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Recent changes in winter Arctic clouds and their relationships with sea ice and atmospheric conditions

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Introduction

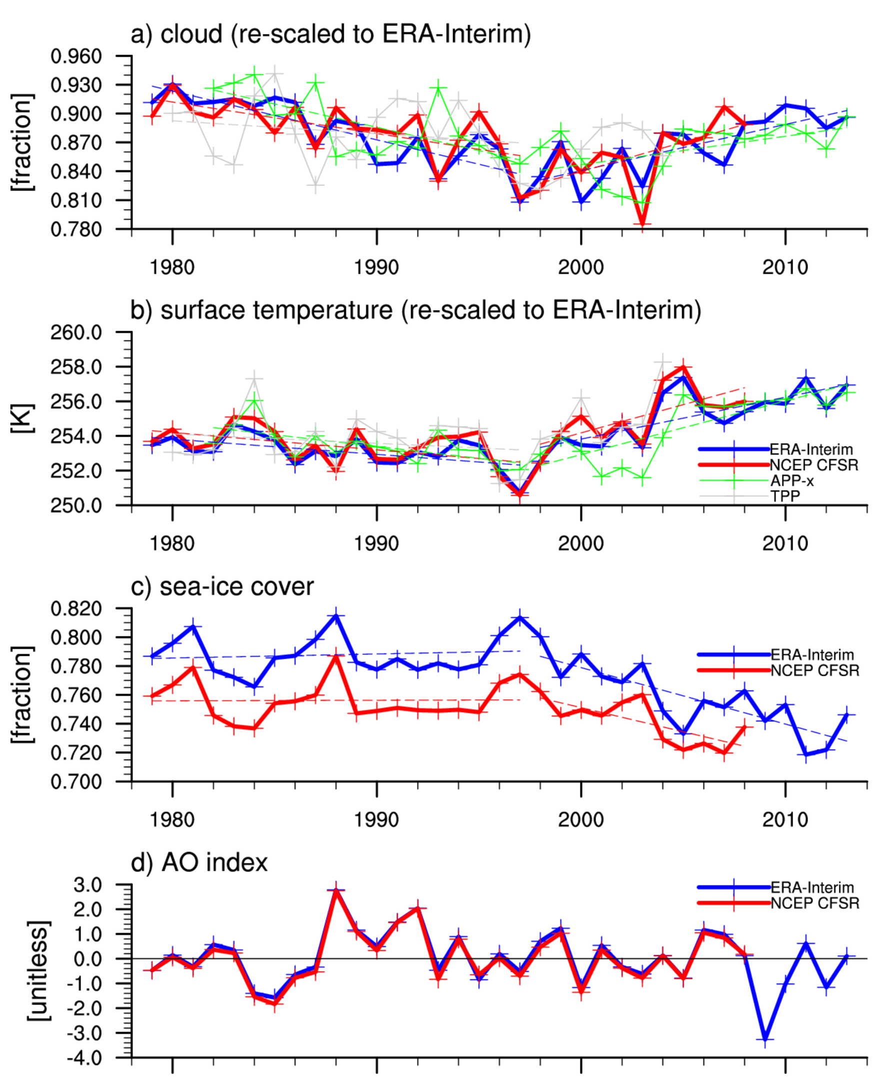
During boreal winter, the net cloud radiative forcing at the Arctic surface is about 20 W m^{-2} despite nearly zero incoming solar radiation (Shupe and Intrieri, 2004).

Since the late 1990s, the Arctic climate has been exposed to radical changes. The accelerated melting of ea ice and the associated ice-albedo feedback has led to considerable warming throughout the Arctic troposphere (Screen and Simmonds, 2010).

Curry et al. (1996) showed that the formation of winter Arctic clouds can be boosted by enhanced turbulent heat fluxes from the surface and subsequent horizontal and vertical convergence of moisture, suggesting a positive feedback effect to the surface temperature.

This study investigates recent Arctic cloud changes and their relationship with Arctic warming and sea ice reduction during boreal winter through examining the interannual variation of Arctic clouds for the winters of three recent decades by comparing two reanalysis datasets (ERA-Interim and CFSR) with satellite observations (APP-x and TPP).

Interannual Variations and Trends of winter Arctic Cloud



Time series of (a) cloud amount, (b) surface temperature, (c) sea ice cover over the Arctic Ocean (north of 67°N), and (d) Arctic Oscillation (AO) index in winter (December through February) from ERA-Interim, NCEP CFSR, APP-x, and TPP datasets. Long-term trends are denoted with dashed lines. The time series of cloud amount, surface temperature, and sea ice cover are re-scaled to adopt the mean and standard deviation of ERA-Interim for comparison.

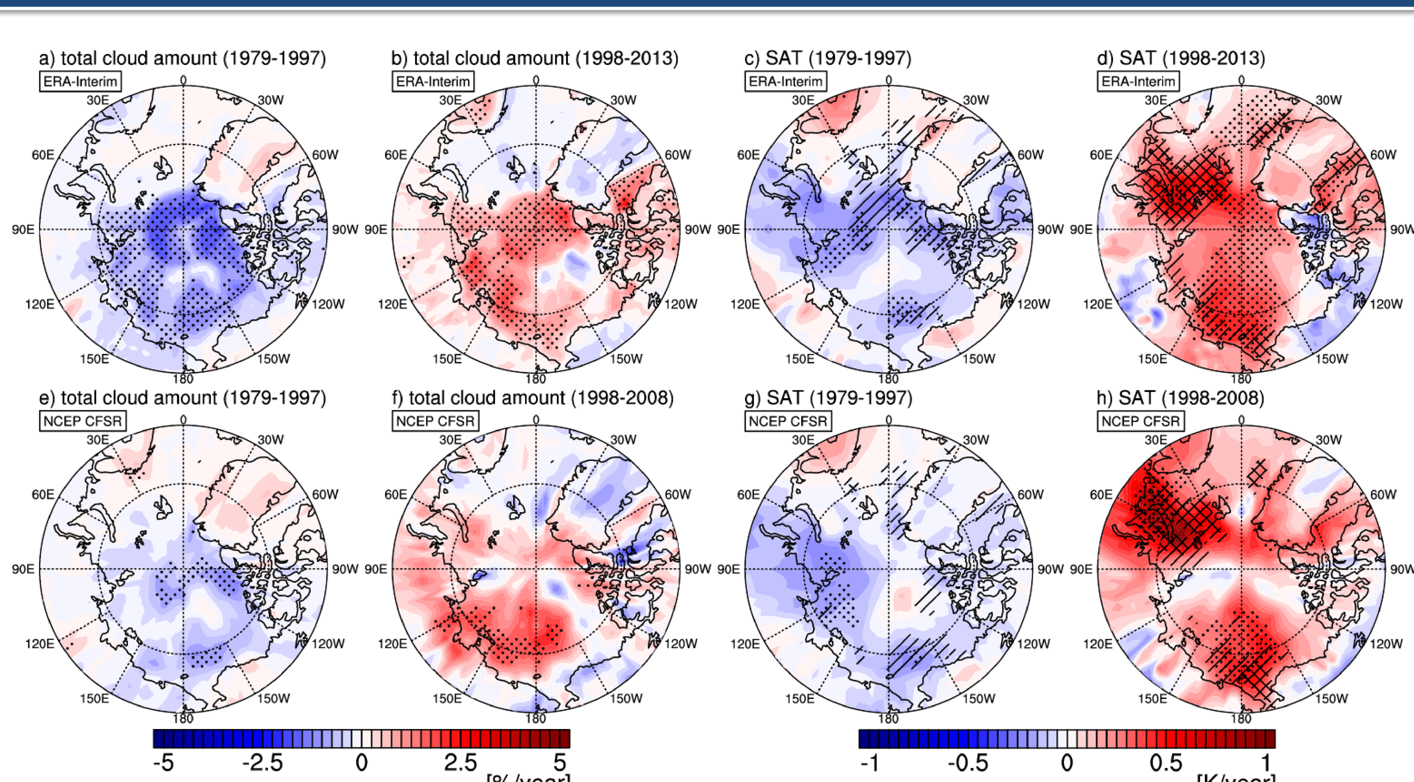
Interannual variations of the total cloud cover from the two reanalysis datasets agree fairly well with each other (correlation coefficient r = 0.82 for 1982–2004), but those from satellite datasets seem to have almost no relationship (r = -0.03 for 1982–2004).

Change point analysis indicates that long-term trend changes actually existed in the variables. The cloud amount, surface temperature, and sea ice cover showed breakpoints of the trend in the late 1990s. The trends in cloud amount changed in 1997 for NCEP CFSR and 2000 for ERA-Interim; those in surface temperature and sea ice cover occurred in 1997 and 1998, respectively.

	Trend of Cloud (% decade^{-1})		Trend of Temperature (K decade^{-1})	
	before 1997	after 1998	before 1997	after 1998
ERA-Interim	-5.08**	4.80**	-0.88**	2.42**
CFSR	-2.32**	4.33**	-.76**	2.48**
APP-x	-10.54**	6.43**	-1.88**	4.27**
TPP	-3.07	18.92*	-0.33	2.76

* / ** : significant at the 90% / 95% confidence level.

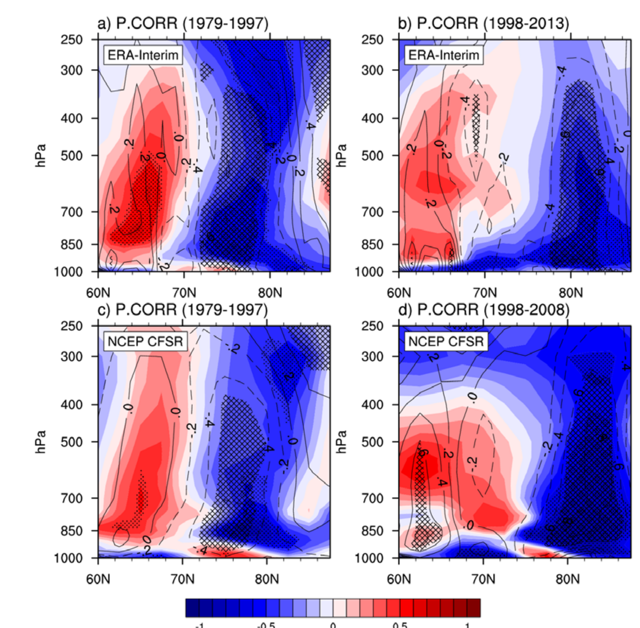
The spatial distributions of linear trends in clouds over the Arctic changed distinctly between the late 20th century (1979–1997; L20C) and the early 21th century (1998–2013; E21C). ERA-Interim showed a significant decrease in cloud amount over the most Arctic region for the L20C period. NCEP CFSR showed a decrease in cloud similarly, although the tendency was overall weaker than the ERA-Interim. In E21C, both reanalysis datasets showed increasing cloud amounts over the most of the Arctic Ocean, although the regions of large increase differed slightly between the two. Vertical distributions of linear trends also show increasing and decreasing at low troposphere during both periods.



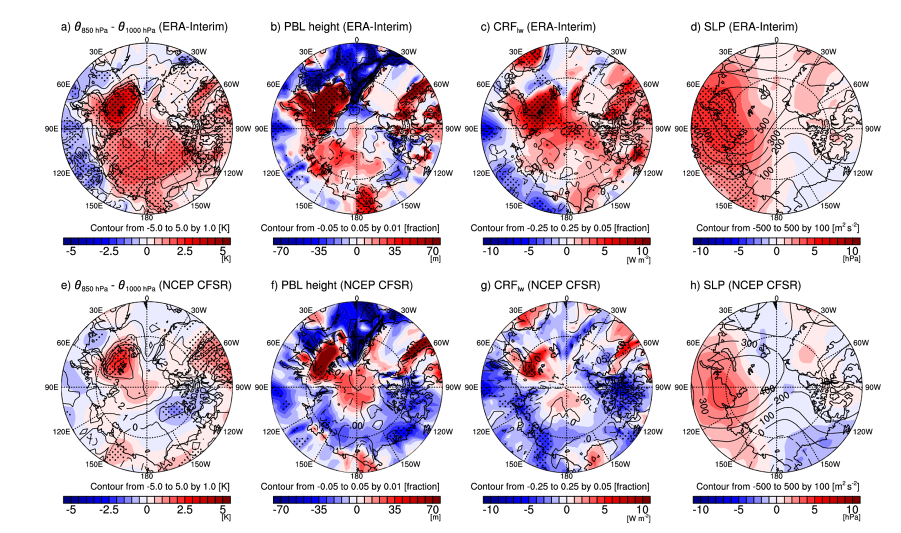
Trends in wintertime (a, b, e, f) total cloud amount and (c, d, g, h) surface air temperature during the late 20th century (1979–1997) and early 21st century (1998–present) from the ERA-Interim and NCEP CFSR. Stippled region indicates trends significant at the 95% confidence level. Oblique and cross-checked regions in SAT plots indicate regions of increased (decreased) sea ice cover above (below) 0.2% year^{-1} and 0.5% year^{-1}, respectively

Effects of sea ice reduction on Arctic clouds

Reduction of sea ice cover during L21C have a large effect on changes in cloud and corresponding relationship between cloud and Arctic environments through altering surface and lower tropospheric condition.

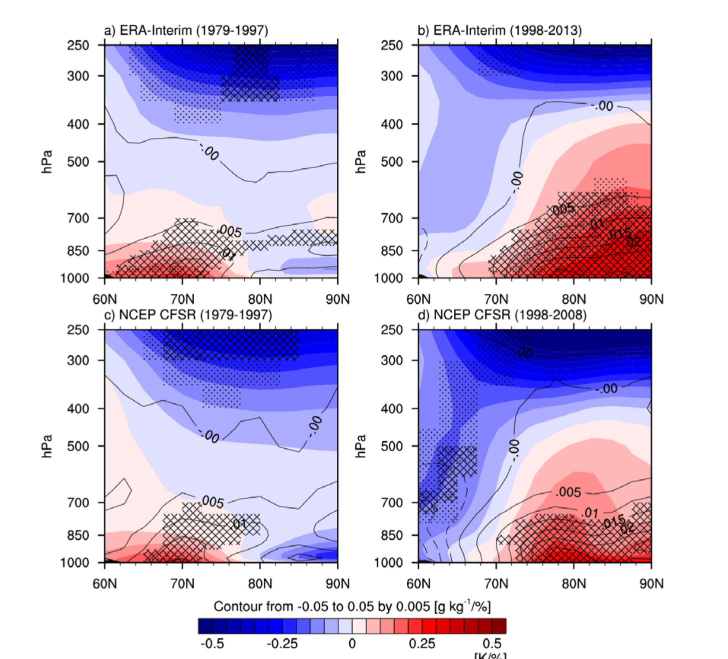


Partial correlations of sea ice cover averaged over the Arctic Ocean (north of 67°N) with zonal averaged cloud water content (shading) and mean upward moisture transport (contour) independent of the Arctic Oscillation (AO) index during the late 20th century and the early 21st century. Stippled (cross-checked) regions indicate that values with shading (contour) are significant at the 95% confidence level. Dashed contour lines indicate negative values.



Differences in (a, e) 850 hPa thickness (shading) and surface air temperature (contour), (b, f) planetary boundary layer (PBL) height (shading) and sea ice fraction (contour), (c, g) longwave cloud radiative forcing (shading) and cloud amount (contour), and (d, h) sea level pressure (shading) and 500 hPa geopotential height (contour) between averages for the early 21st century and the late 20th century. Stippled region indicates differences in shading values significant at the 95% confidence level.

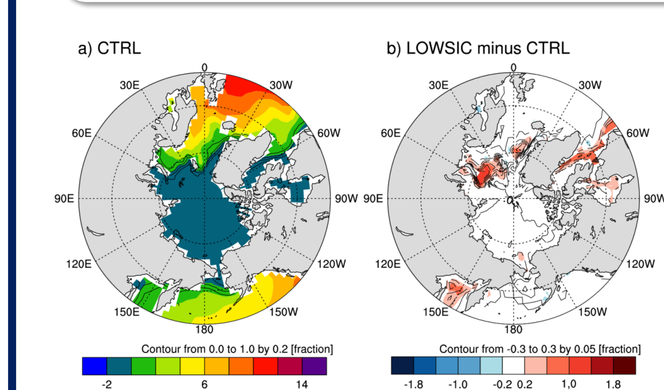
The local connection among clouds, temperature, and moisture over the Arctic strengthened significantly in E21C. During L20C, low-level clouds in the Arctic were positively correlated with lower tropospheric temperature mainly over the southern part of the Arctic. During E21C, the center of temperature correlated with clouds moved to the higher latitudes north of 70°N, and strengthened. The atmospheric moisture also exhibited positive correlation with the low-level clouds.



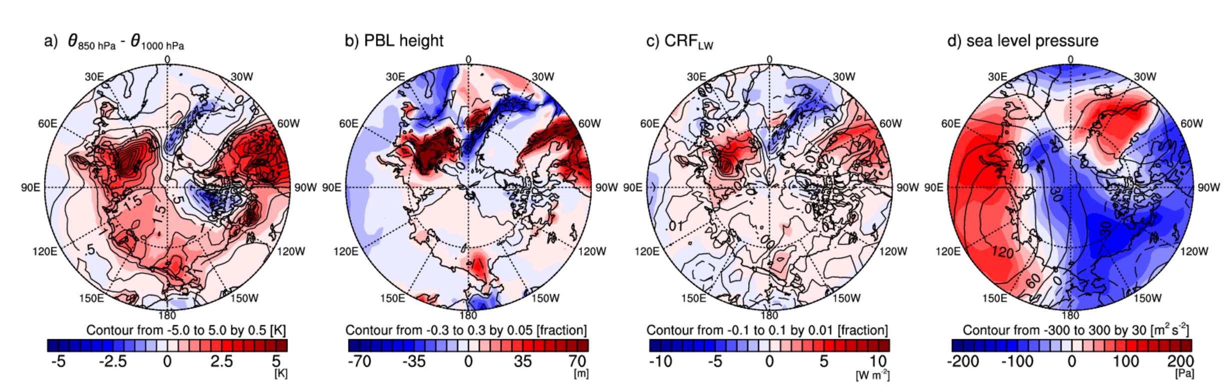
Regression of winter low-level cloud amount averaged over the Arctic Ocean (north of 67°N) onto zonally averaged temperature (shading) and specific humidity (contour) during the late 20th century (1979–1997) and early 21st century (1998–present) from the ERA-Interim and NCEP CFSR. Trends are removed from the raw data before calculating the regression coefficients. Stippled and cross-checked regions indicate regression significant at the 95% confidence level. Dashed contour lines indicate negative values.

AGCM Experiments

To examine whether sea ice reduction was a key factor in the changes in clouds and their relationships with environmental atmospheric conditions, two 50-year NCAR CAM3 simulations including baseline and sensitivity experiments were performed. The CTRL experiments used climatological SST and sea ice cover for 1982–2000 from OISSTv2. The LOWSIC experiment was performed under reduced sea ice condition in the Arctic averaged over 2006–2010.

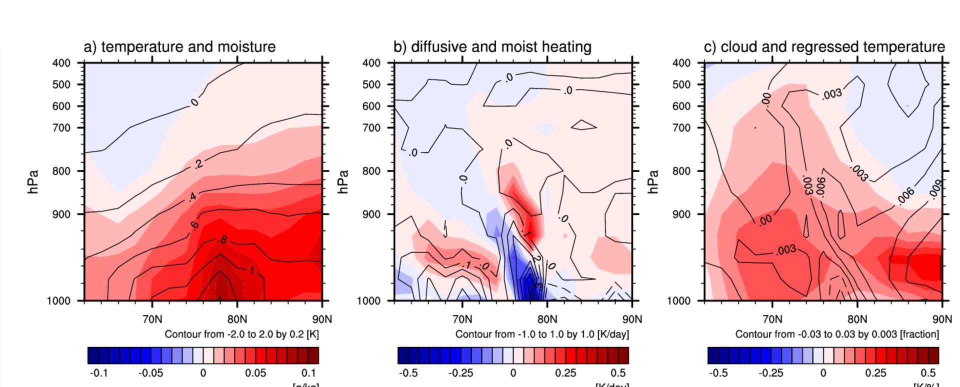


Winter mean sea surface temperature (shading) and sea ice concentration (contour) boundary conditions for (a) the baseline experiment (CTRL) experiment and (b) differences from the sensitivity experiment (LOWSIC) experiment (LOWSIC minus CTRL). Dashed contour lines indicate negative values.



Changes in (a) surface air temperature (contour) and 850 hPa atmospheric thickness (shading), (b) sea ice cover (contour) and planetary boundary layer height (shading), (c) total cloud amount (contour) and longwave cloud radiative forcing (shading), and (d) 500 hPa geopotential (contour) and sea level pressure (shading) from the sensitivity experiment (LOWSIC) experiment compared with the baseline experiment (CTRL).

The atmospheric responses to the imposed sea ice reduction from modeling results showed that surface conditions increased mainly over the reduced sea ice regions, consistent with the difference from observation. In addition, the model experiments successfully capture the warming and moistening, and corresponding cloud-relationships from the lower to mid-troposphere.



Changes in (a) zonal-averaged temperature (contour) and specific humidity (shading), (b) heating by diffusion (contour) and moistening processes (shading), and (c) cloud amount (contour) and regressed temperature of low-level cloud amount over the Arctic (shading) from the sensitivity experiment (LOWSIC) experiment compared with the baseline experiment (CTRL).

Reference

For more detailed description, please visit http://www.tellusa.net/index.php/tellusa/article/view/29130 .

S.-Y. Jun, C.-H. Ho, J.-H. Jeong, Y.-S. Choi, B.-M. Kim, **2016**: Recent changes in winter Arctic clouds and their relationships with sea ice and atmospheric conditions, *Tellus A*, 68, 29130