Cover letter

Dear Editor:

We thank you and two anonymous reviewers very much for the constructive comments and suggestions for the paper 'The sensitivity of landfast sea ice to atmospheric forcing in single-column model simulations: a case study at Zhongshan Station, Antarctica' submitted to *the Cryosphere*. They are very valuable and very helpful for improving our manuscript. We have made a substantial revision according to the comments and suggestions from the editor and the two reviewers, and replied to them one by one below.

Qinghua Yang and Bo Han

On behalf of all the authors

Responses to referee #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.**'

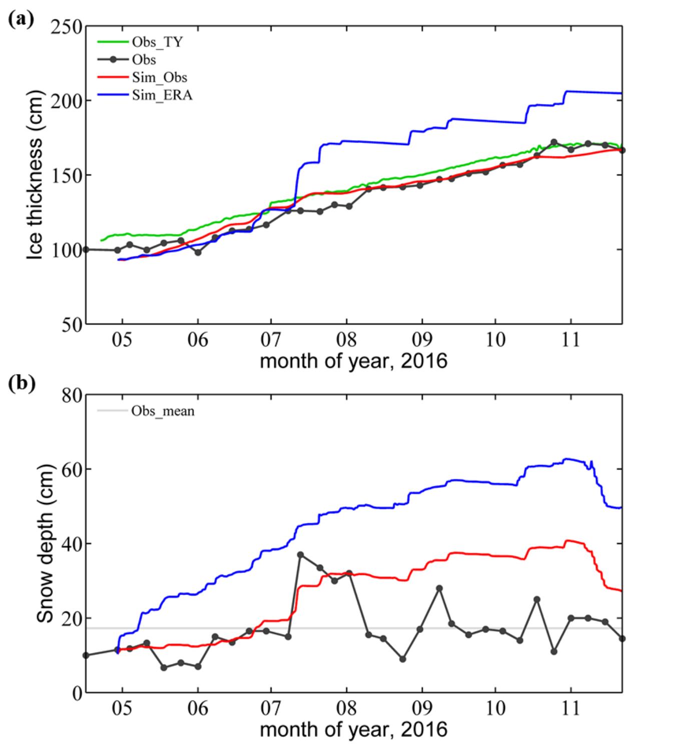

Figure 3 Time series of (a) sea ice thickness and (b) snow depth during the freezing season. Black solid lines with black point show the observations from the drill hole (Obs). **In (b) the gray solid line shows the seasonal mean snow depth observation (Obs_mean).** Green solid lines show the ice thickness 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.

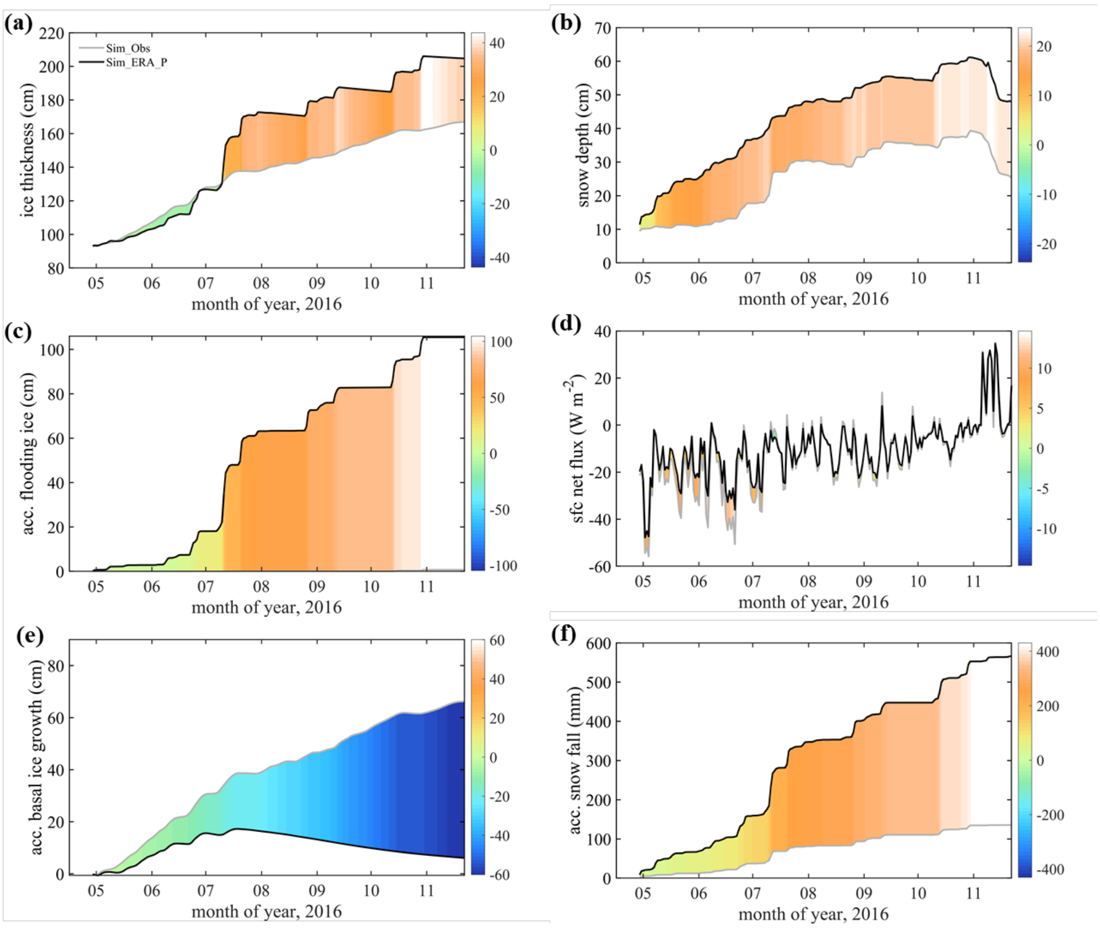

Figure 4: Times series of (a) sea ice thickness, (b) snow depth, (c) accumulated flooding ice, (d) net surface heat flux, (e) accumulated basal ice growth and (f) accumulated snow fall. The gray line represents the simulation using precipitation from observation (Sim_Obs). The black line represents the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

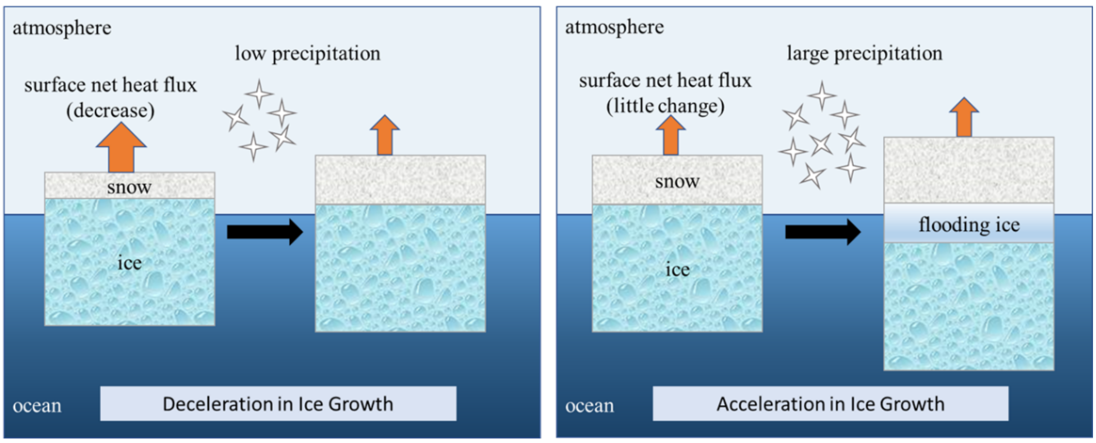

Figure 8 Schematic diagram for (a) low precipitation and (b) large precipitation illustrating precipitation effects on sea ice growth. **The upward arrows represent surface net heat flux. The white stars represent precipitation. The gray squares represent snow depth. The green squares represent sea ice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

Responses to referee #2

Reviewer 2

General comments

This paper used the single-column sea ice model ICEPACK forced by the ERA5 atmospheric reanalysis and by atmospheric in situ observations to simulate snow depth and sea ice thickness at Zhongshan Station, Antarctic. Through some sensitivity experiments, the authors tried to find which variables from atmospheric forcing affected the simulations largely. Overall, the manuscript has a potential value for publishing. However there are some major issues need to be clarify firstly.

Response:

We thank you for the constructive comments which are greatly helpful to improve the manuscript. We have modified the article accordingly below and responded to them one by one.

When assessing the importance of the forcing variables, it is not fair to compare their absolute values. Relative values should be considered.

Response:

We have used bias ratio instead of the absolute value in Table 3. The bias ratio is defined as the ratio between the bias and the observation value in this study.

Table 3 Bias of ice thickness, snow depth and of each forcing variable derived from SEN1. 'All' means using the full set of ERA5 atmospheric forcing

Variable	Bias		Bias ratio (%)
	Ice (cm)	Snow (cm)	Forcing
R_{sd} (W m^{-2})	-0,044	-0.130	**9.031**
R_{ld} (W m^{-2})	3.050	2.243	**-9.672**
T_a (K)	0.001	0.029	**-0.453**
Q_a (10^{-4} kg kg^{-1})	1.099	-1.299	**-9.326**
P (mm day^{-1})	14.519	17.312	**303.509**
Θ_a (K)	-0.483	0.407	**0.112**
ρ_a (kg m^{-3})	0.119	-0.071	**-1.592**
U_a (m s^{-1})	-0.311	-3.421	**50.735**

All	16.824	17.882	/

Some results may be close related to the threshold values in the model parameterization, for example, 1 mm/day in the Figure 7. If yes, please discuss the possible results to use another threshold value. If no, explain the reason why it is 1 mm/day.

Response:

The threshold value is related to sea ice thickness, snow depth and model parameterization. Snow-ice process is based on Archimedes' Principle. The base of the snow is at sea level when

$$\rho_i h_i + \rho_s h_s = \rho_w h_i$$

Where ρ_i=917 kg/m^3, ρ_s=330 kg/m^3 and ρ_w represent the density of ice, snow and sea water respectively. h_i and h_s indicate sea ice thickness and snow depth respectively.

Thus the snow base lies below sea level when

$$h_s > \frac{(\rho_w - \rho_i)h_i}{\rho_s}$$

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 strongly overrules the effect of the larger isolation of the thicker snow layer, which promotes the sea ice growth. **The snow-ice process is based on Archimedes' Principle. Therefore, the threshold value (1 mm/day^{-1}) is related to the density value of ice, snow and water in model parameterization, and also**

related to the sea ice thickness and snow depth. If sea ice and snow density, initial snow depth decrease, or sea water density and initial ice thickness increase, the threshold will increase, and vice versa.'

The discussion is not sufficient. The biases caused by precipitation may come from flooding ice (direct thickness contribution) and thermodynamic insulate effect (indirect). The quantitative contributions from those two aspects should be fully studied and clearly presented. Some oceanic heat flux experiments on OML depth should be considered.

Response:

Thank you for your constructive suggestions. We have revised Figure 6 and quantitatively analyzed the effects of precipitation on flooding ice and thermodynamic insulate effect. We used net surface heat flux to represent the insulate effect of snow layer, but we don't know how much the net surface heat flux will change the sea ice thickness. We have only used the snow-ice formation process and insulate effect to analyze the sensitivity of precipitation on sea ice thickness and snow depth in the text.

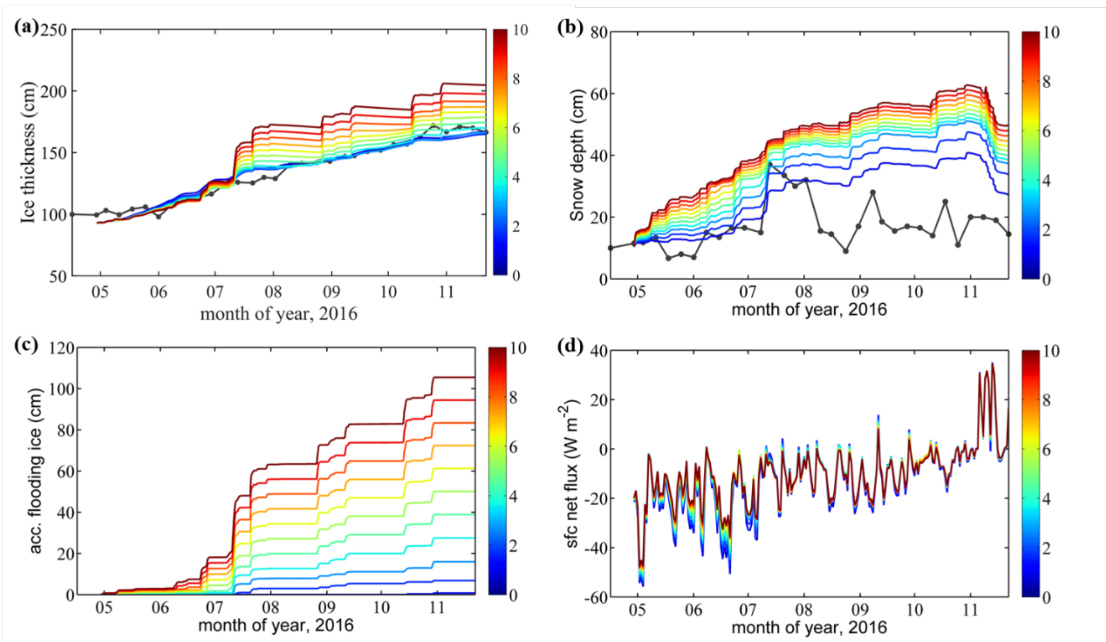

Figure 6 Time series of the simulated (a) sea ice thickness, (b) snow depth, **(c) accumulated flooding ice and (d) net surface heat flux** in the n experiments of SEN2. The black solid line with black points show the *in situ* observations (Obs). The 11

colored lines denote the 11 sensitivity experiments. When n = 0, precipitation is from the *in situ* observation. When n = 10, precipitation is from ERA5.

'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 strongly overrules the effect of the larger isolation of the thicker snow layer, which promotes the sea ice growth.** The snow-ice process is based on Archimedes' Principle. Therefore, the threshold value (1 mm/day^{-1}) is related to the density value of ice, snow and water in model parameterization, and also related to the sea ice thickness and snow depth. If sea ice and snow density, initial snow depth decrease, or sea water density and initial ice thickness increase, the threshold will increase, and vice versa.'

We find that water depth of sea ice observation site is about 10 m in precious study (Zhao et al., 2019). We have changed the MLD to 10 m in the text. Also we find that the change in MLD has little impact on simulation of sea ice thickness in our study. We have done the sensitivity experiments with different oceanic mixed layers, including 10 m and 20 m, and we find the simulation of sea ice thickness and snow depth is not sensitive to this value.

The oceanic mixed layer can modify the oceanic forcing through changing the sea surface temperature. The ocean forcing also plays an important role on sea ice evolution. We admit that there is a lack of sufficient analysis in oceanic forcing. In our future research, sensitivity of the oceanic forcing and their impact on the sea ice simulation will be addressed.

Reference

Zhao, J., Cheng, B., Vihma, T., Yang, Q., Hui, F., Zhao, B., Hao, G., Shen, H., and Zhang, L.: Observation and thermodynamic modeling of the influence of snow cover on landfast sea ice thickness in Prydz Bay, East Antarctica, Cold Reg. Sci. Technol., 168, 102869, 2019.

The writing have a lot of typo errors. For example, the citing of the subplots are wrong for many figures.

Response:

We have revised the text in response to this concern and have checked all the figure references

Specific comments

Lines 163: how about the water depth of the sea ice observation site? Should the real water depth was considered when you set the MLD to 20 m?

Response:

Thank you for your advice. We find that water depth of sea ice observation site is about 10 m in precious study (Zhao et al., 2019). We have changed the MLD to 10 m in the text. Also we find that the change in MLD has little impact on simulation of sea ice thickness in our study.

'The oceanic forcing includes sea surface temperature, sea surface salinity, and oceanic mixed layer depth. The period concerned in this study is from 22 April, when observed sea ice generally starts to grow, to 22 November in 2016. **Since there are no observations of the ocean mixed-layer depth, we set it to 10 m based on a previously published study (Zhao et al., 2019).'**

Reference

Zhao, J., Cheng, B., Vihma, T., Yang, Q., Hui, F., Zhao, B., Hao, G., Shen, H., and Zhang, L.: Observation and thermodynamic modeling of the influence of snow cover on landfast sea ice thickness in Prydz Bay, East Antarctica, Cold Reg. Sci. Technol., 168, 102869, 2019.

Lines 206-208: what is the role of wind on precipitation comparisons? The strong wind caused snow blowing events and the precipitation observation bin could not collect all the snow fall. Do the larger biases occurred during the strong wind events? This should be assessed here.

Response:

Thank you for your advice, and 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 snowfall correctly. This may cause larger bias between ERA5 and observations during strong events**.'

Lines 232: a space missed between the number and the unit, and the same errors should be checked through the paper.

Response:

Thank you for this critical suggestion and we have checked all the number and the unit throughout our revised manuscript.

Lines 251-253: As figure 3b shown, both blue lines and red lines were different compared to black lines. However, in figure 3a, no obvious ice thickness differences occurred for red lines, but the large difference occurred for blue lines. Does this indicated that the ice thickness simulation became more sensitive when the snow biases exceeded some values? What kind of parameterizations in the model caused this phenomena?

Response:

Yes, we have done a sensitivity experiment in section 3.5 and found that the ice thickness simulation is sensitive to the snow simulation bias. When the snow deviation between Sim_Obs and Obs is greater than 24 cm (Figure 7b), the simulated ice thickness will increase rapidly due to the snow-ice transformation in ICEPACK. We added a discussion 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 strongly overrules the effect of the larger isolation of the thicker snow layer, which promotes the sea ice growth. **The snow-ice process is based on Archimedes’ Principle. Therefore, the threshold value (1 mm/day^{-1}) is related to the density value of ice, snow and water in model parameterization, and also related to the sea ice thickness and snow depth.** If sea ice and snow density, initial snow depth decrease, or sea water density and initial ice thickness increase, the threshold will increase, and vice versa.’

Lines 290: the influences of Qa on ice was 1.009, not comparable to the other two variables, therefore its contribution was not that strong.

Response:

We have deleted Qa in the sentence.

Lines 292-293: this sentence is not clear. As Table 3 shown, P should be the largest factor for snow and ice simulations.

Response:

We have deleted this sentence in response to this concern:

‘Comparing the individual biases, it turns out that P and R_{ld} from ERA5 contribute to the bias in sea ice thickness most strongly. For snow depth P, U_a and R_{ld} contribute largest.’

Lines 292: “Ua … the largest …” you cannot compare the absolute value here, you should use the relative percentage. Also the column value “Forcing” in the table.

Response:

This relates to the comment above. We have used bias ratio instead of the absolute value in Table 3. The bias ratio is defined as the ratio between the bias and the observation value in this study.

Table 3 Bias of ice thickness, snow depth and of each forcing variable derived from SEN1. ‘All’ means using the full set of ERA5 atmospheric forcing

Variable	**Bias**		**Bias ratio (%)**
	Ice (cm)	**Snow (cm)**	**Forcing**
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T_a (K)	0.001	0.029	**-0.453**
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P (mm day^{-1})	14.519	17.312	**303.509**
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U_a (m s^{-1})	-0.311	-3.421	**50.735**
All	16.824	17.882	/

Lines 295-297: it is not reasonable to say P caused the major overestimation, based on the current experiment design. Only one sensitivity experiment was run for every single variable, this is not enough. You should design multi-sensitivity experiments for every single variable. If we say the variable P, the additional experiments like 0.5*P, 2.0*P, 3.0*P … should be considered.

Response:

Thank you for your advice. We did not discuss the sensitivity of each variable to the simulation of sea ice thickness and snow depth in this section. We only study the influence of the deviation between the reanalysis and observations on the simulation of sea ice thickness and snow depth. Also we have added sensitivity experiments in section 3.5 and quantitatively analyzed the impact of precipitation on the simulation of sea ice thickness:

'The precipitation from ERA5 not only shows the largest deviation compared to the *in situ* observation, but also contributes largest to the bias in the sea ice and snow simulation. **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.** This procedure increases the magnitude of the precipitation gradually in the experiments, while the timing of the daily precipitation events remains almost unchanged.'

Line 299: not figure 4b, snow is in figure 4d. It is not usual to place (a) (b) (c) vertically in the figure.

Response:

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

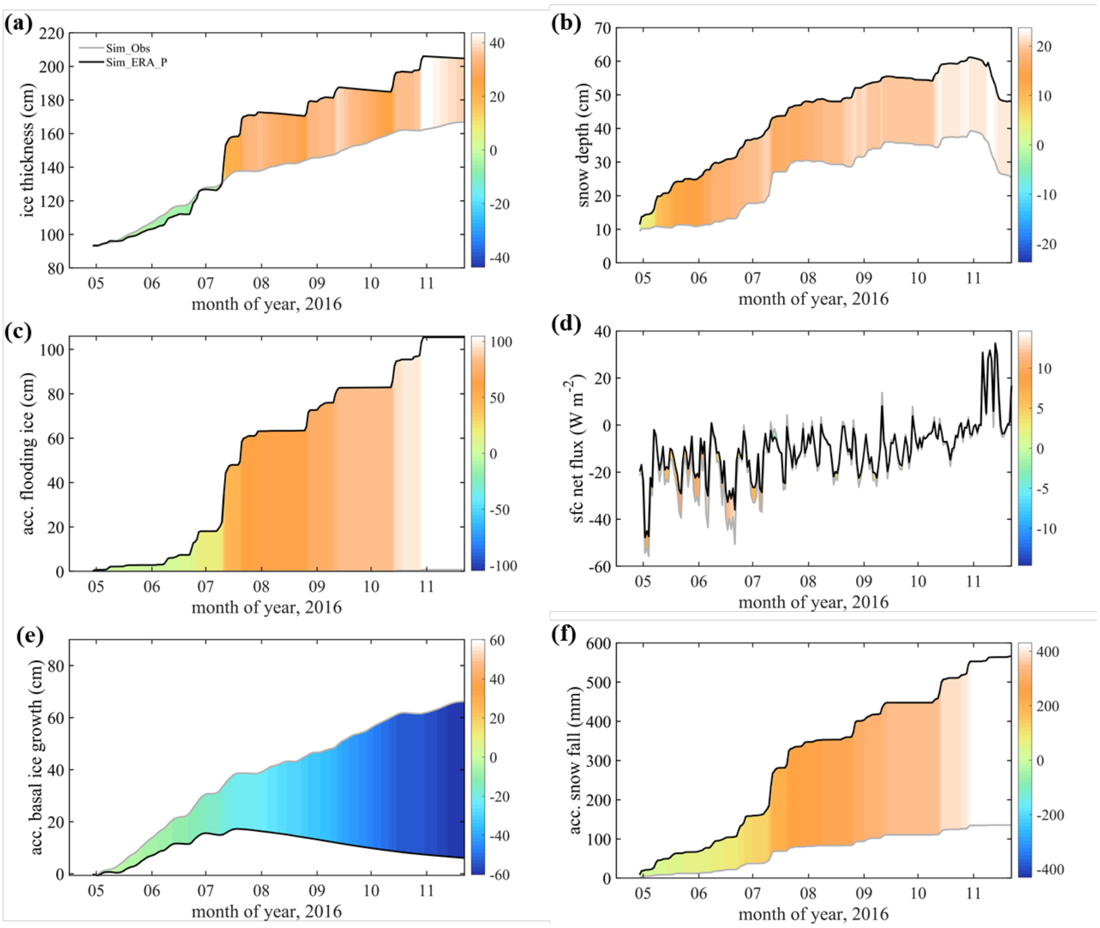

Figure 4: Times series of (a) sea ice thickness, (b) snow depth, (c) accumulated flooding ice, (d) net surface heat flux, (e) accumulated basal ice growth and (f) accumulated snow fall. The gray line represents the simulation using precipitation from observation (Sim_Obs). The black line represents the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

Figure 4c: the accumulated ice growth decreased since middle July. Why? Does that mean ice started to melt in the bottom?

Response:

Yes, we have pointed out the reason in the text:

'The reason for this difference might be that as the snow-ice process occurs, the increase in sea ice thickness will reduce the heat transfer between the ocean and the atmosphere, and inhibit the basal growth of sea ice in winter.'

Lines 318-319: check the subplot label (a) (b) (c) (d), and make sure they were cited correctly.

Response:

As with the problems pointed out above, we have checked all the figure references throughout our revised manuscript.

Lines 320-325: The flooding ice was parameterized to total ice thickness in the model? When water flooded into ice surface layer, snow-ice will formed if snow existed, however we didn't see snow thickness change a lot when accumulated flooding ice rapidly increased in July, why?

Response:

Yes, the total ice thickness contains flooding ice in ICEPACK. When the snow-ice process occurs, the snow depth decreases and the ice thickness increases. We have mentioned in the text why the snow depth changes less when the snow-ice process occurs in July:

'The snowfall (Figure 4f) is calculated by precipitation (Figure 2b) and is converted to new snow depth at the top surface using snow density of 330 kg m-3 in ICEPACK (Hunke et al., 2019). **Comparing Figure 4b with Figure 4f, we find that the change in snow depth (11 cm) is much lower than the accumulated snow fall (57 cm) because of flooding during precipitation event in July.'**

Lines 325-326: Accumulated snow fall was about 400 mm (40 cm) in July, similar to snow thickness (40 cm), I didn't see "much lower" you mentioned here. How the model deal with the relationship between snow fall, snow thickness, flooding ice, snow-ice thickness and total ice thickness should be explained clear in this section.

Response:

We have revised the text in response to this concern:

'When there is heavy snow fall, which happens frequently after July 11, the snow load subpresses the sea ice surface below sea level and sea water is flooding onto the sea ice surface causing the overlaying snow to freeze. **This snow-ice formation process will**

form flooding ice (snow-ice thickness) at the sea ice surface and increase the total sea ice thickness rapidly (Figure 4a). 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). The reason for this difference might be that as the snow-ice process occurs, the increase in sea ice thickness will reduce the heat transfer between the ocean and the atmosphere, and inhibit the basal growth of sea ice in winter (Figure 4e). The flooding induced snow-ice formation happens with a rate larger than 0.5 cm per hour after July 11. **The snowfall (Figure 4f) is calculated by precipitation (Figure 2b) and is converted to new snow depth at the top surface using snow density of 330 kg m^{-3} in ICEPACK (Hunke et al., 2019). Comparing Figure 4b with Figure 4f, we find that the change in snow depth (11 cm) is much lower than the accumulated snow fall (57 cm) because of flooding during precipitation event in July.'**

Reference

Hunke, E., Allard, R., Bailey, D. A., Blain, P., Craig, T., Dupont, F., DuVivier, A., Grumbine, R., Hebert, D., Holland, M., Jeffery, N., Lemieux, J., Rasmussen, T., Ribergaard, M., Roberts, A., Turner, M., and Winton, M.: CICE-Consortium/Icepack: Icepack1.1.1, doi:10.5281/zenodo.3251032, 2019.

Line 321: You proposed a guess here. This could be confirmed by calculating the conductive heat flux and bottom heat flux balance.

Response:

Thank you for your advice. We have checked that basal ice growth is calculated by the conduction heat flux and bottom heat flux in ICEPACK. We have deleted the 'guess' in the text:

'The reason for this difference might be that as the snow-ice process occurs, the increase in sea ice thickness will reduce the heat transfer between the ocean and the atmosphere, and inhibit the basal growth of sea ice in winter.'

Lines 340-341: If wind-blowing was not considered by the model, therefore snow thickness was the accumulation of total snow fall? Or any other processes were included? What caused the differences of snow thickness simulations? Why the surface heat fluxes can affect the snow thickness?

Response:

The simulation of snow depth in the ICEPACK is not only affected by total snowfall, but also includes snow-ice formation process, snow melting because of temperature rising, and snow condensation or sublimation due to surface heat fluxes. Ua can affect the snow depth through modifying the surface heat fluxes in the bulk formulations.

We have revised the text in response to this concern:

'Although the snow-drift process is currently not implemented in ICEPACK, U_a still affects the snow depth through modifying the surface heat fluxes in the bulk formulations (Fairall et al., 2003). **Latent heat changes the snow depth through snow condensation or sublimation process.** Compared with Sim_Obs, Sim_ERA_W simulates in the mean a -2.5 × 104 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.'

Line 369: it should be the bias of sea ice thickness and snow depth

Response:

We have added 'bias' in the text.

Lines 370: why to calculate from 27 July, not the initial day of experiments in April?

Response:

We have tried to calculate the bias from initial day of experiments in April. However, the statistical data is scattered and box plot have many outliers, so we start calculating from 27 July. Different start or end dates of this period do not change this result.

Lines 375-377: what control the threshold value to be 1 mm/day. Was it related to the value in the model parameterization?

Response:

This relates to the comment above. The threshold value is related to sea ice thickness, snow depth and model parameterization. Snow-ice process is based on Archimedes' Principle. The base of the snow is at sea level when

$$\rho_i h_i + \rho_s h_s = \rho_w h_i$$

Where ρ_i=917 kg/m^3, ρ_s=330 kg/m^3 and ρ_w represent the density of ice, snow and sea water respectively. h_i and h_s indicate sea ice thickness and snow depth respectively.

Thus the snow base lies below sea level when

$$h_s > \frac{(\rho_w - \rho_i)h_i}{\rho_s}$$

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 strongly overrules the effect of the larger isolation of the thicker snow layer, which promotes the sea ice growth. **The snow-ice process is based on Archimedes' Principle. Therefore, the threshold value (1 mm/day^{-1}) is related to the density value of ice, snow and water in model parameterization, and also related to the sea ice thickness and snow depth. If sea ice and snow density, initial snow depth decrease, or sea water density and initial ice thickness increase, the threshold will increase, and vice versa.'**

Lines 380: I notice snow had a rapid melt in November (Figure 6). How about the superimposed ice formation in summer, which is caused by snow melt and refreeze? Is it considered in this model?

Response:

Due to the increase in temperature in November (Figure 2a), the snow melts quickly, which may produce superimposed ice. The superimposed ice which is implemented in ICEPACK with melt ponds parametrization is not run in this study. We have discussed the superimposed ice in discussion section:

'Sim_obs is underestimating compared to Obs in November3a). 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 form 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.'**

Lines 408-409: what will happen if we used a different oceanic mixed layer, for example 10 m? Are the results sensitive to this value?

Response:

Thank you for your advice. The same as the comment above, we find that water depth of sea ice observation site is about 10 m in precious study (Zhao et al., 2019). We have changed the MLD to 10 m in the text. Also we find that the change in MLD has little impact on simulation of sea ice thickness in our study. We have done the sensitivity experiments with different oceanic mixed layers, including 10 m and 20 m, and we find the simulation of sea ice thickness and snow depth is not sensitive to this value.

The oceanic mixed layer can modify the oceanic forcing through changing the sea surface temperature. The ocean forcing also plays an important role on sea ice evolution. We admit that there is a lack of sufficient analysis in oceanic forcing. In our future research, sensitivity of the oceanic forcing and their impact on the sea ice simulation will be addressed.

Reference

Zhao, J., Cheng, B., Vihma, T., Yang, Q., Hui, F., Zhao, B., Hao, G., Shen, H., and Zhang, L.: Observation and thermodynamic modeling of the influence of snow cover on landfast sea ice thickness in Prydz Bay, East Antarctica, Cold Reg. Sci. Technol., 168, 102869, 2019.