratio or the temperature difference. The analysis of individual profiles suggested by both reviewers indicates that the increased robustness of ST method derives mainly from the different search direction in the ST method compared to the two existing methods: in the ST method we search upward instead of downward. This avoids isolated depth minima caused by near-surface features. For details on this point, again please refer to our response to the reviewer comments by I. Polyakov.

The revised introduction reads as follows (please find a revised introduction including track changes below and a list of references at the end of the document):

The Arctic Ocean outside the main Atlantic warm water inflow and the shallow marginal shelf seas is usually stratified into a cold and fresh surface mixed layer (SML), which is from $\sim$*5 to* $>$*100 m thick, depending on region and season (Peralta-Ferriz and Woodgate, 2015), a halocline (HCL) below the SML with a base depth* $\sim$*40 to* $>$*200 m (Fig. 4 of Polyakov et al., 2018), a layer of warm and saline Atlantic Water (AW) below the HCL centered near 300 to 500 m in the Eurasian Basin and somewhat deeper in the Canada Basin (Aagaard et al., 1981; Macdonald et al., 2015) , and deep water below. Convection in the SML is driven by surface cooling and brine release during sea ice formation, with maximum SML depth in winter. River inflow and precipitation act as sources of fresh water. Below the SML, salinity increases in the HCL. Within the HCL, one can distinguish between the cold halocline layer (CHL) in the Eurasian Basin, the Pacific Halocline Waters (PHW, modified Pacific Water that originally entered the western Arctic via the Bering Strait) in the Amerasian Basin, and the lower halocline waters (LHW, water of Atlantic origin which is less modified compared to CHL water) (e.g. Alkire et al., 2017; Polyakov et al, 2018; Anderson et al. 2013). In the CHL, the temperature remains close to the freezing point. Several processes have been suggested as contributors to LHW and CHL formation. Based on data from the Oden 1991 cruise, Rudels et al. (1996) found that new halocline formation was initiated by the advection of relatively fresh shelf waters near the surface above denser and more saline water below, when the advection of the fresh water limited winter convection. Support for the importance of such a capping process was provided by Alkire et al. (2017) and Rudels et al. (2004). They argued that capping by fresh water due to sea ice melting in the inflow from the Fram Strait and the Barents Sea can transform AW into halocline water. Another process which has been widely discussed, and which is thought to be especially important for the PHW is the advection of dense and saline shelf waters (where salinity increases due to brine release during sea ice formation especially in winter) below the SML (Aagard et al., 1981; Jones and Anderson,* *1986; Rudeles, 2004). While halocline formation via capping does not require dense shelf waters, capping can also occur in combination with the advection of dense shelf water (Steele and Boyd, 1998; Rudels et al., 2004). While the PHW in the Canada Basin originates from Pacific Water inflow, the LHW is of Atlantic origin also in the Canada Basin (e.g. Anderson et al., 2013). Because of seasonal modifications on the Chukchi Sea Shelf, the PHW in the Canada Basin can be further subdivided into Pacific Winter Water (PWW) and less saline and warmer Pacific Summer Water (PSW) (e.g. Timmermans et al., 2014). The PWW could be referred to as a type of cold halocline water (Zhong et al., 2019), although compared to the CHL in the Eurasian Basin, in the PWW, the salinity is lower and the salinity gradient is smaller. This is why Shimada et al. (2005) called the layer that is formed by PWW a cold halostad (CHS). Similarly, interaction between glacial melt water and Arctic water north east of Greenland forms an intermediate low salinity layer with small salinity gradient which is also called a cold halostad (Dmitrenko et al., 2017). Below, we argue that a lower salinity and a smaller salinity gradient in the CHS compared to the LHW below results in two distinct local stability maxima between the base of the LHW and the SML base: The upper stability maximum is associated with an increase of salinity in the upper PWW. The lower stability maximum is associated with another increase of salinity in the LHW. The lower one of these two stability maxima is absent in the presence of a CHL in the Eurasian Basin (except in regions off the eastern coast of Greenland and also Svalbard where melt water also forms a CHS).*

Because density is more influenced by salinity than temperature if the temperature is low (Aagaard et al., 1981; Roquet et al., 2022) a configuration with warm AW underlying colder halocline water ist stable. The presence of a HCL thus insulates the SML from direct contact with the warm AW and protects sea ice from the warm AW (Aagaard et al., 1981; Lind et al., 2016; Polyakov et al., 2017, 2020). Conversely, a retreat of the CHL in the Eurasian Basin leads to increased vertical mixing as observed and described by Steele and Boyd (1998); Björk et al. (2002); Polyakov et al. (2017). Retreating sea ice, increased surface heat flux and the retreat of the CHL have been called atlantification of the Eurasian Basin (Polyakov et al., 2017). Future climate model projections for a high emission scenario also showed very large temperature gradients directly below the surface mixed layer more frequently, especially during the cold season. The associated heating of the SML in combination with sea ice loss resulted in further increased annual mean upward net surface energy fluxes *outside the Central Arctic along the main warm water inflow pathways (Metzner et al., 2020). While the HCL generally protects sea ice, PSW can be warm enough to participate in sea ice melting (e.g. Timmermans et al., 2014).*

Several methods have been proposed for identifying the HCL and the CHL based on observations. Steele et al. (1995) identified cold halocline water based on conditions for salinity ($34 < S < 34.5$ in the practical salinity scale) and temperature ($T < -0.5°C$). Rudels et al. (1996) defined the boundaries of the CHL by using the 34.3 isohaline. Bourgain and Gascard (2011) used a density ratio threshold to define the base of the HCL. The density ratio is the ratio of temperature and salinity contributions to the vertical stability. A large density ratio implies that the vertical stratification is dominated by temperature and a small density ratio implies that stratification is dominated by salinity. The density ratio threshold suggested by Bourgain and Gascard (2011) assumes that oceanic layers above the CHL base are almost entirely salt-stratified with temperature contributing less than 5% to the total stratification (Polyakov et al., 2018). This density ratio method was adopted among others by others by Polyakov et al. (2017, 2018) and Metzner et al. (2020). Using tracer observations in the western Eurasian Basin, Bertosio et al. (2020) found the base of the LHW to be located at a density of $1027.85\,\mathrm{kg\,m^{-3}}$. Analyzing salinity and temperature observations from the Makarov Basin and along the East Siberian continental slope, Bertosio et al. (2022) again defined the base of the HCL based on density thresholds and compared the results obtained with these definitions to those obtained with other definitions from the literature. A fairly simple and robust method for computing the CHL base depth was proposed by Metzner et al. (2020). In this method, the base of the CHL is determined by a temperature difference of $1\,°C$ between water potential temperature and its freezing temperature. This temperature difference method is very sensitive to warming from below, while the density-ratio method of Bourgain and Gascard (2011) is very sensitive to the salinity profile. One drawback of the temperature difference method is a potential dependence of the optimal threshold value on region (Metzner et al., 2020). Polyakov et al. (2018) proposed an indicator of the potential of the Arctic HCL to prevent vertical mixing based on available potential energy, adapting the density ratio threshold of Bourgain and Gascard (2011) to identify the HCL base.

Here, we propose a new method to identify the HCL base using a vertical stability threshold and compare it to two existing methods using measurements from ice-tethered profilers, ships, and moorings. Our main objective was to *devise a method that uses a threshold value of a variable which is more closely related to the role the HCL plays for insulating the SML from the warm AW . The choice of a vertical stability threshold was motivated by the argument that vertical stability is more directly related to vertical mixing than either density, temperature, or the density ratio. Based on the argument that the presence of PWW forming a CHS on top of LHW creates a stability profile with two distinct local stability maxima, we also propose a method for estimating the depth of the stability maximum that is associated with the CHS and the vertical extent of the CHS. Consistent and robust descriptions of the CHL and cold halostad layer boundaries are important to understand the evolution of the structure of the upper Arctic ocean in the past and the future.*

In the next section, we first describe methods to determine the HULK base depth, starting with two existing methods which are used for comparison, i.e. the density ratio (DR) method by Bourgain and Gascard (2011), and the temperature difference (TD) method by Metzner et al. (2020). We then introduce our new stability (ST) method for determining the HCL base depth. In Section 2.4, we propose a new method for estimating the CHS stability maximum depth and CHS extent, which is based on vertical stability as well. In Section 2.5, we describe a method for estimating the SML base depth because the downward search for the DR and the TD threshold starts at the SML base and because the top of the HCL is assumed to coincide with the SML base. In Section 2.6, we introduce observational datasets used for comparison and testing. In Sect. 2, we compare the new ST method for determing the HCL depth to the existing methods and test the new method for determining the CHS depth and extent. The results are summarized in Sect. 3.

Revised introduction including track changes:

The Arctic Ocean outside the main Atlantic warm water inflow and the shallow marginal shelf seas is usually stratified into a~~the~~ cold and fresh surface mixed layer (SML), which is from ∼5 to >100 m thick, depending on region and season (Peralta-Ferriz and Woodgate, 2015), [I.P]a~~the cold~~ halocline ([I.P]HCL~~CHL~~) below the SML with a base depth ∼40 to >200 m (Fig. 4 of Polyakov et al., 2018), [M.A.]~~and~~ a layer of warm and saline Atlantic Water (AW) below the [I.P]HCL~~CHL~~ centered near 300 to 500 m [I.P]in the Eurasian Basin and somewhat deeper in the Canada Basin (Aagaard et al., 1981; Macdonald et al., 2015) [M.A.], and deep water below. Convection in the SML is driven by surface cooling and brine release during sea ice formation, with maximum SML depth in winter. River inflow and precipitation act as sources of fresh water. [M.A and I.P] Below the SML, salinity increases in the HCL. Within the HCL, one can distinguish between the cold halocline layer (CHL) in the Eurasian Basin, the Pacific Halocline Waters (PHW, modified Pacific Water that originally entered the western Arctic via the Bering Strait) in the Amerasian Basin, and the lower halocline waters (LHW, water of Atlantic origin which is less modified compared to CHL water) (e.g. Alkire et al., 2017; Polyakov et al, 2018; Anderson et al. 2013). In the CHL, the temperature remains close to the freezing point. Several processes have been suggested as contributors to LHW and CHL formation. Based on data from the Oden 1991 cruise, Rudels et al. (1996) found that new halocline formation was initiated by the advection of relatively fresh shelf waters near the surface above denser and more saline water below, when the advection of the fresh water limited winter convection. Support for the importance of such a capping process was provided by Alkire et al. (2017) and Rudels et al. (2004). They argued that capping by fresh water due to sea ice melting in the inflow from the Fram Strait and the Barents Sea can transform AW into halocline water. Another process which has been widely discussed, and which is thought to be especially important for the PHW is the advection of dense and saline shelf waters (where salinity increases due to brine release during sea ice formation especially in winter) below the SML (Aagard et al., 1981; Jones and Anderson, 1986; Rudeles, 2004). While halocline formation via capping does not require dense shelf waters, capping can also occur in combination with the advection of dense shelf water (Steele and Boyd, 1998; Rudels et al., 2004). While the PHW in the Canada Basin originates from Pacific Water inflow, the LHW is of Atlantic origin also in the Canada Basin (e.g. Anderson et al., 2013). [I.P] Because of seasonal modifications on the Chukchi Sea Shelf, the PHW in the Canada Basin can be further subdivided into Pacific Winter Water (PWW) and less saline and warmer Pacific Summer Water (PSW) (e.g. Timmermans et al., 2014). The PWW could be referred to as a type of cold halocline water (Zhong et al., 2019), although compared to the CHL in the Eurasian Basin, in the PWW, the salinity is lower and the salinity gradient is smaller. This is why Shimada et al. (2005) called the layer that is formed by PWW a cold halostad (CHS). Similarly, interaction between glacial melt water and Arctic water north east of Greenland forms an intermediate [M.A.] low salinity [I.P] layer [M.A.] ~~semi-saline layer of water~~ [I.P] with small salinity gradient which is also called a cold halostad (Dmitrenko et al., 2017). Below, we argue that a lower salinity and a smaller salinity gradient in the CHS compared to the LHW below results in two distinct local stability maxima between the base of the LHW and the SML base: The upper stability maximum is associated with an increase of salinity in the upper PWW. The lower stability maximum is associated with another increase of salinity in the LHW. The lower one of these two stability maxima is absent in the presence of a CHL in the Eurasian Basin (except in regions off the eastern coast of Greenland and also Svalbard where melt water also forms a CHS).

[M.A.]Because~~The CHL is also a pycnocline as~~ density is more influenced by salinity than temperature if the temperature is low (Aagaard et al., 1981; Roquet et al., 2022)[M.A.] a configuration with warm AW underlying colder halocline water ist stable. The presence of a HCL thus~~. Therefore, the CHL~~ insulates the SML from direct contact with the warm AW~~Atlantic water~~ [M.A.]and protects sea ice from the warm AW (Aagaard et al., 1981; Lind et al., 2016; Polyakov et al., 2017, 2020). Conversely,~~But~~ a retreat of the CHL in the Eurasian Basin leads to increased vertical mixing as observed and described by Steele and Boyd (1998); Björk et al. (2002); Polyakov et al. (2017). [M.A.]Retreating sea ice, increased surface heat flux and the~~This~~ retreat of the CHL [M.A.]have been called~~has been interpreted as a key feature of the increasing~~ atlantification of the [M.A.]Eurasian Basin~~Arctic Ocean~~ (Polyakov et al., 2017). Future climate model projections for a high emission scenario also showed [I.P]very large temperature gradients directly below the~~increasing atlantification with warm Atlantic water reaching the~~ surface mixed layer more frequently, especially during the cold season. [M.A.]The associated heating of the SML~~This increasing atlantification~~ in combination with sea ice loss resulted in further increased annual mean upward net surface energy fluxes outside the Central Arctic along the main warm water inflow pathways (Metzner et al., 2020). [I.P]While the HCL generally protects sea ice, PSW can be warm enough to participate in sea ice melting (e.g. Timmermans et al., 2014).

Several methods have been proposed for identifying the [I.P]HCL and the CHL based on observations. Steele et al. (1995) identified cold halocline water based on conditions for salinity (34 <S<34.5 in the practical salinity scale) and temperature (T<-0.5°C). Rudels et al. (1996) defined the boundaries of the CHL by using the 34.3 isohaline. Bourgain and Gascard (2011) used a density ratio threshold to define the base of the [I.P]HCL~~CHL~~. [M.A.]~~This density ratio method was adopted among others by Polyakov et al. (2017, 2018) and Metzner et al. (2020).~~ The density ratio is the ratio of temperature and salinity contributions to the vertical stability. A large density ratio implies that the vertical stratification is dominated by temperature and a small density ratio implies that stratification is dominated by salinity. The density ratio threshold suggested by Bourgain and Gascard (2011) assumes that oceanic layers above the CHL base are almost entirely salt-stratified with temperature contributing less than 5% to the total stratification (Polyakov et al., 2018). [M.A.] This density ratio method was adopted among others by others by Polyakov et al. (2017, 2018) and Metzner et al. (2020). [I.P] ~~Bertosio et al. (2020) and Bertosio et al. (2022) distinguished between an upper and a lower CHL.~~ Using tracer observations in the western Eurasian Basin, Bertosio et al. (2020) found the base of the [I.P] LHW~~lower CHL~~ to be located at a density of 1027.85 $\mathrm{kg\,m^{-3}}$. Analyzing salinity and temperature observations from the Makarov Basin and along the East Siberian continental slope, Bertosio et al. (2022) again defined the base of the [M.A and I.P] HCL~~ upper and the lower CHL~~ based on density thresholds and compared the results obtained with these definitions to those obtained with other definitions from the literature. A[I.P]~~nother~~ fairly simple and robust method for computing the CHL base depth was proposed by Metzner et al. (2020). In this method, the base of the CHL is determined by a temperature difference of 1 [I.P] °C~~K~~ between water potential temperature and its freezing temperature. This temperature difference method is very sensitive to warming from below, while the density-ratio method of Bourgain and Gascard (2011) is very sensitive to the salinity profile. One drawback of the temperature difference method is a potential dependence of the optimal threshold value on region (Metzner et al., 2020). Polyakov et al. (2018) proposed an indicator of the potential of the Arctic HCL~~CHL~~ to prevent vertical mixing based on available potential energy, adapting the density ratio threshold of Bourgain and Gascard (2011) to identify the HCL~~CHL~~ base.

[M.A.] Here, we propose a new method to identify the HCL base using a vertical stability threshold and compare it to two existing methods using measurements from ice-tethered profilers, ships, and moorings. Our main objective was to devise a method that uses a threshold value of a variable which is more closely related to the role the HCL plays for insulating the SML from the warm AW . The choice of a vertical stability threshold was~~Here, we define the CHL base based on vertical stability,~~ motivated by the argument that vertical stability is more directly related to vertical mixing than either density, temperature, or the density ratio. [M.A.] Based on the argument that the presence of PWW forming a CHS on top of LHW creates a stability profile with two distinct local stability maxima, we also propose a method for estimating the depth of the stability maximum that is associated with the CHS and the vertical extent of the CHS. [M.A.] ~~In the western Arctic, the CHL splits into an upper CHL and a lower CHL. In between lies water of Pacific origin entering the Arctic Ocean via the Bering Strait. This Pacific water is characterized by lower salinity than Atlantic water, but significantly higher salinity than fresh Arctic surface water (Lin et al., 2021). This leads to an intermediate layer called cold halostad layer Shimada et al., 2005). Similarly, interaction between glacial melt water and Arctic water north east of Greenland forms an intermediate layer of semi-saline water with low salinity gradient which is also called a cold halostad (Dmitrenko et al., 2017).~~ Consistent and robust descriptions of the CHL and cold halostad layer boundaries are important to understand the evolution of the structure of the upper Arctic ocean in the past and the future.

[M.A.] In the next section, we first describe methods to determine the HULK base depth, starting with two existing methods which are used for comparison, i.e. the density ratio (DR) method by Bourgain and Gascard (2011), and the temperature difference (TD) method by Metzner et al. (2020). We then introduce our new stability (ST) method for determining the HCL base depth. In Section 2.4, we propose a new method for estimating the CHS stability maximum depth and CHS extent, which is based on vertical stability as well. In Section 2.5, we describe a method for estimating the SML base depth because the downward search for the DR and the TD threshold starts at the SML base and because the top of the HCL is assumed to coincide with the SML base. In Section 2.6, we introduce observational datasets used for comparison and testing. In Sect. 2, we compare the new ST method for determing the HCL depth to the existing methods and test the new method for determining the CHS depth and extent. The results are summarized in Sect. 3. ~~Here, we propose new diagnostics for the CHL base and the cold halostad layer boundaries and compare our results for the CHL base to the result from two previously suggested methods. The observational datasets on which our analysis is based are introduced in Sect. **??**. Details of the density ratio (DR) method by Bourgain and Gascard (2011), the temperature difference (TD) method by Metzner et al. (2020), and the new stability (ST) method are provided in Sect. **??**. The top of the CHL is assumed to coincide with the base of the SML (see Sect. **??**). We use the kriging method to produce continuous maps of CHL and cold halostad layer boundaries (as explained in Sect. **??**). Results are discussed in Sect. **??**.~~

- It is my understanding that here, the authors equate the CHL base to the point of maximum stability. Wouldn't the point of maximum stability rather be within the "cline" you are considering, and not necessarily at its base? If I misunderstood, I would suggest the authors clarify their method and the physical reasoning behind it, as stated above.

  We are planning to substantially revise our methods section for clarity, and we are planning to take this comment into account. As stated in lines 116f of the original submission, the stability threshold in the ST method was derived based on the density ratio threshold from the DR method. The original motivation behind devising the stability method was that a stable HCL prevents warm Atlantic Water from reaching the surface mixed layer, where it can either melt existing sea ice or prevent sea ice formation. We argue that stability is more closely related to vertical mixing than either the density ratio or the temperature difference.

- The manuscript still lacks an actual evaluation of the performance of each of the detection methods presented here. I like the large scales comparisons, but it lacks some quantitative estimates (which ideally would take into account the varying seasons and basins) and some idea of which method performs best. Because of the diversity of situations, different tests may lead to different rankings of the presented methods. And that is fine, as long as these various results are explicitly presented and discussed.

  In order to evaluate the methods and to better understand the reason behind the different robustness, we investigated individual profiles as suggested by both reviewers. The analysis (please refer to our response to the reviewer comments by I. Polyakov for details) suggests that (a) the ST method captured the beginning new halocline formation directly underneath relatively fresh surface water in the Eurasian Basin, (b) the TD method overestimated the HCL depth in the Eurasian Basin, (c) in the Canadian Basin isolated HCL base minima in the DR and the TD method occurred because of a layer of warm Pacific water, and (d) the ST method slightly overestimated the depths of the HCL base in the Canada Basin. These findings are broadly consistent with summary statistics of HCL depth in Fig. RA1. In the Eurasian Basin, the ST method more

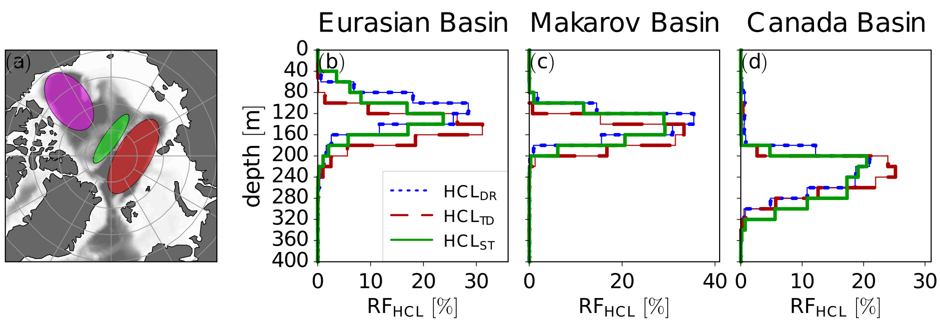

Figure RA1: Map showing elliptical areas over the Canada Basin (purple), the Makarov Basin (green) and the Eurasian Basin (dark red) and ocean floor depth (grey shading) (a). Relative frequency of HCL base depth determined with the density ratio (DR), temperature difference (DR) and the stability (ST) method for the elliptical areas over the Eurasian Basin (b), the Makarov Basin (c), and the Canada Basin (d).

frequently identifies a HCL base not far below the SML base compared to the DR method. Based on suggestions by I. Polyakov, we now interpret this as an indication of the ST method capturing the beginning of new halocline formation (please refer to our response to the reviewer comments by I. Polyakov for details on this point). The TD method overestimates the CHL depth in the Euarsian Basin (Fig. RA1b). In the Canada Basin (Fig. RA1d), the DR method detects a CHL shallower than 160 m for 2.7% of the profiles and the TD method for 0.5% of the profiles, indicative of isolated maxima due to the influence of near-surface warm Pacific water. Slightly increasing the stability threshold in the ST method may lead to a better match between the TD method by moving the HCL base upward and by decreasing the sensitivity to new HCL formation.

- The organization of the manuscript lacks fluid connections, both in the introduction and in the presentation of the results. Subsections seem to be organized thematically but without a clear logical order. I would suggest the authors consider reorganizing the overall manuscript (introduction and results) and the abstract as follows:

1) Clear introduction of what SML, CHL, and cold halostad are, and why they matter (as already done in part for the CHL).

2) Presenting the previous methods that have been used to define these layers, and underlining eventual (knowledge) gaps in these methods.

3) Introducing the new method, the physical reasoning behind its development, and the goal it aims to achieve.

4) Demonstrating how the results of the new method compare to results from previous methods (qualitatively and quantitatively, by adding some basin-wise statistics for example), and what are the gains of the new method.

We have revised the introduction, computed basin-wise statistics (see above), and now use individual profiles in our comparison of the results (for the latter, please refer to our response to the reviewer comments by I. Polyakov). Unfortunately, we have not yet managed to revise the entire manuscript. We would very much appreciate if the Editor provides us an opportunity to revise the rest of the manuscript as well.

Minor comments:

In the introduction in general:

It would be good to improve logical connections between paragraphs. For example, L26-27: what is the connection between Atlantification discussions and CHL characteristics? You could finish the previous paragraph by commenting on possible changes in the strength of stratification within the CHL that could either boost or hinder further Atlantification.

We agree that it would be good to improve the logical connections between paragraphs. However, the first paragraph of the revised introduction is entirely devoted to introducing the different layers and water masses. Atlantification is now only mentioned in the second paragraph, which underlines the importance of these concepts. This provides a very nice and clear separation, but makes a smooth transition difficult.

In general, I would suggest reshaping your introduction as follows (as stated above):

- Defining the broad concepts of cold halocline layer and cold halostad

We followed this suggestion, but also introduce water masses such as PSW and PWW and discuss CHL formation mechanisms, especially the Rudels et al. (1996) mechanism, as explained in our response to your first major comment.

- Underlining their importance for our understanding of the present and future Arctic ocean characteristics

We now introduce layers and water masses in the first paragraph and comment on their importance in the second paragraph.

- Listing criteria for their definition used so far, and eventually pros and cons

We list the criteria. We found a comparison of HCL base depths computed with different methods in Bertosio et al. (2022). But as far as we know, there has been no systematic comparison of the pros and cons so far. We think that the devised methods are all very useful for the purpose they were designed for.

- Explaining clearly the motivation behind creating a new set of criteria, and the problem you aim to address

Regarding the HCL base, the existing thresholds are not as closely related to the role of the HCL as a stable layer which prevents mixing (although Section 2.2.4 of the original manuscript shows that density ratio and stability are indeed related). But we consider this a feature of the methods, and not necessarily a problem. Each of the methods targets different aspects, which may be more or less relevant to the question at hand.

- Finally, introduce the organization of the manuscript (as you already do)

We revised the paragraph, and we are eager to also revise the rest of the manuscript. (Once again, sorry for the delay. We did not manage to finish revising the manuscript before the end of the discussion phase).

L22–26: Remind the readers in 1-2 sentences what Atlantification is. In fact, you partly do so in the following sentence, but this should come earlier. And isn't ice loss a symptom/characteristic of Atlantification, too?

The revised sentence reads as follows: *Retreating sea ice, increased surface heat flux and the retreat of the CHL have been called atlantification of the Eurasian Basin (Polyakov et al., 2017).*

L38–39: Here, and generally throughout the manuscript, please define concepts as early as they appear. This sentence should come as you mention the density ratio, 2 lines above. In short, put the sentence line 37-38 at the end of this paragraph.

Thank you very much. We moved the sentence in lines 37-38 to the end of the paragraph. In the overview of halocline layers and waters in the first paragraph of the introduction, we provide short definitions of the Pacific Halocline Water (PHW) and the Lower Halocline Water (LHW) in parenthesis before expanding on details further below in the same paragraph.

L34–52: It would be best to reshape this series of 3 paragraphs into one, listing all existing used criteria to define the base of the CHL and eventually their pro and cons.

We combined the three paragraphs. Please refer to our response above regarding a discussion of the pros and cons already in the introduction. Thanks to the reviewers' suggestion to focus on individual profiles, we consider ourselves in a much better position to provide a more substantial discussion of the pros and cons in the results and the conclusion section of a revised manuscript.

L57: You already introduced this concept above when citing Bertosio (2020) and (2022). Would be best to merge the descriptions of upper and lower CHL into one paragraph here, keeping the relevant citations.

We merged the paragraphs and kept the citations. The relevant concepts are introduced in the first paragraph of the revised introduction.

L75: "Level III data": This processing level naming convention is rather opaque for unfamiliar readers. State more clearly what this entails (visual inspection, vertical interpolation, salinity spikes or bias corrections… etc)

The data processing for the ITP data is described by Krishfield et al. `http://www.whoi.edu/fileserver.do?id=35803&pt=2&p=41486`. Producing Level III data included removal of corrupted data, corrections for the sensor response behavior, calibrations, and final screening of spurious outliers. We will mention this in a revised version of our methods section.

L91: "Gaussian filter": as above, please introduce each processing method explicitly.

We are planning to revise the sentence as follows: *In order to reduce noise, the data was smoothed using a standard one-dimensional Gaussian filter (convolution with a Gaussian function, e.g. Deng and Cahill, 1993) with a standard deviation of 2 dbar and a truncation at $\pm$10 dbar.*

Where the standard deviation and the truncation are in dbar instead of m because we have re-processed the data at the original vertical resolution without prior re-gridding and reduced the filter width and truncation.

Please note that Gaussian filters are a standard tool in signal processing (`https://en.wikipedia.org/wiki/Gaussian_filter`). Gaussian filters are generally more efficient at filtering high frequency noise compared to box filters (also known as running mean). Bourgain and Gascard (2001) used box filters of different widths for different variables.

L89: Is this reasonable for all profiles? Could some profiles, especially the oldest ones, have a vertical sampling of 5 to 10 m? If that is the case, please state so and briefly discuss why you think such a high-resolution interpolation is appropriate and reasonable. I would also suggest the authors consider a vertical resolution that is less fine and closer to the native profiles' vertical resolutions.

We reprocessed the data at the native resolution.

L139: it seems this sentence has grammar issues.

Yes, thank you. The sentence should have read:

A cold halostad will only be recognized by the algorithm if the vertical distance between the deeper stability maximum and the first upper occurrence of that same stability value is at least 50 m, and this stability layer has at least a relative depth of 0.2 in $log_{10}(N^2)$.

This section will be revised for clarity.

L141:..."only the lowest of these layers is identified as a cold halostad." Why is that, physically?

The sentence in the original manuscript stated that in *rare cases, in which more than one layer fulfills these conditions, only the lowest of these layers is identified as a cold halostad*, although we had not encountered any such cases, and only now added a few lines of code to identify and count such cases. It turned out that no such case occurred. We are planning to revise the statement accordingly.

L169: 25th/75th percentile: This is an extremely stringent test. Can you explain why you took such a high threshold? As the other reviewer stated, it would be good to know how sensitive your results are to the "outlier" threshold you chose.

Outliers were defined as values outside the interval $[Q1-1.5\, IQR, Q3+1.5\, IQR]$, where $Q1$ is the first quartile, $Q3$ the third quartile, and $IQR = Q3 - Q1$ is the inter-quartile range. The section on kriging will be omitted.

L254: In general, I would try to limit references to previous specific figures from previous papers. It is easier if you directly remind the readers what were the findings shown that figure through text, citing the source paper, in discussing your results in light of it.

This discussion will be removed. We have provided updated figures in which we removed the panels showing maps of the SML in our response to the reviewer comments by I. Polyakov.

L314: If you mean "comparatively low-salinity" then use "low salinity".

Yes, thank you very much. We followed your suggestion and corrected this expression in the revised introduction.

Fig. 2 and 7: I like these figures, and it would be great to have one of such plots for -when possible- each subregion and season. Even on one ITP, you could for example indicate when the buoys are in Canada vs. Makarov vs. Amundsen / Nansen basins.

Thank you very much for liking these figures. They were inspired by Polyakov et al. (2017). Our response to the reviewer comments by I. Polyakov includes revised versions of Figs. 2 and 7. Fig. RA1 shows statistics for selected basins.

Fig. 3: This is an interesting visualization, but it is rather under-used in the manuscript. I would suggest the author consider replacing it with plots presenting the vertical profiles, either in the introduction to present your various concepts (SML, upper and lower CHL, cold halostad), or in your results by grouping profiles in similar regions or seasons.

We analyzed individual profiles (please refer to our response to the reviewer comments by I. Polyakov). Fig. 3 will be replaced. Regarding summary statistics, we are planning to include Fig. RA1 in a revised version of our manuscript.

Fig. 4 and 5: I still do not quite get the goal of using 2 interpolation methods (NN and kriging). If there is no other objective that showing the pan-Arctic results in 2 different ways, I would suggest the authors pick one of these methods and eliminate the other, in order to make the manuscript more fluid.

The kriging will be eliminated.

Thank you very much again and please excuse our delay. We very much appreciate your comments. Should the Editor decide to encourage a re-submission, we will be happy to provide more complete answers to some of your comments and a version containing track changes together with the revised manuscript.

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