Web links to the author's journal account have been redacted from the decision letters as indicated to maintain confidentiality.

Decision letter and referee reports: first round

Date: 29th Sep 20

Dear Dr Ding,

Your manuscript titled "The summertime low clouds: bridging large-scale circulation and sea ice variations over the Arctic" has now been seen by two reviewers, and I include their comments at the end of this message. They find your work of interest, but some important points are raised. We are interested in the possibility of publishing your study in Communications Earth & Environment, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter) and the completed checklist:

[link redacted]

** This url links to your confidential home page and associated information about manuscripts you may have submitted or be reviewing for us. If you wish to forward this email to co-authors, please delete the link to your homepage first **

We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

Please do not hesitate to contact me if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Heike Langenberg, PhD

Chief Editor
Communications Earth and Environment

On Twitter: @CommsEarth

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

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Furthermore, please align your manuscript with our format requirements, which are summarized on the following checklist:
Communications Earth & Environment formatting checklist

In the event that your manuscript is accepted, we will provide detailed guidance on our journal policies and formatting. You may however wish to ensure that the manuscript broadly complies with our house style at this stage. See our style and formatting guide Communications Earth & Environment formatting guide for reference.

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In particular, the Data availability statement should include:
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DATA SOURCES: All new data associated with the paper should be placed in a persistent repository where they can be freely and enduringly accessed. We recommend submitting the data to discipline-specific, community-recognized repositories, where possible and a list of recommended repositories is provided at http://www.nature.com/sdata/policies/repositories.

If a community resource is unavailable, data can be submitted to generalist repositories such as figshare or Dryad Digital Repository. Please provide a unique identifier for the data (for example a DOI or a permanent URL) in the data availability statement, if possible. If the repository does not provide identifiers, we encourage authors to supply the search terms that will return the data. For data that have been obtained from publically available sources, please provide a URL and the specific data product name in the data availability statement. Data with a DOI should be further cited in the methods reference section.

Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

General comments:

The manuscript emphasizes the importance of Arctic low cloud response to large scale circulation variability, specifically to trends in Arctic high-pressure systems. This response could actually drive the observed warming and corresponding sea ice retreat in the Central Arctic. More importantly, in my understanding, would be that the actual trend of increasing Arctic high pressure (at least in the focus area studied here) is due to internal variability of the atmosphere, and thus not related to global warming. Thus, what we currently observe as Arctic Amplification might be a natural phenomenon. The authors do not go that far with their conclusions. However, there results may have the potential to trigger a stimulating discussion in the scientific community.
To the best of my knowledge, these findings are original. The authors are using established multivariate statistical analysis tools to show major spatial pattern and temporal variations.

I found the manuscript straight-forward and easy to read. However, I have some difficulties understanding the long-wave-warming argumentation (could be me, though), which I will explain in detail below. If these concerns are resolved, the present manuscript may make an important contribution to the currently very intensively researched Arctic climate change.

Specific comments:

line 66: " ... have a limitation to fully reproduce large scale circulation variability in the real world." Please be more specific as to the reasons for this limitation. Is this due to resolution, inaccurate parameterizations of sub-grid processes, numerical instabilities, ... Or do you have specific limitations in mind that holds for the low cloud formation studied here?

line 96: "... the increasing downwelling LW (LW_down) cloud radiative effect (CRE) at the surface has been observed...": I doubt there are direct observations of CRE in this area. I presume you are referring to satellite products. If so, please consider that surface CRE products from satellite are rather indirect and can be erroneous as passive satellite sensors do not "see" the cloud bottom, which is the major proxy for the LW_down.

line 107: "... sea ice decline because of enhanced LW CRE.": but the increased low cloud fraction should also increase the short-wave cloud cooling effect, leading to reduced sea ice melt in JJA? As far as I remember, for summertime Arctic clouds the cloud SW cooling dominates over the cloud LW warming. I understand that you argue at the end of the manuscript that this is not the case for low clouds. I will come back to this point later.

line 114: "... However, the upwelling SW flux is substantially reduced with decreased surface albedo and thus leads to an increase in absorbed solar radiation.": ... provided there are no clouds above, which mask an increased absorption of SW radiation at the ice-free surface. However, you argue that the (low) cloud amount has increased. May be, reduced sea ice and increased cloud amount compensate each other in terms of surface SW absorption?

line 153: "... enhance the LW_down flux at the surface, ...": but also reduces the SW_down flux at the surface in JJA! I suggest to use the total (LW + SW) flux for your argumentation whether (low) clouds warm or cool the surface.

line 223: "We only nudge the winds above 850 hPa to ERA-I because we would like to 224 give the model some freedom to behave below 850 hPa.": Would that be a sufficient amount of freedom to let the model play out its own physics? Would you get very different results if you nudge winds above 800, 750, ... 500? With this setting, it is not obvious (to me, at least) if the model has enough degrees of freedom to potentially deviate from the observed low cloud fraction trends.

line 238: "... and enhanced LW_down flux ...": again, this could potentially be (over)compensated by reduced SW_down flux.

line 261: "... of low clouds, which are closer to the surface and thus more efficient to

regulate the surface temperature through LW radiation37.": but low clouds are already optically thick and provide a strong solar cooling. Reference 37 is based on a field campaign in August + September. Low clouds in June + July might behave differently due to higher sun angles.
Also, reference 37 states only a small positive LW cloud radiative forcing: "enhanced emission of downwelling longwave radiation from low clouds with increasing cloud liquid water yielded small, but slightly positive net radiation"

Reviewer #2 (Remarks to the Author):

This study mainly focuses on the cause and consequence of summertime Arctic low-level clouds which is increasing in recent decades. More specifically, the authors tackle the two questions:
1) How is recent intensification of upper-level Anticyclone in the Arctic linked to the increase in low-level clouds?
2) What is the role of low-level clouds in the summer sea-ice melt?

To answer the two questions above, the authors analyzed satellite-based observations, reanalysis and model simulation data. Both questions are quite interesting and timely because, in the literature, intense debate is underway about the role of low-level clouds in the summer sea-ice melt. A key chain of explanation starts from the existence of upper-level Anticyclone near the Greenland causing sinking motion and adiabatic warming. The authors suggest these are helpful condition for the formation of low-level clouds. Enhanced downwelling longwave radiation by low-level clouds play a key role for summer ice-melt. Coupled model used in this study doesn't seem to properly capture this observed relation. But, specially designed nudging experiments designed to prescribe the role of upper-level Anticyclone captures the observed linkages well supporting the role of upper-level circulation for the formation of low-level clouds.

I think the topic is important and manuscript is generally written very well. However, before I suggest a positive recommendation, I would raise several critical issues that the autors need to overcome.

1. In Fig. 1, the Anticyclone centers do not coincide with the upward motions in Fig. 2c. If Anticyclone is a main driver of sinking motion, why the two do not coincide? In otherwords, what is the origin of the vertical motions over Chukchi and beaufort in Fig. 2e? Are they driven dynamically or thermodynamically? I believe the authors need to address this issue more carefully.

2. The short-wave reflection by increased low-level cloud should be treated equally in the manuscript (not in supplementary). Low-cloud has both positive and negative impact for sea-ice melt. The authors treat both issues in balance.

3. In Supplementary Fig. 5, both upwelling and downwelling shortwave fluxes are decreasing especially in the Chukchii and East Siberian Sea. What is the implication?

4. In Fig. 4, net SW is increasing as much as downwelling LW. Are Fig. 4e and 4g consistent? How can both increase in spite of cloud reflection ?

5. In L167 or L249, why do the authors regard Z200 Anticyclone natural variability? Provide a plausible explanation.

6. L189 1780 20-year long pseudo ensemble members? Please explain more.

Author Responses: first round

Response to reviewers

Reviewer #1 (Remarks to the Author):

General comments:

The manuscript emphasizes the importance of Arctic low cloud response to large scale circulation variability, specifically to trends in Arctic high-pressure systems. This response could actually drive the observed warming and corresponding sea ice retreat in the Central Arctic. More importantly, in my understanding, would be that the actual trend of increasing Arctic high pressure (at least in the focus area studied here) is due to internal variability of the atmosphere, and thus not related to global warming. Thus, what we currently observe as Arctic Amplification might be a natural phenomenon. The authors do not go that far with their conclusions. However, there results may have the potential to trigger a stimulating discussion in the scientific community.
To the best of my knowledge, these findings are original. The authors are using established multivariate statistical analysis tools to show major spatial pattern and temporal variations.

I found the manuscript straight-forward and easy to read. However, I have some difficulties understanding the long-wave-warming argumentation (could be me, though), which I will explain in detail below. If these concerns are resolved, the present manuscript may make an important contribution to the currently very intensively researched Arctic climate change.

Specific comments:

line 66: " ... have a limitation to fully reproduce large scale circulation variability in the real world." Please be more specific as to the reasons for this limitation. Is this due to resolution, inaccurate parameterizations of sub-grid processes, numerical instabilities, ...
Or do you have specific limitations in mind that holds for the low cloud formation studied here?

Thanks for your suggestions. We should be more specific when we wrote this sentence in the original version. The main idea we would like to emphasize through this statement is that the observed circulation trend in the Arctic in the past few decades is partially internally driven. Thus, it is hard to reproduce a similar pattern in historical simulations (forced by CO_2) and preindustrial simulations (free runs). For your information, here we provide more discussion on this limitation.

Ding et al. (2017) found that unlike observations, which show barotropic, anticyclonic circulation trends over Greenland from the surface to the upper troposphere, circulation trends in CMIP5 and CESM-Large Ensemble (CESM-LE) ensembles are weak and unorganized in the Arctic, and particularly in the lower troposphere. Both CMIP5 and

CESM-LE ensemble means showing an amorphous warming with little circulation change is the typical thermodynamic response in the mid- and high- latitudes to increasing CO_2.

Also, the upper tropospheric circulation in the Arctic has a strong link to variability originating from the tropics (Baxter et al. 2019; Ding et al. 2014). Previous studies demonstrated 50% of the circulation change and the associated warming over Greenland are attributable to internal variability originating from the tropical Pacific Ocean (Wettstein and Deser 2014). Therefore, accurately reproducing this teleconnection would be a key to perfectly simulate the large-scale circulation variability in the Arctic.

Moreover, the model resolution also plays an important role in simulating the Atmospheric circulation and associated changes in sea ice over the Arctic. DeWeaver and Bitz (2006) suggested the biases in both North Polar summer anticyclone and sea ice thickness along the Canadian coast have been reduced when Community Climate System Model version 3 (CCSM3) resolution is increased from T42 (~2.8°) to T85 (~1.4°).

As for the low cloud simulations, it is still quite challenging for current global climate models to fully resolve the sub-grid processes (Klein et al. 2013), particularly for Arctic mixed-phase clouds (Morrison et al. 2012). Therefore, the major limitations regarding to Arctic low cloud simulation includes the inaccurate local microphysical process (e.g., Morrison et al. 2012; Tan et al. 2016), unrealistic cloud response to large-scale synoptic meteorological processes (e.g., Taylor et al. 2019), as well as the incapability to fully resolve cloud response to sea ice loss (e.g., Morrison et al. 2019).

Considering all these limitations, in this study, we use a fingerprint analysis and the nudging technique to add observed winds into a high resolution version (~1°) of CESM1. It seems that these two novel approaches help us better understand impacts of large-scale winds on clouds and sea ice. To be more clear and specific, we revised this statement as below:

Line 65-69: "The main hurdle to understand these underlying processes is that current climate models have a limitation to fully reproduce observed large-scale circulation variability with increasing greenhouse gas emissions[12], possibly due to models' incapability to simulate teleconnections between the tropics and high latitudes[18] and relatively low model resolution[19]."

References:

Baxter, I. *et al.* (2019) How tropical Pacific surface cooling contributed to accelerated sea ice melt from 2007 to 2012 as ice is thinned by anthropogenic forcing. *J. Clim.* **32(24),** 8583-8602.

DeWeaver, E., & Bitz, C. M. (2006). Atmospheric circulation and its effect on Arctic sea ice in CCSM3 simulations at medium and high resolution. *Journal of Climate*, *19*(11), 2415-2436.

Ding, Q., Wallace, J. M., Battisti, D. S., Steig, E. J., Gallant, A. J., Kim, H. J., & Geng, L. (2014). Tropical forcing of the recent rapid Arctic warming in northeastern Canada and Greenland. *Nature*, *509*(7499), 209-212.

Ding, Q. *et al.* (2017) Influence of high-latitude atmospheric circulation changes on summertime Arctic sea ice. *Nat. Clim. Change*, ***7*****(4),** 289-295.

Klein SA, Zhang Y, Zelinka MD, Pincus R, Boyle J, Gleckler PJ (2013) Are climate model simulations of clouds improving? An evaluation using the ISCCP simulator. J Geophys Res Atmos 118(3): 1329-1342.

Morrison AL, Kay JE., Frey WR, Chepfer H, Guzman R (2019) Cloud response to Arctic Sea ice loss and implications for future feedback in the CESM1 climate model. J Geophys Res Atmos 124: 1003– 1020.

Morrison, H., De Boer, G., Feingold, G., Harrington, J., Shupe, M. D., & Sulia, K. (2012). Resilience of persistent Arctic mixed-phase clouds. *Nature Geoscience*, *5*(1), 11-17.

Tan I, Storelvmo T (2016) Sensitivity study on the influence of cloud microphysical parameters on mixed-phase cloud thermodynamic phase partitioning in CAM5. J Atmos Sci 73(2): 709-728.

Taylor PC, Boeke RC, Li Y, Thompson DW (2019) Arctic cloud annual cycle biases in climate models. Atmos Chem Phys 19: 8759-8782.

Wettstein, J. J., & Deser, C. (2014). Internal variability in projections of twenty-first-century Arctic sea ice loss: Role of the large-scale atmospheric circulation. *Journal of Climate*, *27*(2), 527-550.

line 96: "... the increasing downwelling LW (LW_down) cloud radiative effect (CRE) at the surface has been observed...": I doubt there are direct observations of CRE in this area. I presume you are referring to satellite products. If so, please consider that surface CRE products from satellite are rather indirect and can be erroneous as passive satellite sensors do not "see" the cloud bottom, which is the major proxy for the LW_down.

Thanks for your suggestions. Yes, I am referring to CERES-MODIS satellite product here. The surface CRE is not an observed quantity. Instead, it is calculated from a radiative transfer model, but constrained by observed radiative fluxes at the Top-of-Atmosphere and cloud properties. Therefore, we have modified this statement as below.

Line 96-98: "Therefore, the downwelling LW (LW_down) cloud radiative effect (CRE) at the surface has been increasing over the marginal seas in summer, particularly over the AOF (Fig. 1e)."

line 107: "... sea ice decline because of enhanced LW CRE.": but the increased low cloud fraction should also increase the short-wave cloud cooling effect, leading to reduced sea ice melt in JJA? As far as I remember, for summertime Arctic clouds the cloud SW cooling dominates over the cloud LW warming. I understand that you argue at the end of the manuscript that this is not the case for low clouds. I will come back to this point later.

Many thanks for drawing our attention on this issue. We totally agree that clouds have multiple roles to influence surface heat budget. Even the same increase in cloud fractions may simultaneously generate several competing effects, such as a cooling effect due to a reduction of downwelling SW flux or a warming effect due to an increase of downwelling LW flux. To better understand the sensitivity of sea ice to each radiative flux, we further calculate the correlation of LW/SW flux with sea ice and it turns out that LW_down is negatively correlated with sea ice but SW_down shows a positive correlation with sea ice. This indicates that the increasing LW (due to more clouds) may play a more active role to melt sea ice and the reduced SW down could be partially due to changes of surface conditions (less multiple reflections). We thus add more discussion in the revision to illustrate a complete picture of different possible roles of clouds as you suggested. Since this comment voices the same concern as the below one about line 153, please see our detailed response to that question.

We also modified this statement as below to be more objective about the role of clouds.

Line 107-109: "The strongest negative correlations occur over the Beaufort, Chukchi, and East Siberian Seas in August and September (Fig. 1g), suggesting that increasing JJA low CF may lead to subsequent sea ice decline potentially because of enhanced LW CRE."

And we also discussed the changes in SW flux as below.

Line 111-119: "In summer, the SW flux also plays an important role in controlling sea ice melt. The downwelling SW (SW_down) flux has been reduced (Supplementary Fig.5a) because of an increase in low clouds and a reduction in surface albedo. On the one hand, the increased low CF may reflect more incoming solar radiation and reduce the shortwave flux transmission[13,22,23]. On the other hand, the surface albedo has been decreasing with sea ice melt, which substantially reduces the multiple reflections between surface and clouds[24]. In the meantime, the upwelling SW flux is substantially reduced with a much larger magnitude as a result of decreased SW_down flux and surface albedo, thus leading to an increase in absorbed solar radiation (Supplementary Fig.5)."

line 114: "... However, the upwelling SW flux is substantially reduced with decreased surface albedo and thus leads to an increase in absorbed solar radiation.": ... provided there are no clouds above, which mask an increased absorption of SW radiation at the ice-free surface. However, you argue that the (low) cloud amount has increased. May be, reduced sea ice and increased cloud amount compensate each other in terms of surface SW absorption?

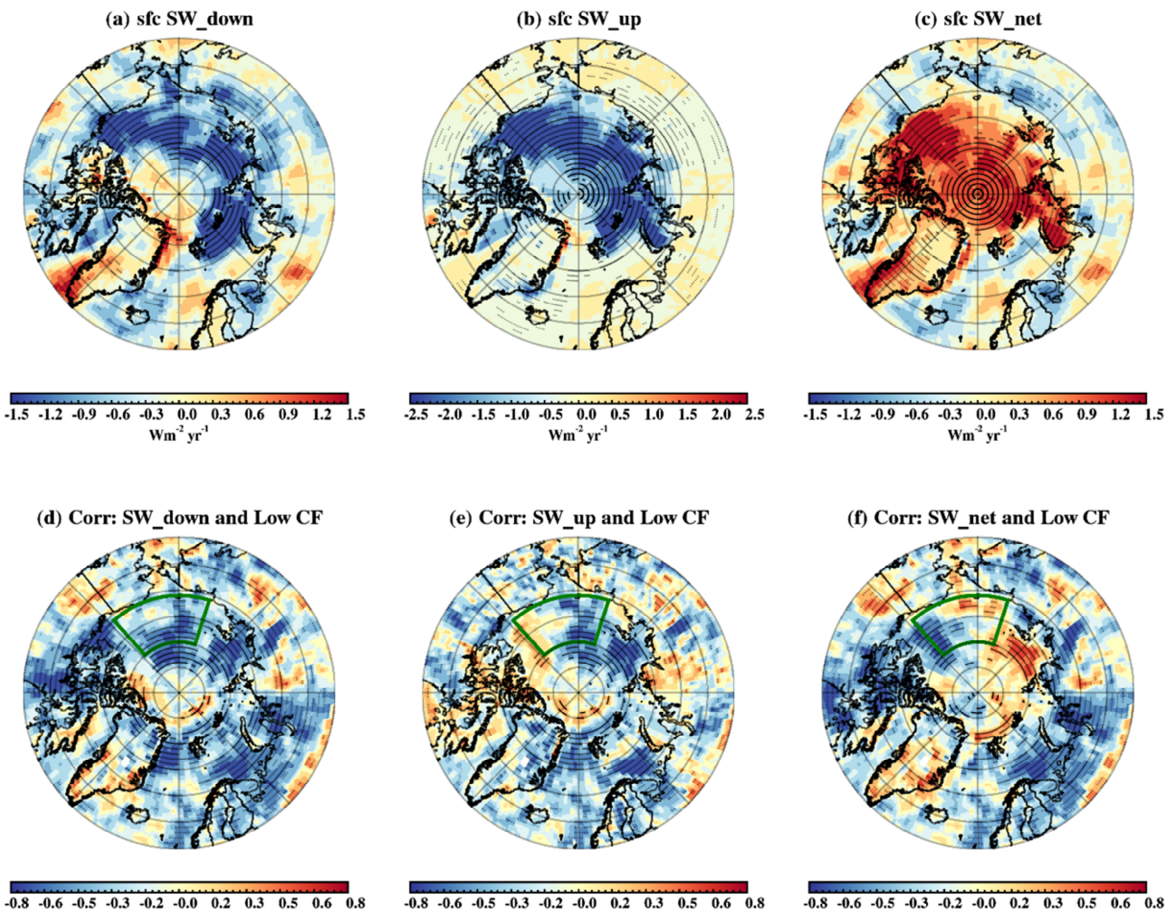
We agree that the reduction in upwelling SW flux is mainly due to the decrease in both downwelling SW flux and surface albedo. Since the magnitude of decreased upwelling SW flux is much larger than that of decreased downwelling SW flux, the surface SW absorption has been increased. In the revision, we provided a more detailed explanation on this issue as below.

Line 111-119: "In summer, the SW flux also plays an important role in controlling sea ice melt. The downwelling SW (SW_down) flux has been reduced (Supplementary Fig.5a) because of an increase in low clouds and a reduction in surface albedo. On the one hand, the increased low CF may reflect more incoming solar radiation and reduce the shortwave flux transmission[13,22,23]. On the other hand, the surface albedo has been decreasing with sea ice melt, which substantially reduces the multiple reflections between surface and clouds[24]. In the meantime, the upwelling SW flux is substantially reduced with a much larger magnitude as a result of decreased SW_down flux and surface albedo, thus leading to an increase in absorbed solar radiation (Supplementary Fig.5)."

line 153: "... enhance the LW_down flux at the surface, ...": but also reduces the SW_down flux at the surface in JJA! I suggest to use the total (LW + SW) flux for your argumentation whether (low) clouds warm or cool the surface.

We totally agree that low clouds can reduce SW_down flux at the surface. As shown in Supplementary Figure 5, the SW_down flux has been reduced, and it also shows the negative correlations with low CF in the northern part of AOF. The increased LW_down flux can be compensated by the reduction in SW_down flux, therefore, the total downwelling (SW+LW) radiative fluxes show a decreasing trend over the AOF (Fig. R1a). Although the magnitude of decreased SW_down flux is slightly larger than the increased LW_down flux, we cannot attribute the changes in SW_down to increased low clouds only. Based on Wendler et al. (2014), the surface downwelling shortwave fluxes depend on incoming solar radiation, cloud albedo as well as surface albedo. The cloud albedo, which strongly depends on the phase of clouds, plays a key role in determining the downwelling shortwave fluxes at the surface (Hu et al. 2010). The surface albedo also becomes very important in the polar regions. As shown in Fig. R2b, the positive correlations between downwelling shortwave flux and the sea ice concentration can be found over large part of the Arctic Ocean. If SW_down flux plays a dominant role to determine sea ice variability, we should expect to see a negative correlation as that observed between LW_down and sea ice (Fig. 1g). Thus, the decreasing downwelling shortwave flux could also be attributed to decreased surface albedo, which substantially reduces the multiple reflections between surface and clouds. Therefore, it is quite challenging to conclude that the low clouds warm or cool the surface based on the decreasing trend of downwelling LW+SW flux only. We provided more discussion on the impacts of cloud cooling effect in the manuscript as below.

Line 274-284: "However, low clouds must work with the surface to determine how much solar radiation could reach the surface. We do see a decrease in JJA SW_down flux during 2000-2016 (Supplementary Fig. 5a), which can compensate the increased LW_down flux in summer. In addition to low clouds, the surface albedo also exerts a large influence on the SW_down flux, particularly in the polar regions. With ice melt, the decreased SW_down flux could be in part explained by a reduction in multiple reflections between clouds and surface[42]. This can be demonstrated by the strong positive pattern correlations between SIC and SW_down flux in June and July (0.57 and 0.65 at 1% significance level). Nevertheless, we cannot rule out the possibility that increase low level clouds may cool the surface through reducing SW_down flux. However, how much of the cloud warming effect can be compensated by the cloud cooling effect remains an open question and needs further investigation."



Supplementary Figure 5. (a) Linear trend of JJA (a) downwelling shortwave (SW_down) flux, (b) upwelling shortwave (SW_up) flux, and (c) net shortwave (SW_net) flux at the surface during 2000-2016 in CERES-EBAF Ed4.0 satellite product. (d) Correlations between detrended JJA SW_down flux and low cloud fraction (CF) (e) Correlations between detrended JJA SW_up flux and low CF. (f) Correlations between detrended JJA SW_net flux and low CF.

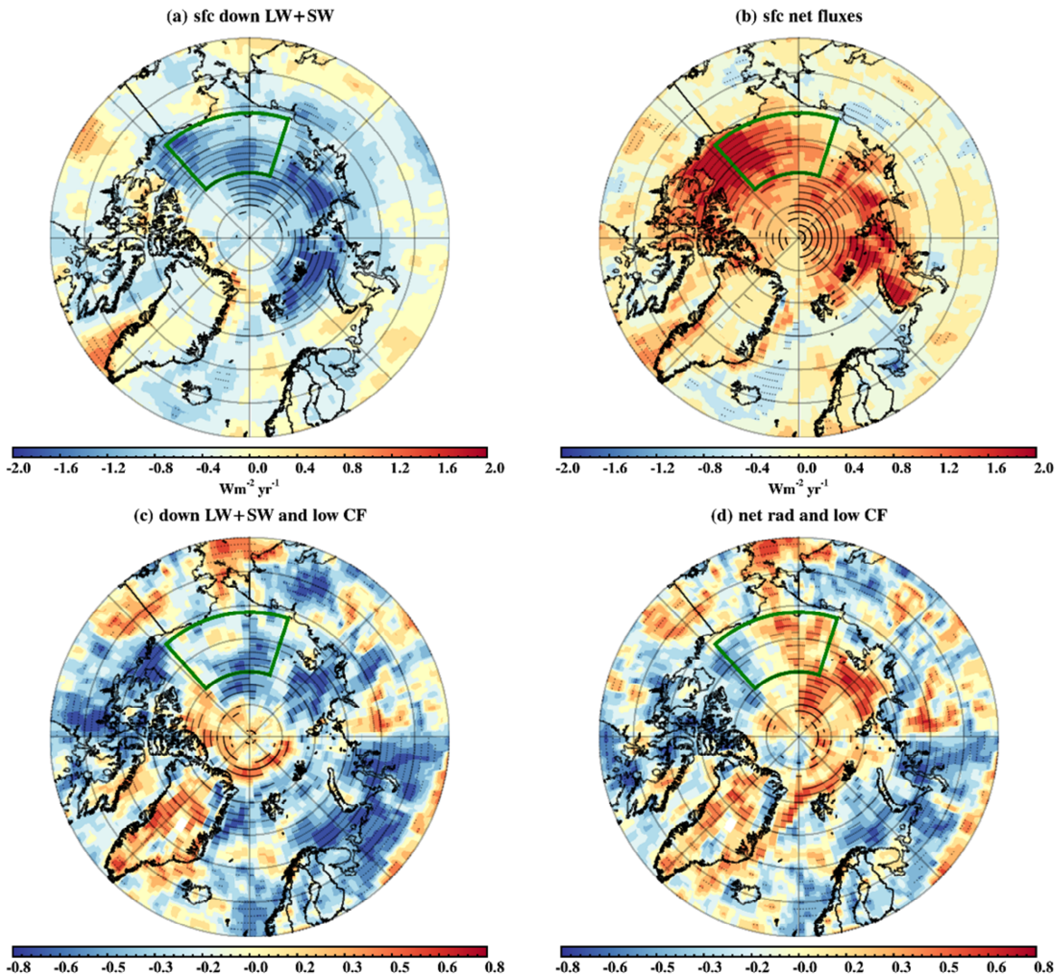


Figure R1. Linear trend of JJA (a) downwelling shortwave (SW_down) and longwave (LW_down) flux and (b) net radiative fluxes at the surface during 2000-2016 in CERES-EBAF Ed4.0 satellite product. (c) Correlations between detrended JJA surface SW_down+LW_down flux and low cloud fraction (CF) (d) Correlations between detrended JJA surface net radiative flux and low CF.

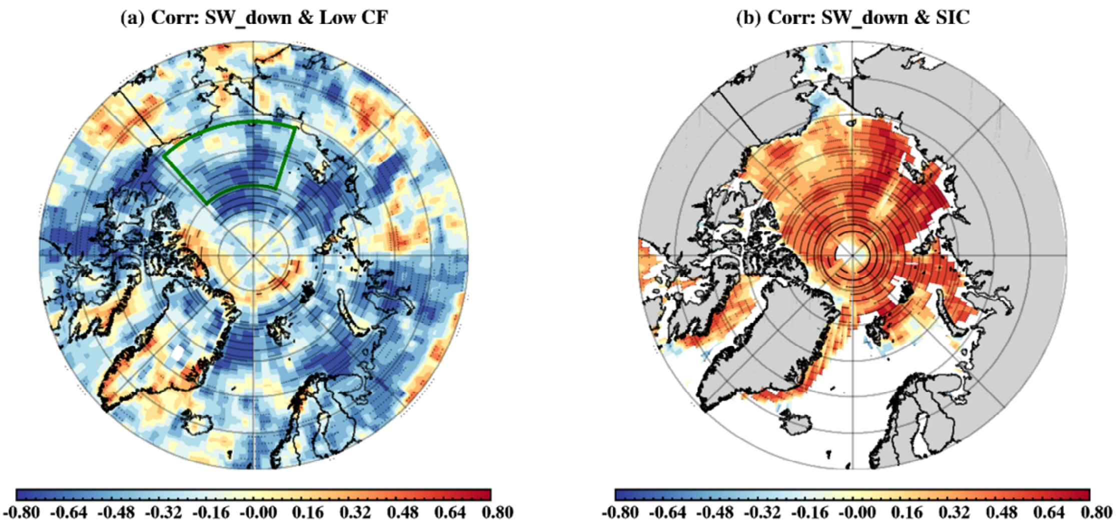


Figure R2. (a) Correlations between detrended JJA SW_down flux and low cloud fraction (CF) (b) Correlations between detrended JJA SW_down flux and sea ice concentration (SIC).

References:

Wendler, G., Moore, B., Hartmann, B., Stuefer, M., & Flint, R. (2004). Effects of multiple reflection and albedo on the net radiation in the pack ice zones of Antarctica. *Journal of Geophysical Research: Atmospheres, 109*(D6).

Hu, Y., *et al.* (2010). Occurrence, liquid water content, and fraction of supercooled water clouds from combined CALIOP/IIR/MODIS measurements. *Journal of Geophysical Research: Atmospheres, 115*(D4).

line 223: "We only nudge the winds above 850 hPa to ERA-I because we would like to 224 give the model some freedom to behave below 850 hPa.": Would that be a sufficient amount of freedom to let the model play out its own physics? Would you get very different results if you nudge winds above 800, 750, ... 500? With this setting, it is not obvious (to me, at least) if the model has enough degrees of freedom to potentially deviate from the observed low cloud fraction trends.

Thanks for your suggestions. We conducted three additional model experiments to check whether the cloud, radiation and sea ice responses are consistent when we nudge the winds at different levels. We used same model setup as Exp-5 in the manuscript, with initial conditions from year 2000 in CESM-LE historical simulation member 23 (b.e11.B20TRC5CNBDRD.f09_g16.023, but nudged the wind fields at different levels (above 820 hPa, 763 hPa, 691 hPa in model's hybrid sigma pressure coordinate, respectively). Overall, the responses in JJA low cloud fraction (Fig. R3), surface LW_down flux (Fig. R4) and September sea ice concentration (Fig. R5) are quite consistent in both spatial coverage and magnitudes across different experiments. Compared to Exp-5 (860 hPa), the Exp-5 (691 hPa) shows a relatively smaller changes in low cloud fraction, particularly over the East Siberian Sea (Fig. R3d). Therefore, both increased LW_down flux (Fig. R4d) and decreased sea ice (Fig. R5d) in Exp-5 (691 hPa) exhibit changes in a smaller magnitude over the marginal seas relative to the Exp-5 (860 hPa).

These relatively weak responses in these new nudging runs are consistent with our understanding of the dynamics. According to Holton and Hakim (2012), the vertical motion depends on the vertical wind shear and the horizontal gradient of absolute vorticity, while the vertical wind shear is strongly determined by the surface roughness and friction. Therefore, we would expect to see weaker sinking motion and associated responses in other fields over the Chuckchi and Beaufort Seas if we put less constraints at the lower troposphere in the model. Overall, we believe that nudging above 860 hPa is a reasonable choice since the formation of low-level clouds mainly occurs below that level. Thus, a sufficient amount of freedom is allowed to let the model play out its own dynamics and physics. To be more clear, we modified and added more discussion about this issue in the manuscript:

Line 228-232: “Here we only nudge the winds above 860 hPa in model’s hybrid sigma pressure coordinate to ERA-I because we would like to give the model some freedom to behave below 860 hPa. We also conducted additional sensitivity experiments, in which the wind fields are nudged above different levels (820, 763 and 691 hPa). The results from these sensitivity experiments are quite consistent, indicating 860 hPa is reasonably selected.”

Reference:

Holton, J. R. and Hakim G.J. (2012). An Introduction to Dynamic Meteorology (Vol. 88, 5th Edition). Academic Press.

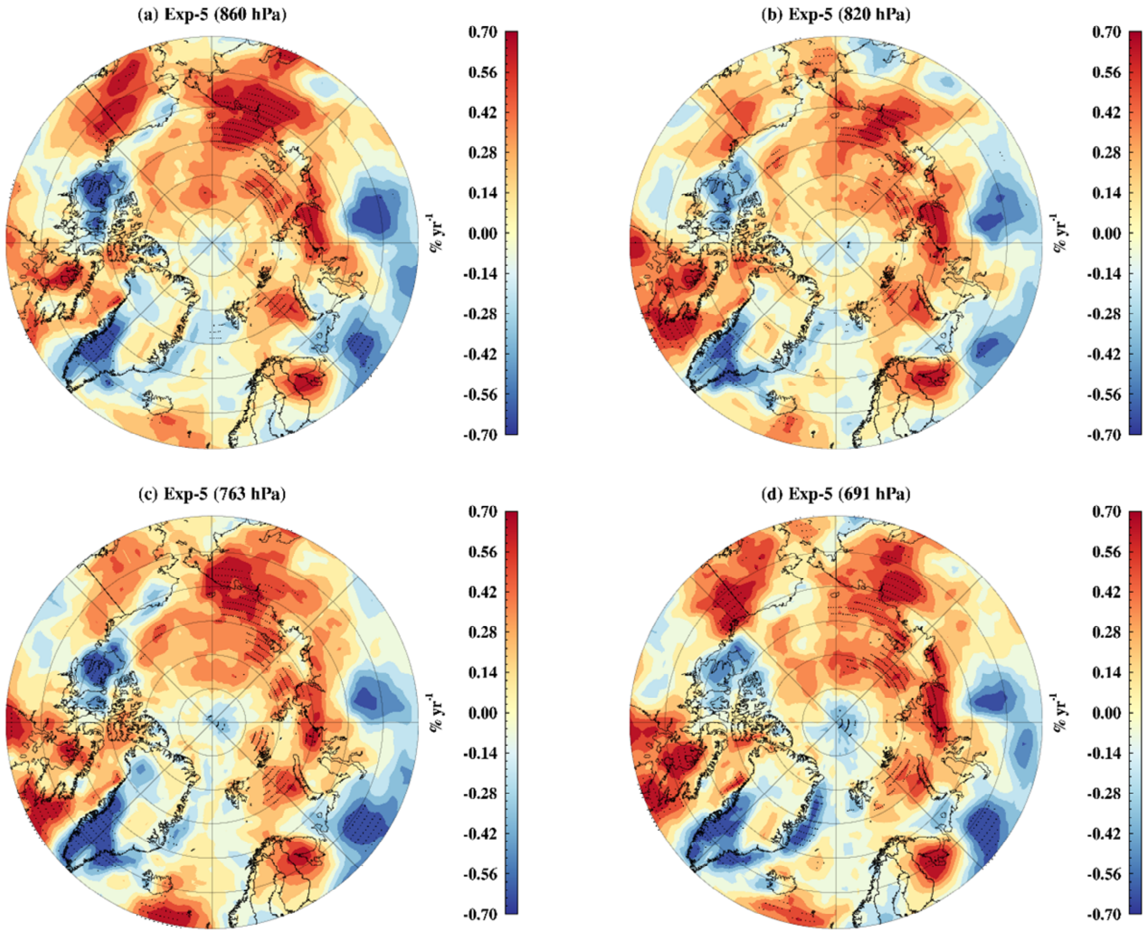


Figure R3. The linear trend of JJA low cloud fraction (below 700 hPa) during 2000-2016 from (a) Exp-5 with wind fields being nudged above 860 hPa; (b) Exp-5 with wind fields being nudged above 820 hPa; (c) Exp-5 with wind fields being nudged above 763 hPa; (d) Exp-5 with wind fields being nudged above 691 hPa.

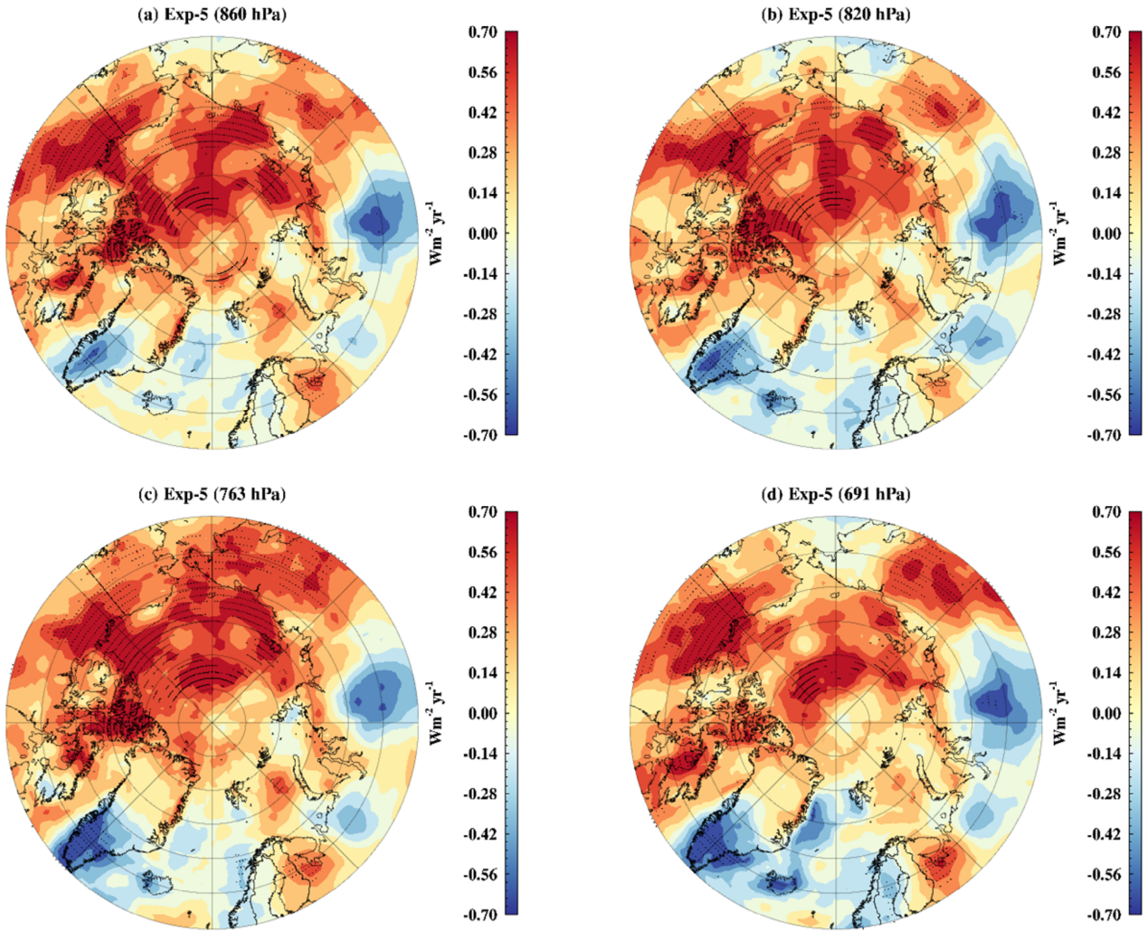


Figure R4. The linear trend of JJA downward longwave flux at the surface during 2000-2016 from (a) Exp-5 with wind fields being nudged above 860 hPa; (b) Exp-5 with wind fields being nudged above 820 hPa; (c) Exp-5 with wind fields being nudged above 763 hPa; (d) Exp-5 with wind fields being nudged above 691 hPa.

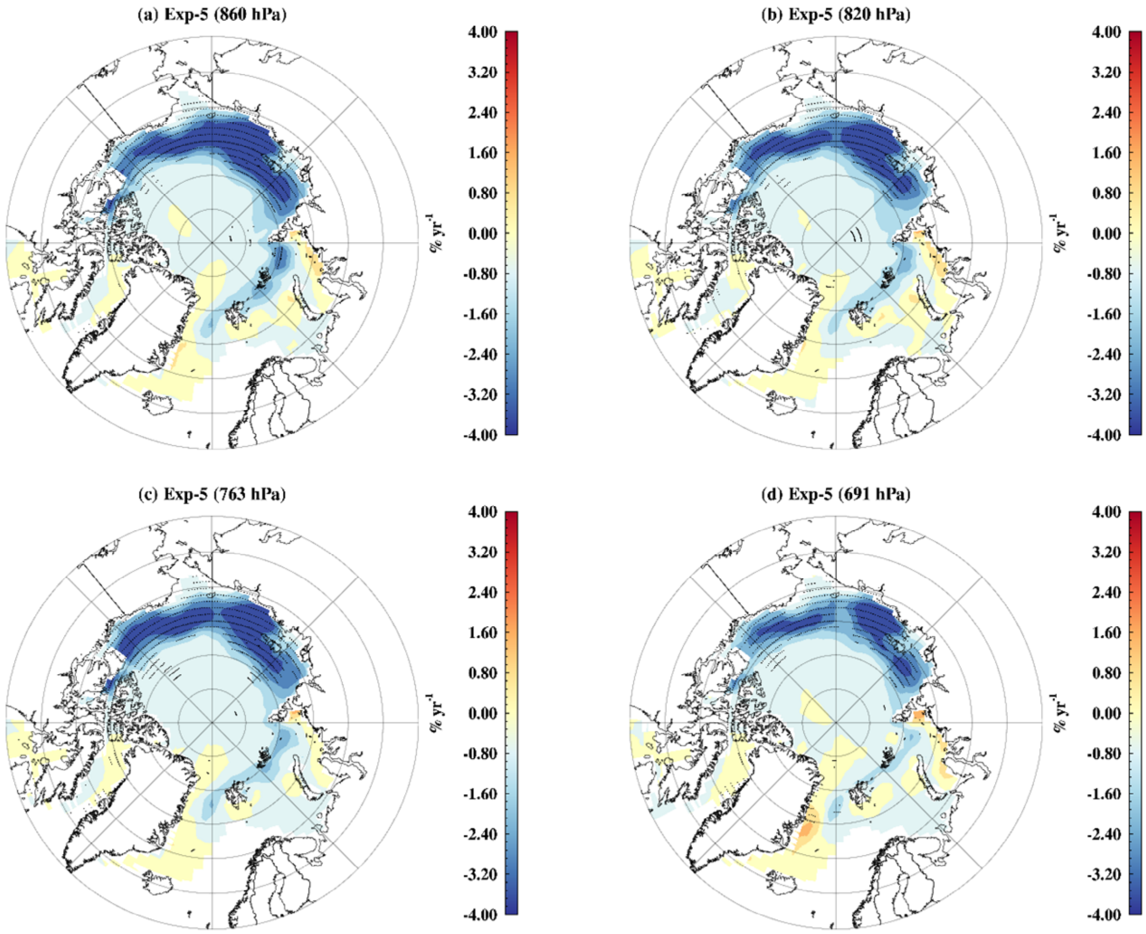


Figure R5. The linear trend of September sea ice concentration in the Arctic during 2000-2016 from (a) Exp-5 with wind fields being nudged above 860 hPa; (b) Exp-5 with wind fields being nudged above 820 hPa; (c) Exp-5 with wind fields being nudged above 763 hPa; (d) Exp-5 with wind fields being nudged above 691 hPa.

line 238: "... and enhanced LW_down flux ...": again, this could potentially be (over)compensated by reduced SW_down flux.

As suggested, we added another panel (Fig.4f) in Figure 4 to show the changes in SW_down flux. And we modified this statement as below.

Line 244-249: "More abundant moisture favors the formation of clouds, thus the increased low CF (Fig. 4d), enhanced LW_down (Fig. 4e) and decreased SW_down flux (Fig.4f) can be found across nearly the entire Arctic Ocean. Note that the low CF (0.7%yr^{-1}) and LW_down flux (0.7 Wm^{-2} yr^{-1}) show comparable magnitude of changes relative to the observations, while the changes in SW_down flux (−0.7 Wm^{-2} yr^{-1}) are almost half of satellite retrievals (−1.5 Wm^{-2} yr^{-1})."

We agree that increase in LW_down flux can be compensated by reduction in SW_down flux, as their magnitude of changes are almost comparable in the nudging simulations. However, as mentioned earlier, the decreased SW_down flux could also be attributed to decreased surface albedo with sea ice melt (Fig. 4g), which substantially reduces the multiple reflections between surface and clouds. Therefore, we also provided some discussion about this issue in the Conclusions and Discussion section:

Line 274-284: "However, low clouds must work with the surface to determine how much solar radiation could reach the surface. We do see a decrease in JJA SW_down flux during 2000-2016 (Supplementary Fig. 5a), which can compensate the increased LW_down flux in summer. In addition to low clouds, the surface albedo also exerts a large influence on the SW_down flux, particularly in the polar regions. With ice melt, the decreased SW_down flux could be in part explained by a reduction in multiple reflections between clouds and surface[42]. This can be demonstrated by the strong positive pattern correlations between SIC and SW_down flux in June and July (0.57 and 0.65 at 1% significance level). Nevertheless, we cannot rule out the possibility that increase low level clouds may cool the surface through reducing SW_down flux. However, how much of the cloud warming effect can be compensated by the cloud cooling effect remains an open question and needs further investigation."

line 261: "... of low clouds, which are closer to the surface and thus more efficient to regulate the surface temperature through LW radiation37.": but low clouds are already optically thick and provide a strong solar cooling. Reference 37 is based on a field campaign in August + September. Low clouds in June + July might behave differently due to higher sun angles. Also, reference 37 states only a small positive LW cloud radiative forcing: "enhanced emission of downwelling longwave radiation from low clouds with increasing cloud liquid water yielded small, but slightly positive net radiation"

Thanks for pointing out this issue. Our first argument here is that compared to other type of clouds, low clouds are closer to the surface and thus more effectively to modulate the surface temperature. Therefore, we modified this statement in the manuscript as below:

Line 269-271: "First, most of studies focus on total clouds[21-23] instead of low clouds, which are closer to the surface and thus more efficient to regulate the surface temperature through the modulation of surface radiative fluxes[41]."

Reviewer #2 (Remarks to the Author):

This study mainly focuses on the cause and consequence of summertime Arctic low-level clouds which is increasing in recent decades. More specifically, the authors tackle the two questions:
1) How is recent intensification of upper-level Anticyclone in the Arctic linked to the increase in low-level clouds?
2) What is the role of low-level clouds in the summer sea-ice melt?

To answer the two questions above, the authors analyzed satellite-based observations, reanalysis and model simulation data. Both questions are quite interesting and timely because, in the literature, intense debate is underway about the role of low-level clouds in the summer sea-ice melt. A key chain of explanation starts from the existence of upper-level Anticyclone near the Greenland causing sinking motion and adiabatic warming. The authors suggest these are helpful condition for the formation of low-level clouds. Enhanced downwelling longwave radiation by low-level clouds play a key role for summer ice-melt. Coupled model used in this study doesn't seem to properly capture this observed relation. But, specially designed nudging experiments designed to prescribe the role of upper-level Anticyclone captures the observed linkages well supporting the role of upper-level circulation for the formation of low-level clouds.

I think the topic is important and manuscript is generally written very well. However, before I suggest a positive recommendation, I would raise several critical issues that the autors need to overcome.

1. In Fig. 1, the Anticyclone centers do not coincide with the upward motions in Fig. 2c. If Anticyclone is a main driver of sinking motion, why the two do not coincide? In otherwords, what is the origin of the vertical motions over Chukchi and beaufort in Fig. 2e? Are they driven dynamically or thermodynamically? I believe the authors need to address this issue more carefully.

According to Holton and Hakim (2012), the sinking motion does not necessarily coincide with the anticyclonic center. The vertical motion depends on the vertical wind shear and the horizontal gradient of absolute vorticity.

Following the equation (6.67) shown in Figure R1, we can roughly estimate the sign of of ω trend and its main action center in the Arctic. To simplify the problem, we just estimate the vertical velocity at 700 hPa by considering the x-direction component since this is the leading term in the equation. Therefore, the equation can be expressed as $\omega \propto (-\frac{\partial u}{\partial p} \times \frac{\partial \xi}{\partial x})$, where $\xi = \xi_g + f$. Here, we use this equation to estimate the trend of omega derived from trends of winds and vorticity in ERA-Interim reanalysis. Raw u, v instead of geostrophic winds are used to simplify the calculations. Otherwise too large numerical errors will destroy the calculation if we calculate geostrophic winds from geopotential. Figure R3 shows the linear trends of u-component wind at 530 and 850 hPa. The positive linear trend of u-wind at lower level (850 hPa) is much larger than that at higher level (530 hPa), therefore, we have $\frac{\partial u}{\partial p} > 0$ over the AOF. In Fig. R4c, we have $\frac{\partial \xi}{\partial x} < 0$ at 700 hPa because the absolute vorticity tends to be more negative from the left side to the right side within the AOF's box. Therefore, the sign of $(-\frac{\partial u}{\partial p} \times \frac{\partial \xi}{\partial x})$ is positive, which means there is a trend favoring stronger sinking motion over the AOF. This is consistent with what we see from ERA-Interim in Figure R5.

Therefore, the sinking motion is located over the place with a large positive product of horizontal gradient of absolute vorticity and the vertical wind shear (in the p coordinate). The latter one is also strongly affected by the surface roughness and friction. That's why we can even observe a stronger downward motion at the 850 hPa (Figure R5) where the vertical shear is significant ($\frac{\partial u}{\partial p}$). To be more clear, we made slight changes to this statement in the manuscript:

Line 126-128:"The increased Z200 associated with the anticyclonic circulation aloft is found to be highly correlated with summertime vertical motion in the lower troposphere[12], that is mainly confined with the AOF."

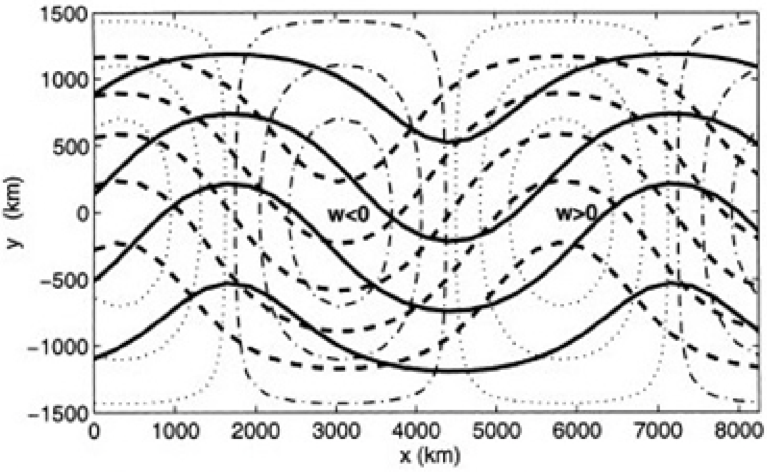


Fig. 6.12 Schematic 500-hPa height contours (solid lines), isotherms (dashed lines), and vertical motion field ($w > 0$ dash-dot lines, $w < 0$ dotted lines) for a developing synoptic-scale system. Upward motion occurs where vorticity decreases moving left to right along an isotherm, and downward motion occurs where vorticity decreases moving left to right along an isotherm.

$$w \propto \left\{ \left[-\frac{\partial \mathbf{V}_g}{\partial z} \bullet \nabla (\zeta_g + f) \right] \quad \begin{matrix} < 0 \text{ east of the 500-hPa ridge} \\ > 0 \text{ east of the 500-hPa trough} \end{matrix} \right.$$

The Sutcliffe form of the QG omega (vertical motion) equation includes advection of the planetary vorticity

$$\left(\nabla^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega \approx \frac{f_0}{\sigma}\left[\frac{\partial \mathbf{V}_g}{\partial p} \cdot \nabla_h \left(\frac{1}{f_0}\nabla^2\Phi + f\right)\right] \qquad (6.67)$$

Figure R1. Figure 6.12 (top),the equation for vertical motion in z-coordinate (middle) and p-coordinate (bottom) from Holton and Hakim (2012).

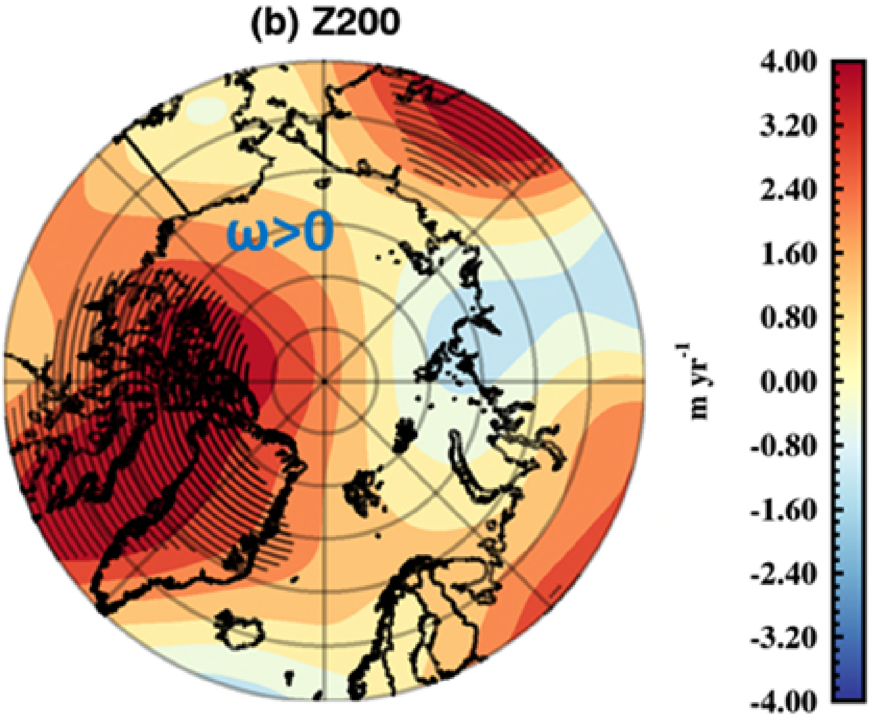


Figure R2. The linear trend of Z200 during 2000-2016 in ERA-Interim and the location of sinking motion based on theory in Holton and Hakim (2012).

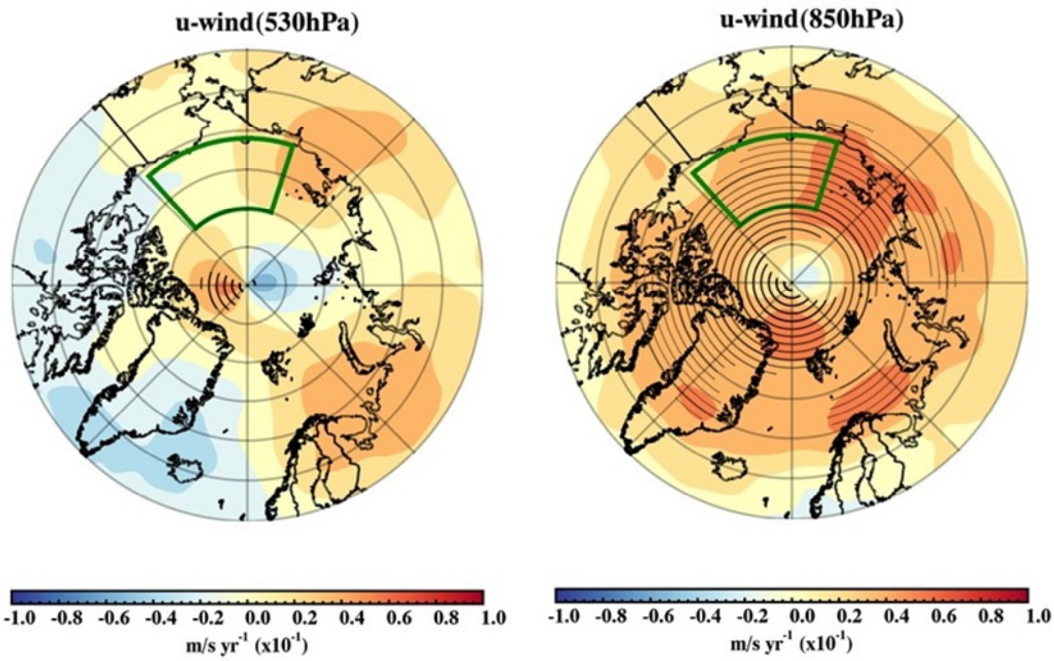


Figure R3. The linear trend of u-component wind at 530 hPa (left) and 850 hPa during 2000-2016 in ERA-Interim reanalysis. The green box marks the area with the most significant increasing trend of JJA low CF. This area is defined as area of focus (AOF, 71˚-80˚N, 162˚-222˚) in this study.

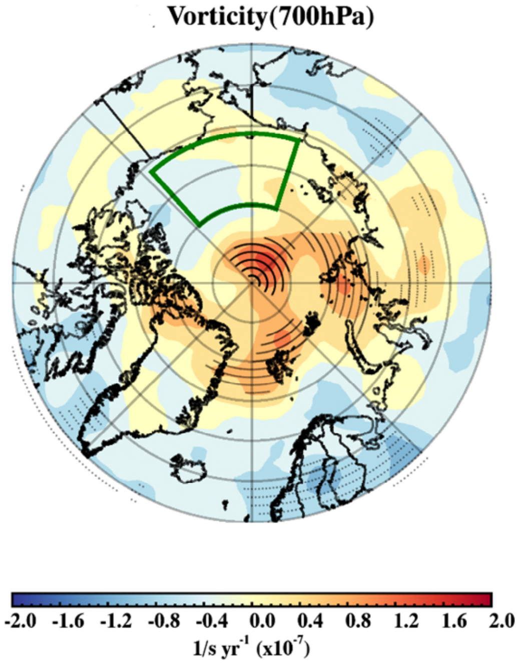


Figure R4. The linear trend of absolute vorticity at 700 hPa during 2000-2016 in ERA-Interim reanalysis. The green box marks the area with the most significant increasing trend of JJA low CF. This area is defined as area of focus (AOF, 71˚-80˚N, 162˚-222˚) in this study.

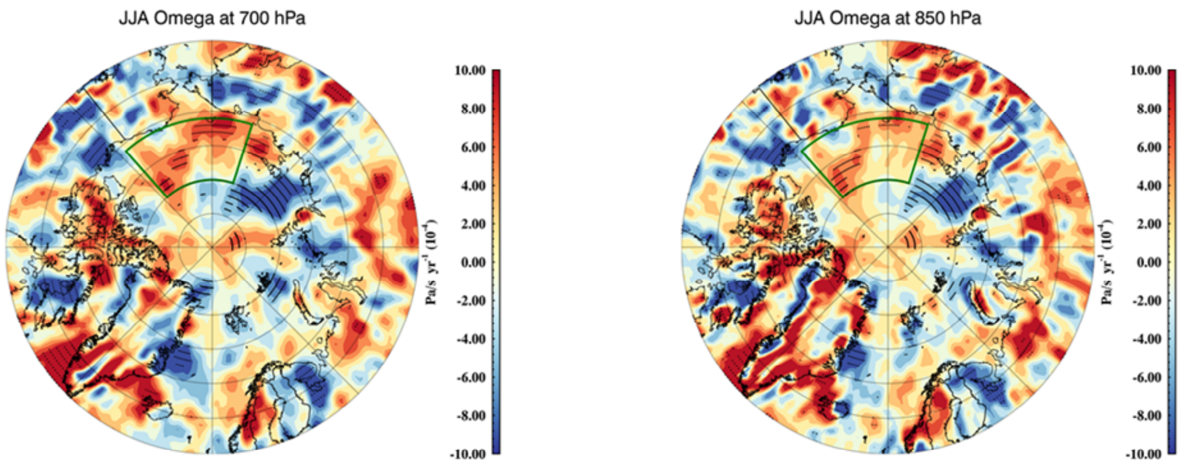


Figure R5. The linear trend of vertical velocity at (left) 700 hPa and (right) 850 hPa during 2000-2016 in ERA-Interim reanalysis. The green box marks the area with the most significant increasing trend of JJA low CF. This area is defined as area of focus (AOF, 71˚-80˚N, 162˚-222˚) in this study.

Reference:

Holton, J. R. and Hakim G.J. (2012). An Introduction to Dynamic Meteorology (Vol. 88, 5th Edition). Academic Press.

2. The short-wave reflection by increased low-level cloud should be treated equally in the manuscript (not in supplementary). Low-cloud has both positive and negative impact for sea-ice melt. The authors treat both issues in balance.

Thanks for your suggestions. We totally agree that low clouds can warm or cool the surface through different types of radiative fluxes. We added another panel (Fig.4f) in Figure 4 to show the changes in SW_down flux and provided more discussion about this addition. As for other figures, we prefer to not add additional panels because they are quite busy in the current manner. However, we provided more discussion about the SW_down flux and cloud shortwave effect in the main text as below.

Line 111-119: "In summer, the SW flux also plays an important role in controlling sea ice melt. The downwelling SW (SW_down) flux has been reduced (Supplementary Fig.5a) because of an increase in low clouds and a reduction in surface albedo. On the one hand, the increased low CF may reflect more incoming solar radiation and reduce the shortwave flux transmission[13,22,23]. On the other hand, the surface albedo has been decreasing with sea ice melt, which substantially reduces the multiple reflections between surface and clouds[24]. In the meantime, the upwelling SW flux is substantially reduced with a much larger magnitude as a result of decreased SW_down flux and surface albedo, thus leading to an increase in absorbed solar radiation (Supplementary Fig.5)."

Line 244-249: "More abundant moisture favors the formation of clouds, thus the increased low CF (Fig. 4d), enhanced LW_down (Fig. 4e) and decreased SW_down flux (Fig.4f) can be found across nearly the entire Arctic Ocean. Note that the low CF (0.7%yr^{-1}) and LW_down flux (0.7 $Wm^{-2}\,yr^{-1}$) show comparable magnitude of changes relative to the observations, while the changes in SW_down flux (−0.7 $Wm^{-2}\,yr^{-1}$) are almost half of satellite retrievals (−1.5 $Wm^{-2}\,yr^{-1}$)."

Line 274-284: "However, low clouds must work with the surface to determine how much solar radiation could reach the surface. We do see a decrease in JJA SW_down flux during 2000-2016 (Supplementary Fig. 5a), which can compensate the increased LW_down flux in summer. In addition to low clouds, the surface albedo also exerts a large influence on the SW_down flux, particularly in the polar regions. With ice melt, the decreased SW_down flux could be in part explained by a reduction in multiple reflections between clouds and surface[42]. This can be demonstrated by the strong positive pattern correlations between SIC and SW_down flux in June and July (0.57 and 0.65 at 1% significance level). Nevertheless, we cannot rule out the possibility that increase low level clouds may cool the surface through reducing SW_down flux. However, how much of the cloud warming effect can be compensated by the cloud cooling effect remains an open question and needs further investigation."

3. In Supplementary Fig. 5, both upwelling and downwelling shortwave fluxes are decreasing especially in the Chukchii and East Siberian Sea. What is the implication?

The downwelling shortwave fluxes at the surface are decreasing because of increased low clouds and reduced surface albedo with ice melt. Based on Wendler et al. (2014), the surface downwelling shortwave fluxes depend on incoming solar radiation, cloud albedo as well as surface albedo. In our case, the increased low clouds may reflect more shortwave radiation to the space, leaving less solar radiation reaching at the surface. This can be demonstrated from the negative correlations between low clouds and downwelling shortwave flux shown in Fig. R6a. On the other hand, the surface albedo becomes very important in the polar regions when we consider the downwelling shortwave flux. As shown in Fig. R6b, the positive correlations between downwelling shortwave flux and sea ice concentration can be found over large part of the Arctic Ocean. Thus, the decreasing downwelling shortwave flux could also be attributed to decreased surface albedo, which substantially reduces the multiple reflections between surface and clouds.

Since both downwelling shortwave flux and surface albedo have been reduced, it is not surprising to see the decrease in upwelling shortwave flux as well. In this case, the majority of shortwave flux has been absorbed by the dark ocean. We provided more detailed explanation on this issue in the manuscript as below.

Line 274-284: "However, low clouds must work with the surface to determine how much solar radiation could reach the surface. We do see a decrease in JJA SW_down flux during 2000-2016 (Supplementary Fig. 5a), which can compensate the increased LW_down flux in summer. In addition to low clouds, the surface albedo also exerts a large influence on the SW_down flux, particularly in the polar regions. With ice melt, the decreased SW_down flux could be in part explained by a reduction in multiple reflections between clouds and surface[42]. This can be demonstrated by the strong positive pattern correlations between SIC and SW_down flux in June and July (0.57 and 0.65 at 1% significance level). Nevertheless, we cannot rule out the possibility that increase low level clouds may cool the surface through reducing SW_down flux. However, how much of the cloud warming effect can be compensated by the cloud cooling effect remains an open question and needs further investigation."

References:

Wendler, G., Moore, B., Hartmann, B., Stuefer, M., & Flint, R. (2004). Effects of multiple reflection and albedo on the net radiation in the pack ice zones of Antarctica. *Journal of Geophysical Research: Atmospheres, 109*(D6).

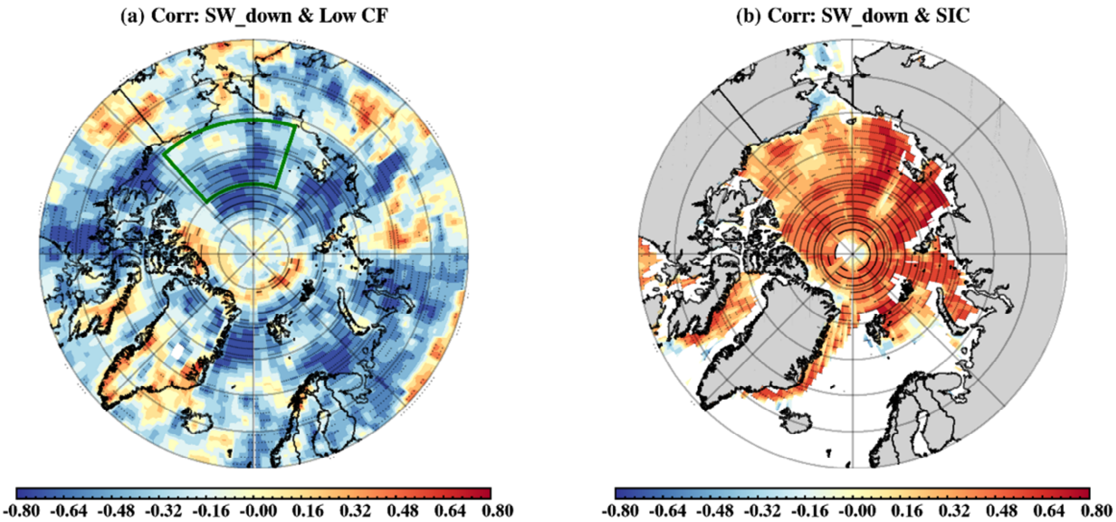


Figure R6. (a) Correlations between detrended JJA SW_down flux and low cloud fraction (CF) (b) Correlations between detrended JJA SW_down flux and sea ice concentration.

4. In Fig. 4, net SW is increasing as much as downwelling LW. Are Fig. 4e and 4g consistent? How can both increase in spite of cloud reflection?

We used different color scale in the original version, which probably caused the confusion.

Actually, the range for surface LW_down flux (Fig. 4e) is −0.7-0.7 W/m^2/yr, while the range for surface net SW flux (Fig. 4h) is −1.5-1.5 W/m^2/yr. Therefore, the magnitude of increasing net SW flux is larger than that of increasing LW_down flux. We do see that the downwelling SW flux has been decreasing in the early 21st century (Supplementary Fig.5a). However, the upwelling SW flux is substantially reduced (with larger magnitude of changes) because of decreased surface albedo and thus all these changes leads to an increase in absorbed solar radiation (Supplementary Fig.5b). In this case, the net SW flux is more likely to be affected by surface conditions. Therefore, we believe that the increased LW CRE enhances the ice melt that in turn could trigger the pan-Arctic ice-albedo feedback.

5. In L167 or L249, why do the authors regard Z200 Anticyclone natural variability? Provide a plausible explanation.

To better demonstrate this point, we plotted linear trends of JJA Z200 in 40 ensemble members and the 40-member ensemble mean from CESM-Large Ensemble (CESM-LE) project and ERA-I reanalysis, as shown in Figure R7. The simulated JJZ 200 linear trends differ considerably across the 40 members in the CESM-LE. Since all 40 ensemble members use the same model and same external forcing with only small round-off level differences in their atmospheric initial conditions in 1920, their spreads in Z200 linear trends can only be attributed to internally generated climate variability (Kay et al., 2015). The comparison between ERA-I with each ensemble member in CESM-LE and the ensemble mean suggests that the observed positive linear trends of JJA Z200 in eastern Canada and Greenland in the early 21st century are most likely due to internal climate variability since only member 3 appears to outperform than all others to capture the observed trend by chance.

In addition, to determine the role of anthropogenic warming on the high-latitude circulation, Ding et al. (2017) also examined the ensemble average trends in JJA geopotential height and winds at 200 hPa over the Arctic region from the historical forcing simulations of the Coupled Model Intercomparison Project Phase 5 (CMIP5) and the CESM-Large Ensemble Project (LENS). The average over the 26-member ensemble in CMIP5 and the 30-member ensemble in LENS display positive trends in Z200 over 1979 to 2014 (Fig. R8). Unlike ERA-I, which show barotropic, anticyclonic circulation trends over Greenland from the surface in the upper troposphere, the circulation trends in CMIP5 and LENS ensembles are weak and unorganized in the Arctic. Therefore, all these evidences suggest that internal atmospheric variability is an important contributor to the recent observed circulation trend in the high latitudes.

One possible driver of this high pressure trend could originate from the tropics where the Interdecadal Pacific Oscillation exhibiting a cooling sea surface temperature (SST) trend in the Eastern Pacific in past decades may generate a teleconnection propagating toward the Arctic. Several early papers (Ding et al. 2019, Baxter et al. 2019) have extensively study this linkage. Thus, we just briefly discussed this idea in our paper since the main focus of this study is the role of circulation in shaping cloud variability over the AOF.

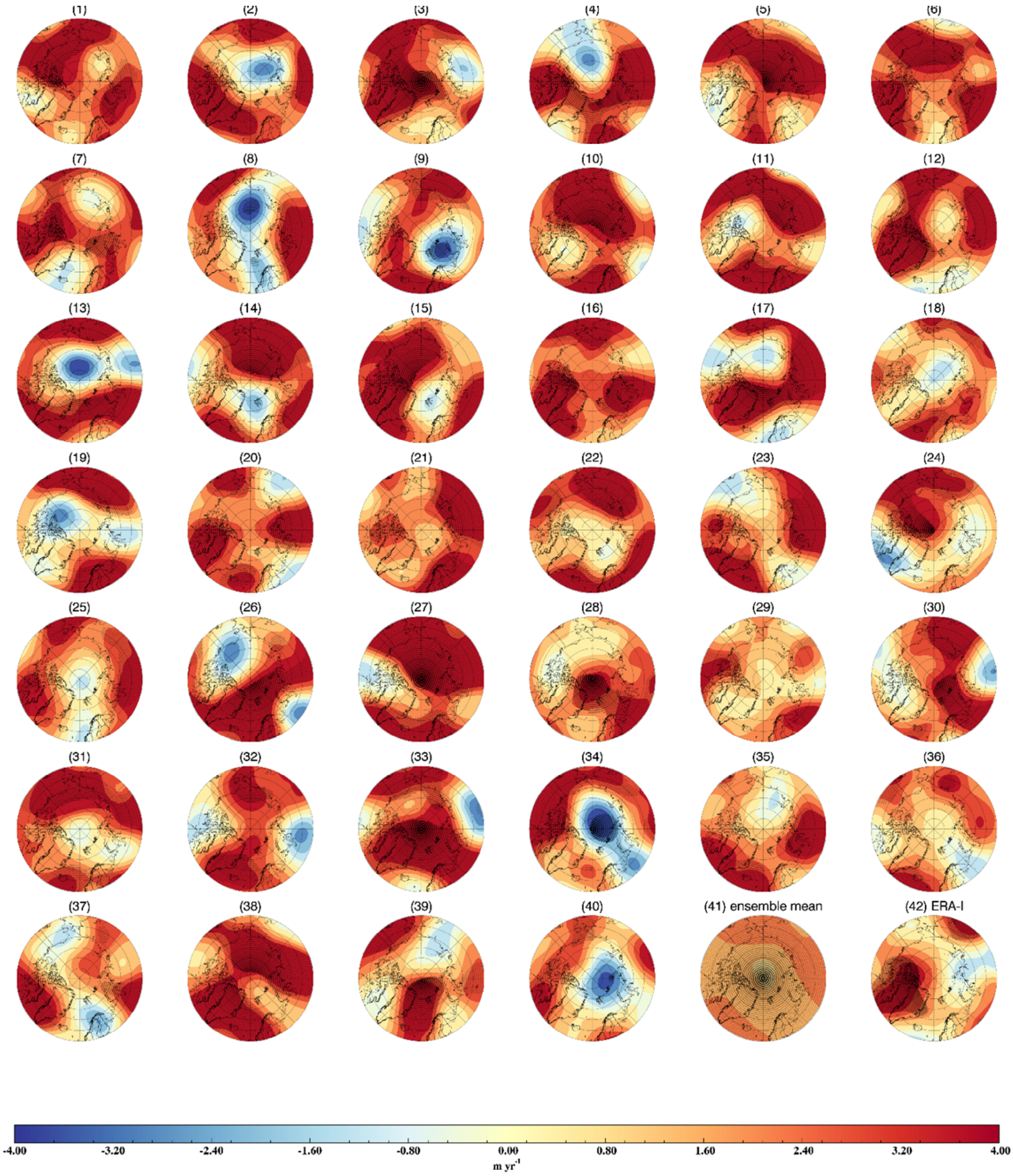


Figure R7. Linear trends of JJA Z200 in (1)-(40) each ensemble member, (41) 40-member ensemble mean during 2006-2022 from CESM-Large Ensemble RCP8.5 simulation, and (42) ERA-I reanalysis.

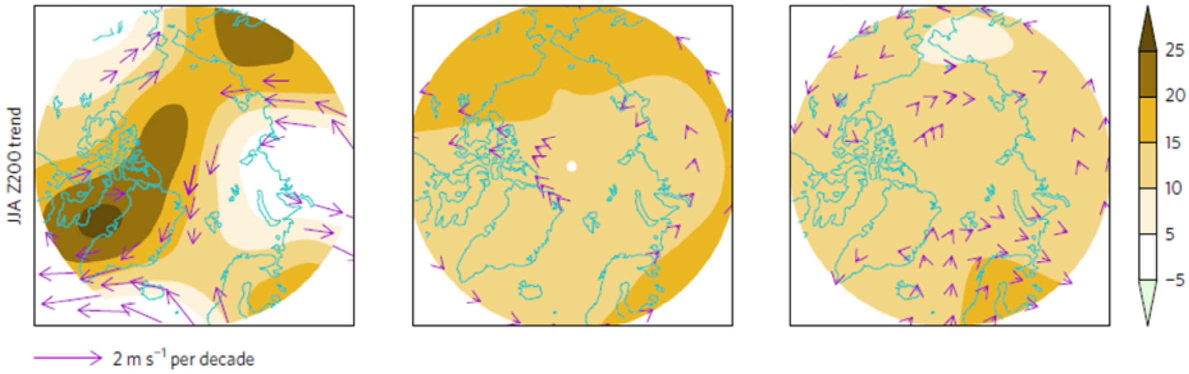


Figure R8. Linear trends of JJA Z200 (m per decade) and zonal and meridional winds from (a) ERA-I, (b) the 26-model ensemble mean from CMIP5 project, and (c) 30-member ensemble mean from CESM-Large Ensemble (LENS) project (Adapted from Figure 4 of Ding et al. 2007, Nat. Clim. Change).

References:

Baxter, I. *et al.* How tropical Pacific surface cooling contributed to accelerated sea ice melt from 2007 to 2012 as ice is thinned by anthropogenic forcing. *J. Clim.* 32(24), 8583-8602 (2019).

Ding, Q. *et al.* Influence of high-latitude atmospheric circulation changes on summertime Arctic sea ice. *Nat. Clim. Change*, ***7*(4),** 289-295 (2017).

Kay, J. E. *et al.* The Community Earth System Model (CESM) large ensemble project: A community resource for studying climate change in the presence of internal climate variability. *Bull. Am. Meteor. Soc.* **96(8),** 1333-1349 (2015).

6. L189 1780 20-year long pseudo ensemble members? Please explain more.

The method to construct the pseudo-ensemble is originally from E. Rosenblum and I. Eisenman (2017). One advantage of this method is to maximize the sample size of an ensemble out of a long continuous integration. In this study, we have 1800 years pre-industrial simulation in hand. To form the pseudo-ensemble, we trim it into many separate consecutive 20-year long members. For example, the first member is from year 1-20, and the second covers year 2-21, … and the last one comes from year 1781-1800. Since each member is not completely independent from neighboring members that share some overlapping years with it, the whole group containing a total of 1780 members is called pseudo-ensemble. We have cited the original paper Rosenblum and Eisenman (2017) in the method part to let readers know the original source of this method.

Reference:

Rosenblum E. and I. Eisenman. Sea ice trends in climate models only accurate in runs with biased global warming. *J. Clim.* **30,** 6265-6278 (2017).

Decision letter and referee reports: second round

Date: 23rd Dec 20

Dear Dr Ding,

Your manuscript titled "The summertime low clouds: bridging large-scale circulation and sea ice variations over the Arctic" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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Please review our specific editorial comments and requests regarding your manuscript in the attached "Editorial Requests Table". Please outline your response to each request in the right hand column. Please upload the completed table with your manuscript files.

If you have any questions or concerns about any of our requests, please do not hesitate to contact me.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Heike Langenberg, PhD

Chief Editor
Communications Earth and Environment

On Twitter: @CommsEarth

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

All concerns have been carefully addressed and the manuscript has been revised accordingly. No further objections from my side. That the reduced SW_down at the surface is so much driven by surface albedo was not what I had thought. However, I trust the authors have properly checked for that in their additional model runs.
I appreciate the detailled responses to my review points.

Reviewer #2 (Remarks to the Author):

I am delighted with the manuscript in its current form.
The authors carefully tackled the issues raised by me and, by this effort, the bridging role of Arctic low cloud is much clarified. Actually, I learned a lot from the authors' responses. Thanks to the authors. Now, I have no further comments and recommend accept as is.

Author Responses: second round

Response to reviewers

Reviewer #1 (Remarks to the Author):

All concerns have been carefully addressed and the manuscript has been revised accordingly. No further objections from my side. That the reduced SW_down at the surface is so much driven by surface albedo was not what I had thought. However, I trust the authors have properly checked for that in their additional model runs. I appreciate the detailled responses to my review points.

Thanks so much for your comments. As mentioned in our response during last round of revision, we totally agree that low clouds can reduce SW_down flux at the surface. However, the decreasing downwelling shortwave flux could also be attributed to decreased surface albedo, which substantially reduces the multiple reflections between surface and clouds. Therefore, it is quite challenging to conclude that the low clouds warm or cool the surface based on the decreasing trend of downwelling LW+SW flux only. Nevertheless, we cannot rule out the possibility that increase low level clouds may cool the surface through reducing SW_down flux. How much of the cloud warming effect can be compensated by the cloud cooling effect remains an open question and needs further investigation. In the future, we would like to continue to work on this important topic.

Reviewer #2 (Remarks to the Author):

I am delighted with the manuscript in its current form.
The authors carefully tackled the issues raised by me and, by this effort, the bridging role of Arctic low cloud is much clarified. Actually, I learned a lot from the authors' responses. Thanks to the authors. Now, I have no further comments and recommend accept as is.

We are grateful for the thoughtful and thorough comments from you and we really appreciate the time you have spent on our manuscript.