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Recent Arctic Climate Change and Its Remote Forcing of Northwest Atlantic Shelf Ecosystems

By the Marine Ecosystem Responses to Climate In the North Atlantic (MERCINA) Working Group |
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http://www.tos.org/oceanography/archive/25-3_mercina.html

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TECHNICAL NOTES

1. The Arctic Oscillation (AO) is the most important mode of interannual to interdecadal climate variability above the Arctic Circle and can be quantified by the AO Index, the first empirical orthogonal function (EOF) of the Northern Hemisphere's winter sea level pressure field from 20°N to the pole (Thompson and Wallace, 1998). The Arctic Ocean Oscillation (AOO) Index quantifies the simulated sea-surface height gradient forced by observed winds near the center of the Arctic Basin; it provides a measure of geostrophic circulation in the Beaufort Gyre, with positive (negative) values corresponding to anticyclonic (cyclonic) circulation (Proshutinsky and Johnson, 1997; Dukhovskoy et al., 2006; McLaughlin et al., 2011). The association between Beaufort Gyre circulation, as measured by the AOO Index, and the generation of Great Salinity Anomalies (GSAs) in the North Atlantic has been relatively consistent since the 1960s. The association between atmospheric circulation in the Arctic, as measured by the AO Index, and the generation of GSAs in the North Atlantic, has changed dramatically since 1980. Prior to 1980, the correlation between the AO Index and the AOO Index was not significant. After 1980, it became strongly negative. Dukhovskoy et al. (2006) suggest that the abrupt switch may be related to either insufficient observational data before the International Arctic Buoy Program began in 1978 or a change in the Atlantic's influence over the Arctic, with a weaker Atlantic influence associated with a reduced correlation between the AO and AOO Indices. Another contributing factor may be the increased coupling between atmospheric and oceanic circulation with the rapid decline in sea ice thickness and extent since 1980 (Giles et al., 2012).

2. A sequential t-test analysis of regime shifts (STARS; Rodionov, 2004) was applied to each of the time series in Figure 1. For analyses of decadal-scale regime shifts, cut-off lengths of $L = 5$ and $L = 10$ years were tested. An L of five years better fit the AO Index and AOO Index time series; an L of 10 years better fit all other time series. Statistically significant regime shifts were detected in all time series at $p = 0.05$. The 1996 regime shift in the AO Index was only found to be significant at $p = 0.10$. STARS was applied conservatively when gaps appeared in the time-series data, with regimes only indicated at L/2 before such gaps and L/2 after such gaps.

3. The term Great Salinity Anomaly (GSA) originally referred to the major pulse of low-salinity water entering the North Atlantic from the Arctic Ocean during the late 1960s. Subsequently, the term has been applied to similar events occurring during the 1980s and 1990s (Belkin et al. 1998; Belkin 2004). Three GSAs have been recognized in the literature (1970s GSA, 1980s GSA, 1990s GSA), each with its own distinctive characteristics (Belkin 2004). All of these GSAs appear to have resulted primarily from the export of ice and/or low-salinity liquid water from the Arctic Ocean to the North Atlantic via either Fram Strait or the Canadian Arctic Archipelago.

4. The distance from the Canadian Arctic Archipelago to Georges Bank is ~ 5,000 km. Estimated propagation speeds for salinity anomalies in the Northwest Atlantic vary from 2–13 cm s^{-1}, with lower values on the shelf closer to the coast and higher values along the shelf-slope break (Belkin, 2004; Sundby and Drinkwater, 2007; Bisagni et al., 2009). Assuming an advective speed of 4 cm s^{-1}, a parcel of low-salinity water would travel 1,261 km yr^{-1}, and therefore the travel time between the Canadian Arctic Archipelago and Georges Bank would be ~ 4 years.

5. The Arctic Dipole Anomaly is an atmospheric pressure pattern characterized by high pressure above the North American Arctic and low pressure above the Eurasian Arctic. The Arctic Dipole Anomaly favors winds that generate a meridional transport of sea ice and upper ocean waters across the Arctic Ocean and into the North Atlantic's Greenland Sea through Fram Strait (Wu et al., 2006; Wang et al., 2009).

6. Individual time series of (a) *Centropages typicus*, (b) *Metridia lucens*, (c) *Oithona* spp., and (d) *Pseudocalanus* spp. abundance index values used in a principal component analysis to define the Small Copepod Abundance Index (Figure TN1). Each time series corresponds to the annual abundance anomaly for late copepodites of each species as determined from Gulf of Maine continuous plankton recorder survey data. Positive values of indices are shaded in red; negative values are shaded in blue. Solid black lines show regime shifts significant at the p 0.05 level.

7. Unusual atmosphere-ocean-cryosphere interactions have been observed in the Arctic since 2005 (see http://www.whoi.edu/beaufortgyre/index.html, http://www.arctic.noaa.gov/reportcard/, http://www.arctic.noaa.gov/future/index.html). During 2007 and 2008, the annual AOO Index was strongly positive (anticyclonic) despite positive (cyclonic) values of the AO Index. Morison et al. (2012) suggest that enhanced cyclonic circulation on the Eurasian side of the Arctic Ocean may explain this unusual behavior. According to their explanation, this recently enhanced cyclonic circulation freshened the Canadian Basin by transporting Eurasian river runoff eastward along the Russian coast and injecting it across the Chukchi Borderland into the Beaufort Gyre. By freshening the Beaufort Gyre, this redistribution of freshwater in the Arctic Ocean served to maintain the gyre's anticyclonic circulation despite countervailing atmospheric winds.

During 2009, the annual AOO Index shifted to negative (cyclonic), with the Beaufort Gyre significantly reduced in strength and the Transpolar Drift becoming negligible. This was the first cyclonic AOO Index observed since 1997. The anticyclonic circulation regime that persisted from 1997–2008 lasted 12 years rather than the typical five to eight years. The climatological seasonality of Arctic Ocean circulation is anticyclonic during winter and cyclonic during summer. Since 2007, this seasonality has shifted dramatically. During 2007, both summer and winter circulations were strongly anticyclonic, with the summer conditions contributing to the catastrophic reduction of sea ice extent observed in the Arctic Ocean. During 2008, the winter circulation was strongly anticyclonic, but summer circulation was unusual with a relatively pronounced Beaufort Gyre and a strong cyclonic circulation cell north of the Laptev Sea. During 2009, the system reversed relative to seasonal climatology, being anticyclonic during summer and cyclonic during winter. These ocean circulation patterns significantly influenced sea-ice extent as well as ocean freshwater and heat content during 2008 and 2009. These changes feed back into the atmosphere and may have long-term impacts on the teleconnections between the Arctic and lower latitudes (Overland and Wang, 2010; Overland, 2011).

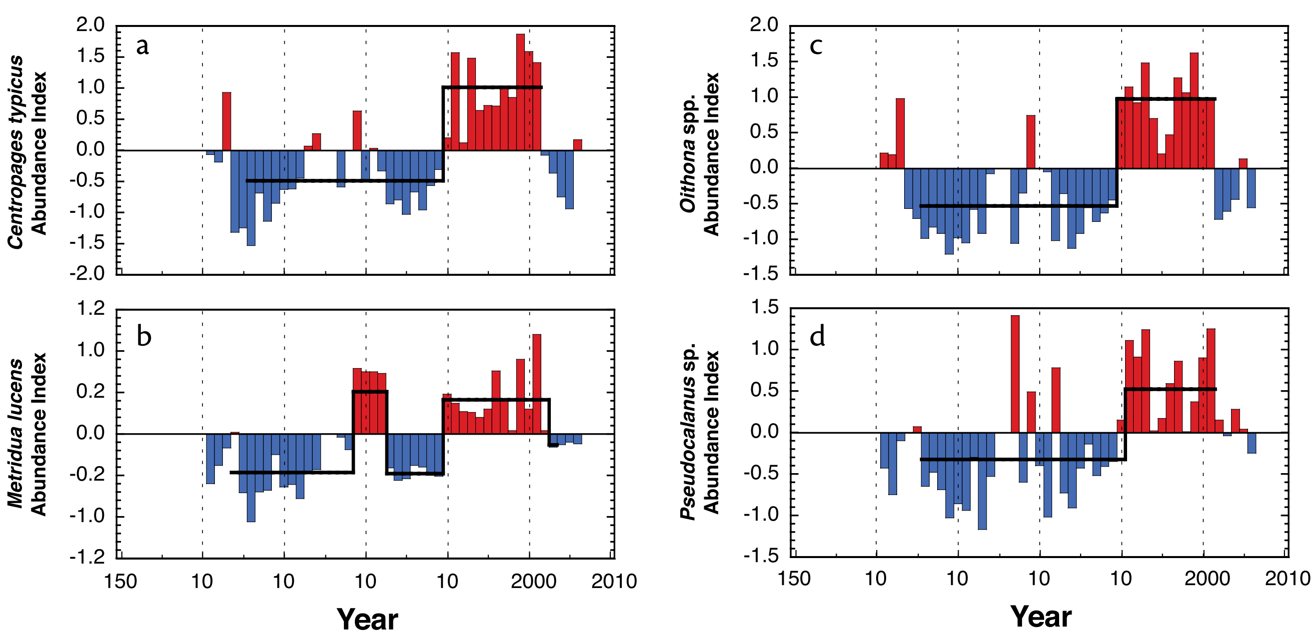

Figure TN1. Individual time series of (a) *Centropages typicus*, (b) *Metridia lucens*, (c) *Oithona* spp., and (d) *Pseudocalanus* spp. abundance index values. Positive values of indices above the climatological means are shaded in red; negative values below the climatological means are shaded in blue. Solid black lines show regime shifts significant at p = 0.05.