Dear Editor and reviewers,

We are very thankful for your efforts reviewing our manuscript and providing us constructive comments. We have revised the manuscript accordingly. The point-to-point responses to your comments are listed in the following. We have quoted the text from the paper and displayed in bold the changes/additions.

Qinghua Yang and Bo Han,

On behalf of all the authors

Reviewer 1

Review of: "The sensitivity of landfast sea ice to atmospheric forcing in single-column model simulations: a case study at Zhongshan Station, Antarctica", by Fengguan Gu et al.

General comments

This manuscript uses a single column sea ice model to investigate the impact of atmospheric forcing on the simulation of snow and sea ice at Zhongshan Station in Antarctica during the 2016 austral winter. The model is forced both with in-situ observations and interpolated data from a reanalysis (ERA5), and the results are compared with in-situ observations of ice and snow thickness. The authors find that the forcings having the largest impact on the simulation of the ice and snow thickness are precipitation and wind speed. Biases in precipitation can have different impacts on the ice thickness, depending on how thick the snow is.

In terms of the originality, scientific quality, and significance I assess this manuscript as good. This is an interesting and useful study: atmospheric reanalyses are widely used to force ocean-ice and sea ice models, and so a detailed understanding and quantification of how the inevitable biases in a reanalysis can impact the model simulation is very valuable, albeit it over a very localised region. In terms of presentation I assess this manuscript as fair and would recommend some re-writing so that the manuscript is easier for the reader to follow, and the conclusions more clearly expressed.

Overall, I feel the paper could benefit from

• A more careful explanation of some of the details of the study – especially the differences between

Obs and Sim_Obs.

• More care when referencing the figures

• A better structuring and bringing together of conclusions in the discussions – I felt there were some interesting results here, but that they could have been expressed more clearly

I hope these comments will prove useful.

Response:

We thank you for your encouragement and pertinent comments. Your constructive comments have indeed greatly improved the manuscript. We have modified the article based on the specific comments below and responded to them point-to-point.

Specific comments

P2 L33-35 Although the manuscript mentions that the ICEPACK model may overestimate the snow-ice formation, I don't think that potential differences in the flooding process between landfast sea ice and pack ice are discussed?

Response:

We have discussed the potential differences in the flooding process between landfast sea ice and pack ice in Section 4:

'The snow-ice formation may be overestimated on the landfast sea ice simulation in ICEPACK. Flooding induced snow-ice formation is a very important process in the Antarctic because of thin ice and heavy snowfall (Kawamura et al., 1997). It can make a significant contribution to the total ice mass (12%-36%) and reduces the snow cover by up to 42-70% of the total snow accumulation depending on the season and location (Jeffries et al., 2001). **The parameterization of flooding in the ICEPACK is based on Archimedes' Principle for the pack ice. However, the flooding should be much smaller for the landfast sea ice with the same mass of snow cover. Hence, snow-ice formation might be overestimated on landfast sea ice when using ICEPACK, especially when ERA5 is taken as atmospheric forcing because of its heavy overestimation of snowfall**. Based on observations from a thermistor-chain buoy, a previous study estimated that a slushy layer of 10 cm depth will refreeze within 3 days (Provost et al., 2017). In ICEPACK, snow-ice can form at a fastest rate of 10 cm in 1 day.'

P3 L64-64 Re-word this sentence to be clearer.

Response:

We have revised this sentence to 'Due to the lack of *in situ* observation, the majority of sea ice studies, especially for the Antarctic, rely on numerical models. **Realistic atmospheric forcing is critical for reliable model simulations**. '

P3 Line 83 Perhaps mention the insulating impact of the snow here as well.

Response:

We agree with you. We have added insulating impact in the text.

'The snow cover exerts influence on evolution of the vertical sea ice-snow column via a number of mechanisms, including the formation of snow-ice aided by flooding (Leppäranta, 1983), superimposed ice (Kawamura et al., 1997) **and insulating impact (Massom et al., 2001)**. Understanding the snow depth is a major concern here.'

Reference

Massom, R. A., Eicken, H., Hass, C., Jeffries, M. O., Drinkwater, M. R., Sturm, M., Worby, A. P., Wu, X., Lytle, V. I., and Ushio, S.: Snow on Antarctic sea ice, Rev. Geophys., 39, 413-445, 2001.

P4 Section 2.1 The information provided about the different observations seems rather inconsistent: compared to the meteorological data, the frequency of measurement of the SW and LW is not mentioned, but there are extra details about the equipment used, plus the uncertainty in SW and LW is mentioned, whereas it is not for the other observations.

Response:

Thank you for your advice. In order to be consistent with respect to the meteorological data, we have added the frequency of shortwave and longwave measurement, and we deleted the introduction of equipment and uncertainty in section 2.1:

'The site of sea ice observation is in the coastal area off Zhongshan Station [(69◦22′S,76◦22′E); Figure 1], East Antarctica. The meteorological data were collected at a year-round manned weather observatory run at Zhongshan Station in 2016, which is 1 km inland from the sea ice observation site and 15 m above sea level. Snow fall is measured every 12 hours at the Russian Progress II station (located ~1 km to the southeast of Zhongshan Station). **The short- and long-wave radiation were measured every minute with a net radiometer mounted 1.5 m above the surface on a tripod (Yang et al., 2016a).** Other meteorological variables are available as hourly data, including 2 m air temperature (T_{2m}), surface pressure (P_a), specific humidity (calculated from dew-point temperature and P_a), potential temperature (calculated from T_{2m} and P_a), air density (calculated by T_{2m} and P_a) and 10 m wind speed (U_{10}) (Hao et al., 2019; Hao et al., 2020; Liu et al., 2020).'

Reference

Yang, Q., Liu, J., Leppäranta, M., Sun, Q., Li, R., Zhang, L., Jung, T., Lei, R., Zhang, Z., and Li, M.: Albedo of coastal landfast sea ice in Prydz Bay, Antarctica: Observations and parameterization, Adv. Atmos. Sci., 33, 535-543, 2016a.

P5 L138-140 Maybe a little more about the interpolation – linear? How many grid points used?

Response:

We have revised the sentence: 'For comparison and evaluation against observations in the Antarctic, **ERA5 is bilinearly interpolated with 4 surrounding grid points to the observation site**'.

P5-6 ICEPACK description. It would be good to be more explicit about the processes that are and are not included here, in particular for processes that are mentioned later the manuscript such as snowdrift and the impact of melt ponds.

Response:

Thank you very much for your helpful suggestion. We have added related text in the end of Table 1:

Table 1 Detailed options of physical parameterizations and model settings for the ICEPACK.

ICEPACK	Value
time step	3600 s
Number of layers in the ice	7
Number of layers in the snow	1
Ice thickness categories	5 (Bitz et al., 2001)
Initial ice thickness	99.5 cm (observed)
Initial snow depth	11.5 cm (observed)
Albedo scheme	CCSM3 (Collins et al., 2006)
Ice thermodynamic	Mushy-layer (Turner et al., 2013)

Shortwave radiation	Delta-Eddington (Briegleb and Light, 2007)
Snowdrift	**Not implemented in ICEPACK 1.1.1**
Melt ponds (superimposed ice)	**Not used in this study**

P56 L156 (Table 1) How were the initial ice and snow thickness chosen?

Response:

We started the simulation on April 29, so the observed ice thickness and snow depth on April 29 were selected as the initial thickness in the model simulation. We have added instructions in Table 1.

Table 1 Detailed options of physical parameterizations and model settings for the ICEPACK.

ICEPACK	Value
time step	3600 s
Number of layers in the ice	7
Number of layers in the snow	1
Ice thickness categories	5 (Bitz et al., 2001)
Initial ice thickness	**99.5 cm (observed)**
Initial snow depth	**11.5 cm (observed)**
Albedo scheme	CCSM3 (Collins et al., 2006)
Ice thermodynamic	Mushy-layer (Turner et al., 2013)
Shortwave radiation	Delta-Eddington (Briegleb and Light, 2007)
Snowdrift	Not implemented in ICEPACK 1.1.1
Melt ponds (superimposed ice)	Not used in this study

P6 L165 – P7 L171 This paragraph seems out of place in a section describing the ICEPACK model. Consider moving to the introduction, or even the discussion. Also, the sea ice response to climate change is mentioned here, but that is not a part of this study. It would be good to be more explicit about this point – I agree that understanding the impact of uncertainties in the forcing in future sea ice changes is important, but I'm not sure whether you are suggesting using a similar methodology to that used in your study to investigate this?

Response:

Thank you for your advice. We have revised the text in response to this concern. We have moved this paragraph from the ICEPACK section to the **Introduction**, and we are referring to current atmospheric forcing rather than to future forcing impacted by climate change.

'Understanding the uncertainty in sea ice simulations as well as the sea ice response pattern to

atmospheric forcing due to imperfect surface boundaries is a prerequisite for successful simulations and needs to be assessed first.'

P7 L182-183 Could you be clearer about what you mean here by the relative deviations, and perhaps include them in Table 2.

Response:

We have used bias ratio instead of the relative deviation in Table 2. The bias ratio is defined as the ratio between the bias and the observation value in this study.

P7 L188 It would be good to be more explicit about why these 3 variables ae chosen. I think it is for these reasons, but this could be expressed more clearly:

- A previous study has shown that these are (the most?) important factors affected the ice thickness
- Ua may also affect the snow thickness
- In this study, P and Ua from the analysis have the largest relative deviation from the in situ observations (and the smallest correlation coefficients compared to the in situ observations)

Response:

Thank you for your constructive suggestions. We have revised the text in response to this concern: 'In general, all eight variables from the two sources follow each other quite closely (correlation coefficients between ERA5 and the observations greater than 0.85), except for *P* and U_a. **In this study, the main attention is on the atmospheric variables Ta, P, and Ua for three reasons: (1) Previous studies have shown that from all atmospheric forcing variables, uncertainties in Ta, P, and Ua exert significant impact on the sea ice thickness (Cheng et al., 2008). (2) surface wind may affect the snow cover in two ways: a) sublimation strongly reduces the snow cover in dry air and strong wind condition (Gascoin et al., 2013), b) surface wind modulates the latent and sensible heat fluxes in the bulk formation (Fairall et al., 2003). (3) P and Ua from the reanalysis show the largest bias ratio compared to the *in situ* observations.**'

References

Cheng, B., Zhang, Z., Vihma, T., Johansson, M., Bian, L., Li, Z., and Wu, H.: Model experiments on snow and ice thermodynamics in the Arctic Ocean with CHINARE 2003 data, Journal of Geophysical Research: Oceans, 113, C9020, 2008.

Fairall, C. W., Bradley, E. F., Hare, J. E., Grachev, A. A., and Edson, J. B.: Bulk parameterization of air–sea fluxes: Updates and verification for the COARE algorithm, J. Climate, 16, 571-591, 2003.

Gascoin, S., Lhermitte, S., Kinnard, C., Bortels, K., and Liston, G. E.: Wind effects on snow cover in Pascua-Lama, Dry Andes of Chile, Adv. Water Resour., 55, 25-39, 2013.

P8 L201 relative deviation? Ties in to point for P7 L182-183.

Response:

We have replaced 'deviation' with 'bias ratio' in Table 2.

P8 L210-212 I'm not sure of the relevance of this point to this discussion about the forcings, although it is clearly an important point in terms of the modelled snow thickness.

Response:

We have revised the text in response to this concern:

'Nevertheless, using precipitation from Progress Ⅱ for Zhongshan Station may be questioned as well because of the distance of about 1 km to Zhongshan Station. **Moreover, strong wind causes snow drift events and the precipitation observation might not collect all snow fall correctly. This may cause larger bias between ERA5 and observations during strong events.**'

P8 L212 Deviation in what, and relative to what?

Response:

We have revised the text in response to this concern:

'A given precipitation rate (snow fall) might cause a range of snow cover patterns because the snowdrift is quite strong and responsible **for the larger deviation in snow depth between Sim_Obs and Obs.**'

P9 L222 Add (Figure 2c)

Response:

Revised as suggested.

P9 L231 The measurement details don't need repeating here – could just say drill hole sea ice thickness measurements or similar, to avoid distraction.

Response :

We have deleted 'by an ice auger (5 cm in diameter)'.

P9 L264 onwards: sections 3.2 and 3.3. I wonder if making more use of the notation in figure 3 (Obs, Sim_Obs etc) would help make the discussion in these sections easier to follow.

Response:

We have replaced the related simulations and observations with notation from Figure 3 in sections 3.2 and 3.3.

P10 L242 add (Figure 3b) to end of sentence

Response:

Revised as suggested.

P10 L244-245 This description does not seem to match the plot, or perhaps it is just unclear what period the seasonal mean covers. I have suggested below that the seasonal mean could be added to figure 3b to clarify things. I was assuming it referred to the entire period, in which case it does not look to me like the snow depth reduces to below the seasonal mean before the secondary peak on 2nd August as described in the text, but it may be that this was intended to refer to the peaks in September and October.

Response:

Thank you very much for your constructive comment. We added seasonal mean snow depth observations in Figure 3b.

'The snow depth increases rapidly up to about 37 cm associated with a precipitation event arising from a single synoptic system. **Then it decreases below the seasonal mean (Obs_mean) followed by two secondary maxima in exceeding the seasonal mean (about 25 cm) on 8 September and 18 October.**'

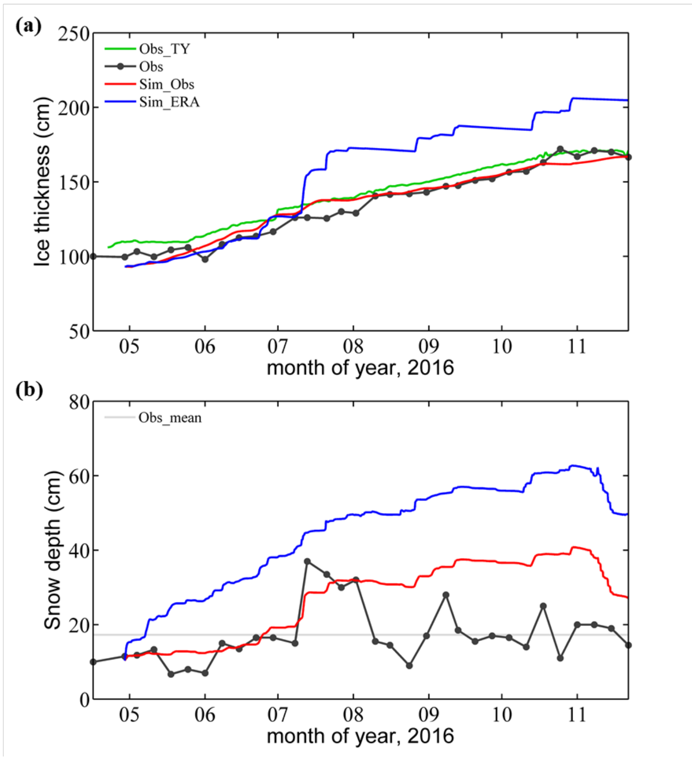

Figure 3 Time series of (a) sea ice thickness and (b) snow depth during the freezing season. Black solid lines with black point show the observations from the drill hole (Obs). In (b) the g**ray solid line shows the seasonal mean snow depth observation (Obs_mean).** Green solid lines show the ice thickness derived from the TY buoy (Obs_TY). Red solid lines show the simulation results under *in situ* atmospheric forcing (Sim_Obs) and blue solid lines are simulation result under ERA5 forcing (Sim_ERA).

P10 L245 onwards: I would suggest starting a new paragraph when discussing the comparison between Obs and Sim_Obs. I don't think the current description of the figure fully captures what is happening – for example Sim_Obs tracks Obs closely until the 11th July precipitation event, but does not capture the magnitude in the increase in snow thickness seen in Obs. It is mentioned that the lack of snowdrift in Sim_obs means that the snow thickness does not decrease again after the precipitation events in the way it does in Obs, but I am not clear why Sim_Obs does not show *increases* of a similar magnitude to Obs, instead producing a more gradual increase in snow thickness.

Response:

Thank you for your constructive suggestions, and we added a new paragraph when discussing the comparison between Obs and Sim_Obs. Also, we added in the revised manuscript the reason why Sim_Obs snow depth cannot capture the magnitude of Obs on 11 July.

'The Sim_Obs snow depth tracks the observation closely before 2 August (Figure 3b). Then, the Obs snow depth decreased quickly from about 30 cm to about 10 cm, while the Sim_Obs snow depth continues to increase gradually until the onset of surface melting in November. We attribute the Obs quick decrease of snow depth to the effect of snowdrift, because the surface wind stayed above 5 m s^{-1} for most of August (Figure 2c), giving rise to snow drift, a process not implemented in the version of ICEPACK used here. **In addition, Sim_Obs snow depth cannot capture the magnitude of Obs on 11 July. As discussed above, using precipitation from Progress II for Zhongshan Station could be questioned. Moreover, a given precipitation rate (snow fall) might cause a wide range of snow cover patterns because the snowdrift is quite strong and responsible for larger deviation in snow depth between Sim_Obs and Obs (Liston et al., 2018).**'

Reference

Liston, G. E., Polashenski, C., Rösel, A., Itkin, P., King, J., Merkouriadi, I., and Haapala, J.: A distributed snow-evolution model for sea-ice applications (SnowModel), Journal of Geophysical Research: Oceans, 123, 3786-3810, 2018.

P11 L265 Mention that the deviation is w.r.t. Obs and Obs_TV.

Response:

We have added 'with respect to Obs'. Because all the deviations described are relative to Obs.

P11 L270 refer to figure 3b in this sentence.

Response:

Revised as suggested.

P11 section 3.3: While section 3.2 discussed some reasons for the difference between Sim_Obs and Obs, this section is purely descriptive of the differences. I presume this is because the reasons for the differences are explored in the sensitivity experiments that follow, but some mention of this and a link into the following sections would be beneficial. Also, it would be good to be more explicit about whether differences described are relative to Sim_Obs or Obs.

Response:

Thank you for your advice. We have added links to following sections at the end of section 3.3.

'The reasons for the differences between Sim_ERA and Obs are explored in the sensitivity experiments sections below.'

In addition, we have replaced 'observation' with 'Obs' to make the description more specific: 'Sim_ERA sea ice thickness is close to Obs before 11 July with only a small positive bias of about 1 cm.'

P12 Section 3.4: there are several places where the figure references are incorrect. I have highlighted some but can this be checked carefully in the revised manuscript.

Response:

Thank you for this critical suggestion and we have checked all the figure references.

P12 L291-292 I think this was mentioned earlier in the paper but can the way this is assessed be clarified.

Response:

We have deleted this sentence in response to this concern. We refer to the bias ratio in Table 2 for the largest deviation.

P13 L299 should read Figure 4d?

Response:

Revised as suggested.

P13 L308 Figure 4e?

Response:

Revised as suggested.

P13 L319 4a?

Response:

Revised as suggested.

P13 L325 4d?

Response:

Revised as suggested.

P15 L342 This sentence needs re-wording. Also I'm not sure where the -5.1 W m-2 comes from – from figure 5b it looks like the difference reaches about -2.5 x 10^4 W m-2. Can this be clarified.

Response:

Thank you for your advice. We have changed -5.1 to -2.5 x 10^4 W m^{-2} and revised the sentence in the text:

'Compared with Sim_Obs, Sim_ERA_W simulates in the mean a **-2.5 × 10^4 W m^{-2}** lower accumulated latent heat (Figure 5b), i.e., a larger sublimation (Figure 5c), and a reduction of about 3.4 cm of the snow depth (Figure 5a). Therefore, when ERA5 is forcing ICEPACK, the overestimation in U_a partly neutralizes the effect of overestimation in P at Zhongshan Station.'

P17 L369 Add ref to figure 7

Response:

Revised as suggested.

P17 L375-378 I struggled to understand this discussion – re-draft to be clearer.

Response:

We have revised the text in response to this concern:

'The simulation bias of the sea ice thickness is quite small before the precipitation increases by about 1 mm per day (Figure 7). In fact, the simulated sea ice thickness even decreases at a rate of -3.4 cm per 1 mm increase in precipitation. It is because the snow-ice formation is small (Figure 6c) and the stronger isolation of the snow layer (Figure 6d) hampers the sea ice growths. **If precipitation is larger than 1 mm day^{-1}, the simulated sea ice thickness quickly increases at a rate of 22 cm/(mm day^{-1}). In contrast, the simulated snow depth deepens rapidly at a rate of 23.9 cm/(mm day^{-1}) when the enforced precipitation remains small, and at a rate of 6.5 cm when the added precipitation is large.** This is because more snow is converted into flooding ice, and the snow-ice formation process overrules strongly the effect of the larger isolation of the thicker snow layer, which promotes the sea ice growth.'

P17 L378 – P18 L380 If figure 8 is to be included I feel it needs more explanation in the text (see also comments in the figures section). I presume it is to illustrate point (4) in the conclusions, but that is not brought out clearly here.

Response:

Thank you for your advices. We added more explanation in the text and comments about Figure 8: 'These different effects of increases in precipitation on the snow and sea ice growth is illustrated in Figure 8 emphasizing the role of flooding via snow-ice formation. **When the snow layer is shallow, increases in precipitation will quickly deepen the snow layer and inhibit the growth of sea ice thickness due to the insulation of snow. The decrease in the surface net heat flux is the dominant factor. While the snow layer is deep and large precipitation is present, the flooding process induces snow-ice formation, and the sea ice growth quickly while the snow depth increases only slowly.'**

Figure 8: Schematic diagram for (a) low precipitation and (b) large precipitation events illustrating the precipitation effect on sea ice growth. **The upward arrows represent surface net heat flux. The white stars represent precipitation. The gray squares represent snow depth. The green squares represent sea ice thickness. The blue squares represent flooding ice.**

P18 Discussions section: This section seems to be primarily about model limitations, so consider renaming to make this clear.

Response:

We have realized that the discussion part is not clear. In our revised manuscript, we want to discuss:

1. Why Sim_obs is underestimating the sea ice thickness compared to Obs in November (Figure 3a).
2. The snow-ice formation may be overestimated on the landfast sea ice simulation in ICEPACK.
3. Besides the atmospheric forcing, the ocean forcing also plays an important role on the sea ice evolution:

'Sim_obs is underestimating compared to Obs in November (Figure 3a). The reason might be that superimposed ice was not considered in this study. Superimposed ice usually corresponds to liquid precipitation or melted snow permeate downward from the ice surface to form a fresh slush layer that refreezes. Superimposed ice is present in early autumn when snow starts to melt (Kawamura et al., 1997) and contributes significantly to sea ice growth (up to 20% of mass) (Granskog et al., 2004). The superimposed ice is implemented in ICEPACK via the melt ponds parametrization but that is not used in this study because it would need deformation forcing which is not available at the study area. Therefore, the simulation may underestimate sea ice thickness and overestimate snow depth and we will apply the melt ponds in the follow-up research work.

The snow-ice formation might be overestimated on the landfast sea ice simulation in ICEPACK. Flooding induced snow-ice formation is a very important process in the Antarctic because of thin ice and heavy snowfall (Kawamura et al., 1997). It can make a significant contribution to the total ice mass (12%-36%) and reduces the snow cover by up to 42-70% of the total snow accumulation depending on the season and location (Jeffries et al., 2001). The parameterization of flooding in the ICEPACK is based on Archimedes' Principle for the pack ice. However, the flooding should be much smaller for the landfast sea ice with the same mass of snow cover. Hence, snow-ice formation is probably overestimated on landfast sea ice when using ICEPACK, especially when ERA5 is taken as atmospheric forcing because of the heavy overestimation of precipitation at the study location. Based on observations from a thermistor-chain buoy, a previous study estimated that a slushy layer of 10 cm depth will refreeze within 3 days (Provost et al., 2017). In ICEPACK, snow-ice can form at a fastest rate of 10 cm in 1 day.

Besides the atmospheric forcing, the ocean forcing also plays an important role on sea ice evolution. Heat flux from the ocean boundary layer modifies the sea ice energy balance (Maykut and Untersteiner, 1971). The ocean heat flux is mainly impacted by summer insolation through open leads, thin ice, and melt ponds (Perovich and Maykut, 1990) and upward transfer of heat through vertical turbulent mixing (McPhee et al., 1999). In this study, the oceanic forcing is determined by specifying the ocean temperature and salinity in an ocean mixed layer of 10 m depth. Oceanic observations under sea ice are even more scarce than atmospheric observation over sea ice. Most sea ice models use empirical values or data from CCSM3 to set the ocean boundary values (e.g., Yang et al., 2016b; Turner and Hunke, 2015). However, just as the atmospheric forcing, the marine forcing needs to be evaluated carefully before using (e.g., Uotila et al., 2019).'

P18 L388-395 As superimposed ice is mentioned as an important process, it could perhaps be mentioned earlier in the manuscript – maybe in the introduction and the model description (as a missing process).

Response:

Thank you for your advice. We have now mentioned superimposed ice in the introduction and in the model description (Table 1).

'The snow cover exerts influence on evolution of the vertical sea ice-snow column via a number of mechanisms, including the formation of snow-ice added by flooding (Leppäranta, 1983), **superimposed ice (Kawamura et al., 1997)** and insulating impact (Massom et al., 2001). Understanding the snow depth is a major concern here.'

Reference

Kawamura, T., Ohshima, K. I., Takizawa, T., and Ushio, S.: Physical, structural, and isotopic characteristics and growth processes of fast sea ice in Lützow-Holm Bay, Antarctica, Journal of Geophysical Research: Oceans, 102, 3345-3355, 10.1029/96JC03206, 1997.

Table 1 Detailed options of physical parameterizations and model settings for the ICEPACK.

ICEPACK	Value
time step	3600 s
Number of layers in the ice	7
Number of layers in the snow	1
Ice thickness categories	5 (Bitz et al., 2001)
Initial ice thickness	99.5 cm (observed)
Initial snow depth	11.5 cm (observed)
Albedo scheme	CCSM3 (Collins et al., 2006)
Ice thermodynamic	Mushy-layer (Turner et al., 2013)
Shortwave radiation	Delta-Eddington (Briegleb and Light, 2007)
Snowdrift	Not implemented in ICEPACK 1.1.1
Melt ponds (superimposed ice)	**Not used in this study**

P19 L419-420 Include reasons for this.

Response:

We added the reason in the text:

'Using atmospheric variables from *in situ* observations to force ICEPACK simulates the sea ice evolution well, but significantly overestimates the snow depth at Zhongshan Station probably **because snow drift process is not implemented in the version of ICEPACK used here.'**

P19 L 431-432 clarify this is for changes in the ice thickness.

Response:

We have revised the sentence to 'The change in the surface net heat flux is suggested to be the dominant factor **for the change in sea ice thickness**'.

Figures

Figure 3b: The text makes frequent reference to the seasonal mean snow depth, so consider adding this as a line on figure 3b.

Response:

Thank you for your advice. We added seasonal mean snow depth from observation in Figure 3b.

Figure 4: The caption is incorrect – surf heat flux and snow depth need to be swapped. Does Sim_Obs have zero flooding? Can this be mentioned and explained in the text (if it is already there somewhere I missed it).

Response:

We have renumbered the Figure 4 and have checked all the figure references throughout our revised manuscript.

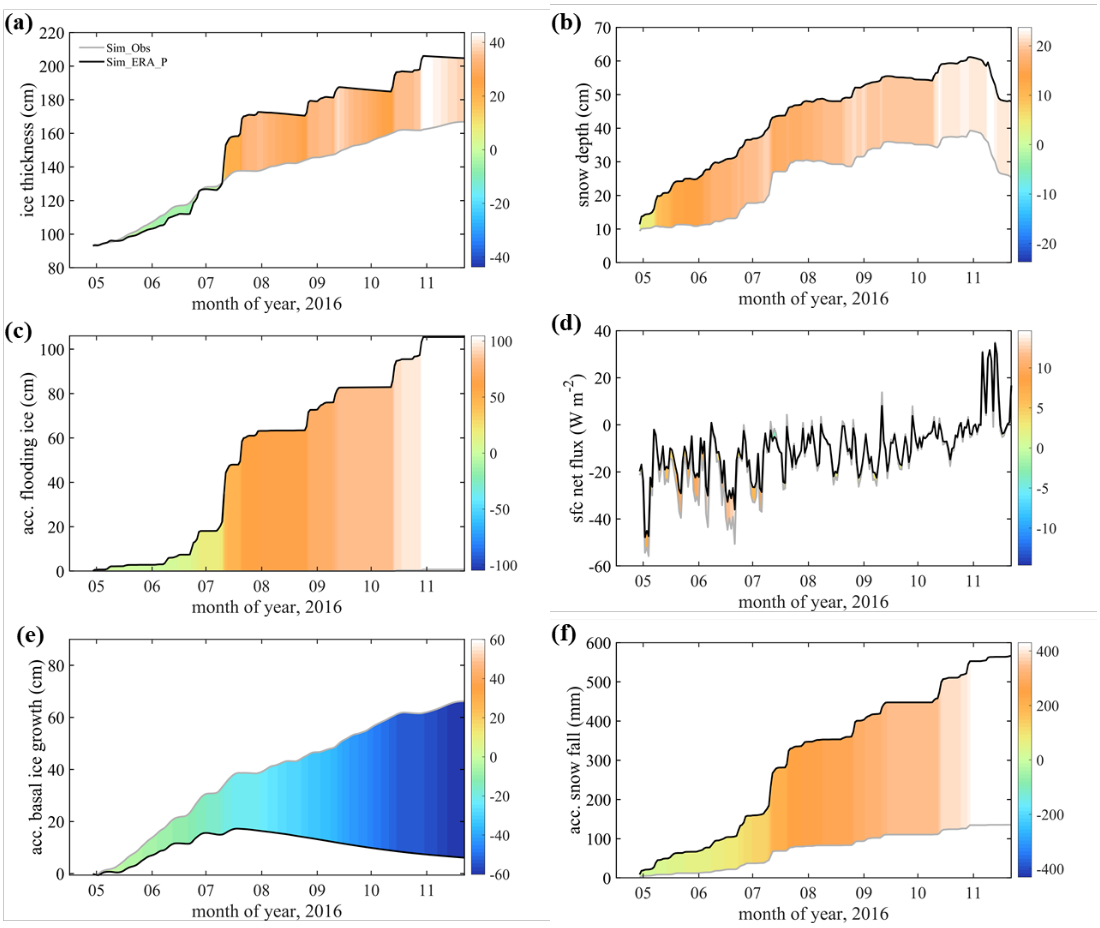

Figure 4: Times series of (a) sea ice thickness, (b) snow depth, (c) accumulated flooding ice, (d) net surface heat flux, (e) accumulated basal ice growth and (f) accumulated snow fall. The gray line represents the simulation using precipitation from observation (Sim_Obs). The black line represents the simulation using precipitation from ERA5 (Sim_ERA_P). The color bar represents their difference (Sim_ERA_P – Sim_Obs).

Sim_Obs has 0.8 cm accumulated flooding ice. The value is too small, so it is obscured by the x-axis in Figure 4c. We have revised the texts in response to this concern:

'The difference (~100 cm) in accumulated flooding ice (Figure 4c) **between Sim_Obs (0.8 cm) and Sim_ERA_P (105.5 cm)** is greater than the difference (~40 cm) in simulated sea ice thickness (Figure 4a), while the net surface heat flux compares well after July 11 (Figure 4d).'

Figure 6: This figure does not seem to be mentioned in the text.

Response:

We added figure reference in the text:

‘To find out how sensitive sea ice and snow are on precipitation, 10 sensitivity experiments are set up, named SEN2 **(Figure 6)**. In the n-th experiment, n×10% of the daily difference between P from ERA5 and the in situ observation is added to the in situ observation on that day.’

Figure 8: I was unclear what this figure is intended to show. (b) has a number for heat flux whereas (a) does not – I did not understand why. If this figure is retained, it would be good to be more explicit about the points it illustrates by expanding the text and/or adding more labelling to the figure - I presume it’s about point (4) in the discussion.

Response:

We have revised Figure 8 in response to this concern. We want to describe the entire physical mechanism instead of discussing the net surface heat flux quantitatively. We added as well more explanation in the text and comments on Figure 8:

‘These different effects of increases in precipitation on the snow and sea ice growth are illustrated in Figure 8 emphasizing the role of flooding via snow-ice formation. **When the snow layer is shallow, increases in precipitation will quickly deepen the snow layer and inhibit the growth of sea ice thickness due to the insulation of snow. The decrease in the surface net heat flux is the dominant factor. While the snow layer is deep and large precipitation is present, the flooding process induces snow-ice formation, and the sea ice grows quickly while the snow depth increases only slowly.**’

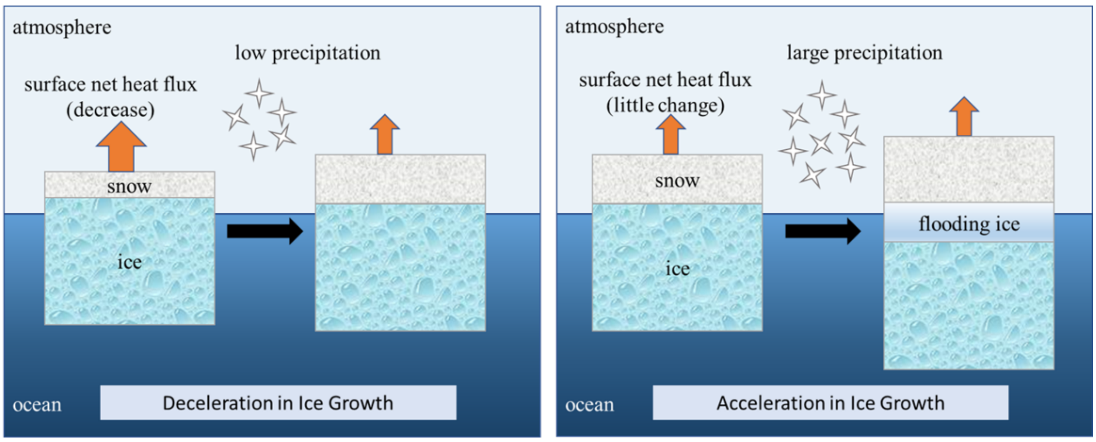

Figure 8 Schematic diagram for (a) low precipitation and (b) large precipitation illustrating precipitation effects on sea ice growth. **The upward arrows represent surface net heat flux. The white stars represent precipitation. The gray squares represent snow depth. The green**

squares represent sea ice thickness. The blue squares represent flooding ice.

Technical corrections

P3 L83 New paragraph for paper outline.

Response:

We have added a new paragraph on the outline of the for paper.

P4 L91 observations

Response:

We have changed ‘observation’ to ‘observations’.

P5 L125 delete ‘temperature’? I think this refers to both temperature and salinity.

Response:

We have deleted ‘For both, the average temperature across three drill holes is recorded’.

P6 L152 no capital needed for initial

Response:

We have changed ‘Initial’ to ‘initial’.

P6 L154 categories

Response:

We have changed ‘category’ to ‘categories’.

P6 L168 remove etc.

Response:

Revised as suggested.

P7 L193-194 Move the citations forward to the end of this sentence.

Response:

Revised as suggested.