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Interrelated changes of the Arctic sea ice and surface air temperature from observations and modeling

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Shrinking of the sea ice cover in the Northern Hemisphere (NH) observed since 1980s is a clear indicator of the warming in the high northern latitudes. Another one is Arctic surface air temperature (SAT) that increases faster then SAT in the NH. This acceleration named as polar amplification reached its maximal value during last two decades. Shrinking of summer sea ice extent (SIE) was also accelerated during this period. Record minimums of September SIE have been registered since 1995 with absolute minimum in 2007. The observed decrease of summer Arctic SIE exceeds global climate model projections and raises debate on projections reliability. Although the ensemble of global climate models has simulated seasonal variations of sea ice parameters adequately the spread between models is significant. Discrepancies between model projections of possible September ice disappearance with further warming are significant as well. Hence direct comparison between model simulations and observations is necessary to find the reasons of differences between them. Here we analyze the relation between SAT and SIE changes from observations and modeling in order to examine how well the modern generation of climate models reproduces the interrelated changes of the SIE and SAT. Observed SAT data from ECMWF Re-Analysis (ERA-40) was used for 1958-1999 together with data from 38 meteorological stations in the marine Arctic for 1951-2007. The marine Arctic here is the area that includes the Arctic Ocean and North Atlantic and Nordic Seas covered with sea ice during winter. Stations are located near the sea shore and on the islands in the Arctic seas from where the summer retreat of the sea ice starts. We constructed two sorts of observed

SAT indices. The first index is monthly SAT averaged over the NH, 40-65˚N, 70-85˚N latitude zones. The second ones are the sum of positive daily SAT for June-August and the sum of negative SAT during November-April. Both sums are averaged over 38 meteorological stations in the marine Arctic. These indexes represent the integral impact of summer condition on the ice retreat and on the winter increase of the sea ice volume. The same indices were constructed using monthly SAT from model simulations. The sum of model SAT's was calculated basing on the data from grid points situated close to the meteorological stations. Comparison between variability of simulated and observed series of monthly SIE in the NH for 1958-1999 shows similarities for model ensemble mean statistics. However, statistics for individual models differ significantly between models and observations. Most of the models overestimate winter SIE and underestimate autumn SIE. Mean model MSD is distributed more uniformly among months comparing to the observed MSD. This is also true for the mean model trend coefficients that are negative but its absolute values are lower than the observed ones. Only several models repeat observed trend distribution. Correlation between monthly SIE and SAT averaged over models show two maximum similar to the observed correlations but with a shift of 1 to 2 months. Correlation between September SIE and sum of summer SAT's in the marine Arctic is weaker for model runs comparing to the observations. Maximal correlation gives coefficient -0.79, minimal one is -0.31 (coefficient for observed series is -0.85). Regression coefficients for model SIE and SAT series are higher significantly for majority of models comparing to the observed ones. This discrepancy is caused by significant underestimating of summer SAT in the models. An extension of observed SAT sums up to 2007 shows fast decreasing of negative SAT sums and increase of positive SAT sums after 1990s with absolute record in 2007. Extrapolation of fit curve for the relation between sum of summer SAT and September SIE up to disappearance of ice gives required value of summer SAT sum. This value can be achieved by 2020 in accordance with extrapolation of fit curve for summer SAT sum during 1979-2007. Model projections of September ice up to the end of the 21^{st} century give later dates starting in 2080. Revealed discrepancies between simulated and observed variability of SIE in NH and their interrelation with SAT will help in improvements of the climate models and better understanding of the interaction between sea ice and climate.

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