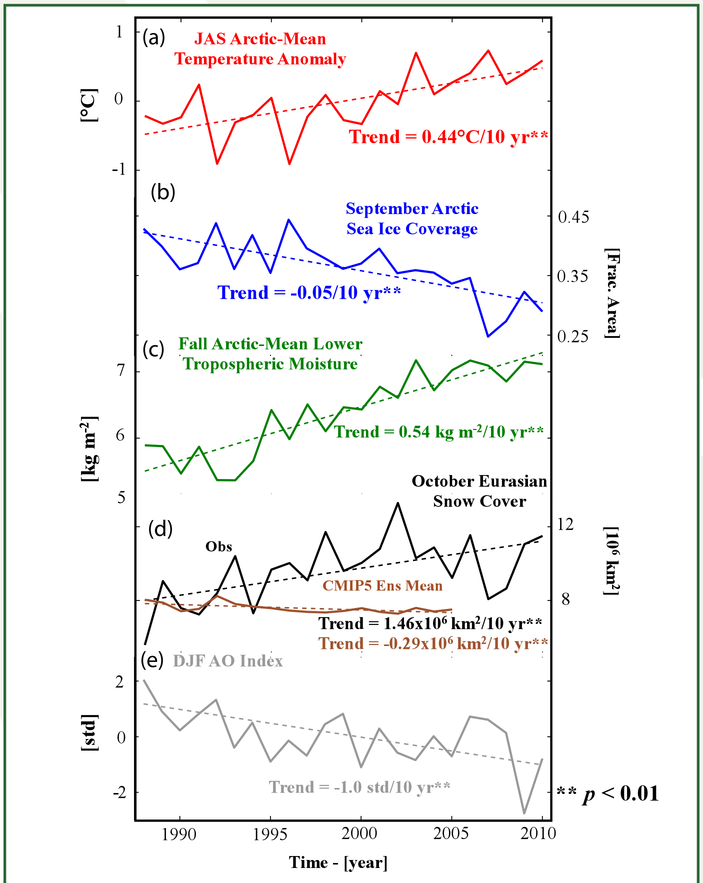
PCIC SCIENCE BRIEF: ARCTIC WARMING, INCREASING SNOW COVER AND WIDESPREAD BOREAL COOLING

A recent paper by Cohen (2012) and colleagues in the journal *Environmental Research Letters* suggests that the large-scale winter cooling trends in eastern North America and northern Eurasia could be due to increased high-latitude moisture and snow cover and probably cannot be attributed to internal variability alone.

Over the past 40 years, the Arctic has experienced nearly twice as much warming as the rest of the world due to a phenomenon known as "polar amplification."[1] However, while the Earth has warmed, winters in large parts of eastern North America and most of northern Eurasia have become cooler with weather becoming more extreme over the last two decades. Working from observational surface temperature records, satellite and weather-balloon observations of moisture in the lower troposphere, snow and sea ice observations, and climate model output, Cohen et al. examined this cooling trend.

The authors confirm that, while the Northern Hemisphere has been warming overall, there has been no overall trend in its winter temperatures, which the authors defined as December, January and February. Moreover, the eastern United States, southern Canada and northern Eurasia experienced winter cooling over this period.

Cohen et al. argue that a reasonable physical mechanism for this lack of winter warming in these regions is as follows. There has been an observed warming trend in the Arctic over July, August and September (see figure, part a). The warming has several effects: it enhances the melting of sea ice (see figure, part b); it increases evaporation and it allows for a greater moisture content in the air (see figure, part c). The increase in the amount of moisture in the atmosphere increases the amount of snow that falls over Siberia in October (see figure, part d, black line). This increase in snow cover differs[2] from the expected negative trend predicted by the ensemble average of global climate model output (see figure, part d, brown line). The increase in snow cover can cause an increase in upward, westward-moving waves (known as Rossby Waves) in the atmosphere that act to slow



Observed Climate Trends from Cohen et al. (2013).
(a) July, August, September average surface temperature anomaly, poleward of 60 °N. (b) September average Arctic sea ice coverage as a fraction of the total Arctic Ocean. (c) September to October average specific humidity between the heights of 700-1000 hPa, poleward of 60°N. (d) October mean Eurasian snow cover from observations (black) and climate models (brown). (e) The average Arctic Oscillation Index over the months of December, January and February. Solid lines are time series, dashed lines are linear trends and double asterisks indicate statistical significance at the $p < 0.01$ level[2].

1. This phenomenon has several causes. One of the main factors is that warming causes the loss of sea ice and, because open ocean reflects less light than sea ice, the ocean can absorb more radiation when the ice melts, which causes further warming.
2. The authors do not speculate on what specific physical processes the models fail to resolve that lead to the discrepancy between observed snow cover and simulated snow cover in Siberia.

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down the eastward-moving winds that circle the Arctic, known as the polar vortex. Because the polar vortex (represented by the Arctic Oscillation index in part e of the above figure) acts to trap cold air at the poles, as it weakens (see figure, part e), some of this cold air escapes and cools parts of North America and northern Eurasia.

The authors then used a statistical technique that compares the winter temperatures over land at a large number of spatial points, with three different indices: (1) an index of the Arctic Oscillation that gauges the strength of the polar vortex, (2) an index of October Eurasian snow cover and (3) an index of Arctic sea ice. These analyses resulted in spatial plots that showed the relationships between the winter temperatures and each of these indices. They found that the association between winter temperatures and snow cover is strongly similar to that between winter temperature and the Arctic Oscillation, suggesting a link between the two patterns of association. Further, Cohen et al. calculate the amount of the winter temperature trend that could be explained by several other patterns that affect climate: the Pacific Decadal Oscillation[3], the Atlantic Multidecadal Oscillation[4], El Niño and trends in sunspot number. They find that only the Arctic Oscillation could explain a large fraction of the winter cooling trend. The authors also note that Eurasian snow cover extent in October has been used successfully in winter surface temperature forecasts. Taken together, these separate lines of evidence suggest that the cooling trend in eastern North America and northern Eurasia might be explained by the increase in high latitude moisture and snow cover associated with the loss of sea ice, via the mechanisms discussed by Cohen and colleagues. The authors also suggest that the models do not simulate this cooling because they do not properly represent changes in snow cover and the associated relationships of snow cover changes with the atmosphere.

Methodology

The authors used surface temperature data from the Climate Research Unit land air temperature data set (CRUTEM3), the Modern-Era Retrospective Analysis for Research and Applications (MERRA), and the National Center for Environmental Protection (NCEP) Reanalysis Project. They calculated lower-tropospheric moisture by vertically summing the specific humidity from MERRA and computed precipitable water using weather balloon data from the Global Radiosonde Archive. The authors used sea ice data from the Hadley Centre Sea Ice and Sea Surface Temperature data set and derived the Eurasian October mean snow cover from satellite data. In order to compute land surface temperatures and Eurasian snow cover extent in October, Cohen et al. used output from ten climate models that took part in the fifth phase of the Coupled Model Intercomparison Project (CMIP5).

The authors first calculated both the annual and the winter land surface temperatures in the Northern Hemisphere, to confirm that they matched earlier findings, and then calculated the spatial distribution of the Northern Hemisphere temperature trends. Following this, the authors calculated the Arctic mean temperature anomaly for July, August and September, the trend in September Arctic sea ice cover, the fall Arctic mean lower tropospheric moisture content, the October Eurasian snow cover and the winter trend of the Arctic Oscillation index. They then calculated the change in precipitable water over Eurasia, in October, from weather balloon data.

Following this, the authors performed a regression of surface temperature anomalies onto three indices (the Arctic Oscillation, Eurasian October snow cover and Arctic sea ice) at every grid point on land. Next, the authors estimated the impact of the Arctic Oscillation, El Niño, the Pacific Decadal Oscillation, the Atlantic Multidecadal Oscillation and sunspot numbers on the wintertime temperature trend by computing that part of the temperature trends linearly related to each of the above, removing them from the overall trend and comparing the remaining trends in surface temperature with observations.

Using these methods, Cohen and colleagues arrive at the conclusions above.

Cohen, J. L., et al., 2012: Arctic warming, increasing snow cover and widespread boreal winter cooling. *Environmental Research Letters*, **7**:014007. doi:10.1088/1748-9326/7/1/014007.

3. The Pacific Decadal Oscillation is an oceanic climate variability pattern indicated by sea surface temperatures in the Pacific Ocean. The Pacific Decadal Oscillation is driven by a combination of atmospheric and ocean circulation influences.
4. The Atlantic Multidecadal Oscillation is, as with the Pacific Decadal Oscillation, an oceanic climate variability pattern. It is indicated by sea surface temperatures in the North Atlantic Ocean. The mechanisms driving the Atlantic Multidecadal Oscillation have not been identified.

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