Uncertainties in Arctic sea ice thickness associated with different atmospheric reanalysis datasets using the CICE5 model

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1. Introduction

- There has been a dramatic change in the Arctic sea ice in recent years.
- Sea ice modeling is an important approach to accounting for these rapid changes and understanding the underlying processes.
- However, all reanalysis data for the Arctic region modeling contain large uncertainties because of the remoteness of the region and the difficulty to observe.
- Few studies have quantified how uncertainty in reanalysis data affects simulated sea ice volumes when used as atmospheric forcing.
- We investigated which forcing variables have more effects on sea ice extent and thickness (volume), and how the uncertainty included in forcing variables influences simulated sea ice conditions.

2. Method

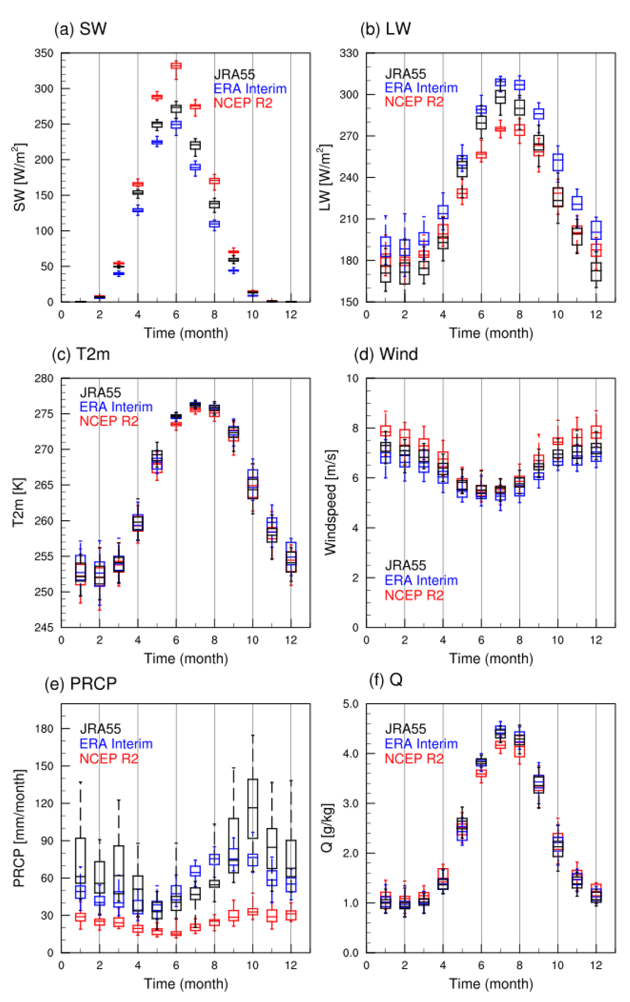
Table 1. Description of the CICE5 model configuration.

Model	CICE5 stand alone
Initial condition	No ice
Atmospheric forcings	Monthly: downward longwave radiation (W m^{-2}), downward shortwave radiation (W m^{-2}), total precipitation rate (kg m^{-2} s^{-1}) 6 hourly: 2 m air temperature (K), 10 m wind speed (zonal and meridional, m s^{-1}), 2 m specific humidity (kg kg^{-1}), air density (kg m^{-3})
Oceanic forcings	Monthly HadISST, constant sea surface salinity (34 psu)
Dynamics	Elastic-Anisotropic-Plastic (EAP)
Thermodynamics	Mushy
Integration period	1982–2014

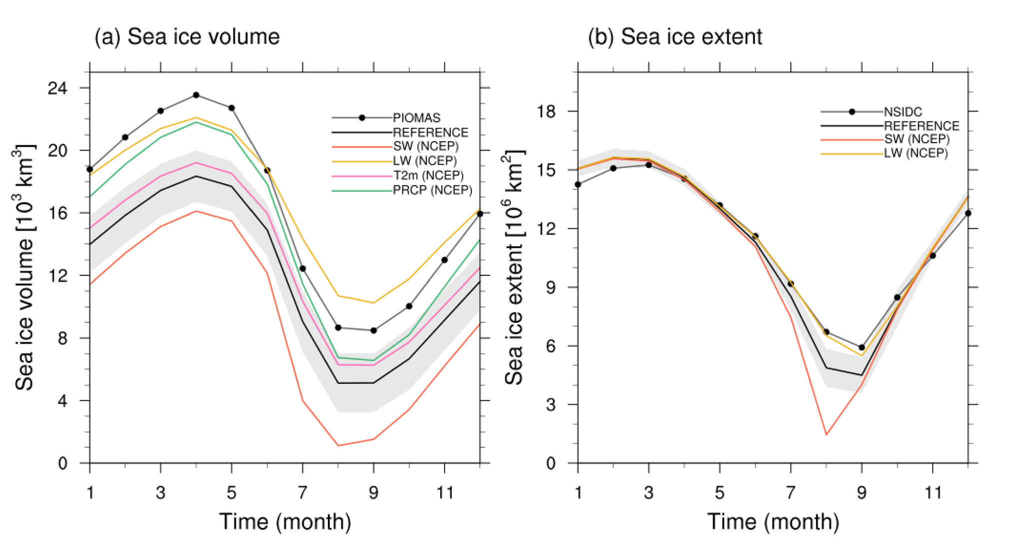
Table 2. Description of the CICE5 response experiments for various atmospheric forcings.

EXP name	Description
REFERENCE	All variables from JRA-55
SW (NCEP or ERA)	Same as REFERENCE except downward shortwave radiation from NCEP R2 or ERA-Interim
LW (NCEP or ERA)	Same as REFERENCE except downward longwave radiation from NCEP R2 or ERA-Interim
T2m (NCEP or ERA)	same as REFERENCE except temperature from NCEP R2 or ERA-Interim
WIND (NCEP or ERA)	same as REFERENCE except U and V wind from NCEP R2 or ERA-Interim
PRCP (NCEP or ERA)	same as REFERENCE except precipitation from NCEP R2 or ERA-Interim
Q (NCEP or ERA)	same as REFERENCE except surface specific humidity from NCEP R2 or ERA-Interim

3. Impact of atmospheric forcings



◀ **Figure 1.** Box plots for average annual cycle (average from 1991 to 2014) of atmospheric variables in the Arctic region (Arctic Ocean north of 65 °N) for each reanalysis dataset. **(a)** SW: Downward shortwave radiation (W m^{-2}); **(b)** LW: downward longwave radiation (W m^{-2}); **(c)** T2m: 2-m temperature (K); **(d)** WIND: wind speed (m s^{-1}); **(e)** PRCP: precipitation rate (mm month^{-1}); and (f) Q: specific humidity (g kg^{-1}). Black, blue, and red boxes are JRA55, ERA-Interim, and NCEP R2 reanalysis datasets, respectively. The bottom, top, and middle line of each box represent the 25th percentile, 75th percentile, and median, respectively; vertical dashed lines are the range between the min and max values.

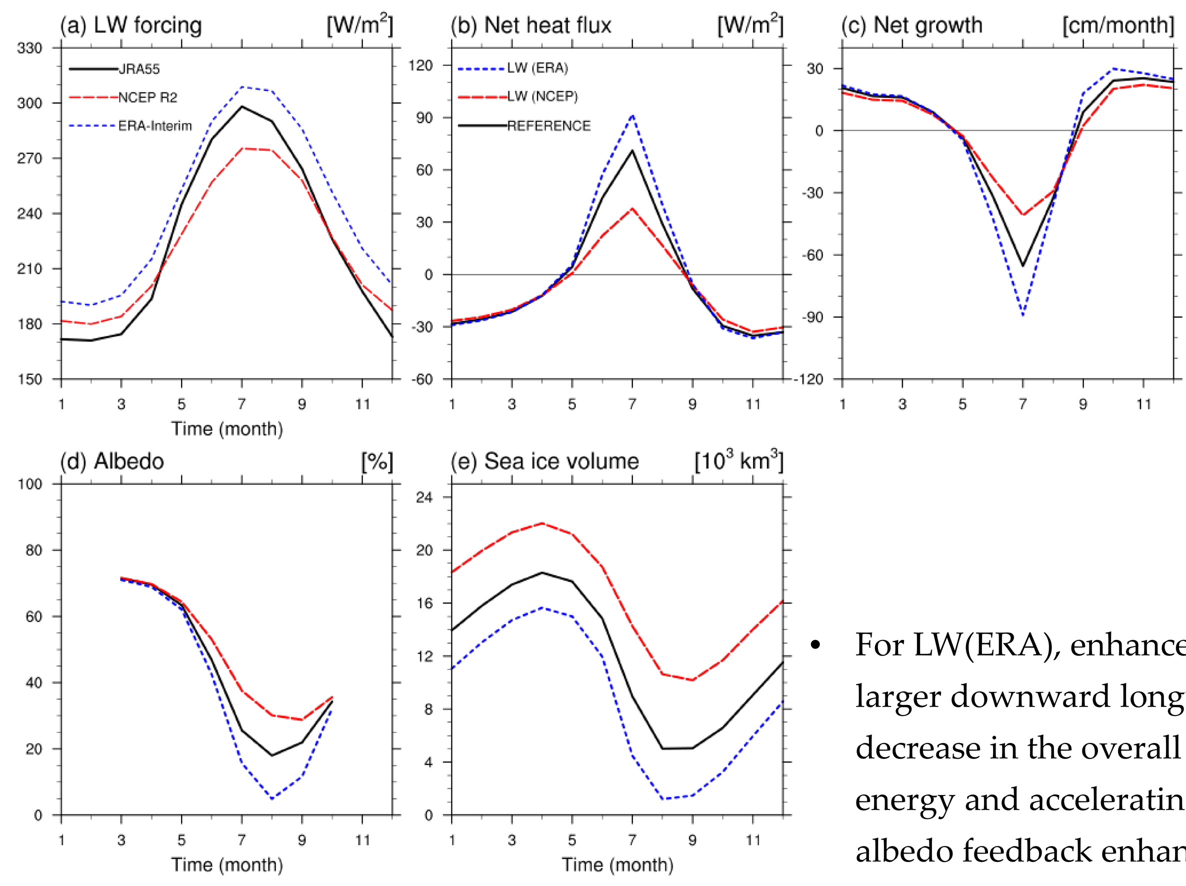


▲ **Figure2.** **(a)** Sea ice volume and **(b)** sea ice extent averaged from 1991 to 2014 in the Arctic region for different simulations and data sets. Shading indicates one standard deviation from REFERENCE.

- Total sea ice volume changed substantially in experiments with higher SW (SW (NCEP)) and with lower LW (LW (NCEP)) radiative forcings compared to those from REFERENCE.
- Although the difference in radiative forcing was larger in SW than in LW, the resultant total sea ice volume difference was larger in LW (NCEP). For the LW and SW experiments, the mean and variability of sea ice volume showed large differences.
- For the T2m experiment, only the variability of sea ice volume had a large spread.
- The NCEP R2 rate was about 1/3 of JRA55 in April (Figure 1(e)). In response to the difference in precipitation, PRCP (NCEP) resulted in about +3,500 km3 more mean sea ice volume than REFERENCE (Figure 3 (a)).

4. Responses of sea ice properties

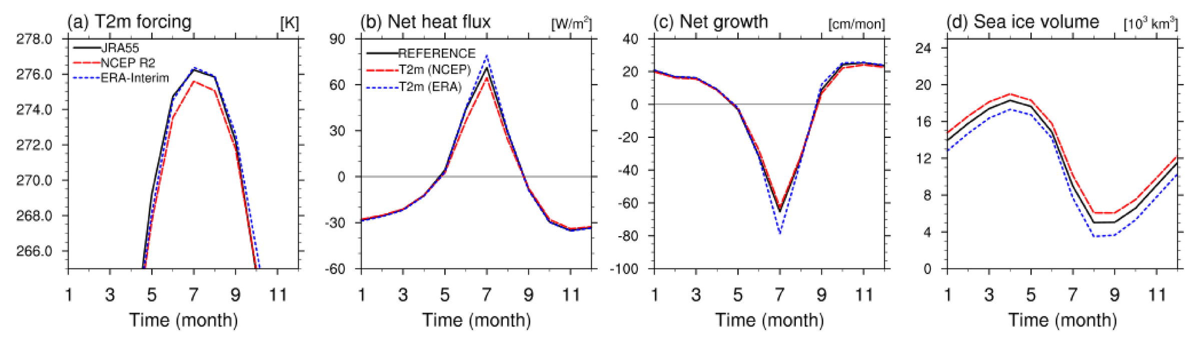
4.1. Sea ice response to radiative forcing



◀ Figure 3. Comparison of the LW experiments. (a) Downward longwave radiative forcing (similar to Figure 1(b)), (b) net heat flux, (c) net growth rate of sea ice, (d) areal mean of snow and ice surface albedo from the available shortwave radiation, and (e) sea ice volume. The ice surface albedo is shown from March through October because the shortwave radiation is zero for most areas in winter (from November through February). (c-e) use the same labels as (b).

- For LW(ERA), enhanced surface melt) in response to the larger downward longwave radiation forcing caused a decrease in the overall mean albedo, increasing the thermal energy and accelerating the melting of sea ice. This sea ice-albedo feedback enhanced the melting of summer sea ice (Figure 3(c)). As a result, the average sea-ice volume in the LW (ERA) experiment was less than that in REFERENCE (Figure 3(e)). This process was similar to that in the SW (NCEP) experiment.

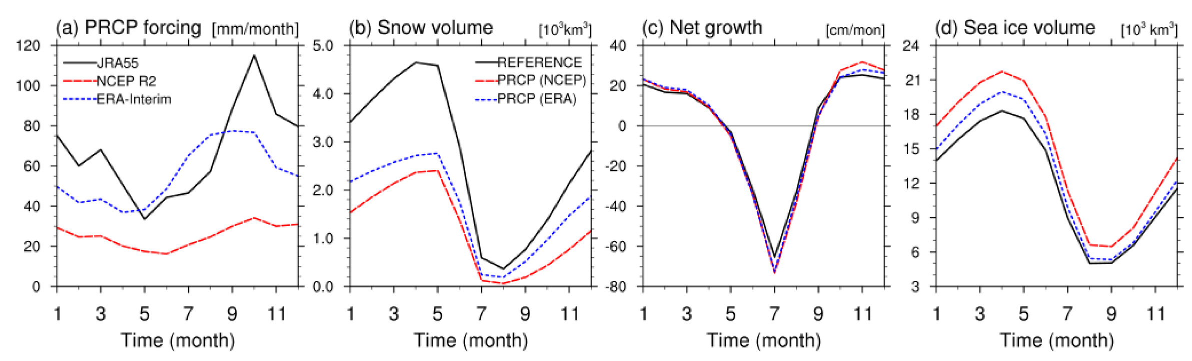
4.2. Sea ice response to temperature forcing



◀ **Figure 4.** Comparison of the T2m experiments. **(a)** 2-m-temperature forcing (similar to Figure 1(c) but focused on summer), **(b)** net heat flux, **(c)** net growth rate of sea ice, and **(d)** sea ice volume. **(c-d)** use the same labels as **(b)**.

- The substitution of temperature forcing changed the F_{net} in summer by modifying the F_{SW} and F_{LW} elements as well as the F_{sens} and F_{lat} . As a result, the sea ice melted less than in REFERENCE during summer in the T2m (NCEP) experiment and melted more in T2m (ERA). This temperature forcing difference in summer directly caused sea ice volume changes.

4.3. Sea ice response to hydrological forcings



◀ **Figure 5.** Results of the PRCP experiment. **(a)** Precipitation forcing (similar to Figure 1(e)), **(b)** snow volume, **(c)** net growth rate of sea ice, and **(d)** sea ice volume. **(c-d)** use the same labels as **(b)**.

- During January through March, over the central Arctic, the snowfall for PRCP(NCEP) was slightly more than that for PRCP(ERA). Thus, although NCEP R2 precipitation was less than ERA-Interim, snow volume for PRCP(NCEP) grew faster than PRCP(ERA) (Figure 5(a) and (b)).
- The energy exchange between air and sea ice in PRCP (NCEP) was larger than in REFERENCE because the insulation provided by snow volume was reduced by half. Thus, PRCP (NCEP) produced more ice during the growth period (Figure 5(c)).

5. Summary

- This study compared the uncertainties involved in atmospheric reanalysis data used for atmospheric forcing in sea ice models. We found that discrepancies in the radiative fluxes, surface temperatures, and precipitation among different reanalysis data can cause large uncertainties in sea-ice model simulations.
- Differences in sea-ice concentration and thickness were primarily caused by differences in downward shortwave and longwave radiations. 2-m air temperature also has a significant influence on year-to-year variability of the sea ice volume.
- In summer, LW(ERA), which is the strongest LW forcing, showed relatively rapid melting compared with other experiments and so reduced the sea ice extent and sea ice volume. Moreover, we showed that, in summer, the model is sensitive to shortwave radiation and 2-m temperature forcings. This implies that the summer observation of radiative variables should be a high priority to reduce the uncertainty included in reanalyses.

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Reanalysis data are known to have relatively large uncertainties in the polar region than at lower latitudes. In this study, we used a single sea-ice model (Los Alamos' CICE5) and three sets of reanalysis data to quantify the sensitivities of simulated Arctic sea ice area and volume to perturbed atmospheric forcings. The simulated sea ice area and thickness thus volume were clearly sensitive to the selection of atmospheric reanalysis data. Among the forcing variables, changes in radiative and sensible/latent heat fluxes caused significant amounts of sensitivities. Dierences in sea-ice concentration and thickness were primarily caused by dierences in downward shortwave and longwave radiations. 2-m air temperature also has a significant influence on year-to-year variability of the sea ice volume. Dierences in precipitation aected the sea ice volume by causing changes in the insulation eect of snow-cover on sea ice. The diversity of sea ice extent and thickness responses due to uncertainties in atmospheric variables highlights the need to carefully evaluate reanalysis data over the Arctic region.

Key words: sea ice model, reanalyusis, uncertainty, Arctic

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전체초청강연

날짜	세션명	좌장	번호	발표시간	발표 구분	제목	저자	발표자	소속
10월 30일(수)	초청강연	민승기 (포항공과대학교)	1	09:40~10:00	초청	4차 산업혁명시대 스마트시티 발전전망과 기상 서비스의 역할	황종성	황종성	한국정보화진흥원
			2	10:00~10:20	초청	아시아 몬순 경년 및 수십 년 변동성의 주요 인자들	하경자	하경자	IBS기후물리연구단, 부산대학교
			3	10:20~10:40	초청	한국형 전지구 수치예보 시스템 개발 현황	홍성유	홍성유	한국형수치예보모델개발사업단