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Atmosphere-Sea Ice Coupling Processes in Observations and CMIP5

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1. Introduction

In this study, we aim to understand the influence of the summertime circulation on Arctic sea ice melt in September and find an important circulation mode with a single cell over Greenland that explains a substantial fraction of sea ice September variability at interannual and decadal time scales. This circulation feature is highly correlated with other key variables affecting the sea ice energy balance, such as vertical velocity and air temperature in the entire troposphere, cloudiness in the lower boundary layer and downwelling longwave radiation at the surface.

2. Hypothesis of mechanism

The mechanism behind these connections is hypothesized as follows: anomalous high pressure causes strong downdrafts in the Arctic and thus adiabatically warms the atmosphere above the sea ice. At the same time, increases in moisture advection and cloudiness are driven by the anomalous anticyclonic circulation pattern centered over Greenland. This combination of a warmer, cloudier, and more humid atmosphere increases downward longwave radiation and leads to increases in sea ice melt. We suggest that the observed circulation trend over the past 40 years resembles this mode and therefore explains as much as 60% of the recent sea ice decline in September.

3. Assessment of anthropogenic contributions

To assess anthropogenic contributions to this circulation trend, we examine an ensemble mean of 26 CMIP5 runs and 30 members of NCAR Large Ensemble Community Project (LENS) runs under anthropogenic forcing since 1979. We find that the observed circulation change around Greenland results from a combination of a hemispherical uniform increase in geopotential height due to anthropogenic forcing and a strong regional barotropic increase from the surface to the upper troposphere centered over Greenland (Fig. 1). Figure 2 shows the height-latitude JJA zonal mean geopotential

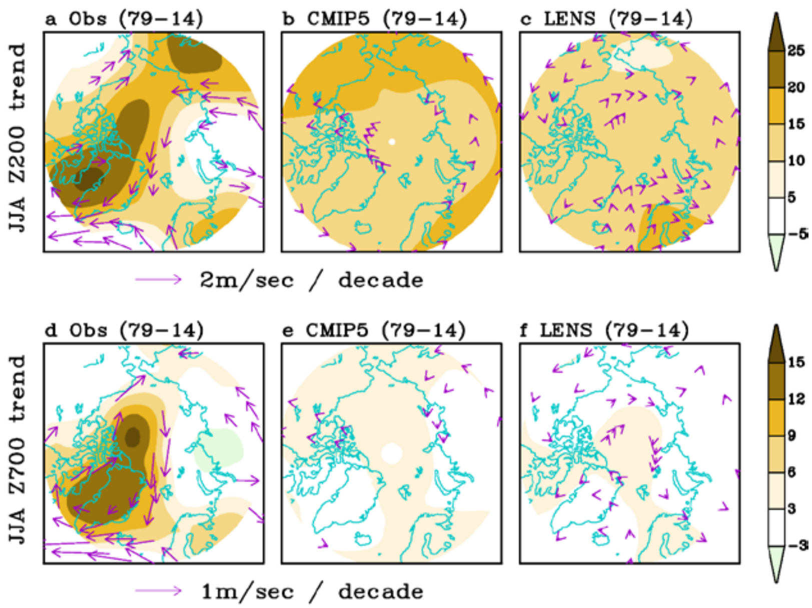

Fig. 1 Observed (reanalysis) and model estimated radiative forced trends in upper and lower tropospheric geopotential height and winds. Linear trends of summer (JJA) geopotential height (m per decade) and zonal and meridional winds at 200hPa (upper panels) and 700hPa (lower panels) for the period 1979–2014 from a) and d) ERA-Interim, b) and e) the 26-model ensemble mean from the CMIP5 project, and c) and f) the 30-member ensemble mean from the LENS project.

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height, temperature and specific humidity trends from ERA-Interim and ensemble means of LENS and CMIP5. The models exhibit different vertical structures from the observations, implying different underlying mechanisms associated with Arctic warming in the models and real world. The anthropogenically forced trend pattern is characterized by a uniform rise of heights everywhere in the Arctic with the larger rise in the upper troposphere. The observation features an obvious barotropic structure that favors the increase of height in the deep Arctic and adiabatic warming increasing towards the surface. The circulation change in the Arctic with a strong barotropic structure is not readily explained by anthropogenic forcing and sea ice feedbacks in summertime (Figs. 1 and 2).

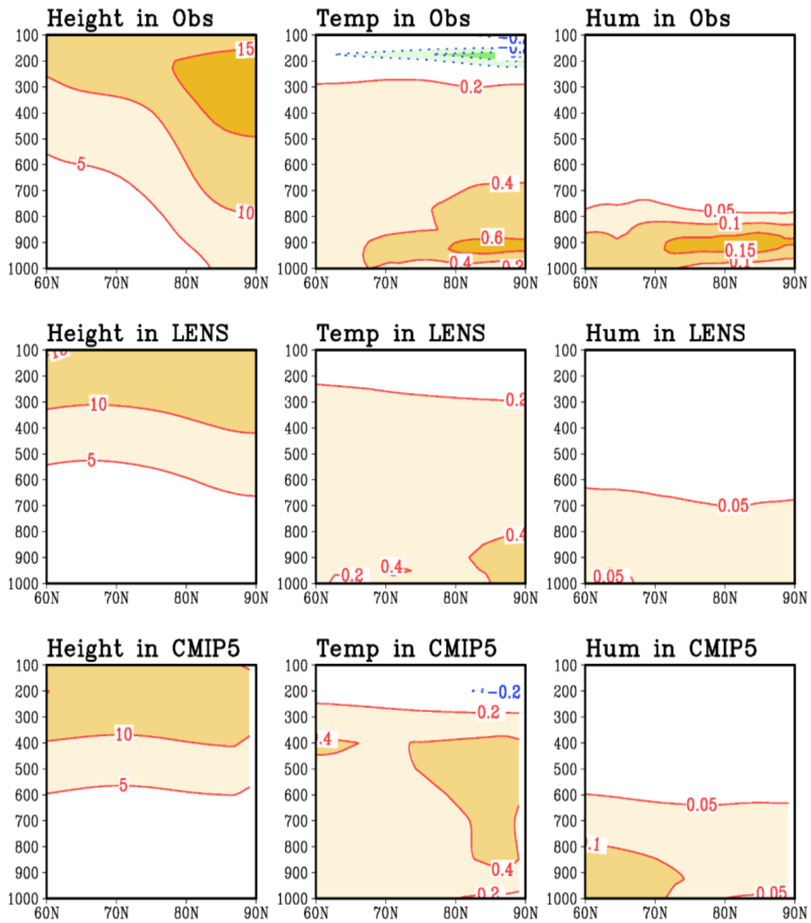

Fig. 2 Linear trends of JJA zonal mean height (unit: m/decade), temperature (C/decade) and specific humidity (g/kg/decade) in the period 1979-2014 from ERA-Interim (upper panels) and the ensemble mean of 26 members of CMIP5 historical runs (middle panels) and 30 members of LEN historical runs (lower panels).

4. Examination of causality

We then use two sets of experiments to examine the direction of causality in the linkage between circulation and sea ice. The first set uses the ECHAM5 atmospheric general circulation model (GCM) coupled with a simple thermodynamic sea ice–ocean model. By nudging the model's wind pattern to observations (reanalysis), we found that the model reproduces patterns of observed changes in temperature, vertical velocity, longwave radiation fields, and a subsequent decline in sea ice. From this set, we conclude that the circulation plays a leading role in modulating the thermodynamic state of the Arctic atmosphere. The second set quantifies the contribution of summer (JJA) circulation changes to sea ice loss in September. We employ a sea ice–ocean model that features sea ice dynamics and ice–ocean interactions but is driven by prescribed atmospheric forcing fields. In the control run, we use observed surface atmospheric forcing from ERA-Interim and reproduce well the observed sea ice decline from 1979 to 2014. In the experiment, we remove any part in the forcing field that is linearly related to the circulation change over Greenland and then use the residual forcing fields to force the ocean–sea ice model again. We find that forcing due to the circulation change over Greenland explains 60% of sea ice decline in September.

To our knowledge, these numerical experiments are for the first time demonstrating the connection between circulation variability and sea ice loss.