Reviewer 1:

*We thank the reviewer 1 so much for the constructive comments on our revised manuscript. Those are helpful for further improving the manuscript by discussing the role of brine rejection in the sea ice variability and providing physical explanation for the statistical relationship among ensemble members. Our point-by-point responses to the reviewer's comments are described below with Italic fonts.*

After some revision, the manuscript has been significantly improved. I have some minor comments/questions regarding the role of brine rejection on sea ice evolution and the uncertainty of the ocean during the early stage of the simulation. What's more, some modifications to the structure of the manuscript are also needed. Therefore, I suggest some minor revisions for this manuscript. The details are as follows:

Line 94-98, I'm still lost in the described mechanism. As far as I know, brine rejection during the sea ice formation is supposed to enhance the vertical mixing and depress the sea ice growth. And Goosse and Zune (2014) describe the physical process as "When sea ice concentration increases in a region, in particular close to the ice edge, the mixed layer depth tends to decrease. This can be caused by a net inflow of ice, and thus of freshwater, that stabilizes the water column", which is a little different from the mechanism described in the manuscript. Please consider elaborating on the description further.

*Goosse and Zunz (2014) stated in their conclusions that the positive feedback occurs near the sea ice edge over a wide domain, but the modifications of the mixed-layer are much weaker than those related to the deep convection that lead to polynya formation and strongly reduced sea ice concentration. Therefore, their mechanism is different from the deep convection mechanism we considered here. We have clarified the difference in the sentence.*

Line 329-346, I suggest moving this part to the discussion, as it is not the main part of this manuscript.

*Since this paragraph first introduces the SPEAR_MED model and describes technical differences with the SPEAR_LO model, it is important to keep the paragraph as a part of methodology section. We have also discussed the differences in the results between the two models in the discussion section.*

Line 400-402, as far as I can see, the polynya during 2016-2017 is not well simulated in SPEAR_LO_DCIS, right? I even can't figure out the position of polynya in 2016-2017 from Figure S3c. Please consider improving the figure to give a better visualization.

*We can see the negative peak of SIC anomalies near the coast of 0ºE in Fig. S4c. This corresponds to the polynya event during 2016-2017, and our model (Fig. S4d) captures the negative SIC anomalies at 0ºE but simulates them slightly equatorward with weaker amplitudes than the observation. We have mentioned this in the sentence.*

Line 434-437, I'm wondering if the larger ensemble spread in the early date is related to the large ensemble spread of the ocean, as the ocean is not well constrained from the data assimilation, and the ocean is only adjusted during the model integration. Can you give some discussion on this issue?

*Our model simulation is constrained by atmospheric and SST initializations, but not by the subsurface ocean data assimilation. Therefore, the larger ensemble spread in the early periods may be related to that in the ocean model. We have mentioned this in the sentence.*

Line 448-450, throughout the manuscript, the simulation from the late 1970s to early 1980s receives great attention, and many diagnostic analyses are based on the model simulation during that period. However, there are some inconsistencies in Weddell Sea SIE between the model simulation and observations (Figure 2b) regarding the trend and magnitude of the anomaly. So I'm wondering is the result robust given the large simulation error?

*The model simulation tends to overestimate the observed negative SIE anomalies in the Weddell Sea from the late 1970s to early 1980s, but the model simulation has large ensemble spreads, indicating a large uncertainty in the amplitude. As mentioned in Subsection 3.2, five out of 30 members reasonably capture the observed negative SIE anomalies in the Weddell Sea. These members are related to relatively smaller amplitude of deeper mixed-layer than the other members, as discussed in Subsection 3.3. It is important to reasonably capture the ocean conditions for simulating the amplitude of the negative SIE anomalies during the periods.*

L628-L632, Yes, I agree. However, I'm curious about the reasons that the positive correlation coefficient exists. Is there any explanation from a physical perspective?

*The positive correlation can be interpreted as the decadal changes in the phase of zonal wind anomalies from the 1970s to the 1980s (Fig. 3a) and may have nothing to do physically with the negative zonal wind anomalies in the 1970s. We have mentioned this in the paragraph.*

L670, From Figure 7d, there is a strong correlation coefficient between Weddell SIE and DCV 5-10 years ahead, which means that the ensemble with a strong DCV tends to simulate a positive anomaly of SIE after 5-10 years. Why is this? Can this positive correlation coefficient be explained physically?

*We find positive correlations with the 5-10 yr leading deep convection anomalies (Fig. 7d), but this can also be interpreted as decadal changes in the phase of deep convection anomalies (Fig. 3d) and may have nothing to do physically with deep convection anomalies in the earlier period. We have mentioned this in the paragraph.*

L889-890, "while atmosphere-ocean interaction at the surface plays more important roles in predicting sea ice increase after the 2000s." However, the correlation coefficient between SIC and atmospheric variables (Taux, Tauy) is also low after the 2000s. Please consider giving more clues to this conclusion.

*The correlation coefficients with zonal and meridional wind anomalies after the 2000s (Fig. 12b, c) are low but more significant than those with the deep convection anomalies (Fig.*

*12f). This suggests that the surface wind variability contributes more to skillful prediction of the sea ice variability than the deep convection after the 2000s. We have modified the sentence accordingly.*

Reviewer 2:

*We thank the reviewer 2 so much for the constructive comments on our revised manuscript. Those are helpful for further improving the manuscript by clarifying the relative roles of subsurface heat buildup and surface wind variability in the sea ice variability. Our point-by-point response to the reviewer's comments are provided below with Italic fonts.*

I went through the revised manuscript and the authors' responses to previous review comments. The manuscript has been substantially improved. However, I am still not convinced that the "heat buildup" in the 1960s is important. If we quantify the role of "heat buildup" in the 1960s vs the other processes that cause the surface salinity increase in the 1970s using surface mixed layer depth (MLD) changes, we will get 50 m vs 300 m increase in MLD due to these two processes. Nevertheless, this does not appear to be a critical point in the revised discussion. I will leave it to the authors to decide whether they want to keep the "heat buildup" discussion. If it is not the wind, I would also hope to see some discussion, or maybe some speculation, of what is driving the larger salinity vertical advection & MLD increase during the 1970s. Right now, the explanation is in a loop (salt advection->MLD increase->salt advection), but what may start this loop?

*We have not claimed that the heat buildup in the 1960s is a single cause of the large negative SIE anomalies in the 1980s, but argued that both the heat buildup in the 1960s and the salinity increase linked to the surface wind variability in the 1970s are important for the large negative SIE anomalies through deeper mixed-layer and warmer SST. The subsurface heat buildup provides a favorable condition for the deeper mixed-layer in the 1960s, but in addition to that, the surface wind variability (i.e., stronger westerly and negative wind stress curl anomaly) also contribute to the surface salinity increase and hence the deeper mixed-layer in the 1970s through upwelling of warm and saline water below the mixed-layer. We have clarified these points in the results section.*

Some suggestions:

[title]: "GFDL SPEAR_LO Model" may be strange to many readers, including myself, even after finish reading the abstract. I would replace it with "a (GFDL) climate model" or just remove it.

*We have specified the model name because our finding is based on our single model and we have not examined other climate models that should be done in future work. So, we have kept the model name in the title as it is.*

[Line 33]: capture the "multidecadal variability" of observed sea ice extent (SIE)?

*We have modified.*

[Lines 258-259]: Only want to remind the authors that deep convection only contribute partly to the overturning circulation, especially in simulations that can resolve the coastal processes of smaller scales.

*We have mentioned this limitation in the following sentence such as "Here we define the deep convection broadly south of 60S because the ocean model does not have a sufficient resolution to simulate the coastal small processes involved in the deep convection"*

[Lines 360-362]: Not necessarily true. Surface wind and some other processes may work together to determine the multi-decadal sea ice changes. It does not necessarily mean that it won't work during the late 1970s and early 1980s if it does not work in the 2000s. While I am not saying that it is the wind that explains everything, there is an asymmetry in wind forcing in driving the surface mixed layer depth changes -- a stronger westerly and negative wind stress curl may help increase MLD from 100 m to 500 m but can only decrease MLD from 100m to, at least, 0 m.

*We have modified the sentence such as "the surface wind variability contributes to a part of the large negative SIE anomalies through the shallower mixed-layer depth, but does not necessarily explain all of the large negative SIE anomalies. "*