Does Arctic sea ice melt affect the Eurasian snow?

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Abstract:

The Arctic climate has been changing rapidly in recent decades. This is evident through the amplification of the more generally rising surface air temperatures and the intensification of the freshwater cycle. A feedback associated with Arctic summer sea ice loss plays an important role in affecting these pan-Arctic climatic changes. Land-surface snow is not only vulnerable to these climatic changes but also plays an important role in the feedback mechanisms. Moreover, recent studies show significant changes in land-surface snow over the high-latitude regions of Northern Hemisphere; though the sign of changes varies over space. We investigate the response of Eurasian snow to the declining Arctic sea ice. Using both observational data and climate model simulations, we search for a sea ice related signal in snow.

We begin our investigation by employing empirical analyses of observed sea ice and snow cover. The primary signal of covariability between Arctic sea ice and Northern Hemisphere snow extent between 1979 and 2007 indicates that a decreasing trend in September sea ice over the Pacific sector is correlated with an increasing trend in fall and early winter snow over Siberia. Historical and future simulations of the fully-coupled Community Climate System Model (CCSM3) shows the emergence of a similar Siberian snow signal during the last half of the 21st century most strongly during late winter; though the hemispheric-scale diminishment of snow is apparent much earlier. These sets analyses do not alone imply any cause and effect relationship between snow and sea ice.

To address the question of causality we used a suite of Community Atmosphere Model (CAM3) experiments in order to identify snow response to different boundary forcings. Comparisons of five specific experiments allow us to discriminate between changes associated with Arctic sea ice / sea surface temperature variations and changes associated with forcing from other regions. Our results suggest a key role played by the high-latitude surface forcings (sea ice and sea surface temperature) in generating the Siberian signal.

Using atmospheric fields, we investigate the physical mechanisms linking sea ice and snow. In summary, this study establishes a causal link between sea ice and snow, which so far is weak and inconclusive in the observed climate, but is expected to strengthen over the coming decades.

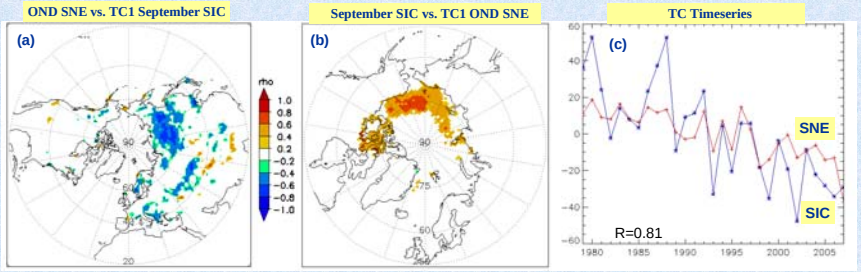
Research Question:

What is the response of land-surface snow to the Arctic sea ice ?

CAM 3 Experiments	Radiative Forcings (Greenhouse gases, Tropospheric and Stratospheric Ozone, Sulfates, Volcanic Aerosoles and Solar Insolation)	Surface Forcings Beyond Tropics (SSTs & Sea Ice polewards of 20º)	Tropical Surface Forcings (SSTs 20° N-20°S)	Time Domain
IPCC	X	X	X	1950-2008
Vanilla	Set at 1990 level	X	X	1950-2008
RADATM	X	Set at Climatology	Set at Climatology	1950-2008
TOGA	Set at 1990 level	Set at Climatology	X	1950-2009
ARCOGA	Set at 1990 level	X (Arctic forcing only)	Set at Climatology	1979-2009

SVD Between September Sea Ice and Fall Snow

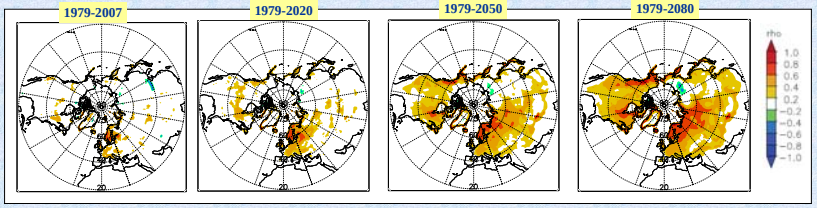
Observational Results [1979-2007]:



Increasing fall/early winter snow over Siberian region correlated with the loss of summer Arctic sea ice

Results based on NCAR CCSM3 Output [21st Century]:

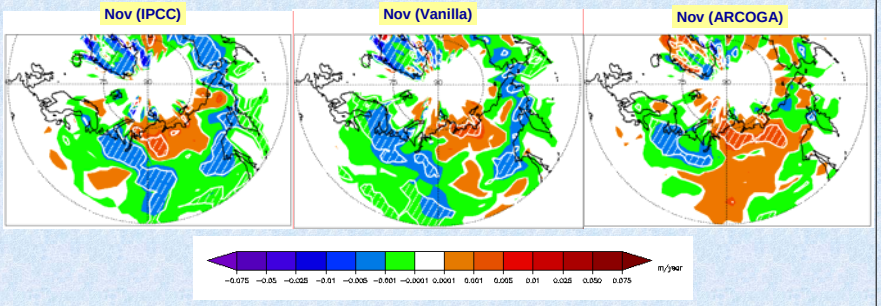
Snow Depth Vs. TC1 September SIC



Loss of fall/early winter snow spreads over the hemisphere; Siberian signal emerging

Trend Analysis – CAM3 Suite of Experiments

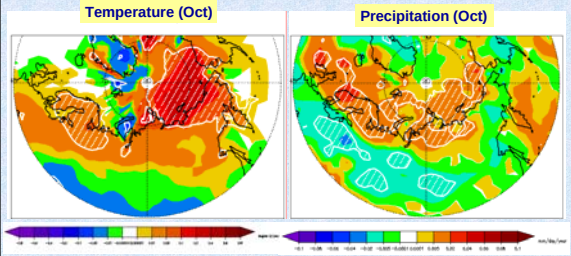
Snow Depth (1979-2007)



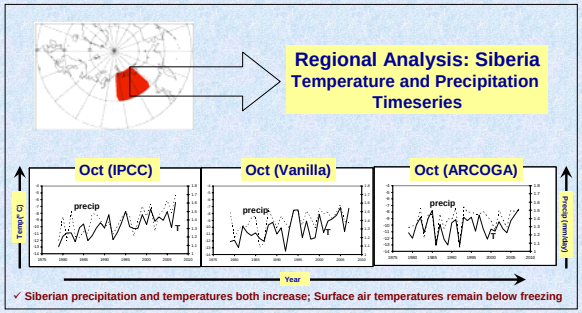
Increased snow depth over Siberia in only three experiments which include time varying Arctic Ocean surface forcings

Physical Mechanism

CAM3 Experiment: ARCOGA



An increase in temperature and precipitation over Siberia



✓ Siberian precipitation and temperatures both increase; Surface air temperatures remain below freezing

Conclusions:

- Empirical analyses of observational data indicate that the increasing fall/early winter snow cover duration over Siberian region is correlated with the loss of summer sea ice over the Pacific sector of the Arctic.
- Results based on CCSM3 simulations indicate that the fall/early winter Siberian-snow signal emerges late in the 21st century. It also reveals diminished snow pack at hemispheric-scale, which is correlated with the retreating summer sea ice.
- Snow depth is found to increase over central and eastern Siberia in only those experiments which include Arctic surface boundary forcings (IPCC, Vanilla and ARCOGA). The other two experiments (RADATM and TOGA) show no such signal. This spatial pattern and the response of snow are consistent with the observational results.
- The increased snow over Siberia in these three experiments is caused by increased surface air temperature as well as precipitation. In a scenario with significant warming, when average monthly temperatures remain below-freezing during the snow season, as they do here, conditions are favorable for increased snowfall and more persistent snow on ground.
- Arctic Ocean surface forcing is necessary and sufficient to produce a Siberian snow signal, but other surface and radiative boundary forcings can modulate the magnitude and geographic extent of the signal.

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