Reply to Reviewer Comment 2 (RC2)

Comment:

This manuscript describes a "new" regional coupled model for the Arctic intended for short-term forecasting and shows some preliminary simulation results. My main issue with this manuscript is that I do not see the novelty here. Similar regional models such as ARCSyM (Lynch et al. 1995), RASM (Cassano, Maslowski, others), Rinke et al. 2000 have not been mentioned here. The "novel" aspect seems only to be the coupling of the MITgcm to the Polar WRF model and perhaps the new C-Coupler. I nearly recommended reject for this manuscript. It seems more like a technical report. Also, the English usage here is confusing and there are a number of grammatical errors that I do not have time to go into here. Here are some specific suggestions that might make this worthy of publication in GMD.

Reply:

The authors thank the reviewer for the insightful comments. Thanks for pointing out that we omit similar works about regional coupled models. We have added these work as reference and re-written the introduction. The motivation of our work is to couple the Arctic ocean-seaice configuration of the MITgcm which is operationally running in our institute (ArcIOPS; Liang et al., 2020), to the Arctic atmospheric model (Polar WRF) in order to get a reasonable seasonal sea ice simulation. Beyond the scope of this work, our destination is operational sea ice seasonal prediction based on the coupled model and data assimilation algorithm. In my opinion, the novelty of our study is that we couple the Polar WRF and MITgcm which both featured with good performances in polar regions for the first time in the Arctic region and that we have solved some technical issues during the coupling process with a new coupler.

We have revised our manuscript by adding discussion on sea ice dynamic during coupling process. We have better motivated the manuscript in the introduction. We have proof-read the manuscript carefully to make it more readable.

Comment :

1. There needs to be more on the novel aspects here. What does this model provide specifically that previous models did not? What time scales is this intended for? Short-term forecasting of weeks? Seasons?

Reply:

Sun et al. (2019) introduced a regional ocean-atmosphere coupled model covering the Red Sea based on the MITgcm and WRF. The novelty of our study is that we couple the Polar WRF and the MITgcm for the first time in the Arctic region and that we have solved some technical issues during the coupling process with a new coupler.

Both Polar WRF and MITgcm have specific features designed for polar regions, we speculate that coupling them will help us to improve seasonal sea ice prediction. We have used MITgcm model to make an operational Arctic synoptic-scale sea ice forecast for several years and showed reasonable results in aspects of sea-ice forecast in synoptic scale (ArcIOPS; Mu et al., 2019; Liang et al., 2020). This work is motivated by the need of a coupled Arctic sea ice-ocean-atmosphere model system for operational sea ice prediction of seasonal timescale (such as initialized at June and predict September sea ice).

Comment:

2. There is no mention of the land component. Is this just the imbedded Polar WRF component? Why is this not important to the Arctic simulations?

Reply:

We apologize that we overlooked the description of land component in the section of Polar WRF. Yes, land component is embedded inside the Polar WRF. This Polar WRF incorporates many modifications to the standard version of the WRF. These adjustments are described by Bromwich et al. (2009), for example, adjustments to the surface parameterizations. The changes made in the Noah land surface model (LSM;

Chen and Dudhia 2001) include using the latent heat of sublimation for calculating latent heat fluxes over ice surfaces, increasing the snow albedo and the emissivity value for snow, adjusting snow density, modifying thermal diffusivity and snow heat capacity for the subsurface layer, changing the calculation of skin temperature, and assuming ice saturation in calculating the surface saturation mixing ratio over ice.

Land component is absolutely important to the Arctic simulation, however at current stage, our coupled model has not capacity of coupling an individual land model, instead, we use the embedded land component in the Polar WRF for technical simplicity. We have added the introduction of land component in the section of Polar WRF description.

Comment:

3. The MITgcm sea ice component is quite old and simplistic. What is the albedo formulation on sea ice? What about on land? What about a sea ice thickness distribution?

Reply:

There are two calculations of surface albedo provided in the MITgcm.

1) from LANL CICE model:

$$\alpha = f_s\alpha_s + (1 - f_s)(\alpha_{i_{min}} + (\alpha_{i_{max}} - \alpha_{i_{min}})(1 - e^{-h_i/h_\alpha}))$$

where f_s is 1 if there is snow, 0 if not; the snow albedo, α_s has two values depending on whether T_s < 0 or not; $\alpha_{i\min}$ and $\alpha_{i\max}$ are ice albedo for thin melting ice, and thick bare ice respectively, h_i is snow depth, and h_α is a scale height.

2) From GISS model (Hansen et al 1983):

$$\alpha = \alpha_i e^{-h_s/h_a} + \alpha_s(1 - e^{-h_s/h_a})$$

where α_i is a constant albedo for bare ice, h_s is snow depth, h_a is a scale height and α_s is a variable snow albedo

$$\alpha_s = \alpha_1 + \alpha_2 e^{-\lambda_a a_s}$$

where α_1 is a constant, α_2 depends on T_s, α_s is the snow age, and λ_a is a scale frequency.

In our coupled model, surface albedo from LANL CICE model is used. Land component is from atmospheric component of Polar WRF mentioned in last reply.

In order to parameterize a sub-grid scale distribution for sea ice thickness, the mean sea ice thickness in each grid can be split into as many as 7 thickness categories in the MITgcm sea ice model. In our coupled model for simplicity, we use 2 thickness categories: open water and sea ice.

Comment:

4. The authors suggest that CMIP5 models represent sea ice in a simple way, but MITgcm is not any more complicated. A number of CMIP5 models used the Los Alamos Sea Ice Model (CICE) which is leading edge. What about CMIP6?

Reply:

We apologize for the improper statement about sea ice representation in the CMIP5 models in the original manuscript. The sea ice physical mechanism is rather complicate in the CICE. We have replaced the improper words in the manuscript. We have also gone through the entire manuscript to revise other improper words.

Comment:

5. The grid staggering discussion and Figure 3 are really not necessary.

Reply:

We agree with the reviewer that the grid staggering discussion and Figure 3 are not necessary. So the part of computation of corner information and Fig. 3 are removed from the revised manuscript.

Comment:

6. The case study they use is the year 2012. The boundary forcing for the atmosphere is from NCEP/NCAR re-analysis and for the ocean from the ECCO model. The sea ice extent is reasonable, but the sea ice volume is biased low compared to PIOMAS.

I believe the problem here is the simplicity of the sea ice thermodynamics and lack of a subgridscale thickness distribution. I feel like the model might be tuned for 2012 and want to see how it performs for other years. Some comparison to IceSAT data would also be beneficial here.

Reply：

We agree that one year is short to validate the model. So we add the runcase of 2016 and add the standalone MITgcm for the comparison. To keep consistency between the coupled model and standalone MITgcm model, the standalone MITgcm simulation is forced by surface variables derived from the CFSR data and uses the same albedo parameters to the coupled model. As the IceSat data covers 2003-2008, we can not validate the sea ice thickness simulations of 2012 and 2016 with the IceSat data. Instead, we choose Cryosat2 and SMOS data to validate sea ice thickness.

In our original manuscript, we make a mistake when calculate sea ice extent in Figure 4a and 4b, which leads to the negative sea ice extent bias in Figure 4a. We confuse sea ice area with sea ice extent. Actually the blue and red curves in Figure 4a and 4b in the original manuscript are sea ice area. We redraw the modeled sea ice extent and add the standalone MITgcm run for the comparison (see the following figure). Compared with the standalone MITgcm run, the modeled sea ice extent in the coupled runs are more closer to the observation. With respect to the one-way coupled run, the spatial distribution of summertime sea ice concentration in the two-way coupled run is more closer to the OSISAF observation.

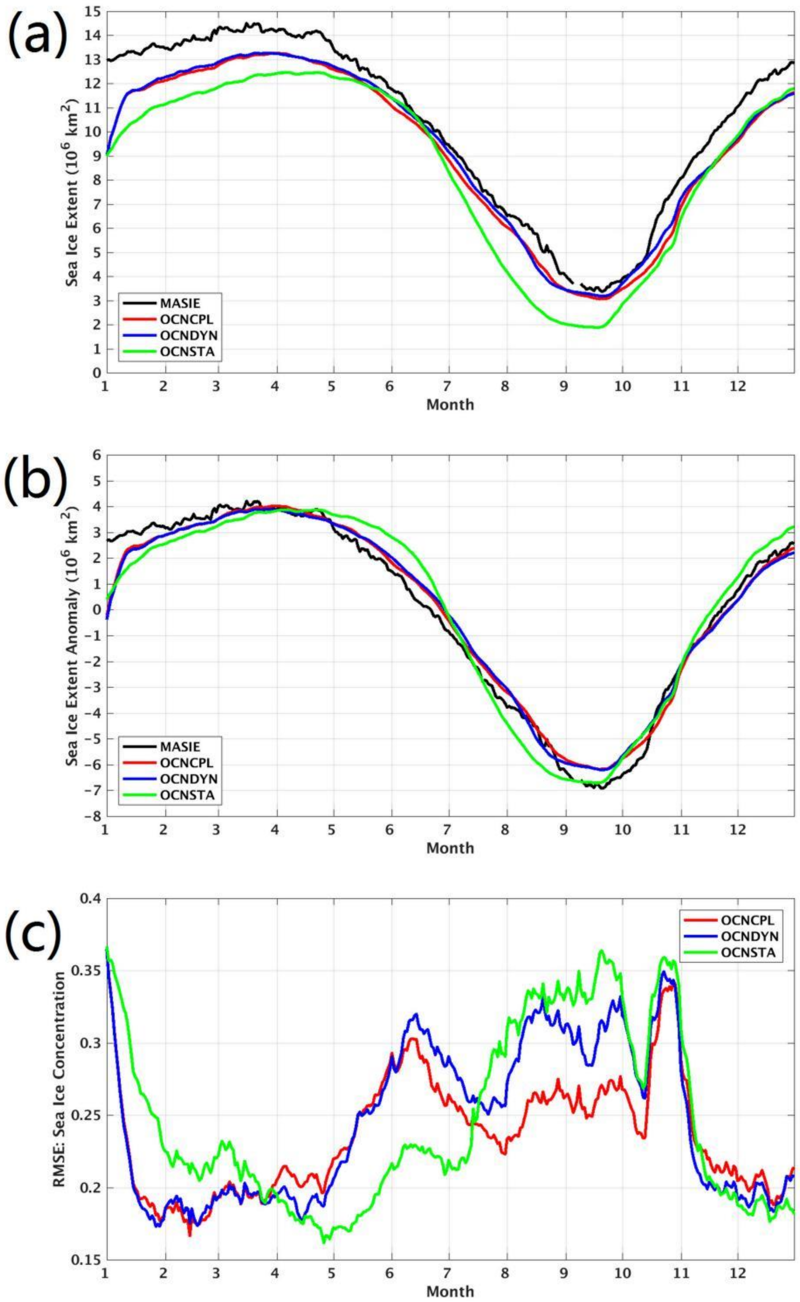

Fig.1 Time series of (a) sea ice extent, (b) sea ice extent anomaly, and (c) root mean square error (RMSE) of modeled sea ice concentration with respect to the OSISAF observation in 2012. The black, red, blue and green lines in (a) denote sea ice extent of the MASIE observation, the OCNCPL run, the OCNDYN run, and the OCNSTA run respectively. The black, red, blue and green lines in (b) denote sea ice extent anomaly of the MASIE observation, the OCNCPL run, the OCNDYN run, and the OCNSTA run respectively. The red, blue and green lines in (c) denote the sea ice concentration RMSE of the OCNCPL run, the OCNDYN run, and the OCNSTA run, respectively.

Results of the modeled sea ice in 2016 are shown as follows:

The year of 2016 is selected because of the next anomalous sea ice extent minima event after 2012 appeared in 2016. We also conduct two-way coupled run, one-way coupled run, standalone MITgcm run for the year of 2016. The initial fields on 2016.1.1 of the MITgcm and the WRF model are derived from the standalone MITgcm simulation forced by JRA55 data and from the CFSR reanalysis data. Time evolution of modeled sea ice extent shows that the two-way coupled run produces more reasonable sea ice extent compared with the MASIE data, although the modeled September sea ice concentration of the two-way run in the Arctic Pacific section overmelts.

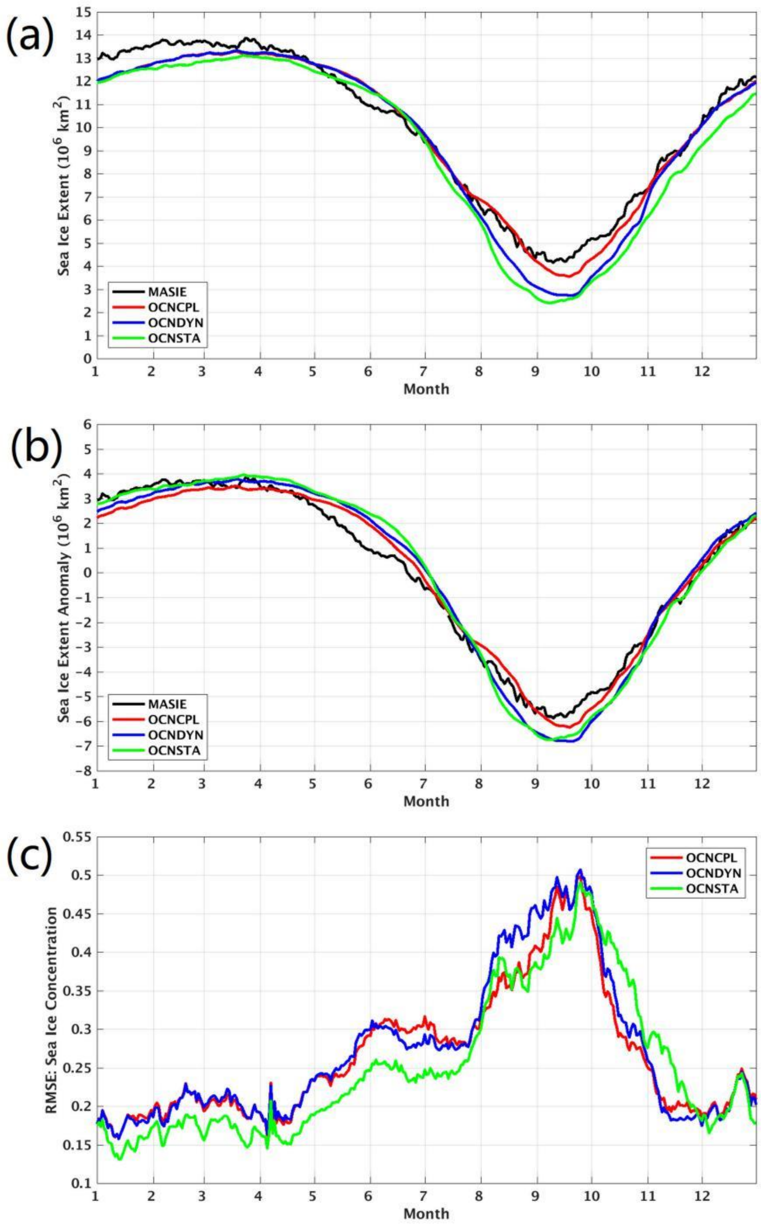

Fig.2 Same to the above figure but for the year of 2016.

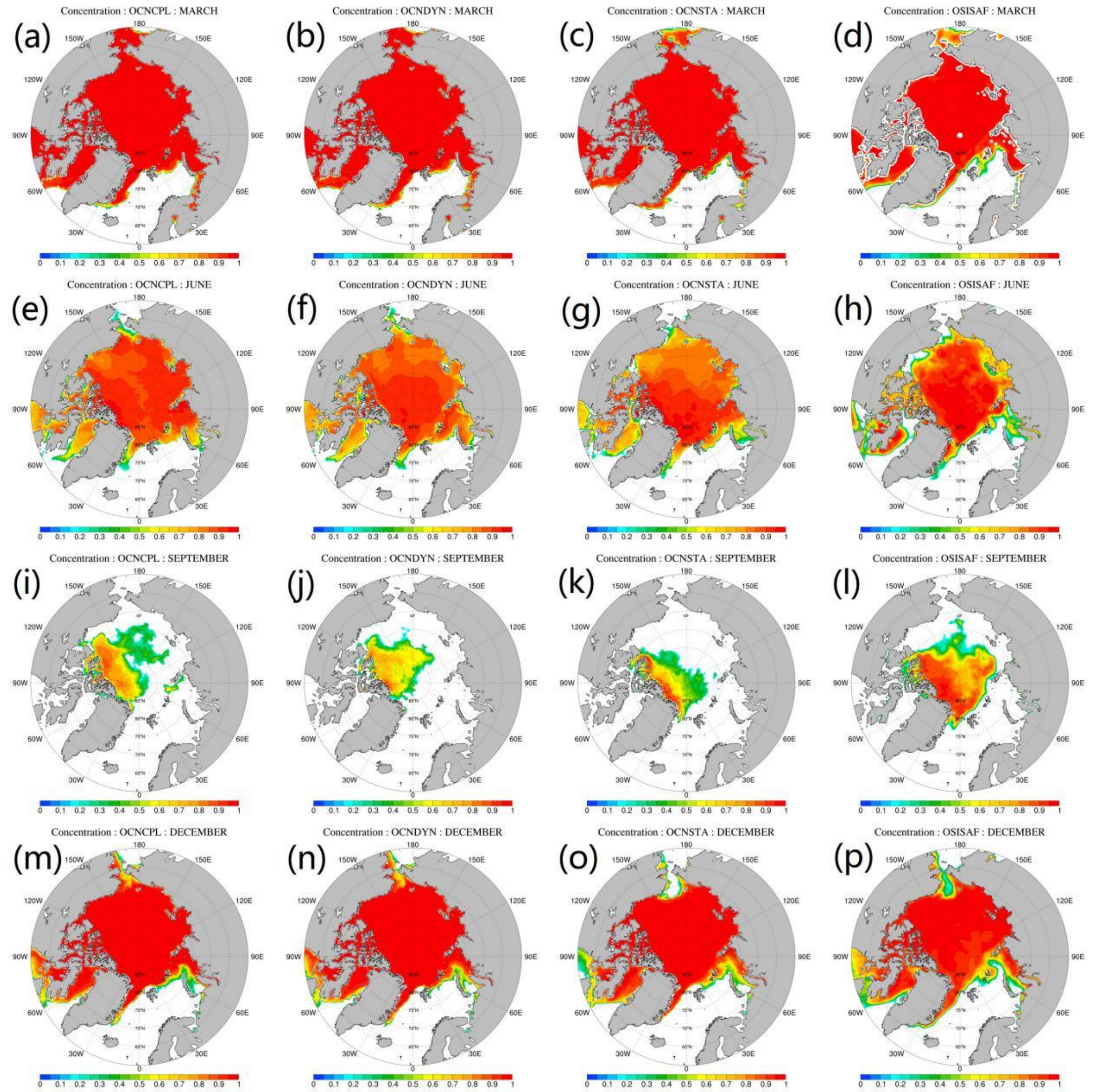

Fig.3 Monthly mean sea ice concentration in 2016. The 1st, 2nd, 3rd, 4th row denotes March, June, September, December. The 1st, 2nd, 3rd, 4th column denotes the two-way coupled run (OCNCPL), the one-way coupled run (OCNDYN), the standalone MITgcm run (OCNSTA) and the observations (OSISAF).

Reference:

Bromwich, D. H., K. M.Hines, and L.-S.Bai, 2009: Development of Polar Weather Research and Forecasting Model: 2. Arctic Ocean. J. Geophys. Res., 114, D08122, doi:10.1029/2008JD010300.

Chen, F., and J.Dudhia, 2001: Coupling an advanced land surface-hydrology model with the Penn State–NCAR MM5 modeling system. Part I: Model implementation and sensitivity. Mon. Wea. Rev., 129, 569–585.

Hansen, J., G. Russell, D. Rind, P. Stone, A. Lacis, S. Lebedeff, R. Ruedy and L.Travis, 1983: Efficient Three-Dimensional Global Models for Climate Studies: Models I and II. Monthly Weather Review, 111, 609 – 662.

Liang, X. and M. Losch, On the Effects of Increased Vertical Mixing on the Arctic Ocean and Sea Ice. Journal of Geophysical Research: Oceans, 2018. 123(12): p. 9266-9282.

Liang, X., et al., Using Sea Surface Temperature Observations to Constrain Upper Ocean Properties in an Arctic Sea Ice-Ocean Data Assimilation System. Journal of Geophysical Research: Oceans, 2019. 124(7): p. 4727-4743.

Liang, X., et al., Evaluation of ArcIOPS sea ice forecasting products during the ninth CHINARE-Arctic in summer 2018. Adv. Polar. Sci., 2020, 31(1), 14-25.

Sun, R., Subramanian, A. C., Miller, A. J., Mazloff, M. R., Hoteit, I., and Cornuelle, B. D.: SKRIPS v1.0: a regional coupled ocean–atmosphere modeling framework (MITgcm–WRF) using SMF/NUOPC, description and preliminary results for the Red Sea, Geosci. Model Dev., 12, 4221-4244, 10.5194/gmd-12-4221-2019, 2019

Mu, L., et al., Arctic Ice Ocean Prediction System: evaluating sea-ice forecasts during Xuelong's first trans-Arctic Passage in summer 2017. Journal of Glaciology, 2019. 65(253): p. 813-821.

Winton, M, 2000: A reformulated Three-layer Sea Ice Model. Journal of Atmospheric and Ocean Technology, 17, 525 – 531.

Van Pham, T., et al., New coupled atmosphere-ocean-ice system COSMO-CLM/NEMO:

assessing air temperature sensitivity over the North and Baltic Seas. Oceanologia, 2014. 56(2): p. 167-189.