LETTER

Climatological influence of land and atmospheric initial conditions on North America and Eurasia surface temperature and circulation in the past 57 years (1958–2014) reforecasts

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Abstract

This study demonstrates the potential impact of land and atmospheric initial conditions (ICs) on the mean state of land surface temperature (SKT) and mid-troposphere circulation over Eurasia and North America (NA) using the Climate Forecast System version-2 (CFSv2) ensemble seasonal reforecasts for 1958–2014. The land ICs and atmosphere ICs have assembled from several different data sources before and after 1979 in January initialized reforecasts (JIR). Therefore, two-time periods have defined, earlier period (1958–1978) and later period (1994–2014). The climatological difference between JIR P58-78 and P94-14 depicts enhanced cold SKT and sub-surface temperature at 0–10 cm over northern Eurasia and northeast region of NA from May to June. Model overestimates snow cover fraction from May to June in JIR P58-78 than JIR P94-14, which leads to excessive upwards-shortwave radiation in the northern latitudes. Due to cold temperature from the surface to mid-troposphere, model depicts lower geopotential heights in mid-troposphere, which leads to increase westerly winds at mid-troposphere over northern latitudes from May to June. The climatological differences between earlier and later periods of JIR from May to June are similar to differences between reforecasts initialized in winter and spring as reported by some recent studies. The climatological difference between JIR P58-78 and P94-14 depicts enhanced cooling from surface to 600 hPa over northern latitudes in January. As lead months increase, the magnitude of cold temperature decreases gradually from February to March. Most prominent centers of geopotential height from surface to mid-troposphere over northern latitudes in climatological differences between earlier and later periods of JIR in January vanish in February. The different sources of ICs and the nature of land conditions before and after 1979 are main causes of large differences in JIR from May to June over northern latitudes.

1. Introduction

Many previous studies have shown that the land surface state including snow cover, land surface temperature, soil moisture, deep sub-surface temperature (SUBT) and vegetation can affect mean climate on sub-seasonal to seasonal time scales using observations and numerical simulations (e.g. Shukla and Mintz 1982, Barnett et al 1988, Koster and Suarez 2003, Koster et al 2004, 2011, Guo et al 2006, Seneviratne et al 2006, 2010, Koster et al 2010, van den Hurk et al 2011, Santanello et al 2018, Shukla et al 2019a, 2019b, Shukla and Huang 2020). The reader is referred to my recent papers (Shukla et al 2019a, 2019b, Shukla and Huang 2020) for the motivation of this research and detail introduction about the importance of the land surface states. Koster and Suarez (2003, 2004) demonstrated that accurate land initialization in a global model could improve seasonal forecasts of precipitation and temperature.
Few studies have demonstrated an impact of the atmospheric initial conditions (AICs) on the skill of seasonal forecasting (e.g. Reichler and Roads 1999, Hudson et al. 2011, Materia et al. 2014). Therefore realistic representation of land initial conditions (LICs) and AICs in the state-of-the-art coupled general circulation models (CGCMs) is an important condition in simulation and reforecasts for the mean states and interannual variability on sub-seasonal to seasonal time scales. Many previous studies (e.g. Trenberth et al. 2007, Jones et al. 2016) have demonstrated that land conditions (e.g. land surface temperature) over the Northern Hemisphere were different before and after 1979 mainly in the winter season (please also see figure S1 (available online at https://stacks.iop.org/ERL/15/124045/mmedia)).

Using the National Centers for Environmental Prediction (NCEP) Coupled Forecast System version-2 (CFSv2; Saha et al. 2014) Reanalysis and Reforecast (CFSR; Saha et al. 2010), He et al. (2016, 2018) found that CFSv2 is capable to reproduce monthly spatial structure of snow cover fraction (SCF) and snow water equivalent (SWE) at a lead-time of 1–3 months in Eurasia but as lead months increase, the model produces excessive SCF and SWE in spring season due to overactive snow-albedo feedback. Using CFSR, Broxton et al. (2017) found that model produces much colder near-surface temperature and more SWE in April–June over the northern latitude in winter initialized reforecasts (e.g. on 1 January) than reforecasts made later (e.g. on 1 April) do. Using CFSR, Dirmeyer (2013) found that the model depicts significant prediction skill of precipitation in the first month of reforecasts over most locations when initial soil moisture anomalies are large. Using CFSR, Yuan et al. (2011) also reported CFSv2 shows significant skill of land surface air temperature and precipitation in month-1 reforecasts. Recently, Shukla et al. (2019a) and Shukla and Huang (2020) demonstrated that February initialized reforecasts (FIR) produce colder temperatures from surface to 600 hPa over the northern Eurasia and northeast region (NER) of North America (NA) during spring and produce excessive snow cover over there in spring during 1979–2008. Due to cold temperature bias, the geopotential heights are lower in the mid-troposphere over middle and high latitudes, which in turn contribute to a large-scale atmospheric circulation bias at 500 hPa on the southern flank of the lower geopotential height. Shukla et al. (2019b) explored the potential triggering effect of major cold bias in the model’s deep soil temperature (100–200 cm) during summer on the excessive Eurasian snow cover in early winter in CFSv2 simulation.

In the study, I have explored the influence of LICs and AICs using a set of 20-member ensemble CFSv2 seasonal reforecasts for 58 years (1958–2015; Huang et al. 2017). For generating the seasonal reforecasts of CFSv2, LICs and AICs have assembled from several different data sources before and after 1979 (Huang et al. 2017) in January and April. The purpose of the work is to clarify the edge of the influence of initial conditions (ICs) on the mean state of surface temperature and large-scale atmospheric circulations in the seasonal reforecasts. Therefore, it may raise a question: Is there any impact of LICs and AICs on the mean state of surface temperature and large-scale atmospheric circulations in the seasonal reforecasts? To answer this question, I have defined two-time periods of 21 years in January initialized reforecasts (JIR) and April initialized reforecasts (AprIR), the earlier period (1958–1978; hereafter P58-78) and later period (1994–2014; hereafter P94-14). The climatological difference between JIR P58-78 and P94-14 depicts cold temperature from surface to mid-troposphere over NER of NA and central Eurasia during May and June, which leads lower geopotential heights at 500 hPa over mid latitudes therefore the westerly jet at 500 hPa in JIR P58-78 than JIR P94-14 is enhanced between 30°N and 45°N over the Eurasian continent and NER of NA. In my recent papers (Shukla et al. 2019a, Shukla and Huang 2020), I have discussed climatological bias of several variables (e.g. land surface temperature (SKT), SWE, SUBT, geopotential height, and circulation) in the FIR and May initialized reforecasts (MIR) over the Eurasia and NA region during 1979–2008. The nature of bias in these variables of JIR for period 1994–2014 (not shown) is similar to biases in FIR for period 1979–2008 (Shukla et al. 2019a, Shukla and Huang 2020). Therefore, I have not discussed the biases of these variables in JIR P58-78 and JIR 94-14 in the current paper.

The ocean ICs were taken from instantaneous restarts files of the European Centre for Medium Range Weather Forecasts (ECMWF) Ocean Reanalysis System 4 (ORAS4) for 1958–2014 but the quality of ocean ICs is different before and after 1979, therefore, its impact on the mean state of sea surface temperature and rainfall in the tropic has discussed in a separate paper (Shukla 2020).

The remainder of this paper is organized as follows. Section 2 briefly describes the model, the experimental design, and verification datasets. Section 3 presents the impacts of LICs and AICs on the land surface temperature and circulations over NA and Eurasia. A summary and discussion are given in section 4.

2. Model description and experimental design

The CGCM used in this study is NCEP CFSv2 (Saha et al. 2014), which includes atmospheric, oceanic, sea ice, and land components. The multi-seasonal ensemble reforecasts for 57 Years (1958–2014) reforecasts are generated using the revised version of CFSv2 (Huang et al. 2015). The ocean ICs were taken from five instantaneous restart files of the ECMWF ORAS4
Environ. Res. Lett. 15 (2020) 124045

R P Shukla

3 Results

To explore the impact of LICs and AICs in seasonal reforecasts of period 1958–2014, figure 1 depicts the climatological differences of surface temperature (SKT; figures 1(a) and (b)), SUBT at 0–10 cm (figures 1(c) and (d)), and upward short wave radiation (SWRU; figures 1(e) and (f)) between JIR P58-78 and P94-14 from May to June. It is found that climatological difference between JIR P58-78 and P94-14 depicts enhanced cooling at the surface of northern western Eurasia between 50° N–65° N and 3.5 °C and NER of NA up to 3 °C from May to June (figures 1(a) and (b)) therefore model also depicts large cold SUBT at 0–10 cm over the northern Eurasia and NER of NA up to 3 °C (figures 1(c) and (d)).

(Balmaseda et al. 2013) for the period 1958–2014. The land, atmosphere, and sea ice ICs were taken from the Climate Forecast System Reanalysis (CFSR, Saha et al. 2010) for the period 1979–2014. For the period 1958–1978, the AICs were interpolated from the ERA-40 reanalysis (Uppala et al. 2005) and the LICs were taken from the reprocessed 3 h National Aeronautics and Space Administration (NASA) Global Land Data Assimilation System, version 2.0 analysis on a 1° × 1° (Rodell et al. 2004). The stratospheric aerosols are not included in the ICs. The CO2 mixing ratio includes a climatological seasonal cycle (average of 1956–2010) superimposed on the observed estimate at the initial time for years prior to 2010 (Saha et al. 2010). After 2010, a 1% annual growth rate is assumed. Other greenhouse gas concentrations are fixed at climatological values based on Mlawer et al. (1997). The solar cycle is based on observations through 2006, after which the 22 year cycle repeats. An ensemble reforecast of 20 members is generated by matching each of the five ocean ICs at 00Z 1st of January (April) with the atmospheric and LICs at 00Z of the first four days of January (April) while the sea ice initial state is fixed at 00Z 1st for all ensemble-members. More details about January and AprIRs are found in Huang et al. (2017) and Shukla and Shin (2020). I have also used surface temperature from the Climatic Research Unit at the University of East Anglia (CRU 3.21; Harris et al. 2014), which is based on objective analysis of station observations and thus independent of model-based reanalysis products.

Figure 1. (a) Spatial distribution of the climatological difference of May surface temperature (SKT) between January initialized reforecasts (JIR) for mean of earlier period (1958–1978; P58-78) and later period (1994–2014; P94-14). (b) as in (a) but for June. The scale for magnitude for SKT and sub-surface temperature (SUBT) at 0–10 cm in °C is shown below these panels. (c), (d) as in (a), (b) but for May and June SUBT at 0–10 cm. (e), (f) as in (a), (b) but for May and June upward short wave radiation (SWRU). The scale for magnitude for SWRU in W/m² is shown below panels.
On this background, the difference between JIR P58-78 and P94-14 depicts more enhanced SCF up to 20%–30% in JIR P58-78 over western Eurasia and NER of NA from May to June (figures S2(a) and (b)). The CFSv2 shows a slow snow-melting rate in winter initialized reforecasts due to the positive snow-albedo feedback therefore model depicts enhanced SWRU over there in JIR P58-78 (figures 1(e) and (f)). The model predicted surface sensible heat flux is less in JIR P58-78 over northern western Eurasia and NER of NA from May to June due to cold SKT (figures S2(c) and (d)).

Due to large cold SKT over the northern latitudes in JIR P58-78 than P94-14, the climatological difference of mean temperature averaged from 1000 hPa to 600 hPa (MT, hereafter) between JIR P58-78 and P94-14 depicts enhanced cooling of SKT (figures S4(a) and (b)), SUBT at 0–10 cm (figures S4(c) and (d)) and MT (figures S6(a) and (b)) from May to June over the northern latitudes in comparison to difference in JIR based on 21 years period. Therefore JIR P58-68—JIR P04-14 depicts more SCF (figures S5(a) and (b)), SWRU (figures S4(e) and (f)), and much lower H500 over the northern latitudes of northern Pacific Ocean (figures 2(d) and (e); shading). Due to the geostrophic balance, JIR P58-78 depicts stronger westerly winds at 500 hPa up to 2.5 m s⁻¹ over northern Eurasia, Northern Pacific and NER of NA than JIR P94-14 (figures 2(d) and (e); vector). As lead month increases (e.g. July; figures 2(c) and (f)), the magnitude of MT, H500 and winds at 500 hPa are much lower than its magnitude in June over the northern latitudes. The possible impact of cold temperature from surface to 600 hPa on geopotential height and winds from 850 hPa to 600 hPa over the northern latitude from May to June is displayed in figure S3.

It is necessary to mention that when I have defined two-time periods of 11 years in JIR, the earlier period (1958–1968; P58-68) and later period (2004–2014; P04-14), than climatological difference between JIR P58-68 and P04-14 depicts enhanced cooling of SKT (figures S4(a) and (b)), SUBT at 0–10 cm (figures S4(c) and (d)) and MT (figures S6(a) and (b)) from May to June over the northern latitudes in comparison to difference in JIR based on 21 years period. Therefore JIR P58-68—JIR P04-14 depicts more SCF (figures S5(a) and (b)), SWRU (figures S4(e) and (f)), and much lower H500 over the northern latitudes of northern Pacific Ocean (figures 2(d) and (e); shading).
Figure 3. Same as figure 1(a), but for (a) January, (b) February, (c) March and (d) April SKT in JIR. Same as figure 1(a), but for (e) January, (f) February, (g) March and (g) April MT in JIR.

from May to June (figures S6(d) and (e); shading) which lead stronger westerly winds at 500 hPa on the southern flank of lower H500 in comparison to difference in JIR based on 21 years period.

One should note that these results demonstrate a large difference in the magnitude of SKT, SCE, SWR, MT, H500, and winds at 500 hPa from May to June over the northern latitudes in the just difference between earlier and later periods of JIR. Similar kinds of differences in the magnitude of these variables are discussed from May to July in the difference between FIR and MIR for period 1979–2008 over Eurasia (Shukla et al 2019a) and NA (Shukla and Huang 2020). It seems that the possible causes for large difference in magnitude of those variables between JIR P58-78 and P94-14 over the northern latitude are mainly due to the (i) different sources of LICs and AICs before and after 1979, and (ii) different nature of land and atmospheric conditions before and after 1979.

To demonstrate the potential impact of different sources of LICs and AICs before and after 1979, figure 3 depicts monthly climatological difference of SKT (figures 3(a)–(d)) and MT (figures 3(e)–(h)) between mean of JIR P58-78 and P94-14 from January to April while the corresponding difference patterns for snow depth (figures 4(a)–(d)) and SUBT at 0–10 cm (figures 4(e)–(h)) are shown in figure 4. It is found that climatological difference of SKT between earlier and later periods depicts enhanced cooling over northern Eurasia up to 3 °C mainly between 55°–70°N and northern region of NA up to 4 °C mainly between 38° N and 58°N in January (figure 3(a)). As lead months increase in reforecasts, the magnitude of cold SKT decreases gradually over northern Eurasia and northern region of NA from February to April (figures 3(b)–(d)). The magnitude of cold SKT in April over northern Eurasia is around 1.0 °C–1.5 °C and it is 2 °C–2.5 °C over NER of NA. One possible cause for large cold SKT over the northern latitudes during January (figure 3(a)) in JIR P58-78 than JIR P94-14 is the different sources of LICs and AICs before and after 1979 in the seasonal reforecast. But it is necessary to mention that even though climatological difference of observed surface temperature between mean of period 1958–1977 and 1994–2013 is
calculated from the same source (e.g. CRU3.21; figure S1(a)), a large difference in cold surface temperature is found over the northern Eurasia and NA region in January. Many previous studies (Trenberth et al. 2007, Jones et al. 2016) have discussed that nature of surface temperature is different before and after 1979 mainly during winter. It may argue that different sources of LICs and AICs in seasonal reforecasts before and after 1979 are not just main cause for large cold SKT over northern latitudes in January of JIR P58-78 than P94-14 but also land conditions were different before and after 1979 (figure S1(a)).

On this background, the climatological difference of MT between mean of JIR P58-78 and P94-14 depicts enhanced cooling over the northern Eurasia and NA region in January. As lead-months increase, the magnitude of cold MT decreases gradually over there from February to April (figures 3(f)–(h)). It is interesting to mention that snow depth is larger over northern western Eurasia and NER of NA in January of JIR P58-78 than JIR P94-14, and depth of snow decrease gradually there from February to April (figures 4(b)–(d)). Model depicts larger cooling of SUBT at 0–10 cm in January over northeastern Eurasia and central region of NA in JIR P58-78 than JIR P94-14 but warm SUBT at 0–10 cm over northwestern Eurasia and NER of NA. One possible cause for warm SUBT at 0–10 cm over there in JIR P58-78 than JIR P94-14 is larger snow depth over there in January. As lead months increase, the magnitude of warm SUBT at 0–10 cm gradually decreases from February to April (figures 4(f)–(h)) over western Eurasia and NER of NA, which is consistent with reduction of snow depth gradually there (figures 4(b)–(d)).

To further examine the differences in AICs before and after 1979 in the seasonal reforecasts, figure 5 depicts climatological difference of geopotential height (winds) at four levels between JIR P58-78 and P94-14 from January and February. Model depicts much lower geopotential heights in January over northern Eurasia, northern region of NA, and northern Atlantic Ocean mainly between 30° N and 45° N.
at 500 hPa–45 gpm (figure 5(a); shading), 600 hPa–35 gpm (figure 5(c); shading), 700 hPa–24 gpm (figure 5(e); shading), and 850 hPa–21 gpm (figure 5(g); shading) in JIR P58-78 than JIR P94-14 whereas larger heights at four levels over northern western Pacific in JIR P58-78 than JIR P94-14. Model depicts stronger western winds over NER of Eurasia and NER of NA at 500 hPa (figure 5(a); vector), 600 hPa (figure 5(c); vector) and 700 hPa (figure 5(e); vector) in JIR P58-78 than JIR P94-14. Most prominent centers of geopotential height at all pressure levels in January (figures 5(a), (c), (e), (g)) over northern latitudes vanish in February (figures 5(b), (d), (f), (h)). It may conclude that the impact of AICs in reforecasts vanishes or much weaker at most dominant centers of heights at four levels in second months of the seasonal reforecasts.

As expected, the difference between JIR P58-68 and P04-14 depicts enhanced cooling of SKT (figure S7(a)) and MT (figure S7(c)) in January over northern Eurasia and NA, and snow depth (figure S7(d)) is also larger in JIR P58-68 than JIR P04-14 in comparison to differences in JIR based on 21 years period. Consistent with it, the model depicts lower geopotential height at 500 hPa (figure S8(a)), 600 hPa (figure S8(c)), 700 hPa (figure S8(e)), and 850 hPa (figure S8(g)) over the northern latitudes and northern Atlantic Ocean, and larger height at four levels over northern western Pacific in JIR P58-68 than JIR P04-14. Most dominant centers of height in

Figure 5. Same as figure 1(a), but for (a) January and (b) February H500 (shaded) and 500 hPa-winds (vector) in JIR. The scale for magnitude for H500 (H600) is shown below this panel (left side). Same as figure 1(a), but for (c) January and (d) February H600 (shaded) and 600 hPa-winds (vector) in JIR. Same as figure 1(a), but for (e) January and (f) February H700 (shaded) and 700 hPa-winds (vector) in JIR. The scale for magnitude for H700 (H850) is shown below this panel (right side). Same as figure 1(a), but for (g) January and (h) February H850 (shaded) and 850 hPa-winds (vector) in JIR.
reforecasts vanish or much weaker in second month of reforecasts (figures S8(b), (d), (f), (h)).

I have performed a similar analysis with AprIR, the climatological difference between AprIR P58-78 and P94-14 depicts cooling of SKT (figure 6(a)) and MT (figure 6(e)) over northern latitudes in April but as lead months increase, the model gradually reduce cooling of SKT (figures 6(b)–(d)) and MT (figures 6(f)–(h)) over there from May to July. The climatological difference between AprIR P58-78 and P94-14 depicts little warming over northern latitudes in July (figure 6(d)). Model depicts cooling in SKT (figure 6(c)) and MT (figure 6(g)) over northern western Eurasia and NER of NA during June, which is consistent with lower geopotential height (figure 6(k)) over there in AprIR P58-78 than AprIR P94-14.

To quantify the magnitude in the climatological difference of SKT between mean of 1958–1978 and 1994–2013 in CRU3.21, JIR, and AprIR, figure 7 shows the area-averaged of climatological difference of SKT over central Eurasia (outlined by red box in figure 1(a): 55° N–70° N, 30° E–120° E; figure 7(a)), NER of NA (outlined by yellow box in figure 1(a): 44° N–58° N, 275° E–298° E; figure 7(b)) and central NA region (outlined by green box in figure 1(a): 38° N–58° N, 245° E–298° E; figure 7(c)). The observation (CRU3.21) shows enhanced cooling over central Eurasia (black line in figure 7(a)) in earlier period than later period during winter upto 1.6 °C and magnitude of SKT decreases gradually from June to September. Similar tendency in CRU3.21 has also found over central NA (black line in figure 7(c)) upto 1.2 °C and NER of NA (black line in figure 7(b)). It may possible that the quality of CRU3.21 SKT is not same for periods 1958–1978 and 1994–2013. The JIR depicts larger cooling over central Eurasia in January upto 1.6 °C (figure 7(a); red line). As lead months increase, the magnitude of SKT decreases gradually from February to March in JIR. From April to June, magnitude of cold SKT increases gradually. From July to September, magnitude of cold SKT decreases drastically. A similar feature of area-averaged SKT over the NER of NA is found (figure 7(b); red line). The tendency of area-averaged MT over central Eurasia (figure 7(d); red line) and NER of NA (figure 7(e); red line) is similar as tendency of SKT over there (figures 7(a) and (b)) respectively. The AprIR depicts enhance cooling in SKT and MT over central Eurasia (figures 7(a) and (d); green line) and NER of NA (figures 7(b) and (e); green line) in April but as lead months increase, magnitude of SKT and MT decreases gradually till summer. Both JIR (figure 7(c); red line) and AprIR (figure 7(c); green line) depict large cooling in the month-1 reforecasts over central NA region but magnitude of SKT decreases gradually as lead months increase.
4. Summary and discussion

This study investigates the potential impact of the LICs and AICs on mean state of SKT and atmosphere circulation at mid-troposphere over the northern latitudes in the seasonal reforecasts for period 1958–2014, which is initialized in January and April. The LICs and AICs were assembled from several different data sources before and after 1979, therefore, two-time periods of 21 years are defined earlier period (1958–78) and later period (1994–2014) in both JIR and AprIR.

The climatological difference between JIR P58-78 and P94-14 depicts large cold SKT up to 3.5 °C and SUBT at 0–10 cm up to 3.0 °C over the northern Eurasia and NER of NA from May to June. The model depicts large SCF up to 30% over western Eurasia and NER of NA in JIR P58-78 than JIR 94–14 therefore model depicts larger SWRU over there from May to June. Due to larger cold SKT in JIR P58-78 than JIR 94–14, the climatological difference of MT between JIR P58-78 and P94-14 depicts large cooling up 2 °C over northern Eurasia and NER of NA, which leads to lower geopotential heights at 500 hPa over there. Due to the geostrophic balance, model depicts stronger westerly winds at 500 hPa on the southern flank of the lower H500 over northern Eurasia, Northern Pacific, and NER of NA for May to June in JIR P58-78 than P94-14.

Recent studies by Shukla et al (2019a) and Shukla and Huang (2020) demonstrated that the differences between FIR and MIR depict enhanced cooling in FIR from surface to mid-troposphere over the Eurasia and NER of NA, which leads to lower geopotential height in the middle troposphere over middle and high latitudes from May to July, which in turn to enhance the westerly winds at 500 hPa over there. I have found similar kinds of differences in SKT, SCF, SWR, MT, H500, and 500 hPa-winds over the northern latitudes from May to June in the climatological difference between JIR P58-78 and JIR P94-14 as discussed in Shukla et al (2019a) and Shukla and Huang (2020). The climatological difference between earlier and later periods of JIR depicts enhanced cooling from surface to mid-troposphere over northern Eurasia and NA region up to 4 °C in January. Model reproduced larger snow depth over western Eurasia and NER of NA in January of JIR P58-78 than JIR P94-14, which consists with warm SUBT at 0–10 cm over northern western Eurasia and NER. Model depicts lower geopotential height in mid troposphere over the northern latitude in January of JIR P58-78 than
JIR P94-14. But as lead-months increase, the magnitude of cold SKT and MT gradually decreases over northern latitudes from February to March. The magnitude of snow depth also decreased over there, which may be a possible cause for decrease in warm SUBT at 0–10 cm over there in JIR P58-78. Most prominent centers of geopotential height in January over the northern latitude in mid-troposphere vanish in February. The JIR P58-78 depicts enhanced cold surface during May over the northern latitude than JIR P94-14. The magnitude of SKT and other variables during May in the climatological difference between JIR P58-78 and P94-14 over northern Eurasia and NER of NA is similar to differences between FIR and MIR during 1979–2008. The nature of wintertime land conditions in observation was different before and after 1979 (figure S1). The possible causes for the large differences in variables of figures 1 and 2 between earlier and later periods of JIR are mainly due to the different sources of LICs and AICs before and after 1979 and different nature of land conditions before and after 1979.

The results of this work demonstrate a significantly greater dependence of state-of-the-art coupled model seasonal reforecasts on ICs than previously thought. The scale of ICs influence is too large, which raises the question of ways to improve modeling.

Data availability statement

The data that support the findings of this study are openly available at the following URL: DOI: 10.5281/zenodo.4021351.

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